OCS Study
MMS 2005-066

Proceedings: Twenty-Third Gulf of Mexico Information Transfer Meeting

January 2005

MMS U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

OCS Study
MMS 2005-066

Proceedings: Twenty-Third Gulf of Mexico Information Transfer Meeting

January 2005

Editors

Melanie McKay
Copy Editor

Judith Nides
Production Editor

Prepared under MMS Contract
1435-00-01-CA-31060
by
University of New Orleans
Office of Conference Services
New Orleans, Louisiana 70814

Published by

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

New Orleans
December 2005

DISCLAIMER

This report was prepared under contract between the Minerals Management Service (MMS) and the University of New Orleans, Office of Conference Services. This report has been technically reviewed by the MMS and approved for publication. Approval does not signify that contents necessarily reflect the views and policies of the Service, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. It is, however, exempt from review and compliance with MMS editorial standards.

REPORT AVAILABILITY

Extra copies of this report may be obtained from the Public Information Office (Mail Stop 5034) at the following address:

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region
Public Information Office (MS 5034)
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394
Telephone Numbers: (504) 736-2519
1-800-200-GULF

CITATION

This study should be cited as:

McKay, M. and J. Nides, eds. 2005. Proceedings: Twenty-third Gulf of Mexico information transfer meeting, January 2005. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. OCS Study MMS 2005-066. 612 pp.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

ACKNOWLEDGMENTS

The Minerals Management Service (MMS) thanks all the participants who made this Information Transfer Meeting a success. In particular, we thank the speakers for their informative presentations. The meeting would not be possible without the team effort of the chairpersons and co-chairpersons who are responsible for the agenda. We thank the University of New Orleans (UNO) Conference Services for planning and conducting the workshop logistics and the staff at the Hilton Hotel for their support efforts and excellent refreshments. In particular, we thank Patricia Arteaga of UNO for making the planning process seem effortless. We also thank Melanie McKay and Judy Nides for the production of the final product. Finally, we thank the support of all those who attended and participated in the discussions for making this truly a transfer of information meeting. The MMS Environmental Studies Program funded this workshop.

INTRODUCTION

Every year for over twenty years, and now every other year, the Information Transfer Meeting (ITM) brings together people from all over the country and the world to discuss the various topics funded by the Environmental Studies Program and related areas of interest to the Minerals Management Service (MMS). As always, the ITM provides a forum where interchange on topics of current interest relative to environmental assessments of the offshore oil and gas industry can occur. The accomplishments of the MMS Environmental Studies Program for the Gulf of Mexico and of other research programs or study projects were presented. The ITM is a place to foster an exchange of information of regional interest among scientists, staff members, and decision-makers from MMS, other Federal or State governmental agencies, regionally important industries, and academia.

The 23rd ITM focused on several topics from benthic ecology of the deep sea to deepwater technology. One highlight this year was the presentation of research funded through the Louisiana Oil Spill Research and Development Program. Interesting stories about the pioneers of the oil industry were shared along with many old photos. Again, three sessions focused on acoustics and marine mammals, particularly the Sperm Whales in the Gulf of Mexico. Physical Oceanographers presented their most recent findings of the movement of currents in deepwater using various models. The results from the most complete evaluation of deep sea ecology were presented. Other sessions focused on air quality, operational discharges, and deepwater technology. Once again, the meeting reflected the broad areas of interest to MMS and the excellent scientists studying these topics.

Following are the summaries of the presentations that were given by all the excellent speakers.

SESSION 1A

ENVIRONMENTAL FATES AND EFFECTS OF DISCHARGES

Co-Chairs: Margaret C. Metcalf, Minerals Management Service

Jill Leale, Minerals Management Service

MINERALOGIC AND COMPOSITIONAL STUDIES OF BARITE SAMPLES

James P. McKinley, Battelle Marine Sciences Laboratory

Three barite samples of different provenance were studied using several characterization methods. The samples were received with the designations FIT-Blend (FIT), High Metal Barite (MI-High), and Low Metal Barite (MI-Low), along with compositional data for the elements Cd, Cr, Cu, Fe, Hg, Mn, Pb, and Zn. Cu was present at 100–200 ppm, Hg at 0.4–7 ppm, and Pb at 250–1,400 ppm; the FIT sample consistently included the highest concentrations of these elements. Additionally, small samples of the barites were provided that had been acid-leached to remove trace-element bearing phases.

The samples were initially examined as grain mounts by X-ray diffraction (XRD) and scanning electron microscopy (SEM) to determine bulk mineralogy and grain sizes. Only barite ($BaSO_4$) was observed in XRD patterns. Image analysis of grains scattered on a conductive planchette indicated that the grain sizes for the FIT and MI-High samples were similar but that the MI-Low samples consisted of smaller grains. Specific equivalent diameters for each sample were FIT, 5.62 µm; MI-High, 4.75 µm; MI-Low, 1.35 µm.

The barites were prepared as thin sections by a commercial laboratory and examined using electron and X-ray beam instruments. The sample powders were imbedded in epoxy and the resultant solid was affixed to a glass slide and ground and polished to a uniform thickness. The slides were carbon coated to assure electrical conductivity in the electron beam instruments.

Sample analysis in the form of compositional imaging used several methods that provided complementary information. The general variation in mineral components was imaged in the SEM and electron microprobe (EMP) using a backscattered electron (BSE) detector. BSE detectors rely on the correlation between the electron backscatter coefficient and the sample's average atomic number to provide an image of atomic number contrast in solid phases. The resolution is at a sub-µm spatial scale. Compositional imaging in the EMP with respect to individual elements of interest used wavelength-dispersive spectrometers (WDS), tuned individually to those elements. The samples were moved under the electron beam and the characteristic X-ray flux from the tuned spectrometers was composited into a false-color map for each element at µm scale, with a detection limit of approximately 200 ppm. For imaging with a lower detection limit, the X-ray microprobe (XMP) capability at the Advanced Photon Source was used. The samples again were moved under the beam consisting of focused X-rays at high flux. The experiment was conducted in air, using an energy dispersive detector (EDS), which detected characteristic fluorescent X-rays. The detection limit was approximately 1 ppm, but the spatial resolution was 5–10 µm, and the instrument was insensitive to low-Z elements (e.g., Si, S). The energy dispersive detector provided simultaneous collections of elemental abundances. Elemental abundance maps from EMP and XMP instruments were overlain on BSE images using Photoshop. This procedure allowed the direct identification of individual grains containing relatively high concentrations of the elements of interest. Qualitative compositional information for single grains was collected using an EDS detector in the scanning electron microscope. In the electron beam instruments, this detector can provide compositional information at the µm scale, with a detection limit of approximately 1000 ppm; this method is thus ideal for identifying minerals that include trace elements detected by more sensitive means. The combined methods (in acronyms, SEM, EMP, XMP, EDS, WDS, and BSE!) provided a complementary set of detection capabilities to localize and identify the hosts for trace elements, particularly Pb, Hg, and Cu.

The samples included minute, broadly dispersed grains of lead sulfide, and an unidentified Pb phase that did not include sulfur or phosphorous. Because the samples were imbedded in an organic substrate and carbon coated, the identification of carbonate phases was difficult: the unidentified phase may have been a lead carbonate. In the FIT sample, Hg was found within a subset of the Pb sulfide grains, along with Cu, and a Sr sulfide was observed. Fe was present in all samples, as an oxide and a sulfide. The Fe sulfides were much less abundant in the MI-High and MI-Low samples. Also in the MI-High and MI-Low samples, Cu was observed as a sulfide without associated Pb. Finally, Cr, present at 7 and 15 ppm, respectively, in the MI-High and MI-Low samples, was observed as sub-µm oxide particles in the MI-High sample and as a chromium oxide component of Fe-rich, >10 µm lithic fragments in the MI-Low sample.

The detected trace metals in the barite samples were components of very minor discrete mineral phases within the more abundant barite grains. Abundant inclusions of Fe oxides, sulfides, and quartz were also observed.

James P. McKinley joined Battelle in 1987 and is currently a Senior Research Scientist in the Environmental Dynamics and Simulation Group. He earned a Ph.D. in geology from the University of New Mexico in 1990, an M.S. in geology from the University of New Mexico in 1983, and a B.S. in geology from California State University in 1977. His professional experience includes geochemical experimentation with metal adsorption, field investigations of anaerobic biogeochemical systems, combined laboratory-field investigations of vadose and saturated sites contaminated with radionuclides and metals, and electron microscopy and spectroscopy applications to geochemical problems. He has authored peer-reviewed papers on biogeochemical processes, groundwater evolution, adsorption phenomena, and lunar geochemistry.

BARITE SOLUBILITY AND THE RELEASE OF TRACE COMPONENTS TO THE MARINE ENVIRONMENT

Eric Crecelius, Brenda K. Lord-Lasorsa, and Jill Brandenburger, Battelle Marine Sciences Laboratory

This is a synopsis of the presentation given by Eric Crecelius on 11 January 2005 in New Orleans at the MMS meeting on Environmental Fate and Effects of Discharges.

During the last 18 months Battelle and the Florida Institute of Technology (FIT) have been conducting a research project for MMS to address the solubility of barite and solubility of trace metals contained in barite when barite is discharged into the marine environment. The scope of work is divided into the following six tasks. James McKinley presented the synopsis of Task 4; Task 5 was conducted by John Trefry at the Florida Institute of Technology.

- Task 1: Determine the solubility of barite
- Task 2: Determine the amount of trace metals released from barite
- Task 3: Determine the rate at which barite dissolves
- Task 4: Determine the trace metal species within the barite structure
- Task 5: Evaluate the effects of acidic environments on the solubility of barite and release of selected metals into solution
- Task 6: Evaluate the dissolution of barite after burial

The composition of the three types of barite and the Gulf of Mexico (GOM) sediment used in these tasks are listed in the Table.1A.1 The concentrations of trace metals in these barite samples includes "Low Metal Barite" that has environmentally acceptable concentrations of mercury (< 1 ug/g) and cadmium (<3 ug/g), two barite samples that exceed the mercury (Hg) criteria, and one sample that exceeds the cadmium (Cd) criteria.

Table 1A.1. Concentration of elements in barite samples and Gulf of Mexico (GOM) shelf sediment, ug/g (ppm) dry weight.

	Hg	Cd	Ba	Cr	Cu	Fe	Mn	Pb	Sr	Zn
Low Metal Barite (MI Low)	0.44	0.35	538000	15	98	6603	625	318	5940	35
High Metal Barite (MI High)	5.90	0.77	524000	6.5	88	9267	541	243	103000	167
Lab Blend Barite (FIT)	6.70	7.00	507000	11	189	29623	1321	1368	73380	1211
Clean Barite (GOM Criteria)	1.00	3.00	—	—	—	—	—	—	—	—
GOM Shelf Sediment	0.05	0.33	713	55	17	27300	442	21	156	86

The solubility of barium (Ba) and several other metals were determined in seawater under conditions that are expected to occur in the GOM. Figure 1A.1 shows the concentration of dissolved Ba over time in one liter of seawater containing 20 g of barite. The Ba concentrations ranged from about 40 ug/L, approximately the solubility of Ba in seawater, to 10 ug/L.

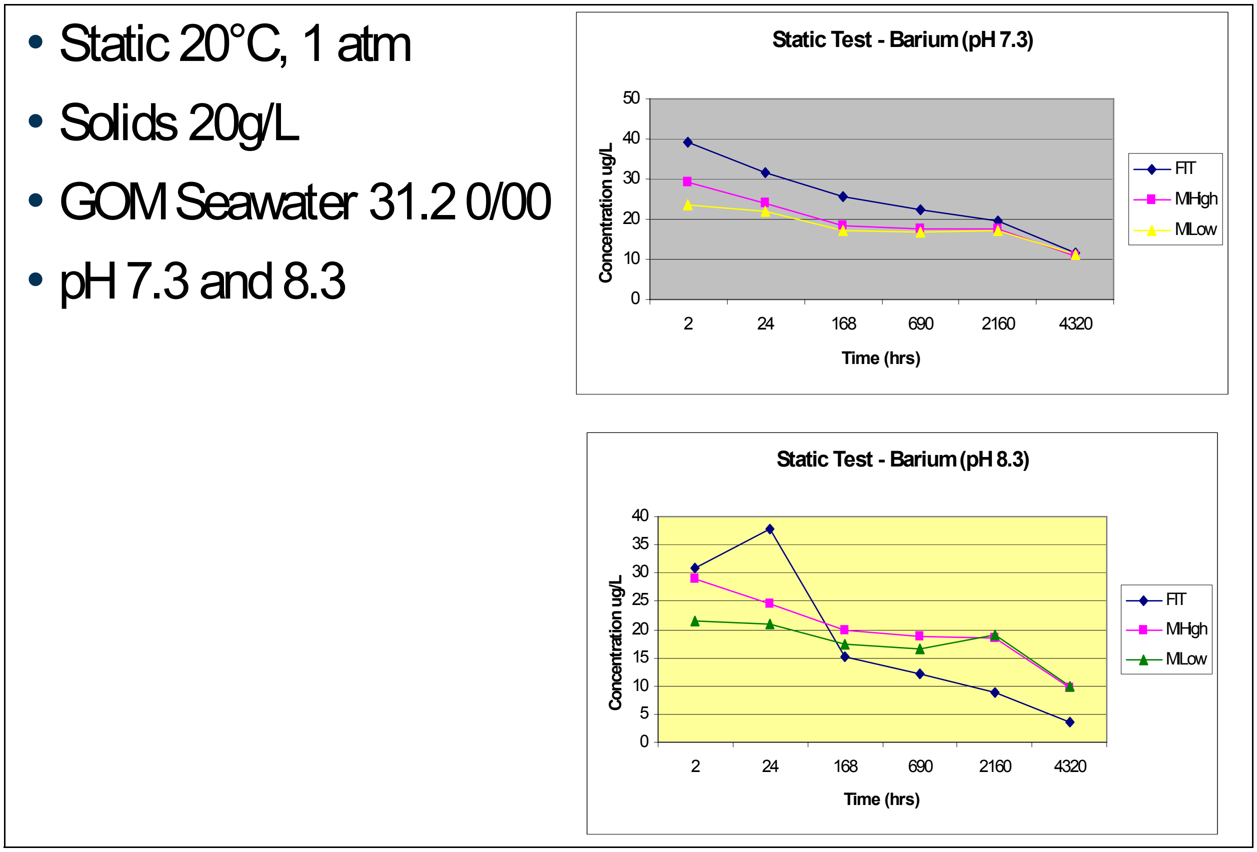


Figure 1A.1. Solubility of barite—static test.

The solubility of several metals, including Hg, Cd, and zinc (Zn) in seawater at two pH concentrations are show in the Figures 1A.2 and 1A.3. The concentrations of these metals tended to increase with time for at least several months. The concentrations of metals were greatest at pH 7.3 and for the FIT-Blend barite, which contained the greatest concentration of these three metals.

Experiments were conducted at FIT to determine the solubility of metals in acidic water. The following Figure 1A.4, 1A.5, and 1A.6 show the concentrations of Ba, Cd and Zn at several different pH concentrations for three barite samples. Very little Ba dissolved, less than 0.01%. However, most of the Cd dissolved and about a third of the Zn dissolved. Very little of the Hg dissolved, less than 0.1%.

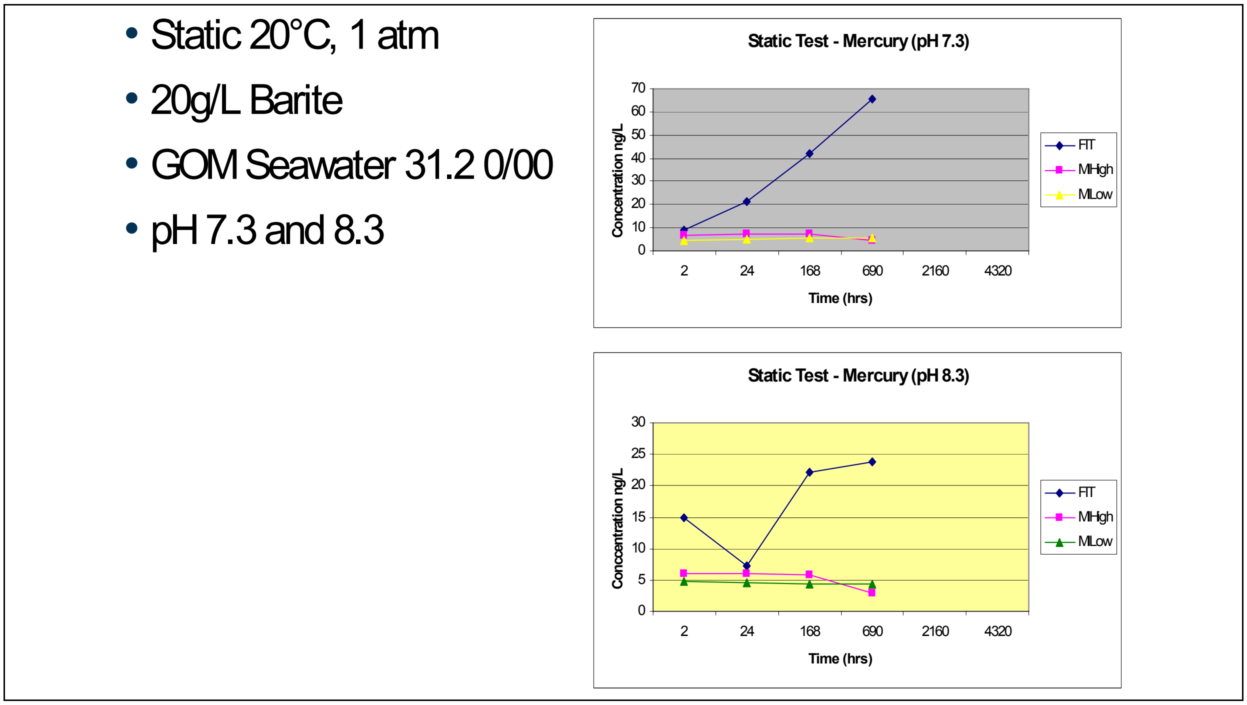


Figure 1A.2. Solubility of trace metals—static test.

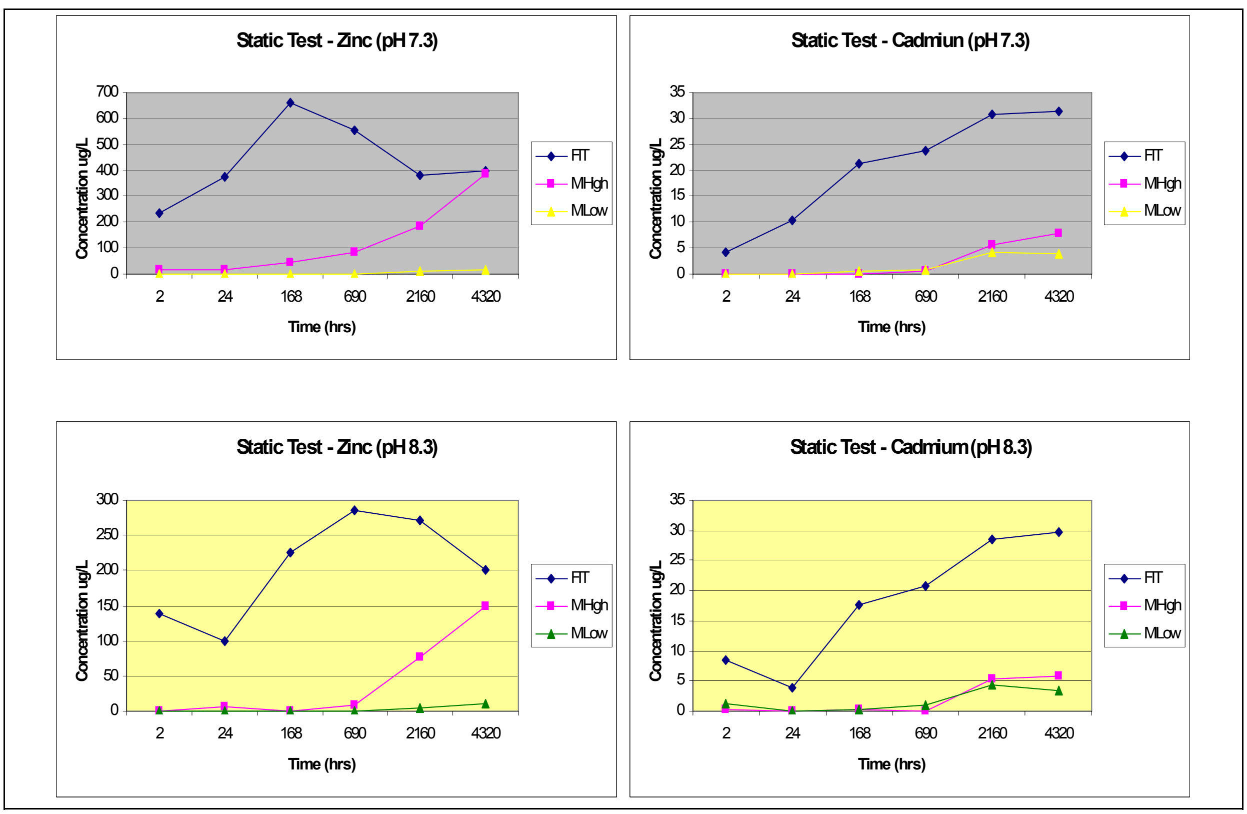


Figure 1A.3. Solubility of trace metals—static test (continued).

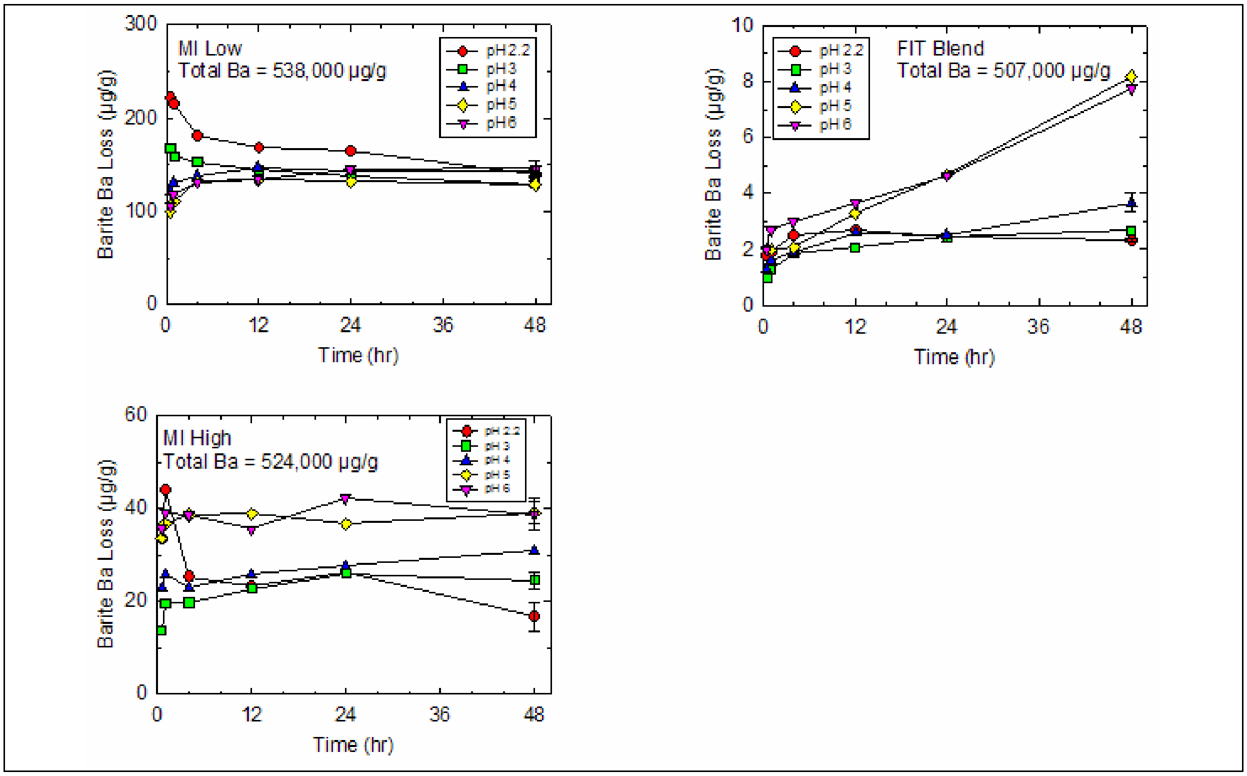


Figure 1A.4. Amounts of barium lost from the solid phase in ug/g. (Results provided by John Trefry, FIT.)

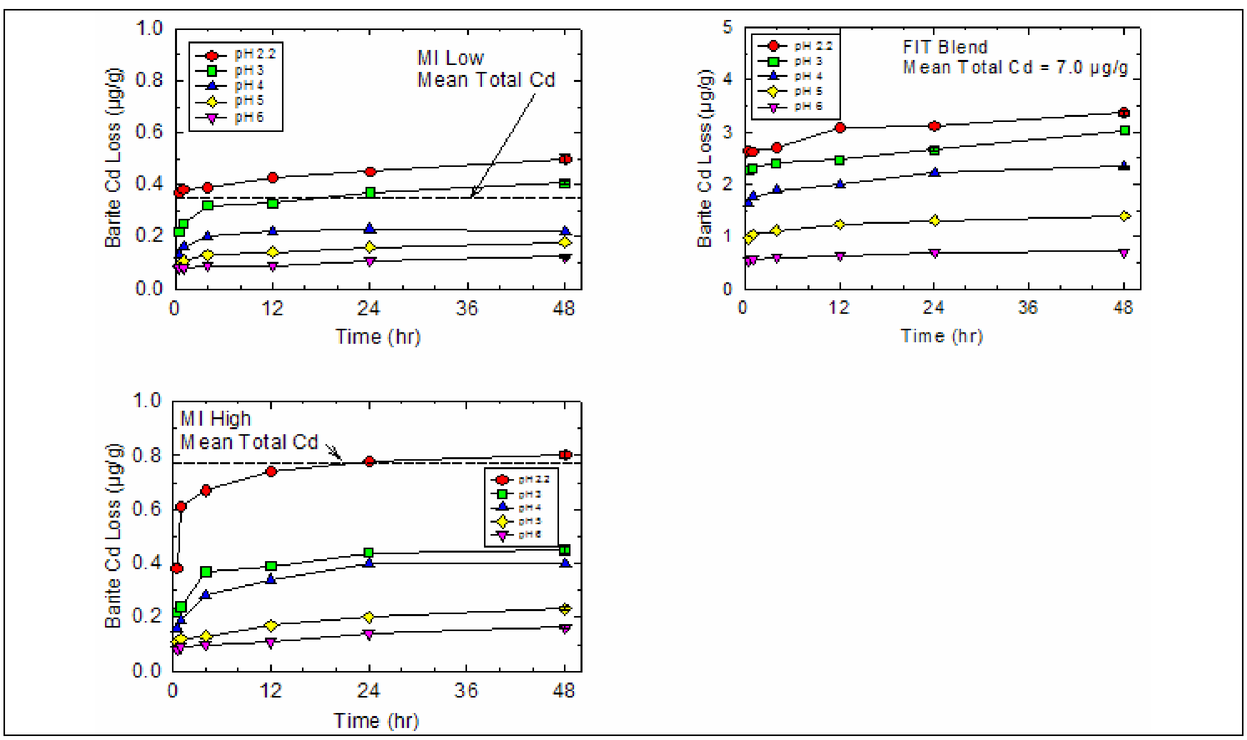


Figure 1A.5. Amounts of cadmium lost from the solid phase in ug/g. (Results provided by John Trefry, FIT.)

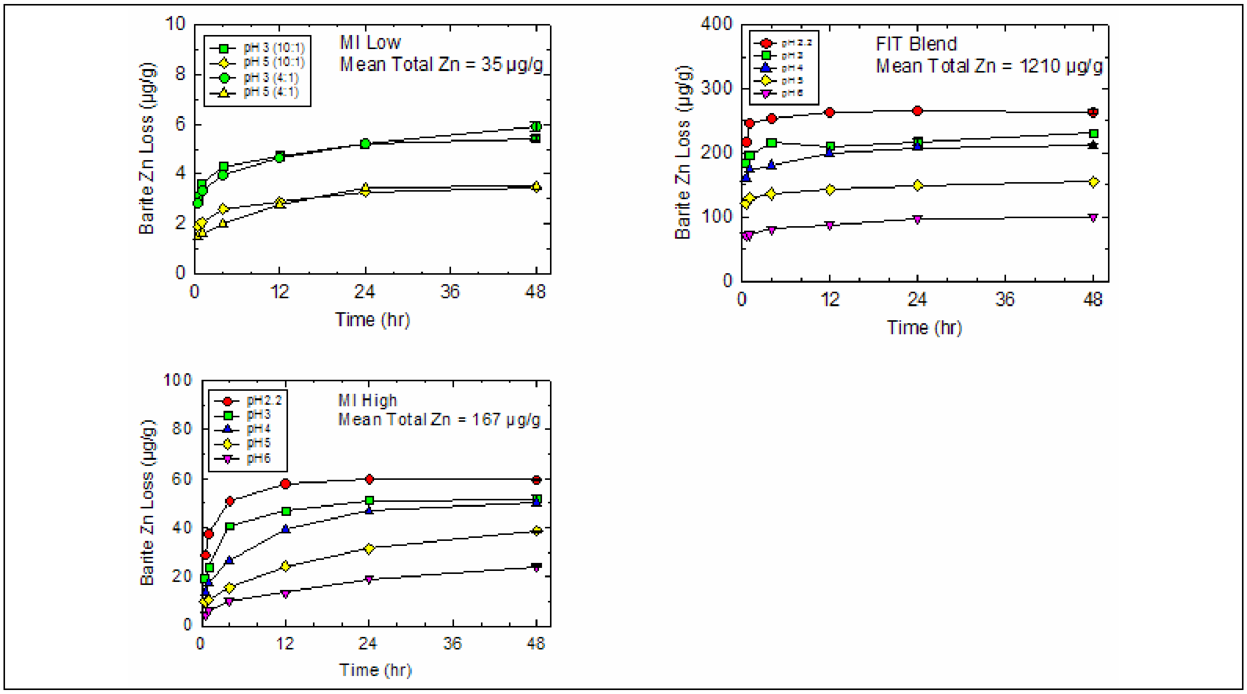


Figure 1A.6. Amounts of zinc lost from the solid phase in ug/g. (Results provided by John Trefry, FIT.)

The solubility of barite in anoxic sediment was examined. Relatively high concentrations of Ba, 1000 to 7000 ug/L, were measured in the porewater of anoxic sediment that contained barite, as shown in the Figure 1A.7. Relatively low concentrations of other metals were in the porewater. Experiments are continuing with barite in sediment.

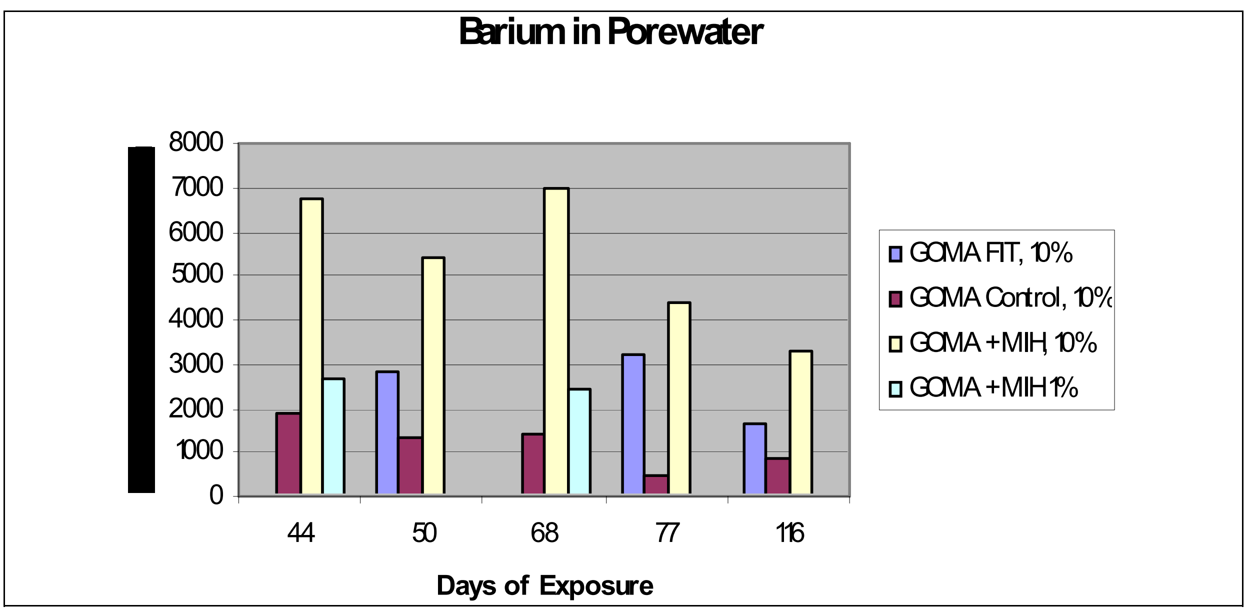


Figure 1A.7. Dissolution of barite after burial (porewater).

Eric A. Crecelius, Technical Group Manager, of Battelle Marine Sciences Laboratory, received his B.S. in general science at Oregon State University in 1967; his M.S. in oceanography at the University of Washington in 1970; and his Ph.D. in oceanography at the University of Washington in 1974. He manages a staff of 18 involved in chemistry projects. Dr. Crecelius has over 30 years' experience in freshwater and marine geochemistry with emphasis on the concentration, speciation, and fate of trace elements in marine ecosystems. He has been the project manager of research contracts that required collecting and analyzing water, sediment and organisms, and seawater samples for butyltins, trace metals, and organic compounds, including nine years of analyses of NOAA Mussel Watch bivalve and sediment samples. Dr. Crecelius is internationally recognized in the field of marine pollution and trace metal analysis. He is frequently an invited participant or session chairman for workshops or scientific meetings that deal with arsenic speciation, marine monitoring, and the fate of contaminants in coastal waters. He has authored or coauthored nearly 80 journal articles and nearly 75 technical reports that apply geochemistry to diverse environmental issues.

Brenda K. Lord-Lasorsa, Research Scientist V, Marine Chemistry & Ocean Processes at Battelle Marine Sciences Laboratory, received her B.S. in geology at Ohio State University in 1983 and her M.S. in geology at Ohio State University in 1986. Ms. Lasorsa is responsible for ongoing analyses as well as methods development for mercury and sulfide analysis. Experience includes assisting in development of both total and methyl mercury analysis systems and analysis of mercury in various media including tissues and sediment at the ng/g level and water at the ng/L level by cold vapor atomic fluorescence. Ms. Lasorsa has applied these speciation methods to a wide variety of matrices including tissue, sediment, hair, and water samples. She has also been responsible for the development of an acid volatile sulfide analysis system and appropriate sample handling methods associated with the system. The analytical experience with acid volatile sulfides includes an interlaboratory calibration study with the U.S. EPA in Duluth on sediments from three freshwater lakes in Minnesota, analyses of samples including experimental work on the quantity of metals released during oxidation of acid volatile sulfides (AVS) for the EPA, and analysis of dissolved sulfides and AVS in fly-ash pond sediments for EPRI.

Jill Brandenberger, Research Scientist, Marine and Environmental Chemistry, Battelle Marine Sciences Laboratory, received her B.S. marine sciences at Texas A&M University, Galveston in 1993 and her M.S. in environmental sciences at Texas A&M University, Corpus Christi, in 2001. She has a strong background in water quality issues, having been awarded a grant by the Texas Water Resources Institute to characterize arsenic concentrations in water resources of the Nueces River basin, including surface and ground waters. She designed and implemented a research project to characterize the water quality of Lake Corpus Christi Reservoir, Texas, as a function of temporal and event-driven cycling of trace metals with respect to present water chemistry and historical trends derived from sediment cores data. Ms. Brandenberger manages programs involving sediment evaluations in support of dredging operations. She specializes in trace-level mercury analysis, including the collection, preparation, digestion, and analysis of all sample matrices for mercury speciation. She also analyzes sediment and water for acid volatile sulfides (AVS/SEM).

BIODEGRADATION OF SYNTHETIC-BASED DRILLING FLUIDS

Alan H. Nguyen and Deborah J. Roberts,
Department of Civil and Environmental Engineering, University of Houston

Introduction

Offshore drilling operations in the Gulf of Mexico (GOM) generate cuttings that are contaminated with synthetic based fluids. Synthetic based fluids (SBF) are used in the drilling mud compounds to aid in the deep water drilling operation to lubricate the drill bit, control pressure, and carry cuttings to the surface. While the majority of the drilling mud is separated from the cuttings and recovered for reuse, residues left on the cuttings are discharged back to the sea floor.

The overall objective of this study is to model the natural attenuation of SBF in the deep-sea sediments. A conceptual model has been developed based on advection-diffusion-reaction equations and has been previously presented (MMS ITM 2002). The calibration of the model is performed by splitting up each term and designing experiments that isolated each term. Based on simulations using the uncalibrated model, the anaerobic reaction term (sulfate reducing reaction) was believed to be the term of most variability that directly affects the fate of SBF in the sediment. The results of the experiments designed to isolate the anaerobic SBF degradation reaction term are presented here.

Experimental

Samples of sediments from various depths in the GOM ranging from 66 m to 1135 m were selected for the experiments. The sediments were collected from both near-field and far-field locations surrounding the drilling platforms represented contaminated and uncontaminated conditions. All samples were incubated at 4^{o}C and under either atmospheric pressure or at pressurized conditions relevant to the depth of collection.

In this study, ethyl oleate was spiked into the sediments to serve as an ester surrogate component of SBF, and tetradecene was used as an olefin surrogate component of SBF. Sulfate and SBF surrogate concentrations were monitored using Ion chromatography or extraction and GC analysis, respectively.

Results

The results from this study indicate that the bacteria present in the Gulf sediments had the capability to degrade SBF. Similar decay curves for both ethyl oleate and tetradecene were obtained when the sediments were incubated under pressurized or atmospheric conditions (Figure 1A.8). There was no significant barometric effect on the degradation of SBF in GOM sediments. The anaerobic degradation of SBF in the sediments occurs simultaneously with sulfate removal, implying the activities of sulfate reducing bacteria (Figure 1A.9). In all experiments, biodegradation of the ester-based fluids occurs sooner and at a faster rate than that of the olefin based fluids.

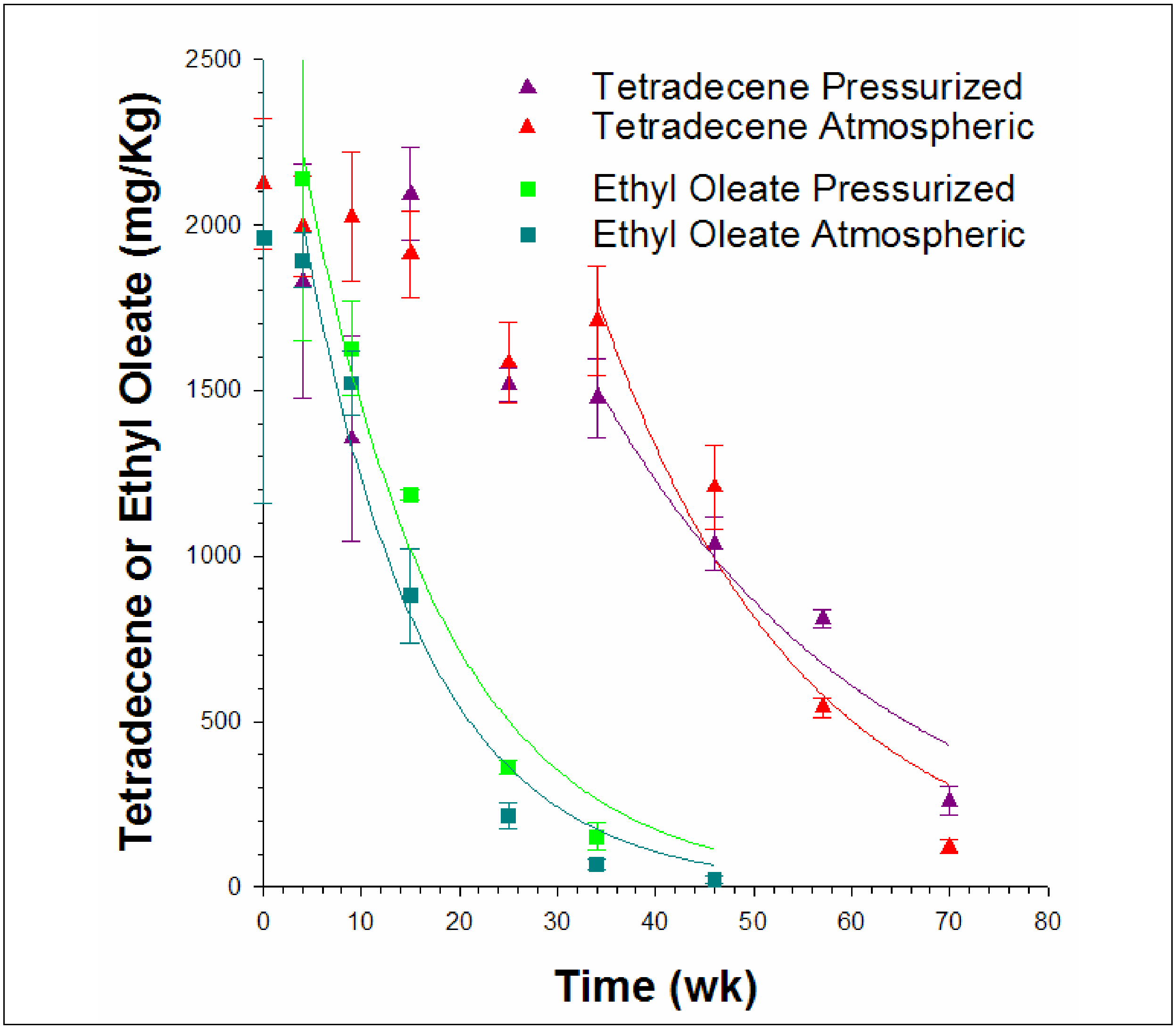


Figure 1A.8. Concentrations of ester and olefin SBF surrogates during incubation in MP299 near field sediment at 4°C and at atmospheric pressure or pressurized to 97 psi hydraulic pressure. The data points represent the average of triplicate samples and the error bars represent one standard deviation.

All experiments in this study showed anaerobic biodegradation of SBF surrogates. The biodegradation of SBF could be modeled as a first order decay with various lag times. In general, ethyl oleate decayed at the rate of 0.12 $week^{-1}$ in the uncontaminated far-field sediments and at the rate of 0.21 $week^{-1}$ in the contaminated near-field sediments. Olefin surrogates decayed at much slower rate ($k = 0.04$ $week^{-1}$) and also required a longer lag time in near field sediments. Tetradecene has not been shown to be degraded in far field (uncontaminated) sediments to date (75 weeks of incubation).

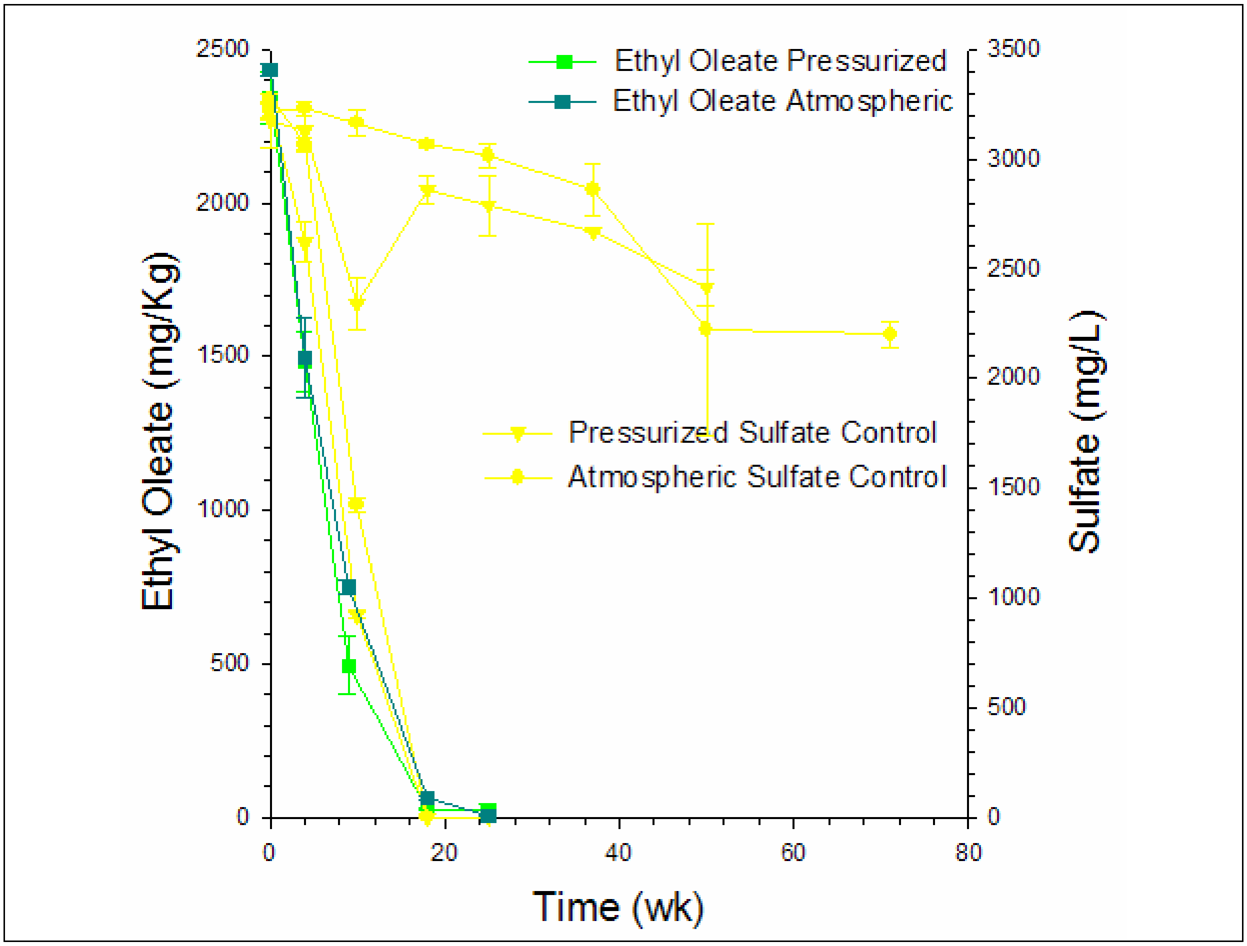


Figure 1A.9. Concentrations of sulfate in control and spiked GC112 near field sediments incubated at 4°C and at atmospheric pressure or pressurized to 97 psi hydraulic pressure. The data points represent the average of triplicate samples and the error bars represent the average of triplicate samples and the error bars represent one standard deviation.

Conclusion

Sulfate reducing reaction is a primary mechanism in the degradation of SBF. Furthermore, there is no significant barometric effect seen in the degradation rates of SBF in GOM sediments.

A lag period is required for sulfate bacteria to acclimate to the ester or olefin based fluids before biodegradation begins, this lag time is more extended in uncontaminated sediments where the bacteria have not been previously exposed to the compound. Therefore, a lag phase must be considered when modeling the degradation of olefin and ester base fluids.

The decay rates of $k = 0.12$ week^{-1} can be used to model Ester based-fluids and $k = 0.04$ week^{-1} can be used to model Olefin based-fluids.

Alan H. Nguyen obtained a B.S. in chemistry and an M.S. in analytical chemistry from Lamar University – Beaumont, Texas. From 1994 to 1999, he was a Research Scientist at Southwest Research Institute. In 2002, he joined the University of Houston's Civil and Environmental Engineering Department and is pursuing a Ph.D. in environmental engineering. He currently develops experiments to calibrate the model for predicting the attenuation of synthetic-based drilling fluids in the Gulf of Mexico sediments.

Deborah Roberts received her B.S. and Ph.D. in microbiology from the University of Alberta. She is currently an associate professor in the Department of Civil and Environmental Engineering at the University of Houston.

CHARACTERIZATION OF MICROBIAL POPULATIONS SUBSISTING UPON SYNTHETIC-BASED DRILLING FLUIDS

Kavita Swaminathan and Deborah J. Roberts,
Department of Civil and Environmental Engineering, University of Houston

Introduction

The environmental impact of cuttings contaminated with oil-based drilling mud has resulted in severe restrictions of their use in many parts of the world and has led to the development of more environmentally friendly, synthetic-based drilling fluids (SBF).

During biodegradation in the deep-sea, SBF are used as carbon sources and electron donors by microorganisms. Initially oxygen is used as an electron acceptor. Since oxygen is limited to only a few centimeters of the sediment, the next most abundant electron acceptor under marine conditions, sulfate, will be used followed by carbon dioxide. In terms of anaerobic biodegradability, theory suggests that ester-based synthetic fluids will be the first to undergo degradation under anaerobic conditions followed by alpha olefins and then internal olefins. The least degradable would be the paraffins. The possible SBF degraders include aerobes (which are mainly Eubacteria) and anaerobes (which are mainly sulfate reducing bacteria (Eubacteria) and methanogens (Archaebacteria).

This research focuses on the study of some anaerobic populations in deep-sea sediments obtained from pristine as well as oil exploration impacted areas of the Gulf of Mexico (GOM). The objective is to examine the changes in the microbial populations of GOM sediment upon exposure to SBF. This will be achieved by the use of both growth-based and molecular tools to enumerate the microorganism present in the sediment.

Sediment from sites identified as MP299 (~65m), GC112 (~500m), and VK916 (~1,100m) were used for the microbial tests. Samples of fresh sediment from near-field and far-field locations as well as the far-field samples after incubation with SBF surrogate ethyl oleate were analyzed by both the molecular-based fluorescent *in situ* hydrization technique (FISH) and the growth-based most probable number technique (MPN).

Fluorescent *In-Situ* Hydrization (FISH)

The use of FISH allows the visualization and quantification of whole microorganisms based on a partial sequence of 16S rRNA, unique to the organisms by species, genus or other genetic groupings. The cell envelopes are first weakened and then oligonucleotide probes which are fluorescently labeled are added to the samples. The probes adhere to the 16S rRNA. The cells are collected on a membrane filter and observed and counted using an epifluorescent microscope. The total number of cells present in the sample is determined using a non-specific DNA stain DAPI (4'-6-diamidino-2-phenylindole dihydrochloride). Probes used in this study were complementary to sulfate reducing bacteria (SRB385), all Eubacteria (EUB338), Clostridia (Clost I) and Archaebacteria (methanogens) (Arch915).

Most-probable number (MPN) Technique

The most-probable number growth-based technique was used to enumerate general anaerobes (using a general organic rich medium), sulfate reducing bacteria (using a sulfate medium with acetate as the electron donor), aerobic hydrocarbon degrading bacteria (using a C14 overlay on mineral salts medium), and methanogenic organisms (using a mineral salts medium with H_2 and acetate as electron donors). The media were tested for their usefulness using shoreline sediments before use with the deep Gulf sediments. A shoreline sediment was used as a control in all incubations.

Results

FISH

The application of the FISH technique to the sediment samples from the GOM was problematic. There was significant interference from organic material present in the sediment that could not be separated from the cells without significant loss of cell numbers. The detritus interference resulted in the operator having to exercise a lot of personal judgment.

All of the counts from FISH analysis were in the 10^8 range regardless of the sediment history. The total counts were not very different from the Eubacterial counts or SRB counts, suggesting that the eubacteria and SRB are being over counted or that the total counts are too low. Even though our confidence in the absolute numbers obtained is not high, examining the results in terms of the objectives suggest that the FISH analysis showed that NF (contaminated) sediment had slightly higher numbers of total counts and SRB for GC 112. This was not apparent for VK916 or MP299.

A more direct measure of the response of sediment microbes to SBF is the comparison of the numbers before and after incubation with ethyl oleate. The DAPI (total counts) increased for both the GC112 (from 9×10^7 to 1×10^9) and VK916 (1×10^8 to 7×10^8) sediments after exposure to ethyl oleate for 50 and 44 weeks respectively. The FISH analysis of SRB showed only slight increases in SRB if any increases at all.

One confounding factor in the FISH analysis is that the control cultures (not spiked with ethyl oleate) also showed increases in numbers in most of the phylogenetic groups examined.

MPN

The lower limit of the number of organisms to be observed in the case of MPN depends of the dilution series selected for the different nutritional groups. Analysis of the MPN results indicate that at time T=final there was an increase in the number of sulfate reducers when compared to those present at time T=0 (numbers). The general anaerobes at T= final also showed an increase in numbers except for VK916FF.

Conclusions

1. FISH is not the best tool to use to examine GOM sediments.

2. The analysis shows that the SRB population is increasing due to the exposure of the sediments to SBF.
3. Both FISH and MPN gave similar numbers of SRB after incubation with ethyl oleate. This suggests that the SRB in the sediment are present up to 10^8 cells/g dry sediment but are not all active until they are stimulated by the addition of carbon substrate. This contradicts the idea that the FISH probe is only measuring active organisms.

Kavita Swaminathan received her B.S. in Chemical Engineering from Bangalore University in India. She is currently pursing a Master of Science in the Department of Civil and Environmental Engineering at the University of Houston. She has been working on this project since 2003.

Dr. Deborah Roberts received her B.S. and Ph.D. in microbiology from the University of Alberta. She is currently an associate professor in the Department of Civil and Environmental Engineering at the University of Houston.

UNDERSTANDING THE PROCESSES THAT MAINTAIN THE OXYGEN LEVELS IN THE DEEP GULF OF MEXICO

Ann E. Jochens, Texas A&M University

The Minerals Management Service (MMS)-sponsored study, "Understanding the Processes that Maintain the Oxygen Levels in the Deep Gulf of Mexico," began in July 2002. Scientists with expertise in physical and biogeochemical oceanography from Texas A&M University conducted the research. The study area is the deepwater Gulf of Mexico (GOM), defined as that part of the Gulf in water depths of 400 m or more. Vertically the study area extended from sea surface to sea floor.

The objectives were to assemble and quality control the historical dissolved oxygen data base in the study area and to synthesize and re-analyze the data to understand the processes occurring in the deep GOM that effect and maintain the levels of dissolved oxygen. An evaluation was made of the effects of oil and gas activities on the dissolved oxygen levels. A simple box model was developed. Data and knowledge gaps were identified, including an evaluation of the quality of the data and how representative the data base is of the Gulf's basin environment. Methods for filling the data gaps were recommended.

Dissolved oxygen data were acquired from MMS, other state and federal agencies, national laboratories, universities, Mexican institutions, and the private sector. Two types of data were acquired: titrated measurements of water-bottle samples and measurements from oxygen sensor sensors. Dissolved oxygen data from bottle samples were obtained at nearly 4,000 stations from approximately 270 cruises in the GOM. Data from oxygen sensors were obtained for approximately 1,800 stations. It is not clear whether the sensor data were properly calibrated, so these data were not used in the analyses. The dissolved oxygen data were collected from 1922 through 2001, when this study ceased data assembly. Waters at or below 1,500 m are not well sampled, with less than 650 stations sampling from only a few bottles at those depths. Only the decades of the 1960s and 1970s had station coverage throughout the Gulf basin.

The GOM is a semi-enclosed sea with its major inflow at the Yucatan Channel and major outflow at the Florida Straits. The Yucatan Channel has a sill depth of ~2,000 m, which is deep enough to allow transport of oxygen-rich deep-source waters from the Atlantic Ocean into the Gulf from the Caribbean Sea. The Yucatan Current, which becomes the Loop Current, brings these waters in. The Florida Straits sill is shallow enough (~800 m) that the deep oxygen rich waters can mix into the interior of the Gulf rather than flowing directly out with the Loop Current.

The sources of dissolved oxygen in the upper waters (~100-200 m) in the GOM are from exchanges with the atmosphere everywhere at the sea surface, mixing mainly by wind and wave action, and local contributions from photosynthesis in the photic zone. Oxygen-rich water masses are transported into the GOM from the Caribbean Sea through the Yucatan Channel. There is no water mass formation in the GOM to replenish the deep oxygen concentrations. So, the deep circulation of the Gulf, which itself is not well-understood, and its associated mixing are the mechanisms that replenish the deep oxygen. The simple box model also found that the distribution of dissolved oxygen is primarily controlled by extra-basin effects, i.e., the source of dissolved oxygen to the deep waters is the transport and mixing of oxygen-rich water masses into the GOM through the Yucatan Channel.

The major sink of oxygen in the Gulf, as elsewhere in the world's oceans, is oxidation of organic matter. The organic matter consists of living organisms, detritus from living organisms (fecal pellets, secretions, dead organisms, etc.), natural hydrocarbon seeps that are prevalent in the Gulf, continental detritus washed into the ocean through river runoff, and anthropogenic inputs (water-borne or air-borne organic pollutants as well as inputs from hydrocarbon extraction, transportation, and consumption). The rate of oxygen consumption by organic material has not been measured in the GOM and is not easily measured in the world's ocean. However, these rates are known to decrease exponentially with increasing depth.

Early studies, using known high quality data sets, found that below approximately 1,500 m there was "no clearly discernable horizontal variation in dissolved oxygen in these waters" and "only slight vertical oxygen gradients" (Nowlin et al. 1969). Analysis of the additional data sets used in this study suggests the deep Gulf waters may have slightly different oxygen values in three different regions: the southeastern Gulf with mean dissolved oxygen concentrations of 4.99 $mL\cdot L^{-1}$, the northern Gulf with a mean of 4.95 $mL\cdot L^{-1}$, and the southwestern Gulf with mean of 4.87 $mL\cdot L^{-1}$. However, the quality of the data sets is variable enough that this finding is not definitive.

Comparison of data sets from the 1970s with those from 2000/2001 indicates that there has not been any discernible change in the vertical or horizontal distribution of dissolved oxygen in the GOM. This suggests that the transport mechanisms that replenish the oxygen are adequate to balance the oxygen consumption from decay of organic matter, including that from oil seeps and anthropogenic sources.

NRC (2003) reports that an estimated 140,000 ± 60,000 tons of hydrocarbons are introduced into the GOM from natural seeps each year. This seepage begins at the sea floor and rises through the water column to the surface, so potentially it can affect the total water column. Although this natural leakage of hydrocarbons into the Gulf has been occurring for millions of years, results of this study show dissolved oxygen levels throughout the water column have been stable over the period during which measurements are available. No significant large-scale perturbations in the dissolved oxygen content of the deep Gulf waters have been observed to result from this input.

NRC (2003) also reports that anthropogenic sources of hydrocarbons to the GOM are estimated at approximately 2000 tons from extraction (1,700 tons of which are from produced waters), 1,600 tons from transportation, and 6,800 tons from consumption. These inputs are widespread throughout the Gulf. A comparison was made between the dissolved oxygen content of selected reservoirs in the deep Gulf and the dissolved oxygen that would be consumed if all the hydrocarbons from these sources were totally oxidized within each reservoir. The results show that the impact of anthropogenic hydrocarbons on dissolved oxygen concentrations is negligible over the large scale in the deepwater GOM. Localized effects, however, might be measurable at discharge sites, but data are insufficient to evaluate these potential effects. Most of these anthropogenic discharges occur at or near the sea surface, so there would be essentially no effect on the dissolved oxygen concentrations of the deep waters.

Catastrophic oil spills can introduce hydrocarbons at two to three times the rate of the natural seeps. The effect of such spills on the dissolved oxygen concentrations would depend on many factors, including chemical characteristics of the spilled material, location in the water column and nature of the spill, residence time in the water column of labile components of the hydrocarbon as the spilled material rises toward the sea surface, and environmental conditions at the spill site, including sites to which the material may be transported. In the large scale, the impact is expected to be minimal. Effects on dissolved oxygen concentrations are expected to be local but potentially could be severe for short periods. Effects on dissolved oxygen concentrations in the deepwater Gulf of anthropogenic hydrocarbon discharges likely would be most substantial at the sediment-water interface at a discharge site or at the sea surface reached by the plume, not within the water column itself. Further study is needed to examine such effects because they are localized and complex.

References

National Research Council (NRC). 2003. Oil in the Sea III: Inputs, Fates, and Effects. Washington D.C National Academy Press. 280 pp.

Nowlin, Jr., W.D., D.F. Paskausky, and H.J. McLellan. 1969. Recent dissolved-oxygen measurements in the Gulf of Mexico deep waters. Journal of Marine Research. 27 (1) 39–44.

Ann Jochens is an Associate Research Scientist in the Department of Oceanography at Texas A&M University and Program Manager for SWSS. She has a B.S. in Mathematics and Statistics with Honor from Southern Methodist University (1974), a D.J. with background specialty in ocean law from the University of Oregon (1977), and an M.S. and a Ph.D. in oceanography from Texas A&M University (1989; 1997). Her research focus is in physical oceanography with specific interests in processes at the boundary of the coastal and open oceans; integration of physical and biogeochemical observations to analyze circulation and property transports through the ecosystem with emphasis on coastal environments; meso- and large-scale ocean circulation and property distributions with emphasis on shelf and slope regions; Gulf of Mexico physical oceanography; and development of ocean observing systems.

TOXICOLOGICAL INTERACTIONS BETWEEN METALS AND POLY-NUCLEAR AROMATIC HYDROCARBONS IN THE BENTHIC COPEPOD *SHIZOPERA KNABENI*

John W. Fleeger, Sidney J. Marlborough, Kevin R. Carman, and Soraya J. Silva, Louisiana State University

The mixture toxicology of sediment-bound contaminants (i.e., phenanthrene, lead, cadmium and mercury) frequently associated with offshore oil production platforms was investigated with the estuarine meiobenthic harpacticoid copepod *Schizopera knabeni*. Adult females were exposed to sediment amended with single contaminants and in combinations of each in 96-h LC_{50} lethality bioassays. Sublethal assays were carried out using a feeding-rate endpoint following Lotufo (1997). Contaminant effects in mixtures were delineated using toxic unit (TU) methodology and factorial experiments.

LC_{50} values for single-contaminant exposures to phenanthrene (342 mg kg^{-1}) and Cd (230 mg kg^{-1}) and a mixture of Pb, Hg, and Cd in a ratio of 5:3:2 (1,462 mg kg^{-1}) suggest that adult *S. knabeni* are very tolerant to these compounds. No significant mortality above controls was expressed by exposure to Hg and Pb below sediment saturation concentrations. However when Pb, Cd, and Hg were combined with phenanthrene, a greater than additive toxic response with a TU of 0.65 was demonstrated; the mixture was 1.54 x more toxic than predicted by separate exposures (Figure 1A.10). In addition, joint Cd and phenanthrene exposures exhibited a TU of 0.42 (2.83 x more toxic than predicted by separate exposures, Figure 1A.11). A TU_{50} was expressed at combined equi-toxic concentrations (162 mg kg^{-1}) that may be ecologically relevant. An antagonism between Hg, Pb and Cd was also apparent, and this antagonism may have moderated the observed Cd-phenanthrene synergism. A Cd-phenanthrene synergism was also observed in aqueous exposures suggesting that the synergism was dose, rather than exposure, related. Cd did not influence phenanthrene toxicokinetics (based on experiments using ^{14}C labeled phenanthrene) suggesting that phenanthrene does not interfere with Cd sequestration.

Feeding rate decreased with increasing concentrations of the metal mixture and with increasing concentrations of phenanthrene. However in combination (a single concentration of phenanthrene was added to increasing metal concentrations), effects appeared additive. Effects on feeding rate do not appear to explain the strong synergism between Cd and phenanthrene.

Results suggest that an increasing diversity of contaminants increases uncertainty in predicting mixture effects and that complex synergisms and antagonisms may be common in metal-hydrocarbon mixtures. Our work also suggests that published sediment quality criterion for phenanthrene and cadmium are protective of adult *S. knabeni,* however the strong observed synergism between Cd and phenanthrene suggests that these criteria may be not be protective in sediments with mixtures of metals and hydrocarbons, especially for the more sensitive juvenile stages.

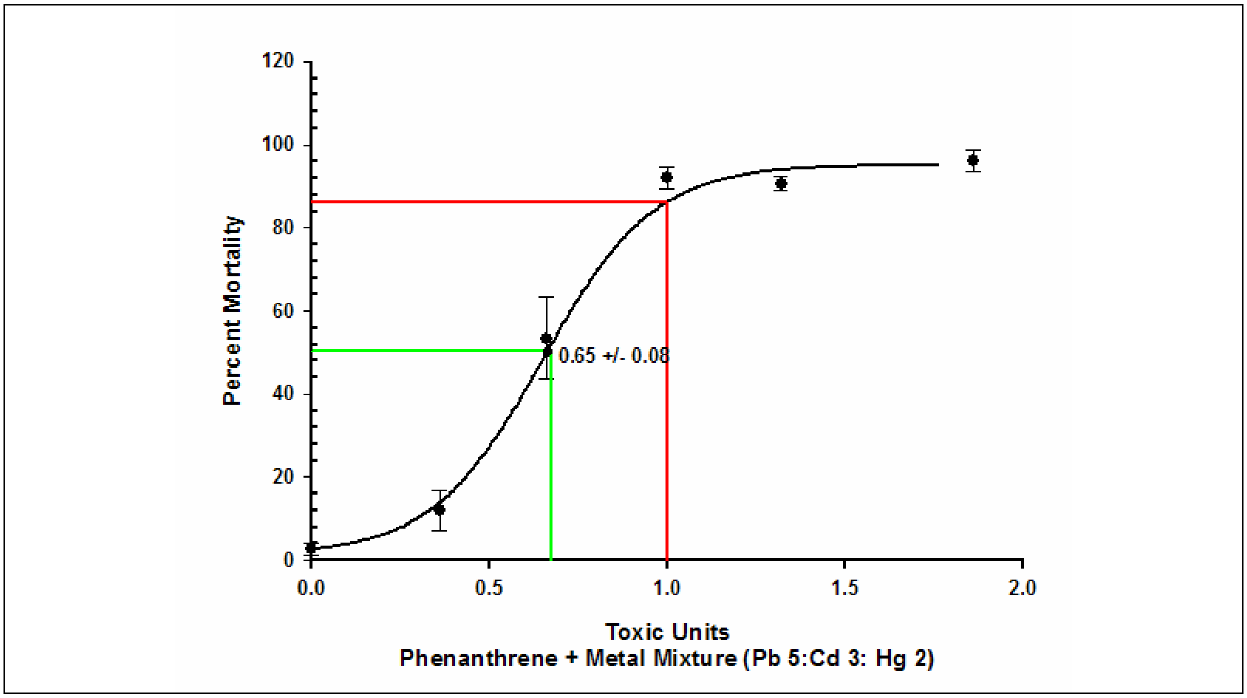


Figure 1A.10. Toxic unit results of experiments with S. knabeni combining a mixture of metals with phenanthrene. Results suggest a greater-than-additive effect.

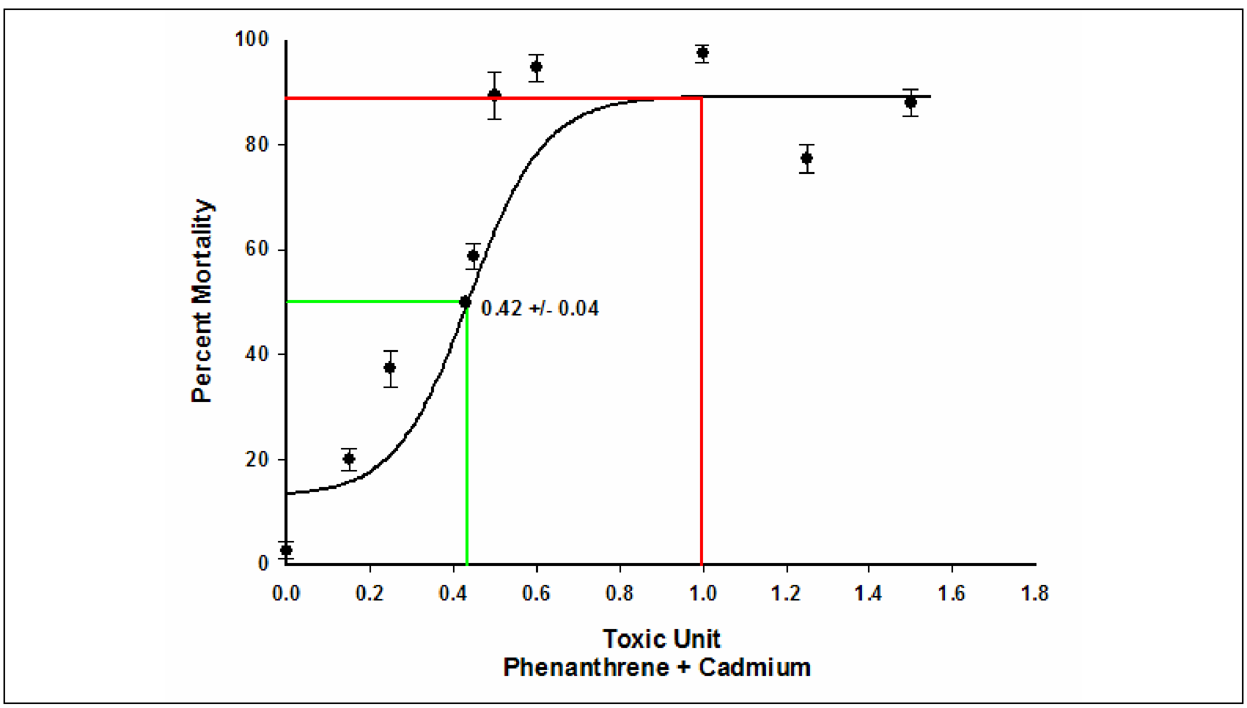


Figure 1A.11. Toxic unit results of experiments with S. knabeni combining Cd with phenanthrene. Results suggest a greater-than-additive effect.

References

Lotufo, G.R. 1997. Toxicity of sediment-associated PAHs to an estuarine copepod: Effects on survival, feeding, reproduction and behavior. Marine Environmental Research 44:149–166.

John W. Fleeger is a George C. Kent Professor of Biological Sciences at Louisiana State University. Dr. Fleeger (Ph.D. University of South Carolina 1977) is a benthic ecologist who conducts research on population dynamics and community structure of macrofauna and meiofauna. He also conducts research in the area of ecotoxicology, especially the effects of metals, hydrocarbons and mixtures. Current research projects examine the effects of nutrient addition and predators on salt-marsh communities, the effects of carbon dioxide sequestration on benthic communities in the deep sea and the effects of contaminant bioavailability on deposit feeders. His publications include over 100 articles in professional journals and chapters in books.

Sidney J. Marlborough is a research associate III with Dr. John Fleeger's lab at Louisiana State University in Baton Rouge. He conducts aquatic toxicity testing with benthic invertebrates as well as manages the research lab. He has four years of environmental and regulatory experience with the Louisiana State Department of Environmental Quality. He received both his undergraduate and graduate degrees from Louisiana State University in environmental management systems and environmental science (toxicology), respectively.

Kevin R. Carman is a professor at the Department of Biological Sciences, Louisiana State University. Dr. Carman (Ph.D. Florida State University 1989) is a biological oceanographer whose research interests include coastal marine foodwebs and the ecotoxicological effects of contaminants on estuarine communities. He is also conducting deep-sea research to examine the potential effects of CO_2 sequestration on deep-sea benthos. Dr. Carman teaches Principles of Ecology and Introductory Biology at the undergraduate level; he also teaches a graduate class on the topic of invertebrate-microbe interactions. He has published over 40 articles in peer-reviewed journals and books.

Soraya J. Silva is a Ph.D. student at the Department of Oceanography and Coastal Studies at Louisiana State University. Her research focuses in the study of the effects of diesel and copper contaminants on benthic microalgae community composition. Soraya received a masters degree in microbiology at the University of Zulia, Venezuela (1996), where she studied the effects of copper on the growth of diatoms in culture. She has been involved in several research projects related to the improvement and maintenance of a microalgae culture collection, and the coordination and performance of toxicity assays using microalgae as test organisms.

SESSION 1B

NORTHERN GULF OF MEXICO CONTINENTAL SLOPE HABITAT AND BENTHIC ECOLOGY STUDY RESULTS, PART I

Chair: **Greg Boland, Minerals Management Service**

Co-Chair: **James Sinclair, Minerals Management Service**

DEEP GULF OF MEXICO BENTHOS INTRODUCTION

Gilbert T. Rowe, Texas A&M University

The Deep Gulf of Mexico Benthos (DGoMB) study has been focused on the characteristics, faunal composition, and general well-being of sea-floor ecosystems of the deep Gulf of Mexico (GOM) in anticipation of continued extension of oil and gas exploration and production into deep-water environments. Faunal community structure is being used to test hypotheses about what controls the distribution of animal communities. Community function/dynamics is being investigated by measuring critical fluxes in the near-bottom food web. The field work has covered the entire northern GOM continental margin from depths of 200 to greater than 3,700 meters (almost two miles) in Mexican waters out on the Sigsbee and Florida abyssal plains.

DGoMB was designed to improve the ability to predict variations in the structure of animal assemblages in relation to depth, geographic location, year-to-year time-dependence, small-scale physiographic features (basins, canyons, etc.), surface-water primary production, and association with methane seeps. The structural characteristics measured were diversity, similarities in taxonomic composition between geographic locations (zonation, for example, with depth), variations in biomass and abundance, and mean size of individuals within functional size categories. An underlying premise has been that deep-sea communities are all food limited. A second assumption is that community dynamics and community structure are interdependent. An initial broad survey of community structure in the year 2000 followed by an investigation of community dynamics in 2001 and 2002. The studies of community function were limited to a seven targeted sites, with specific locations being selected on the basis of extremes in standing stocks.

Principal investigators included William Bryant (geology), a host of physical oceanographers from TAMU, John Morse and Luis Cifuentes (biogeochemistry), Bobby Joe Presley and Terry Wade (contaminant chemistry), Paul Montagna (meiofauna), Richard Haedrich (multivariate analyses of faunal data), Joan Bernhard (forams), Rowe and Fain Hubbard (macrofauna), Rowe (photography), Doug Biggs (remote sensing), Ian MacDonald (mapping), Gary Wolff (data management) and Jody Deming (bacteria). Mahlon C. Kennicutt was the Associate Program Manager.

Detailed taxonomic analyses have been conducted on the polychaete annelids (Fain Hubbard and Yuning Wang), the aplacophoran mollusks (A. Scheltema), the bivalve mollusks (Min Chen, Roe Davenport, and Mary Wicksten), the amphipod crustaceans (John Foster and Yousra Soliman), the isopod crustaceans (George Buz Wilson), the harpacticoid copepods (Yonsol Lee, Jeff Baguley, and Paul Montagna), the tanaid crustaceans (Richard Heard and Kim Larsen), the megafauna (Mary Wicksten, Daphne Fautin and associates) and the demersal fishes (John McEachran and Richard Haedrich). These are supplemented by quantitative estimates of the standing stocks of the bacteria (Jody Deming), foramiferans (Joan Bernhard), meiofauna, macrofauna, megafauna and fishes; and extensive measurements of the physico-chemical environment.

Dr. Gilbert T. Rowe completed his B.S. in zoology and M.S. in oceanography at Texas A&M before receiving a Ph.D. in zoology at Duke. He worked for 11 years as a research scientist at WHOI and eight years as a research scientist at the Brookhaven National Lab on Long Island. In 1987 he returned to Texas A&M to become Head of the Oceanography Department. He transferred to the Galveston campus in 2002 as Head of Marine Biology. Since 1999 he has been the Program Manager of MMS's Deep Gulf of Mexico Benthos project (DGoMB), now nearing completion.

PHYSICAL OCEANOGRAPHY OBSERVATIONS OF THE GULF OF MEXICO DURING DGoMB: 2000–2002

Steven F. DiMarco, Ann E. Jochens, and Matthew K. Howard,
Texas A&M University

Introduction

The earliest attempt at a comprehensive synthesis of the physical oceanography of the Gulf of Mexico (GOM) is found in Capurro and Reid (1972). Since then, and particularly in the last 15 years, the study of the physical oceanography of the GOM has greatly accelerated. Much, if not most, of this increased study has been funded by the MMS acting in response to intense energy exploration and production activities on the shelf, slope, and rise.

The GOM is a semi-closed basin with both broad and narrow continental shelves surrounding a deep abyss reaching ~3,800 m. Nowlin et al. (2001) examined the available measurements of currents in the deepwater GOM and determined the background currents by extracting the maximum, mean, and standard deviation for each instrument. They found that the highest maximum and mean current speeds were near the sea surface with maxima reaching up to 200 $cm \cdot s^{-1}$ in the eastern Gulf and 100 $cm \cdot s^{-1}$ in the western Gulf. Current speeds decreased with depth tending toward a minimum near 1,000 m. Current speeds increased somewhat with depth below that level, likely due to bottom intensification of currents.

Wind stress forcing is second only to the forcing by the Loop Current system in providing energy to the circulation in the Gulf. Wind forcing occurs both as low-frequency regional circulation patterns forced by low-frequency regional wind patterns and as episodic currents forced by high frequency atmospheric events including tropical cyclones, extratropical cyclones, cold air outbreaks, and other frontal passages.

The world's third largest river, the Mississippi River, and dozens of lesser rivers discharge tremendous volumes of fresh water into the GOM. This affects stratification over large areas and enhances wind-driven coastal jets along frontal boundaries. Thus, thermohaline forcing is important over the Gulf shelves, e.g., buoyancy forcing by river discharge affects the nearshore coastal currents over the shelves. However, no thermohaline forcing of consequence is known to occur in the deepwater Gulf.

Data

Standard physical oceanographic instrumentation and sampling procedures were used to collect measurements on the DGoMB cruises. All such sampling was done to the same standards and using similar types of equipment as used on the MMS-sponsored programs LATEX-A and NEGOM-COHS. Data taken consisted of four types—continuous profiles, discrete measurements, ADCP measurements (shipboard and moored), and supplementary underway measurements. Continuous vertical profiles were collected for seawater conductivity/salinity, temperature, pressure/depth, fluorescence, light transmission, optical backscatterance, downwelling irradiance, and dissolved oxygen. Discrete water samples were taken for analysis of dissolved oxygen and nutrients (phosphate, silicate, nitrate, nitrite, ammonium, and urea), phytoplankton pigments, particulate matter, and particulate organic carbon at most stations and salinity at selected stations.

CTD stations (60 total) were taken on the May/June 2000 (DG1), June 2001 (DG2), and June 2002 (DG3A) cruises. None were taken on the August 2002 (DG3B) cruise. Water samples were collected at the CTD stations.

ADCP measurements were made along track on DGoMB cruises in May/June 2000 (DG1), June 2001 (DG2), and June 2002 (DG3A). Although not paid for by the contract, ADCP data were collected on the August 2002 (DG3B) cruise as a complementary data set. Either a 150-kHz broadband (S/N 1183) ADCP or a narrow-band (S/N 355) ADCP was operated simultaneously with an Ocean Surveyor 38 kHz **(**OS-38**)** ADCP (S/N 8). No 38 kHz data were collected on the June 2001 cruise. All ADCP instruments were manufactured by RD Instruments (RDI) of San Diego, California. The OS-38 is on loan from the U.S. Navy.

A 300-kHz Workhorse ADCP (Model 300S Sentinal rated to 6,000 m) was deployed during the June 2001 and 2002 cruises at selected experimental stations. The instrument was lowered and left at the sea floor at the beginning of each experimental station. Locations, dates, and times of deployment are given in Table 1B.1.

Table 1B.1. Locations, dates, and times of deployment of the moored ADCP.

Name	Start Date/Time	End Date/Time	Latitude (°N)	Longitude (°W)	Depth (m)	Station Name
2001-1	03 June 2001	04 June 2001	28.2210	89.4991	935	MT3
2001-2	06 June 2001	07 June 2001	28.2501	88.4168	755	S42
2001-3	09 June 2001	12 June 2001	28.9200	87.6690	1823	S36
2001-4	13 June 2001	14 June 2001	26.9999	88.0000	1740	MT6
2002-1	03 June 2002	05 June 2002	25.0000	90.0000	3525	Sigsbee
2002-2	10 June 2002	11 June 2002	24.2500	85.5000	3410	Low_curr2

Although not contractually required, one or two thermosalinographs were operated intermittently during the DGoMB cruises. One system collected data from approximately 2.5-m depth; the other from about 3.5-m depth. The systems logged temperature and conductivity continuously at approximately 1- or 2-minute intervals on DGoMB cruises DG1, DG2, and DG3A.

Water Properties

Temperature and salinity measurements were made on the DGoMB cruises in May/June 2000, June 2001, and June 2002. Measurements of nitrate, phosphate, silicate, and dissolved oxygen concentrations were made on the cruises in 2000 and 2001. The vertical patterns of these water properties were analyzed. The station spacing did not allow detailed or meaningful examination of horizontal patterns. However, the vertical patterns were related to features in the circulation field shown by the sea surface height fields.

The general salinity pattern for all stations consists of four major characteristics. Most notable is lack of horizontal variability in salinity below depths of approximately 1000 m. This is present in all station CTD data. Second is a salinity maximum. This maximum erodes the farther from the source waters the station is located. However, this is not simply a function of distance from the Loop Current. The third characteristic of the salinity profiles is the salinity minimum at about 500–1,000 m or σ_θ of 27.3-27.5 kg·m^{-3}. This is associated with the Antarctic Intermediate Water that is brought into the Gulf by the Loop Current. The depth at which this minimum occurs is variable. It appears to be related to the type of eddy feature the station sampled or the proximity to the bathymetric effect of the slope. The fourth characteristic is the variability in the near-surface salinity values. Here are considered the salinities in the upper 50–100 m. These upper waters have lower salinity concentrations at that depth. Part of this, of course, is related to the presence of the salinity maximum. However, part of the variability is due to the mixing of low salinity water discharged from the Mississippi River with the near-surface oceanic waters. Of the selected stations shown in Figure 1B.1, the lowest near-surface salinity values occur at S36, which is located southeast of the Mississippi River. Other stations west as well as east of the Mississippi River mouth exhibit low salinity. In the cases examined, there were circulation features adjacent to the Mississippi River mouth that likely transported shelf water, which had been diluted by mixing with river water, to the slope regions adjacent to the river. This situation has been observed in other programs (Belabbassi et al. 2004).

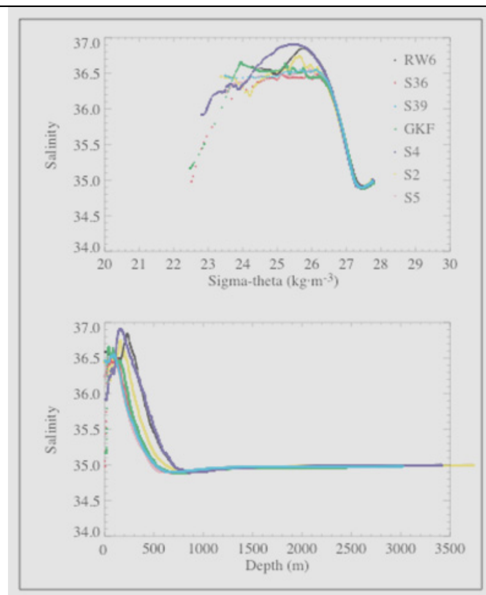


Figure 1B.1. Selected station data showing salinity versus density (top) and depth (bottom). Shown are stations RW6 (2000) in a Loop Current Eddy in the western Gulf, S36 (2000) in a cyclonic eddy in the eastern Gulf, GK-Furrows (2001) at the edge of a Loop Current Eddy in the central Gulf, S4 in the Loop Current, S2 at the edge of a Loop Current Eddy in the south central Gulf, and S5 at the edge of a cyclone in the eastern Gulf.

Moored Current Observations

During the 2001 summer cruise, a 300-kHz ADCP was deployed at each of four process stations (MT3, S42, S36, and MT6). The instrument was placed 35 m above bottom in a downward-looking configuration. The deployments were short, ranging from 20–60 hours. Because of the short deployment period, these observations should be considered as a representative snapshot of the physical conditions that existed while each process station was occupied. The current observations should not be considered as the climatology of currents possible at each location. To determine the current climatology, a much longer current meter record is required.

The near-bottom currents at the four process stations during summer of 2001 were generally weak with record-length mean speeds of about 2.5, 7.5, 2.5, and 5 cm/s at stations, MT3, S42, S36, and MT6, respectively (Figure 1B.2). Mean directions were generally aligned along local bathymetry. Vertically, current speeds decreased slightly with closeness to the bottom. Standard deviations of speed were generally consistent for all four deployments at 1-2 cm/s. The sea temperature at the ADCP transducer head was nearly constant throughout each deployment at 5.0°, 6.0°, 4.1°, and 4.2°C. Vertical and error velocities (an indicator of the amount of horizontal inhomogeneity of currents in the water column) were small (1-2 cm/s) for all deployments.

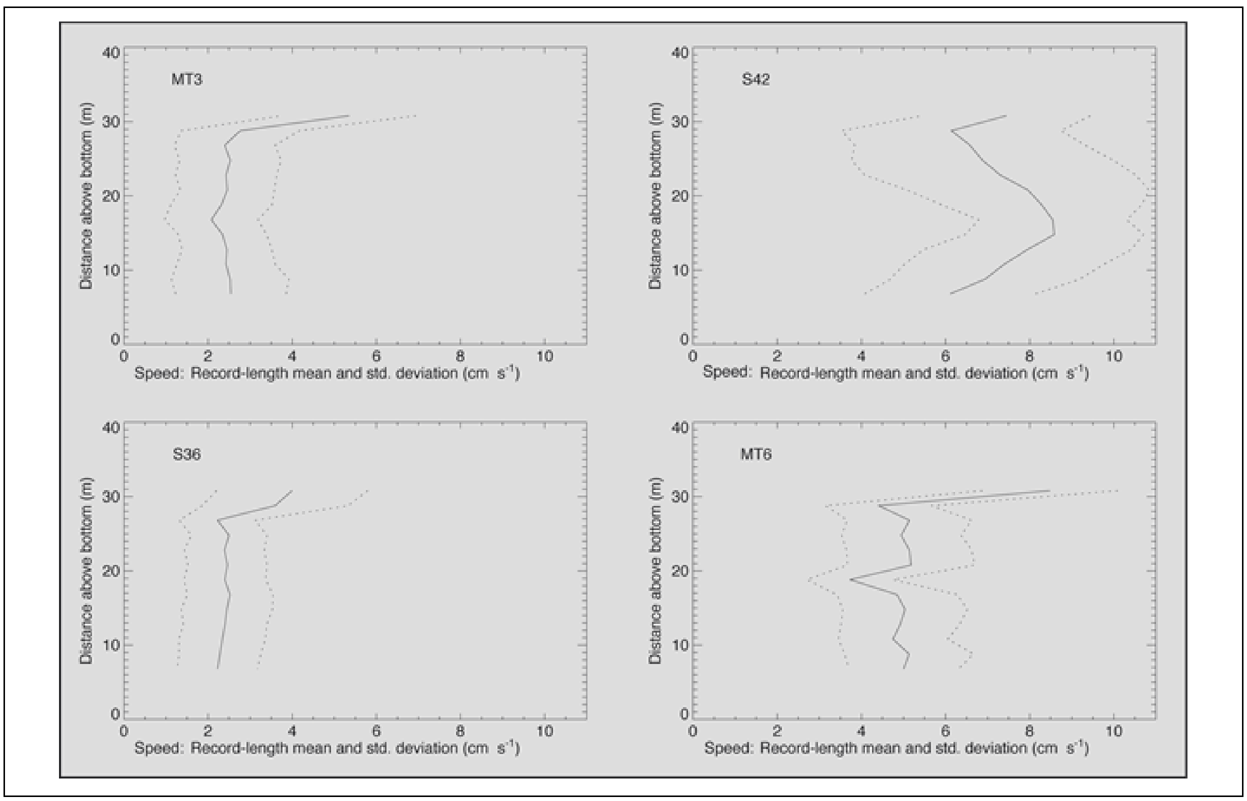


Figure 1B.2. Record-length mean speed (solid) and plus and minus one standard deviation (dashed) of currents measured using a bottom-moored downward-looking 300-kHz ADCP during four deployments in 2001. Instrument was 35 mab. Deployment sites are: MT3 (top left), S42 (top right), S36 (bottom left), and MT6 (bottom right).

At S42, there was some vertical structure as the record-length mean cross-slope velocity changed sign at about 20 m above bottom; down-slope below 20 m and upslope above 20 m. There was no change in the along-slope component. Both velocity components were dominated by a near-diurnal oscillation with amplitude of about 7 cm/s and about 6 hours out of phase. Because of the short deployment, it is not possible to determine whether this oscillation is due to tidal forcing or of inertial origin. Diurnal oscillations were also present at stations MT3, S36, and MT6, although significantly weaker then at S42, i.e., amplitudes of 2–3 cm/s.

Shipboard Current Observations

Shipboard ADCP observations of near-surface currents along the cruise track of each cruise were obtained using 150 kHz and 38 kHz ADCPs. During the summer of 2002, the track of both cruises extended from the northern Gulf to the Loop Current. During Cruise 4 in June 2002, the cruise track passed through or near several energetic circulation features including the Loop Current, a detached Loop Current Eddy (24°N, 94°W), a strong cyclone northwest of the Loop Current, and other weaker features. In general, currents were aligned with altimeter contours of sea surface height. The strongest observed currents during this cruise were associated with the Loop Current and the currents associated with anticyclonic features. In the Loop Current, currents exceeded 135 cm/s in the upper 100 m and 100 cm/s in the upper 150 m. Useful observations were limited to the upper 200 m because of the operation frequency (153-kHz) of the ADCP used (the 38-kHz ADCP failed to produce useful data).

Currents in the weak anticyclone near 27°N, 90°W peaked above 60 cm/s and averaged greater than 30 cm/s in the upper 200 m. Similar values were found on the eastern limb of the Loop Current Eddy. Mean currents in the upper 200 m of the water column ranged from 38 cm/s at 10 m depth to 13 cm/s at 200 m. The standard deviation similarly ranged from 25 cm/s at 10 m to 10 cm/s at 200 m.

During Cruise 5, August 2002, the central GOM was nearly devoid of energetic circulation features as evidenced by a nearly flat SSH field (Figure 3). The dominant feature was the Loop Current, which extended slightly further northward than seen in June 2002. Currents in the Loop Current exceed 180 cm/s to 50 m depth and 120 cm/s to 150 m (Figure 1B.3). The standard deviation of currents while in the Loop Current is nearly constant with depth at about 13 cm/s. Record length mean currents for this cruise decay from about 30 cm/s at the surface to about 10 cm/s at 200 m.

Acknowledgments

The authors thank Ou Wang (now of JPL) and Yue Fang (TAMU) for ADCP data processing. This work was sponsored by the U.S. Minerals Management Service under Contract No. 1435-01-99-CT-30991.

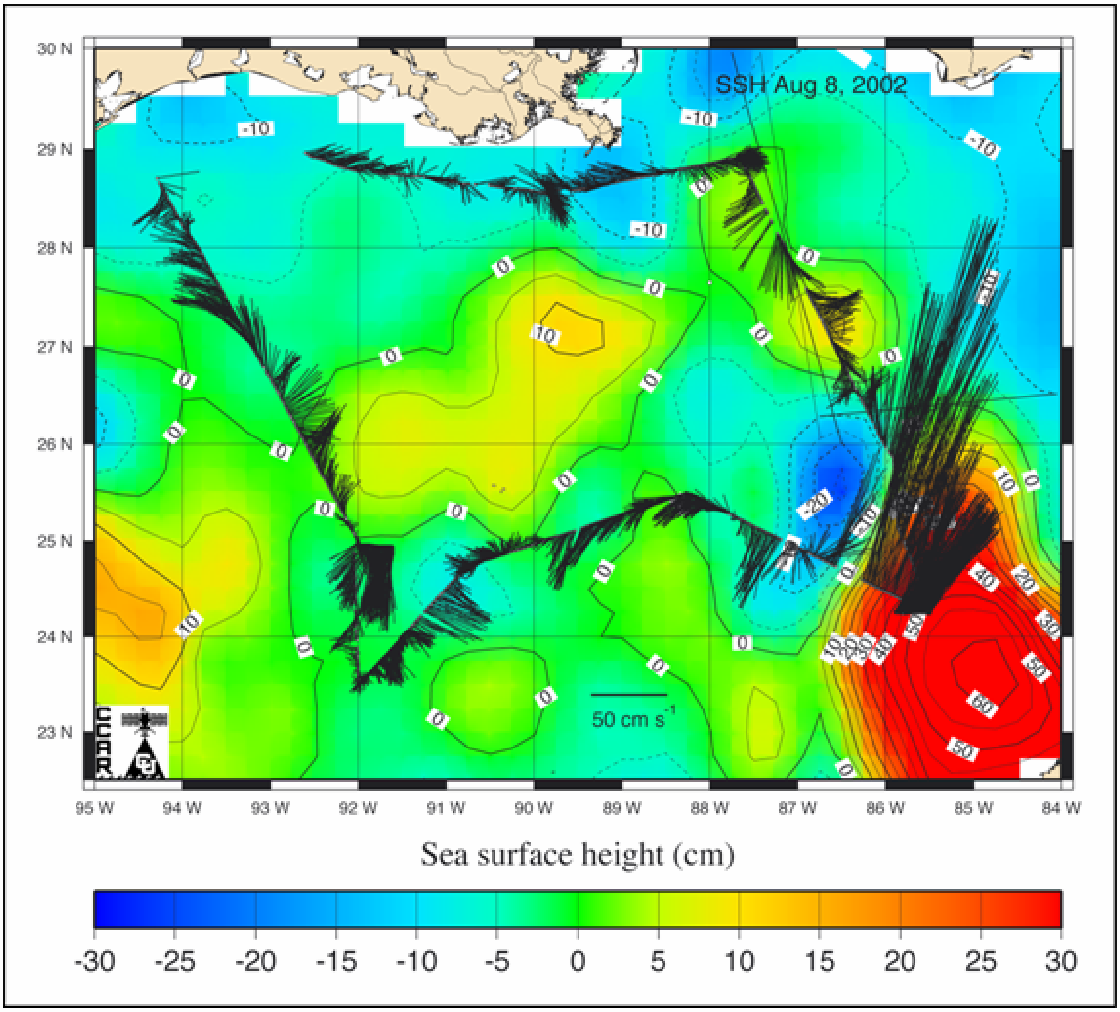


Figure 1B.3. Contours of sea surface height from satellite altimeter data and near-surface velocity vectors from shipboard ADCP during August 2002. SSH data are from 8 August 2002 and courtesy of R. Leben (CU).

References

Belabbassi, L., W.D. Nowlin, Jr., A.E. Jochens, D.C. Biggs, and P. Chapman. 2004. Summer-time nutrient supply to near-surface waters of the northeastern Gulf of Mexico: 1998, 1999, and 2000. In preparation.

Capurro, L. R.A., J.L. Reid, eds. 1972. Contributions on the Physical Oceanography of the Gulf of Mexico. Galveston, Texas: Texas A&M University Oceanographic Studies. 288 pp.

Nowlin, Jr., W.D., A.E. Jochens, S.F. DiMarco, R.O. Reid, and M.K. Howard. 2001. Deepwater Physical Oceanography Reanalysis and Synthesis of Historical Data: Synthesis Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2001-064. 528 pp.

Steve DiMarco is an Associate Professor at Texas A&M University. His professional interests include physical oceanography of the Gulf of Mexico and the southwest Indian Ocean, hypoxia of the northern Gulf of Mexico, ocean observing systems, nonlinear surface wave interaction and impact of extreme wind events on shelf circulation

Ann Jochens is an Associate Research Scientist in the Department of Oceanography at Texas A&M University and Program Manager for SWSS. She has a B.S. in Mathematics and Statistics with Honor from Southern Methodist University (1974), a D.J. with background specialty in ocean law from the University of Oregon (1977), and an M.S. and a Ph.D. in oceanography from Texas A&M University (1989; 1997). Her research focus is in physical oceanography with specific interests in processes at the boundary of the coastal and open oceans; integration of physical and biogeochemical observations to analyze circulation and property transports through the ecosystem with emphasis on coastal environments; meso- and large-scale ocean circulation and property distributions with emphasis on shelf and slope regions; Gulf of Mexico physical oceanography; and development of ocean observing systems.

Matthew Howard is an Assistant Research Scientist in the Department of Oceanography at Texas A&M University.

SeaWiFS OCEAN COLOR AT DGoB STATIONS

Douglas C. Biggs, Department of Oceanography, Texas A&M University
Chuanmin Hu and Frank E. Müller-Karger,
College of Marine Science, University of South Florida

Synopsis

The amount of particulate organic carbon reaching the seabed is set by the annual primary production in near-surface waters, less losses from grazing and/or remineralization in the water column. Because primary production covaries as the time rate of change in phytoplankton biomass in near surface waters, we used SeaWiFS ocean color data to calculate biweekly averages of the chlorophyll concentration (CHL) in surface waters at each of the 44 DGoMB stations in the northern Gulf of Mexico (GOM). In a previous ITM presentation, we described the annual cycle of CHL at a typical deep water DGoMB location, and we also showed how in the northeastern GOM this deepwater cycle is modified when slope eddies often entrain and transport Mississippi River water eastward and off margin. For this year's ITM presentation, we review these patterns and summarize how the 1998–2000 time series that we've presented previously has been extended using SeaWiFS data through September 2004, and by follow-on field surveys of the 1,000 m isobath in the NE GOM in summers 2001–2003.

Introduction

Phytoplankton pigment concentration in the first optical depth in the deepwater GOM undergoes a well-defined seasonal cycle that is generally synchronous throughout the region. Müller-Karger et al. (1991) reviewed monthly climatologies of near-surface phytoplankton pigment concentration from multiyear series of coastal zone color scanner (CZCS) images for the period 1978–1985. They reported that highest near-surface CHL occurs between December and February and lowest values occur between May and July. They also reported there is only about a three-fold variation between the lowest (~0.06 mg m^{-3}) and highest (0.2 mg m^{-3}) deepwater near-surface CHL.

At the previous ITM (January 2003), we reported our analysis of 1998–2000 ocean color data collected during the follow-on Sea viewing Wide-Field Sensor (SeaWiFS) mission (Biggs et al. 2003). At the 22 DGoMB stations over the continental slope in the western GOM (west of 91^{o}W), we saw essentially the same annual cycle in magnitude and phase of CHL that was reported from the predecessor CZCS mission. However, at the 22 DGoMB stations over the continental slope in the eastern GOM (east of 91^{o}W), we reported there were large biweekly variations in both magnitude and phase of the mean CHL concentration. These variations were correlated with the presence of mesoscale eddies that occur along or near the continental slope in the eastern GOM. Because especially in summer these slope eddies can entrain low salinity, high CHL Mississippi River water, and transport this green water off shelf and into the deepwater of the eastern GOM, the highest near-surface CHL concentrations in the NE Gulf were not present exclusively in December–February; rather, they reached annually highest levels in May–July.

Results and Discussion

Table 1B.2 summarizes the annual mean CHL at western versus eastern northern GOM DGoMB stations for the three-year period 1998–2000. Note that the annual mean averages 4.9 times higher in the east than in the west, and that there is greater variability about the mean in the east as well. These relative differences are best seen by animating the biweekly scenes, as we did at the previous ITM (January 2003) to show the year-year period as a movie that runs January 1998 through December 2000. In that animation, the biweekly-composite scenes clearly show the periodic entrainment and transport offshore of high-CHL Mississippi River water by mesoscale eddies in the eastern GOM. An extension of these SeaWiFS biweekly composites through September 2004 has recently been completed, which shows that the off-margin transport of green water in the NE Gulf continued in summers 2001, 2002, and 2003 (Biggs et al. 2005). The full seven-year time series, October 1997 through September 2004, will be available in CD-ROM format to an appendix to a monograph on "New Developments in the Circulation of the Gulf of Mexico." That monograph is expected to be published later in 2005.

Table 1B.2. Summary of remotely-sensed chlorophyll concentrations, 1998–2000.

DGoMB region	Mean SeaWiFS CHL	Number of Stations	Std Dev of Mean CHL
W of 91°W and N of 26°N	0.19	22	0.03
E of 91°W and N of 26°N	0.93	22	0.59

Figure 1B.4 shows the seasonal cycle of CHL at the nine deepest of the "Deepwater Stations" in the western GOM (RW6, AC1, W5, W6, NB5, B1, NB4, B2, and B3). Water depth at each of these nine stations was greater than 2 km. The top panel in Figure 1 shows the average biweekly CHL at each of the nine stations for the three years 1998–2000, while the bottom panel graphs the average biweekly concentration (averaged for the three years). In the top panel, each of the three-year time series were fit station-by-station using spline fits. In the bottom panel, the annual cycle has been summarized by a quadratic fit to the averages of three years of biweekly data at the westernmost deepwater station, RW6. Both of these visualizations show the pattern previously reported from analysis of the CZCS archives by Müller-Karger et al. (1991): deepwater CHL is lowest in spring-summer (Julian Days 100–250) and highest November–February (Julian Days 330–60).

East of 91°W, the "typical" deepwater annual cycle in CHL was often swamped by unusually high CHL, especially during summertime. Figure 1B.5 shows that high surface CHL in summertime was evident at the three stations along the Eastern Transect (S44, S43, S42), at five of the six stations on the Mississippi Trough Transect (MT1-MT5), and at the three stations farthest upslope along the Central Transect (C1, C7, C4). High summertime CHL generally occurred, as well, at three of the stations farthest upslope along the DeSoto Canyon Transect (S35, S36, S37). Because of this, the annual mean CHL concentration at the 22 DGoMB stations east of 91°W averaged 0.9 rather than 0.2 mg m^{-3} (Table 1B.2).

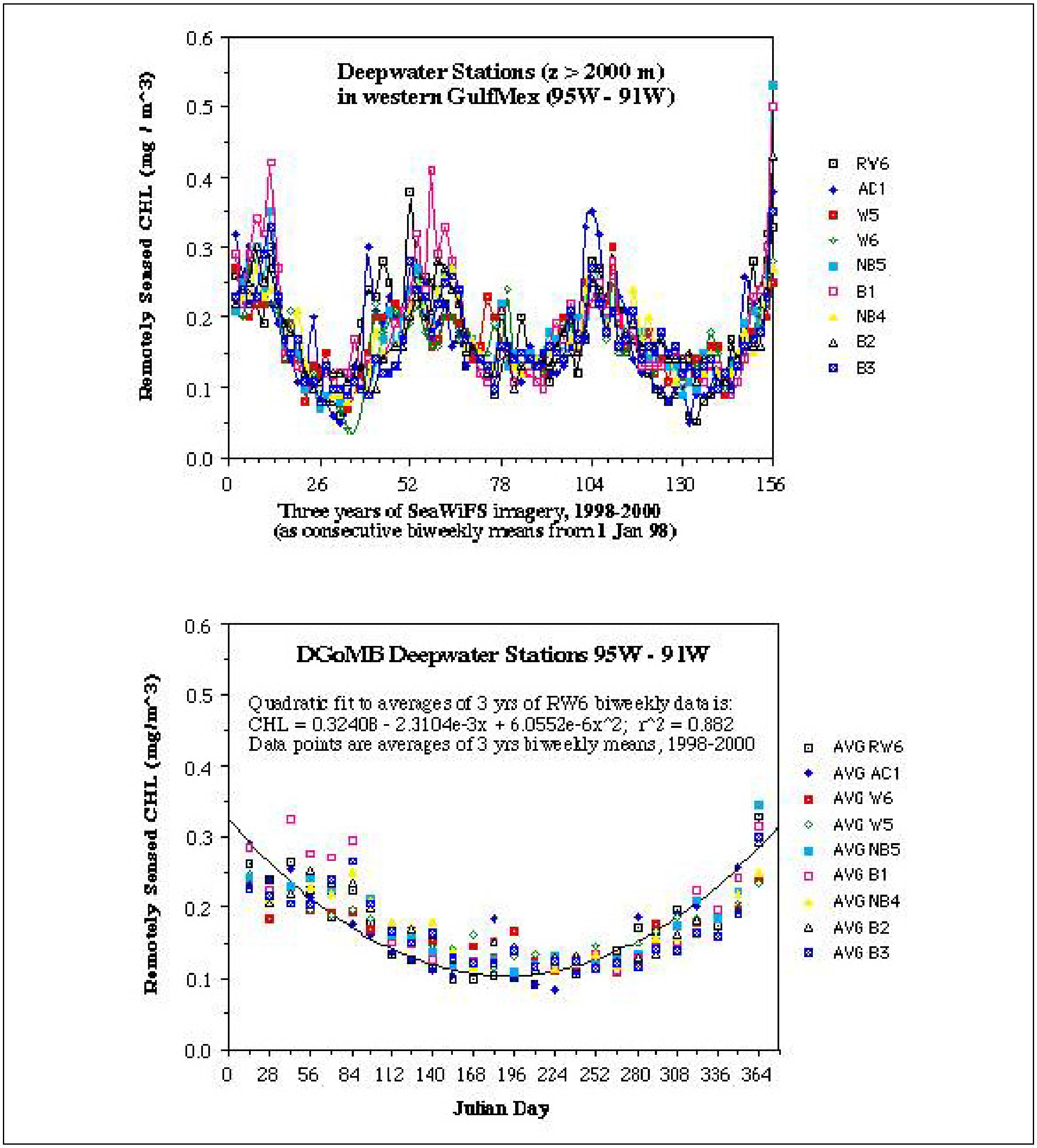


Figure 1B.4. Top panel: Three year climatology of biweekly composited SeaWiFS ocean color data 1998–2000 at the nine DGoMB stations in water depth > 2000 m in the western Gulf of Mexico. Bottom panel: The average annual cycle of chlorophyll at these western Gulf of Mexico deepwater stations, illustrating the typical annual range from summertime lows of about 0.1 mg m^{-3} to November–February highs of about 0.3 mg m^{-3}.

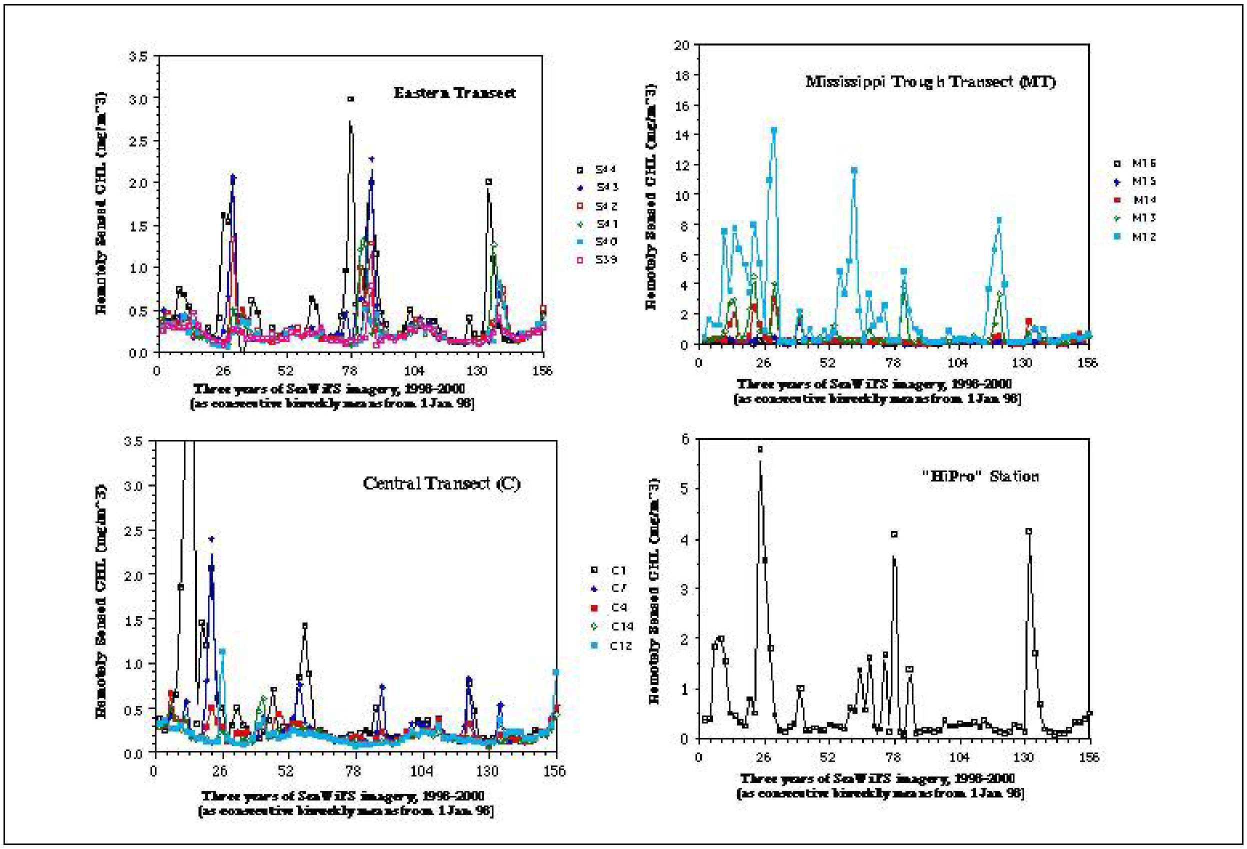


Figure 1B.5. Three year climatology of biweekly averaged SeaWiFS ocean color data 1998–2000 at the DGoMB stations east of 91°W in the eastern Gulf of Mexico. Ocean color was converted to chlorophyll concentration (mg m^{-3}) using SeaDAS4.4 software.

A combination of remote sensing altimetry data and hydrographic data collected from R/V *Gyre* in support of the Northeastern GOM Chemical Oceanography and Hydrography program (NEGOM) has provided the explanation why this occurs. Both ship and altimetry data show that in summers 1998, 1999, and 2000, warm slope eddies (WSEs) were centered over the deepwater of the DeSoto Canyon. In general, anticyclonic eddies with SSH > 25 cm are considered to be strong WSEs, while those with SSH of just 10–20 cm are considered to be weaker WSEs. A strong WSE that was centered south of 28°N in summer 1999, as well as less strong WSEs located farther north on the slope in summers 1998 and 2000, all acted to entrain low salinity, high CHL "green water" from the Mississippi River and transport this green water plume seaward into deepwater. As a result, high surface CHL in summertime was evident at most of the DGoMB stations on the Mississippi Trough Transect (MT1-MT5), and at the three stations farthest upslope along the Central Transect (C1, C7, C4), and at the three stations farthest upslope along the DeSoto Canyon Transect (S35, S36, S37). High summertime CHL occurred, as well, at three of the stations along the Eastern Transect (S44, S43, S42).

That WSEs in deepwater of the eastern GOM do indeed entrain low salinity Mississippi River water and transport it off margin has been verified by Belabbassi (2001), from analysis of near-surface salinity data collected during R/V *Gyre* NEGOM cruises in summers 1998, 1999, and 2000. By carrying out high performance liquid chromatography (HPLC) analyses of the phytoplankton pigments collected from R/V *Gyre* in these low salinity plumes during these same cruises, Qian et al. (2003) verified that this low salinity water had locally high CHL standing stocks.

Colored dissolved organic matter (CDOM) fluorescence and light absorption coefficient were also measured along with surface salinity and chlorophyll during most of the R/V *Gyre* NEGOM cruises conducted in 1998–2000. Strong correlations between the CDOM absorption coefficient (a_{g443}) and CDOM fluorescence (330 nm excitation and 450 nm emission filters) were consistently observed (Nababan 2005). Relatively high a_{g443} (≥ 0.1 m^{-1}) was generally observed inshore (inner shelf) near the major river mouths, but this a_{g443} also decreased rapidly with distance from shore except when riverine waters were entrained and transported offshore by WSEs. Because CDOM as well as CHL contributes to the ocean color signal measured by SeaWiFS, in our time series of biweekly composites we have likely over-estimated CHL at the shallower DGoMB stations. Specifically, the CHL spikes > 10 mg m^{-3} shown in Figure 2 at stations MT1 and MT2 close off the Mississippi River delta may be overestimated by perhaps 30–50%.

Slope eddies contribute biological and physical heterogeneity along the continental margin of the northern GOM. Temporal and spatial variations in the geometry of the eddy field along the middle slope determine whether low salinity green water flows off-margin or high salinity blue water flows on-margin. We hypothesize that more surface primary production sinks out from green water than from blue water regions. We also hypothesize that green water features that persist for weeks to months in time likely are the most important in the export of POC from surface waters.

How much phytoplankton production of these surface waters reaches the seabed? If on average 10% of the primary production sinks out of the photic zone, and if 3–10% of this flux in turn reaches the seabed, then at a western GOM deepwater location just 100–360 mg C m^{-2} y^{-1} might reach the benthos. However, productivity in "hot spots" of locally higher nutrient concentrations over the continental slope can be more than an order of magnitude higher than the typical 100–150 mg C m^{-2} d^{-1} (Biggs and Ressler 2001). Specifically, we hypothesize that in such "hot spots" and at most of the stations in water depths < 2,000 m along central and eastern DGoMB transects C, MT, and S, POC input rates to the benthos are likely to be at least 0.93/0.19 = 4.5 times higher-than-average.

Acknowledgments

TAMU support came from MMS contracts 1435-01-97-CT-30851, 1435-01-99-CT-30991, and 1435-01-02-CA-85186. USF support came from NASA contracts NAS5-97128 and NAG5-10738. SeaWiFS data are property of Orbimage Corporation and data use here is in accordance with the SeaWiFS Research Data Use Terms and Conditions Agreement of the SeaWiFS project.

References

Belabbassi, L. 2001. Importance of Physical Processes on Near-Surface Nutrient Distributions in Summer in the Northeastern Gulf of Mexico. M.S. Thesis, Department of Oceanography, Texas A&M University, College Station, TX. 85 pp.

Biggs, D.C., A.E. Jochens, M.K Howard, S.F. DiMarco, K.D. Mullin, F.E. Müller-Karger, and C. Hu. 2005. Eddy-forced variations in on-margin and off-margin summertime circulation along the 1000 m isobath of the northern Gulf of Mexico, 2000–2003, and links with sperm whale distributions along the middle slope. In: New Developments in the Circulation of the Gulf of Mexico. American Geophysical Union.

Biggs, D.C., A.W. Remsen C. Hu, and F.E. Müller-Karger. 2003. Ocean color climatology of chlorophyll at DGoMB stations in 1998, 1999, and 2000, and its use as a proxy for POC flux to the seabed. Proceedings, Information Transfer Meeting, January 2003. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-067.

Biggs, D.C. and P.H. Ressler. 2001. Distribution and abundance of phytoplankton, zooplankton, ichthyoplankton, and micronekton in the deepwater Gulf of Mexico. Gulf of Mexico Science. 19:7–35.

Müller-Karger, F.E., J.J. Walsh, R.H. Evans, and M.B. Meyers. 1991. On the seasonal phytoplankton concentration and sea surface temperature cycles of the Gulf of Mexico as determined by satellites. Journal of Geophysical Research 96:12645–12665.

Nababan, B. Bio-optical Variability of Surface Waters in the Northeastern Gulf of Mexico. 2005. Ph.D. Dissertation, Department of Marine Science, University of South Florida, St. Petersburg, FL. 124 pp.

Qian, Y., A.E. Jochens, M.C. Kennicutt II, and D.C. Biggs. 2003. Spatial and temporal variability of phytoplankton blooms and community structure over the continental margin of the northeast Gulf of Mexico based on pigment analysis. Continental Shelf Research 23:1–17.

Douglas Biggs is a Professor of Oceanography at Texas A&M University. In addition to his service as a co-PI on DGoMB, Biggs was a co-PI on MMS-sponsored NEGOM-COH and GulfCet-II projects and he is presently working to define the oceanographic habitat use by cetaceans in the NE Gulf of Mexico as part of an interagency MMS-ONR-NSF study known as the Sperm Whales Seismic Studies program (SWSS).

Chuanmin Hu is a research scientist and Executive Director of the Institute for Marine Remote Sensing (IMaRS) at the College of Marine Science University of South Florida. He has

participated in the NASA sponsored SIMBIOS and MMS-sponsored NEGOM projects. He is working on ocean color remote sensing in coastal waters and is principal investigator on several NASA and USGS funded projects.

Frank Müller-Karger is Professor and Director of IMaRS at the College of Marine Science, University of South Florida. Müller-Karger's research focuses on primary production in the sea, and he uses remote sensing (ocean color, SST, SSH) to study the importance of continental margins, including areas of upwelling and river discharge in the global carbon budget.

GEOLOGY

William Bryant, Texas A&M University

The deep Gulf of Mexico (GOM) surface sediment that affects the deep-living biota is composed for the most part of terrigenous lutite. A carbonaceous sand fraction, composed of pelagic foram tests, can reach 20 to 30% by weight at eastern sites on the Florida margin but remains below 10% west of the Mississippi Cone. Deep sites on and below the Sigsbee and Florida Escarpments are often etched by deep furrows the size of buses. These furrows are parallel to the bathymetry and are or have been formed by strong currents, presumably, although direct evidence for this is as yet lacking. Intermittent meso-scale (5 to 10 km diameter) basins and mounds are the product of halokinesis, or the remolding of subseafloor salt deposits. These basins may create unique habitats for benthic biota by trapping sedimenting POC. Some are characterized by hydrocarbon seeps. No evidence exists thus far that such basins without seeps contain any sort of peculiar faunal assemblages. An effect of small-scale topographic variation within the basins on biological distributions has yet to be established, but ought to be considered in future studies. Vertical profiles of sediment physical properties appear to vary between sites across the entire northern GOM. It is suggested that the variability of shear strength within cores is directly proportional to bioturbation intensity.

Dr. William Bryant is the Enron Professor in the Department of Oceanography at Texas A&M University, College Station, TX. He recently initiated a program in archaeological oceanography in collaboration with the Institute of Nautical Archaeology and the Department of Anthropology at Texas A&M.

CONTAMINANT CHEMISTRY: POLYCYCLIC AROMATIC HYDROCARBONS (PAH) AND TRACE ELEMENTS

Terry L. Wade, Gary A. Wolff, and Bobby J. Presley, Texas A&M University

Introduction

The concentrations of polycyclic aromatic hydrocarbons (PAH) and trace elements were determined for the surface (top 2 cm) sediment samples collected from the Gulf of Mexico (GOM) on DGoMB cruises 1, 2, 3a, and 3b. These samples represent 50 stations. Some of the trace elements determined are known to be major constituents of drilling fluids (Ba, Cr), others, such as antimony, arsenic, beryllium, cadmium, copper, lead, manganese, mercury, molybdenum, nickel, silver, tin, thallium, vanadium, and zinc are of environmental concern. In addition, aluminum, calcium, iron and silicon were determined to facilitate recognition of sediment trace metal natural variations, differences in sediment texture and mineralogy. All PAH and trace element analyses had acceptable spike recoveries and acceptable results for standard reference materials which validate the analytical results.

Results and Discussion: PAH

PAH are major toxic components of petroleum. The sources of PAH to offshore sediments include natural petroleum seepage, production platform operations, atmospheric deposition and spills. Previous studies of production platforms indicate that the sediments close to the platform (<500m) contain elevated concentrations of PAH and selected trace elements (Ag, Ba, Cd, Hg, Pb, and Zn). PAH and trace elements at the platform sites were below concentrations expected to cause biological effects in biota. None of the sites reported here were within 500 m of any platforms. Concentrations for total PAH ranged from not detected (ND) to 1,033 ng/g with a mean of 140 ng/g. Some sites were sampled and analyzed as replicates from one cruise. Some sites were sampled during more than one cruise.

Perylene is a PAH produced by biological processes as well as by combustion. Perylene is often detected as the major PAH in sediments from relatively pristine areas. In the sediment samples analyzed for this study, the percentage of perylene of total PAH ranged from 0 to 63%. Perylene concentrations ranged from ND (<1 ng/g) to 110 ng/g with a mean of 17 ng/g. Other PAH are predominantly from anthropogenic sources. The geographic pattern of perylene concentrations is complex, and it does not co-vary with the total PAH distribution. The six (6) highest perylene concentrations are at sites S26, MT1, C1, B2, NB4, and RW6. These sites are found through the sample area with no discernable geographic pattern.

Sites with higher concentrations of total PAH include MT1, MT3, and C1. These sites, based on their PAH distribution, can be divided into two types of sites with PAH predominantly from oil and those with PAH predominantly from combustion sources. For sites MT1 and MT3, oil appears to be the major source of PAH. For C1, combustion sources predominate. Combustion PAH in the sampling area may be discharged from ships or platforms (e.g., bilge pumping) or come from atmospheric deposition of PAH from onshore industrial areas or sediments transported from coastal areas. The ship/platform operations are the most likely sources as atmospheric deposition would be expected to produce similar PAH concentrations over large regions. The geographic distribution of PAH indicates a possible input from PAH in transported sediments from the Mississippi River.

When the frequency distributions for total PAH found in this study are compared to those for near shore studies (NOAA NS&T and EPA-EMAP-NC), the median PAH concentrations for this study are lower by about a factor of four. Total sediment PAH concentrations greater than 4,000 ng/g are expected to elicit a biological effect 10% of the time (Long and Morgan 1990). The highest total PAH concentration found in sediments from this study (1,033 ng/g) is four times less than the biological effects level. Therefore, it is unlikely that the PAH at any of these sites are having a major effect on the associated biota.

Results and Discussion: Trace Elements

The sedimentation rates at the abyssal plain Gulf sites, as well as the source, mineralogy, and grain size of the sediments there, are different from those at the continental shelf and slope sites. For this reason, trace element data for these two areas are discussed separately. Average concentrations of the potential contaminant metals Ag, Cd, Cu, Hg, Pb, and Zn in the shelf and slope samples are similar to average crustal abundances and to average values for areas of the northern Gulf of Mexico thought to be low in anthropogenic metals. Average values are not the best way to evaluate this data due to the relatively small number of samples and the considerable variability in the data. It is better to consider the slope of a best-fit line through the data for each element versus Al or Fe scatter plot. Either Al or Fe can be used to normalize trace metal concentrations in these samples, as these two elements exhibit a strong co-variance. Trace metal concentrations strongly co-vary with Al and Fe in "normal" sediments. Data points that fall above a best-fit line on these plots imply anthropogenic influence or some mineralogy or biogeochemical processes.

When concentrations of several elements in the DGoMB continental shelf and slope samples are plotted against Al, most data points are close to a best-fit line and have almost the same slope as plots for Mississippi River Delta sediments. This is expected because the Mississippi River is the most likely source of most of the silicate fraction of the sediments at these sites. A good line fit is found for Be, Co, Cr, Fe, Si, Tl, V, K, Mg and Zn, all of which have positive slopes on the metal versus Al plots and for Ca and Sr, which have negative slopes. Thus, for these metals there is no indication of additions from human activity or other geochemical processes. Rather, the metal concentrations in a particular sample are a function of the relative amounts of trace metal rich Mississippi River derived silicate material and trace metal poor plankton derived carbonate in the sample. The interpretation is more complicated for the elements Ni, Pb, Cd, As and especially Cu whose concentrations show considerable scatter on the metal versus Al plots. Furthermore, the slopes suggest a general enrichment in these elements of 25 to 50% over Mississippi River derived material.

Concentrations of Mn are more variable and much more elevated over Mississippi Delta material than are concentrations of any of the other elements. It is very unlikely that this observed Mn enrichment is due to human influence. Rather, it is likely the result of remobilization of Mn from depths in the sediment column where reducing conditions exist. The Mn released at depth diffuses up through the sediment column and re-deposits in near-surface sediment when it encounters oxidizing conditions. This phenomenon has been well documented for northern GOM sediments (Trefry and Presley 1982). Other metals have been shown to respond to the same remobilization and precipitation process that affects Mn (e.g., Presley et al. 1992) and it seems likely that these processes are functioning in the DGoMB area. Even though there is not a strong correlation between Ni, Pb, Cd and Cu concentrations and Mn, it seems likely that all have been affected by similar biogeochemical processes. The variable between these metals may result from intensity of reducing conditions at the different sites and by differences in the amounts of available sulfide, which would more readily precipitate some metals than others.

In contrast to the elements discussed above, barium (Ba) concentrations at selected sites are higher than those of average clay-rich sediments but are typical of sediments from near oil well platforms in the northern Gulf of Mexico. In the case of Ba, it seems likely that the enrichments, as high as a factor of ten, are due to disposal of oil well drilling mud. Drilling mud can contain 90 % Ba (Boothe and Presley 1985). Thus, small amounts of mud could account for the Ba enrichments seen in the sediments. The Ba-enriched samples are from the three shallowest water sites in the Mississippi Trough (sites MT1, 2 and 3) and from site C1 and WC5 just to the west of these. All are in an area of intense petroleum exploration and development. Previous studies have found even greater enrichments of Ba near drilling platforms (e.g., Boothe and Presley 1989). Even at the most Ba-enriched sites in the present study, the concentration is well below that thought to adversely affect organisms (e.g., Neff et al. 1989).

The four abyssal plain sites sampled in this study were widely separated geographically. These deep water samples were typically about 10% Ca (mostly from $CaCO_3$) compared to the 1% Ca in shelf sediments. This additional $CaCO_3$ diluted the clay in these sediments, resulting in a reduction in Fe and Al concentrations. There was considerable variation in the concentrations of the major elements, Ca, Fe. Al and Si, between sites and between replicate cores at a given site showing the "patchiness" of surface sediment lithology (i.e., $CaCO_3$ content) in the deep Gulf. Nickel, and especially Cu and Mn concentrations are higher in the deep Gulf samples than would be expected for shelf samples with equivalent Fe and Al concentrations, but this was not true for Cr and Zn. One could propose that the carbonate phase of these deep samples is enriched in Cu and Mn, but it seems more likely that these metals have been mobilized by reducing conditions at depth, have migrated up through the pore water, and been re-oxidized and precipitated in the near surface sediments resulting in an enrichment there. This is the same process that affected some slope sediments, as was discussed above.

Silicon and Ti in the deep samples have been diluted by the added carbonate by about the same percentage that Fe and Al have, as would be expected. Strontium is much higher in the deep samples, again as would be expected based on the carbonate content. However, Mg does not seem to be enriched. The carbonate in these deep samples is about 5% Sr except for anomalously low Sr at site S1. We have no explanation for the low Sr values or the lack of Mg enrichment but assume it is related to the type of carbonate present at the different sites.

Summary

The concentrations of PAH measured for the DGoMB project from offshore sites are low, as expected. Perylene, a PAH with a biogenic source, is the major PAH detected at many locations indicating a biological origin. Sites that have higher PAH concentrations (MT3, MT1 and C1) also have high barium concentrations. This indicates that drilling operations in the vicinity of these sites is one likely source of PAH. Total sediment PAH concentrations at all sites were less than 1,033 ng/g. It is unlikely that the PAH concentrations found at any of these sites would have a major adverse effect on the biota living in these sediments. The carbonate-rich deep Gulf (abyssal plain) samples collected on DGoMB differ in metal concentrations from the clay-rich shelf and slope samples. However, there is no indication that these deep sediments have been affected by human activity. Rather, natural depositional and biogeochemical processes are responsible for the differences found. The shelf, slope, and abyssal plain samples analyzed for this project were a mixture of carbonate and terrigenous silicate materials and thus varied considerably in major element (aluminum, calcium and iron) concentrations. Trace metal concentrations also varied considerably, as would be expected with a varied mineralogy. In the shelf and slope samples, concentrations of the elements Al, Ca, Sr, Na, K, Mg, Be, Co, Hg, Cr, Ti, V, and Zn were normal for coastal Gulf of Mexico sediments with equivalent Fe concentration. Copper, As, Cd, Pb, Ni and especially Mn concentrations were found to be somewhat higher than those in Mississippi Delta and shallow GOM samples but were not unexpectedly high considering the deeper water from which the present samples came. The enrichments are likely due to complex natural transport and biogeochemical processes, not to human activity. The strong Ba enrichments of up to almost a factor of ten in a few samples are likely due to the presence of residues of oil well drilling muds discharged from the many drilling platforms in the area. Based on literature data, none of the metal concentrations in the study area sediments are high enough to adversely affect marine organisms.

References

Boothe, P.N. and B.J. Presley. 1985. Distribution and behavior of drilling fluids and cuttings around Gulf of Mexico drilling sites. American Petroleum Institute, Washington, DC. 140 pp.

Boothe, P.N. and B.J. Presley. 1989. Trends in sediment trace element concentrations around six petroleum drilling platforms in the northwestern Gulf of Mexico. In: Proceedings, 1988 International Conference on Drilling Wastes, Calgary, Canada, 5–8 April. Pp. 3–21.

Long, E.R. and L.G. Morgan. 1990. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program. NOAA Technical Memorandum NOS OMA 52. Seattle, WA: U.S. Dept. of Commerce, National Oceanographic and Atmospheric Administration. 215 pp.

Neff, J.M., R.J. Breteler, and R.S. Carr. 1989. Bioaccumulation, food chain transfer, and biological effects of barium and chromium from drilling muds by flounder (*Pseudopleuronectes americanus*) and lobster (*Homarus americanus*). In: Engelhardt, F.R., J.P. Ray, and A.H. Gilliam, eds. Drilling Wastes. London: Elseveir Applied Science Publishers. Pp. 439–460.

Presley, B.J., R.J. Taylor, and P.N. Boothe. 1992. Trace metal concentrations in sediments of the eastern Mississippi Bight. Marine Environmental Research 33:267–282.

Trefry, J.H. and B.J. Presley. 1982. Manganese fluxes from Mississippi Delta sediments. Geochimica et Cosmochimica Acta 46:1715–1726.

Dr Terry L. Wade received his Ph.D. in oceanography in 1978 from the University of Rhode Island. Dr Wade is the Deputy Director for Environmental Sciences with the Geochemical and Environmental Research Group and an Adjunct Professor in the Oceanography Department at Texas A&M University.

Dr. Gary A. Wolff and Dr. Bobby J. Presley have recently retired from their positions at Texas A&M University.

BIOGEOCHEMISTRY OF THE NORTHERN GULF OF MEXICO SEDIMENTS: A COMPONENT OF THE DEEP GULF OF MEXICO BENTHOS (DGoMB) PROJECT

John Morse, Texas A&M University

A wide variety of related biogeochemical features were measured in association with the DGoMB project. Solid phase and pore water constituents included organic carbon and nitrogen, DOC, inorganic nutrients, DIC, stable carbon isotopes, and terminal electron acceptors iron, manganese, sulfate and sulfide, oxygen and nitrate/nitrite. Organic carbon varied from a fraction of a percent on the abyssal plain to just over 1% in the Mississippi Trough, which is a remarkably small range. Lower values were encountered in the sandy sediments in the eastern region than in the central area adjacent to the Mississippi River outflow. Population densities of bacteria, meiofauna and macrofauna correlated with organic carbon in the sediments. Oxygen penetration depth into the sediments (OPD) was minimal in areas of high biomass (Mississippi Trough) near shore but extensive in deep water offshore (abyssal plain), reflecting low respiration rates in areas with low organic enrichment. Sulfate reduction was not encountered at any site. Manganese reduction was observed in the Mississippi Trough on the upper slope, but nowhere else. Bioturbation rates, measured using radionuclide tracers, correlated with macrofaunal biomass. Sediment oxygen consumption, measured with a free-vehicle lander carrying incubation chambers, declined exponentially with water depth.

John Wilbur Morse was born in Fort Dodge, Iowa. His education included a B.S., Institute of Technology, University of Minnesota (geology) , and an M.S. and Ph.D. from Yale. He served on the faculties at the University of Miami and Florida State University prior to joining Texas A&M. He is an Associate Editor of *Marine Chemistry* and the Editor-in-Chief *Aquatic Geochemistry*. His research interests include application of chemical thermodynamics, surface chemistry, and chemical kinetics to the study of natural waters and sediments; sedimentary biogeochemistry of carbonate and sulfide minerals; chemistry of trace metals in anoxic sediments; benthic fluxes; mechanism of vein filling of fractures and carbonate reactions in the subsurface, chemical evolution of early oceans on Earth and Mars.

SEDIMENT BACTERIA ABUNDANCE, BIOMASS, RESPIRATION AND PRODUCTION: NORTHERN GULF OF MEXICO CONTINENTAL SLOPE AND ABYSSAL PLAIN

Jody Deming and S. Carpenter,
School of Oceanography, University of Washington

Bacteria were sampled from replicate box cores during the Deep Gulf of Mexico Benthos (DGoMB) studies in order to map distributions as a function of water depth, physiographic features, and sediment biogeochemical properties. Counts of living bacteria were made in the sediments using a combination of acridine orange and DAPI stains. As a result, the densities of bacteria in surficial sediments can be mapped across the entire area. Highest numbers were encountered in the upper Mississippi Trough and the De Soto Canyon. Surprisingly, there was no statistically significant relationship with depth, when all the data were lumped together, due to high densities on the abyssal plain. At the six process sites, incubations were conducted using C-14 labeled dissolved free amino acids at *in situ* temperature and pressure to determine uptake, respiration and production as a function of depth in the sediments. Production was also measured using tritiated thymidine incubations.

Bacterial biomass was the highest of all the living components of the benthos at all sites, and the relative importance of the bacteria relative to the invertebrates increased with increasing depth and distance from shore. This high biomass suggests that the bacteria function as an important intermediate between relatively unreactive organic detritus in the sediments and the metazoans at higher levels of the food web. Because the respiration and production rates for the bacteria measured experimentally using tracers were considerably below the entire sediment community oxygen consumption (based on *in situ* chamber incubations), the role of the bacteria in organic matter cycling in deep-sea sediments however remains equivocal.

Dr. Jody Deming grew up in Houston on the outskirts of River Oaks. She did her undergraduate work at Smith College in Springfield MA and her Ph.D. under Dr. Rita Colwell at the University of Maryland. Following post-doctoral work at Scripps with Dr. Art Yayanos, she took a position on the faculty at the University of Washington, where she is now a Professor in the School of Oceanography. Her ground-breaking work on bacterial processes in extreme environments led to her election to the National Academy of Sciences in 2003.

Ms. Shelly Carpenter is an accomplished researcher who has worked with Dr. Deming for more than a decade.

SESSION 1C

OFFSHORE OIL ORAL HISTORY PROJECT

Chair: **Harry Luton, Minerals Management Service**

Co-Chair: **Kimberley Cook, Minerals Management Service**

THE OFFSHORE OIL AND GAS HISTORY PROJECT: INTRODUCTION TO THE SESSION

Harry Luton, Minerals Management Service, Gulf of Mexico OCS Region
Diane Austin, Bureau of Applied Research in Anthropology, University of Arizona

This is the second ITM that included a session on the MMS Offshore Oil and Gas History Project, and it will probably be the last since the History Project is nearing conclusion. The MMS Studies Program in the Gulf supports many and varied socioeconomic research efforts, but even so the History Project is unusual.

Its budget totals nearly a million dollars, more that twice that of the next largest socioeconomic study and five or six times their average cost. Oceanographic and biological studies are expensive; socioeconomic ones tend not to be.

The History Project has also drawn on the efforts of an unusual number of institutions. Organizations that have played significant roles include

- LSU Center for Energy Studies
- University of Arizona Bureau of Applied Research in Anthropology
- University of Houston Department of History and History International, LLC
- ULL Public History Program and Sociology Department
- Nicholls State Archives
- Louisiana Technical Colleges

The History Project is more humanities-oriented than the average socioeconomic study that MMS funds; it collects reminisces of individuals rather than data that directly supports economic or social analysis. The History Project stresses the collection of information rather than its analysis; indeed, it was intentionally designed to collect more than it was budgeted to analyze.

MMS funds applied research—research that provides information and analysis that supports management decisions on the OCS—and while the History Project may be unusual in applied socioeconomics, these characteristics express the very reasons the study was funded.

The offshore petroleum industry is a complex multitude of businesses engaged in finding, producing, transporting, and marketing oil and gas from beneath the ocean that make up an enormous and dynamic piece of the worldwide economy. However, offshore oil began small, in coastal Louisiana, and what it has become is due in large measure to the hard work, inventiveness, and entrepreneurship exhibited by south Louisiana residents in adapting land-based activities to ocean environments. This transformation is one of the more poorly documented and understood chapters in the history of the industry. This dearth of information led the agency to fund the History Project for several reasons:

- Knowing this history would provide the agency with a better understanding of the types and causes of social and economic effects that the industry has had.
- The study would serve as "scoping" for environmental assessments; the people that have experienced the industry would be identifying salient impacts from their points of view.
- The study would provide a form of "mitigation"; by providing to the public the material it collects, it will be giving back to impacted communities a thing of value.
- The founders of the industry are in their 70s, 80s and 90s. If the information was to be collected, someone had to begin soon.

The fourth reason actually ties the others together and helps explain the History Project's focus on data collection, the earliest decades of the industry, and MMS's commitment to moving forward with adequate support. Although this study, like all agency-funded studies, is applied, agency personnel from the top down also saw it as the right thing to do.

The History Project has been active for almost three years, and during that time it has accomplished a great deal. It has emphasized the collection of oral histories. To date:

- Over 450 people have been interviewed.
- All interviews are being transcribed.
- All interviews are being summarized and catalogued.

These interviews reflect the agency's applied aims and other concerns. They

- Focus on 1940s, 1950s, and 1960s
- Focus on highly impacted communities
- Include people from a wide range of sectors and companies

In addition to the interviews, the study team has digitized historic photographs offered by the interviewees as well as interviewee descriptions of each. To date:

- Over 900 digital copies of photos have been collected.
- A database describing each photo has been developed.
- Interviews and transcripts to accompany photos have been included.

While the History Project has focused on these collections, it has a large analytical component as well:

- An interim report of analytical essays is available.
- A final report is due in the summer of 2005.
- Conference papers and presentations have been given.
- Journal articles have been published.

Finally, the History Project includes a substantial public educational and outreach component. The study team and MMS are making efforts to get the word out:

- A traveling exhibit will open 23 January 2005 at the Southdown Plantation Home in Houma, LA. From there it will probably move next to Lafourche.
- The study team is working in collaboration with National D-Day Museum to archive interviews and film interviewees for permanent exhibit on connections between WWII and the offshore oil and gas industry.
- Educational websites and accompanying materials will be completed by summer 2005.

MMS sees the History Project as providing a valuable resource to the community. All the interviews and photos that have been collected include waivers allowing for their non-commercial use. MMS plans to place all these materials into the public domain, in places were they will be easily accessible. The agency is proud of what the History Project has accomplished. However, one hope has yet to materialize—the hope that the agency's actions will stimulate other institutions to continue this work. For more information go to the following web site:
www.gomr.mms.gov/homepg/regulate/environ/history_louisiana.html

---

Harry Luton was born in Michigan. He received his undergraduate degree from the University of Michigan, a master's degree from the University of Pennsylvania, and his doctorate from the University of Michigan. Since 1982, he has worked in MMS's environmental assessment branch, first in Alaska, then Headquarters and, for the last nine years, the Gulf of Mexico OCS Region.

Diane E. Austin is an assistant research anthropologist in the University of Arizona's Bureau of Applied Research in Anthropology (BARA). She specializes in the development of community-based participatory research methodologies and coordinates BARA's internship program. Her major interests include environmental anthropology; social impact assessment; environmental justice; community development; and research methods and analysis. She began studying the impacts of the offshore oil and gas industry on southern Louisiana in 1996.

TERREBONNE PARISH AND THE OIL SERVICE INDUSTRY: THE CASE OF FLOATPLANE AVIATION

James L. Sell, University of Arizona

This is a discussion of how the oil industry can affect the historical development of a community. My area of operation was Terrebonne Parish, which is very much in the center of the Louisiana coastal oil field. Its development is complementary to much of the rest of the area. I say complementary, rather than parallel, because of certain distinctive features in its history.

The most distinctive aspects of Terrebonne Parish were its

1. Land base, which was accessible for both land and water transport.
2. The large oil fields inshore of the barrier islands, which led to its concentration on inshore rather than offshore activities.
3. The role of Texaco as the major producer in the parish, which was the major employer of oil workers and service businesses.
4. The development of a large set of oil service industries that, at first served the inshore fields, and later had to adapt from a local to a global business model as inshore gave way to offshore production.

Our primary approach is through oral history, which has some effects on the information received. The most evident effect is the creation of "chains of informants" that comes from the final interview question—"Who else should I talk to?" One of the clusters of people in our set of interviews about Terrebonne Parish happened to be floatplane pilots. This shouldn't come as a surprise, considering the watery nature of the Parish oil fields, but I hope to use the rise and fall of the floatplane industry as an example of the way oil-field service businesses needed to cope with changes in the industry.

The view of the early oil fields that comes from the interviews has been one of a free-wheeling work environment, in which certain problems arise that need rapid solution, such as the need for mud to hold down gas pressure, casing to shore up loose rock strata, and fishing tools to recover lost equipment. The oil service businesses develop as people see a need and either adapt an existing technology or develop a new one to meet that need. Within that field, some businesses succeed and others fail as technologies and conditions change. It is also easy to assert, that to some extent, the problems solved in the inshore fields were necessary precursors to the move offshore.

The problem addressed by the aviation industry is the isolation of the oil fields.

Business Climate

The climate in which business was conducted was one of

1. Remote, Mobile Drilling Sites. Not only were many of the areas isolated, but the drillers themselves were on mobile drilling barges, moving along channels dredged in the wetlands.
2. Dispersed Decision Power. The primary decision maker for drilling business (at least before 1980) was the toolpusher at the drilling site. Sales and service people had to approach this supervisor directly.
3. Money Secondary to Production. The primary need was speed in getting the wells ready for production. The high cost of drilling a well meant that any problem that stopped the process was expensive; therefore, the toolpusher on the spot had a large budget.

So as CJ Christ noted, this decision power was a huge responsibility for someone who rose through the ranks from roughneck to driller to toolpusher:

> Here's a guy, a lot of times with no formal education, he got all of his experience on the drilling rig … and he's got a budget of millions. His basic instruction is to go out there and drill that well—"You know the area. You know the problems you are likely to encounter. You know the people you can count on. Just go out there and drill that well." That puts a big responsibility on his shoulders because now he is lavishly entertained all the time, and there was a lot of profit in this business, a lot of profit (Christ 2003).

Terrebonne Parish is about 60 miles south-southwest of New Orleans. As this land use map shows, it's mostly wetland. The planning department notes that the parish has 8% buildable land (dry land) and 92% "environmentally sensitive" land (read waterlogged—marshland, wetland, and swamp).

This is a view of the "landscape" today. Once, much of the area was forested, but now the forest is mostly gone, from a combination of over-cutting and saltwater intrusion. This gives a good impression of the waterlogged oil field environment and shows why floatplanes were so useful.

Pilots who were primary informants for the study include:

- Lloyd Geist. 1945–92. He fell in love with flying after riding with barnstormers who came to Houma in 1930. A fighter pilot in Europe during WWII, he returned home after the war and set up a charter service and flying school in Houma in 1946. Lloyd is the dean of floatplane pilots. He was one of the first to replace wheels with pontoons and qualify himself as a floatplane pilot, because nobody else had any experience when he started. He started the first seaplane base in Houma in 1950.

- CJ Christ. 1956–89. He was a Korean War B-29 pilot. He worked as a mud engineer for Magnet Cove Barium until they found a need to train mud engineers as pilots to make their rounds easier; so he worked as Chief Pilot for them until 1964. Then he opened Houma Aviation Services at the Houma Airport from 1964–89. Caught in the 80s Bust, he stayed in operation long enough to pay off his debts. Then he closed down the business and went to work as a boat captain at age 61.

- Charlie Hammonds. 1956–. The son of an oil worker, he started working for Lloyd Geist in the 1950s, washing planes. He soon graduated to pilot status and opened Hammonds Air Service. His company grew to the point that it was running a passenger service to oil towns along the Gulf as well as providing basic oil field service—checking pipelines, flying personnel and needed equipment, collecting reports. Charlie was able to survive the 80s Bust and now runs a scaled-down charter service. The other pilots cite Charlie as the most experienced floatplane pilot in Louisiana, and possibly in the United States.

- Ken Perry. 1976–. He started as a "flying salesman" in the 1970s. After years of sales work, he "went pro" and opened an operation at the Patterson Airport.

In the early days (oil was first discovered in Terrebonne Parish in 1928), it became obvious that seaplanes were needed to allow quick access to the oil fields. Texaco set up an airstrip for amphibious aircraft (or "flying boats") about 1934. This would later become the Houma Airport. Since the flying boats landed on land or water, they were well suited for the district superintendent to use to check on his far-flung drillers. Lloyd Geist noted the first plane Texaco based at Houma was a Vintage Keystone, which was a biplane attached to the top of a boat. Later would come the Goose and Mallard flying boats, used for transporting managers.

The real progress came after Geist put pontoon floats on a light Cessna and opened his seaplane base on the Gulf Intracoastal Canal. The floatplanes opened up access to people doing sales and service calls. Now they could cover a large area quickly:

> My first flying job in 1976 was a floatplane and I was a salesman. I flew out to production facilities and drilling facilities inshore along the Mississippi River down to the mouth of the River and the bays along the coastline and sold chemicals, treating chemicals for wells and cleaning chemicals and we did compressor valve repairs and starter repairs on these big compressors that compressed the gas… You used your seaplane like a pickup truck (Perry 2003).

Flying in the wetlands was a challenge in many ways, including taking off on the busy Intracoastal Canal. But these floatplanes had no fixed landing strip, had to land on the water in all sorts of directions, and had to yield right of way to all sorts of heavy shipping. Naturally, the floatplanes had no brakes and had to stop in the water by colliding with their target. It required a special set of operations and a real sense of judgment and timing:

> Well, you've got currents to contend with. A lot of times you've got to land cross wind. A lot of time you have to land down wind. You don't have a choice, you know? And then tying up … to these drilling rigs and barges and boats. So you

> had to know time, when to stop the engine. But you had to hurry. Get out on the float and go hold it off so you didn't bang into something. And to catch and be able to tie to whatever you were going to moor to. Cross winds and currents I guess were the biggest thing in the water. Rough water and smooth is all different (Geist 2003).

Clearly, the floatplanes were out-muscled by the drilling barges and practically anything else on the water. This led to a lot of damage to the aircraft, as the planes were often battered by wind and current. Ken Perry mentioned the hard use of the aircraft:

> The big part, the hard part about the floatplanes is the docking and undocking, especially if you are a salesman and you are by yourself most of the time. Planes want to weather-vane into the wind and you are always banging wing tips and running into something. So they are not very pretty after they have been worked for a while. They are good tough airplanes, but you'd beat the hell out of them (Perry 2003).

At the peak, in the late 70s it was estimated that there were about 400 floatplanes operating in southern Louisiana, 90 in Houma. A decade later, 90% of them were gone. Charlie Hammonds made this comment:

> In the heyday, I speak of the heyday being especially during the mid 70s for us, we had nine float planes. There were 90 float planes, 90 float planes based here in Houma and just to give you a comparison, now we have three; we really need two. And there are only seven seaplanes left here in Houma as we speak. So it went from 90 down to seven. So it just gives you an idea of the dramatic downturn in the industry as it pertains to us (Hammonds 2002).

The Bust came in the early 1980s as Texaco sold off inshore to go offshore, and an oil glut dropped prices below $10 per barrel. Like many other oil businesses, the aviation industry was over-leveraged and hit hard. Charlie Hammonds had expanded greatly and was caught by surprise:

> I had built this particular facility here at a cost of about $750,000. I built that hangar next door for a couple of hundred thousand. I bought some very expensive airplanes to run the commuter because we just had such a demand. I can remember and I questioned myself as I look back on my life, you know, buying brand new airplanes, paying an interest rate of something like 23%, but the demand was just, was there. And it was the most phenomenal thing that I could ever see or could ever imagine. It was just, everything was just blow and go and we, like everybody else in Houma, thought it would continue for a long time and when it stopped, it was like turning a valve off. And I know in our own business where we made a lot of money in one year, we just, we lost $2–3–4 million and we are a small operator (Hammonds 2002).

While the general downturn was terrible for all businesses, the floatplane aviators were not able to recover along with everyone else because they could not operate in the Gulf itself. The sea outside the barrier island was too rough to land and take off, and even so, tying onto the high steel offshore platforms would hammer the plane to pieces. The rise of the helicopter really dates from the shift to offshore and the building of helipads right on the platforms.

Hammonds and Perry weathered the downturn and have scaled down operations. Geist had retired by then, and Christ closed his company by 1989. At age 61, CJ went back to work as a boat captain; his love for the sea was as big as his love of the air.

Besides making the inshore oil rigs accessible, the low price of the floatplanes made it possible for people to go into business without a major investment. This is indicative of one of the major qualities of oil work in this pioneering period: People without major financial backing could go into business for themselves and make a success of it. As Perry noted, floatplanes were more cost effective than helicopters:

> So it was you could buy ten float planes for what you could buy 1 helicopter …. You could set up a pilot and usually you got a plane, a company car, an expense account and then the whole thing, even if you bought a brand new airplane, you probably had less than $75,000 invested in it in the first year. And it didn't take a lot of sales to get that money back from that and so that was, a small company could compete with a big company back then. You know, you could level the playing field pretty well (Perry 2003).

The shift away from floatplanes was a shift toward more expensive helicopters, with insurance and maintenance needs that required professional training. Most helicopter pilots are trained by the military because of the great expense. The cost really required corporate backing, so businesses like PHI (Petroleum Helicopters Incorporated) are listed on the New York Stock Exchange and have a very sophisticated maintenance and traffic control system.

The floatplanes' heyday of is over. But an examination of their history really shows their function. While the drilling barges enabled the oil drillers to spread out and drill quickly over a wide area of operation, the floatplanes served as the glue that held that field of operations together:

1. They provided the ability for sales and service personnel to move rapidly around the work area.
2. They provided critical communications between the field and the district headquarters–picking up drilling and production reports, well logs, and survey information. This, in the days when radio was the only other way to maintain information exchange.
3. They moved personnel and key pieces of equipment back and forth, far more quickly than possible by boat.

4. And they formed a link in the informal communication between workers and between workers and their families back home. Charlie Hammonds is especially known for flying passengers back for free, if he had an extra seat. This is a critical function in building a sense of community in the oil fields.

We can see the floatplane aviators creating a niche in the oil industry that was later taken up by the helicopters when the industry moved offshore. The floatplanes, then, were a necessary step in the development of oil field aviation.

We can also see that they represented a time when oil field operation was more informal and the playing field was more level than is the case today. A person could buy an airplane, learn to fly it at a reasonable cost, and use these skills to enter oil work without taking on a major debt burden. This person was, more often than not, a salesman or service specialist rather than a professional pilot.

The history of oil development can be seen as a set of puzzles that needed solutions. The problem-solvers often created businesses to sell their solutions. In this case the early isolation of the oil fields was offset by the floatplane aviators. Now the wide spread of the offshore platforms is offset by the helicopter aviators. The technology is different, but the need is much the same.

James Sell received a Ph.D. in geography, with a minor in psychology, from the University of Arizona in 1983. He has been engaged in teaching, research, and planning consulting in the geography and landscape architecture programs at the University of Arizona. He was engaged to work on the BARA/MMS Oil History Project in 2002. He is currently teaching geography and planning at Northern Arizona University. Interested in public perception and landscape, he has published work on the Mt. St. Helens eruption, landscape perception, and perception of environmental change.

A SOCIAL HISTORY OF MORGAN CITY

Jamie Christy, University of Houston

Although most people think of Morgan City, Louisiana as strictly a twentieth-century boom-and-bust oil town, the city has a long history whose cumulative impacts prepared it for the arrival of the petroleum industry. It is important to recognize that past not only for historical reasons but also because the aggregate of these past events laid the groundwork for the eventual entrance and predominance of the oil industry.

Morgan City's location at the mouth of the Atchafalaya River and the Gulf of Mexico (GOM) and as the western terminus of the New Orleans Opelousas Great Western Railroad (NOOGW) has always been a determining factor in its evolution. This terminus was the reason for the Union invasion of 1862. The Federals, dubbing this area the land of milk and honey, determined early on to take Morgan City (then named Brashear for a local sugar planter of Dr. Brashear) and close off and destroy the potential of its vast sugar cane plantations, railway, and port, as part of Winfield Scott's Anaconda plan to "strangle" southern resistance.

After the Civil War, the large plantations held by a few wealthy families for centuries were broken up and sold off to former Union soldiers and land speculators. Northerners like Cornelius Vanderbilt and Charles Morgan realized the town's potential and invested in rail lines and steamship ports in the area. Morgan spent over $2 million to improve the NOOGW, and also dredged a deeper channel through the Atchafalaya Bay to accommodate his fleet of steamboats. Brashear, forced to rely on the capital of outsiders, was renamed for the Connecticut-born Morgan in 1876. Many locals noted that Morgan rarely set foot in the city that bore his name and gave nothing to the town in the way of a park, public building, or large donation. Indirectly, however, he was the community's benefactor since the enterprises in which he engaged to earn a fortune for himself also made the area a booming port and rail city and laid the groundwork for future growth and development.

Following the war and the southern defeat, Morgan City's residents, now lacking material wealth and rapidly losing their farms and plantations, relied on hunting and trapping for survival. Local hunters and trappers began to leave their homes and families for extended periods to go into the swamps to procure the animals that were their livelihood. They were accustomed to hard work and to spending the majority of their time outdoors. These men possessed a thorough knowledge of the swamps, bayous, and rivers. They could navigate south Louisiana's treacherous waterways and currents and understood the severe storms and fog that often bewildered foreign captains and swallowed unsuspecting vessels.

At the turn of the century, timber became Morgan City's main industry. Logging, like hunting and trapping, was rough work and required workers to spend extended periods of time away from home. Those who felled trees for the lumber mills usually lived out in the swamps and marshes and only returned to their families on their off-time. The lumber industry was dangerous, and laborers in the swamps and in the mills lost fingers, toes, arms, and legs, and work-related deaths were not uncommon. The men who worked for the lumber companies were denied insurance, workmen's compensation, or any sort of retirement. They lived in camps or on boats, were paid in script, and were forced to shop at the company store. Labor unions were strongly discouraged and none were ever able to successfully organize in Morgan City.

Lumber companies bought up large tracts of land at an incredible rate, again concentrating the land in the hands of a few. Thus, companies like Norman-Beaux, Waddell-Williams, and Brownell and Drews acquired huge amounts of property along the water, and this land ultimately proved to be some of the area's richest oil fields.

Two of Morgan City's largest landowners, Hugh and Byrnes Young, who had been leasing acreage to the lumber mills, realized the industrial potential of their bayou-side property and offered their land for use during both world wars. The federal government was particularly interested in Morgan City's excellent port facilities during World War II. The United States government awarded it lucrative government contracts to build war vessels for the United States Navy. The defense industry began to pour money into Morgan City during the 1940s and when Chicago Bridge and Iron Works constructed dry docks on Bayou Boeuf, the town was established as a fabricating area.

In the late 1930s, another industry began to take hold in Morgan City when large quantities of shrimp were discovered off of Louisiana's coast. Morgan City's citizens and administration realized that the increased channel traffic that resulted from this booming industry warranted a re-dredging of the channel and convinced Congress to declare this an emergency project. The work was completed in 1940.

In the 1940s there was a huge influx of families from the east coast determined to take advantage of the new deep-sea shrimping industry that had emerged in south Louisiana. These new shrimpers combined with the workers who moved to the community to man the dry docks for Chicago Bridge and Iron caused a housing shortage in this area bounded by water and strained Morgan City's inadequate municipal facilities. The city was forced to expand west into Berwick, Bayou Vista, and Patterson and east to the Bayou Boeuf and Amelia. Roads were paved, bridges were constructed, public services improved, and the channel dredged ever deeper.

The interviewees that were chosen for this project are representative of the preceding aspects of Morgan City's history. They are the descendants of sugar planters, farmers, and ex-slaves displaced after the Civil War. They were hunters, trappers, and shrimpers, who grew up on the water, some speaking French as their first language and some still unable to read or write at the time of their interview. They were former cypress mill employees, welders, and World War II veterans. These men had toiled under the toughest of conditions with poor treatment and compensation at their various occupations and were happy to have the work the oil companies provided. Locals like Jerrel Frederick, whose father had been the foreman at Norman-Breaux Lumber Company and who also worked at the mill and then served with Patton's Third Army, were overjoyed at the opportunities the oil industry provided. They could not believe their luck to receive benefits, insurance, and retirement plans. Interviewees like Richard Davis and John Written proudly called themselves "Texaco men" and "Shell men" while loyal employees like Rene Seneca and Alden Vining remembered driving miles out of their way to buy gas at their Texaco or Shell station.

With the entrance of companies such as the Texas Company, Shell, Humble, Mobil, Gulf, Phillips, Sun, Kerr-McGee, and many others, local men continued to traverse the swamps, bayous, and eventually the GOM to seismograph, haul pipe, and drill wells. As the work moved offshore, they converted shrimp boats to crew boats and guided, serviced, and played host to the companies in ever deeper water. A few Morgan Citizens like Parker Conrad, Victor Guarisco, and Red Adams made fortunes with service companies that they started from nothing. Most of the locals, whether successful service company owners or roughnecks, viewed the coming of the oil companies as the best thing that could have happened to Morgan City.

The arrival and success of the oil companies in Morgan City cannot be taken out of historical context; the lens of history is vital to understanding the industry. The southern defeat and removal and redistribution of the lands of the great sugar planters, the expansion of the port and railroad by investors like Morgan and Vanderbilt, the loss of control over the economy by local residents, the knowledge gained of the waterways and boats by trappers and shrimpers, the acclimation to difficult and dangerous industrial work gained from working at Chicago Bridge and Iron and the cypress mills, the inability of labor unions to organize in the area, the consolidation of lands in the hands of a few lumber mill owners, the population booms of the 1930s and 1940s due to shrimping and industry that led to the eastward and westward expansion of Morgan City, the appreciation that men who had been exploited by the lumber mills felt at being treated fairly by the oil companies, and the optimism that local rags to riches stories gave to the community are all vital to understanding the oil industry in this area.

The oral histories of these successful businessmen, geologists, and engineers, combined with those of seismic crews, drillers, gaugers, roustabouts and roughnecks, and their wives are important because they represent the cumulative history of Morgan City in particular and the oil industry in general. The memories and stories that they have shared with this project are the history of oil in southern Louisiana.

Jamie Christy is a native of Morgan City, Louisiana. She received her undergraduate degree at Louisiana State University and is pursuing her doctorate at the Graduate Studies in History Department of the University of Houston. Her current interests focus on Mexico's oil industry and U.S. expatriate workers and companies involved in that industry.

PLATFORM DISASTERS AND CHANGING INDUSTRY MINDSETS OF HEALTH AND SAFETY ISSUES

Tyler Priest, Director of Global Studies,
C.T. Bauer College of Business, University of Houston

This paper explores the changing nature of health and safety problems in the GOM offshore industry, focusing on the hazards of offshore operations during the early years and identifying when and how the industry really got serious about safety questions.

It is difficult to measure trends in accident frequency, injury rates, fatalities, etc. on the OCS from easily accessible data. Individual company statistics are confidential, and neither the MMS nor the Offshore Operators Committee historically has required the reporting of incidents in a consistent manner which would allow calculations of injury frequencies. Furthermore, statistics have not been compiled in a way that offers easy comparisons with other occupations and industries.

Records are much worse, of course, for the early years, before 1970. The USGS did produce a series of monthly engineering reports during the years 1954–1966, which I've examined in the National Archives. There is some reporting in these reports that you don't find in press accounts. However, they are incomplete. I counted 90 reported fatalities during these years, which is most certainly low, and there was virtually no reporting on non-fatal accidents. Many of the oral histories we have collected fill in these gaps with first-hand and anecdotal perspectives on the risks and dangers of working offshore. The MMS also maintains an "events file" on injuries and accidents. I haven't looked at this, but I have reviewed studies that did analyze these events for the 1970s and 1980s (after 1985, events lists only those injuries directly associated with blowouts, explosions, fires, significant pollution incidents or major accidents).

> I retired with a little over 30 years of service and I have still got all of my fingers and all of my toes. And if you look at a lot of old oil field hands, people that have worked in the oil field back in the old days, you look and they do not have all of their fingers and all their toes, particularly the people who worked on drilling rigs. The people who worked on drilling rigs, fingers and toes and hands and feet, they were just a commodity that you had to learn to live without because you were not going to keep them very long (Written n.d.).

The quote from Mr. J.H. Written testifies to the fact that offshore oil is and has long been a very dangerous business. The oil business in general has long been dangerous. In any business or occupation that involves people working with extremely heavy equipment, such as drill pipe, combustible materials, such as oil and natural gas, and imperfect technology, there are going to be accidents and, unfortunately, fatalities. Oil operations offshore, of course, have faced added challenges from the marine environment. Just figuring out how to build and operate structures to drill and produce in the ocean, not to mention a part of the ocean that was exposed to hurricane-force wind and waves, have called for untested designs in drilling vessels, platforms, and wells. These conditions have led to a host of problems that engineers and oil-rig workers had never encountered before World War II. In addition to the awful physics of the machinery itself, workers had to contend with bad weather, dangerous boarding procedures, drilling mishaps, fires, and explosions far from land.

Hazards presented themselves in different forms in different phases of operation in the early offshore industry. During the early years, from the late 1940s through the mid-1950s, one of the biggest safety issues was personnel transfer from crew boats to platforms during rough weather. This could be an exciting, if not terrifying, experience. One of the first methods tried and used with "moderate success," in the words of John Donhaiser, a Pure Oil official, was an overhanging ramp extending out from the platform deck with a Jacob's ladder reaching down to the water level. Numerous accidents, resulting from the ladder is becoming fouled in the ship's rigging led companies to experiment with the so-called a "swinging-rope boarding method," in which a person is hatched by hooks to a rope that would be swung by a cantilevered beam from the boat to a landing platform (Donhaiser 1995). Other companies had employees throw their gear into a cargo net and hang on to the outside, "jumping on it like a bunch of monkeys," as one witness described it (Pugh n.d.). Back injuries, often contracted in transferring from boat to platform, were among the most common afflictions from working offshore. "Getting off those platforms in rough weather onto a boat was an interesting experience," said Sam Paine, a Shell production executive. "You would swing out on this rope, try to catch the boat at its peak and then drop off on it. I wouldn't do it again! But I was young in those days." Paine saw two Halliburton employees killed this way trying to board the jack-up vessel, *Mr. Gus*, when the crew boat drifted and the rope pulled them up through the mast and rigging, knocking them off about 20 or 30 feet above the boat (Paine n.d.).

First introduced in 1948, but not widely adopted until the mid-1950s, helicopters provided greater economies of speed and safety in transferring crews, saving workers from the sickness-inducing 8- to 12-hour rides that often left them in no shape to work for an entire day after they arrived on board. On the other hand, helicopters posed their own risks. The USGS monthly engineering reports from the late 1950s and 1960s are littered with deadly helicopter crashes. In 1958 alone, there were 14 reported fatalities from helicopter accidents in the Gulf of Mexico (GOM) OCS. Over time, Gulf helicopter travel appears to have been less safe than commercial airliners, but more safe than private civilian aircraft. Although not common, relative to the number of man-hours flown, helicopter accidents in bad weather and during night travel happened regularly (12 fatalities in 2003, deadliest in last two decades) (USGS 1954–1966; Houston Chronicle 2004).

Early marine seismic work also proved to be dangerous business. Before the introduction of Vibroseis pulsing systems, the sound source came from dynamite, and deaths and injuries from on-board explosions did occur, especially when crews tried to speed up operations by making up more than one charge at a time. "When the boats are moving along at, say, six or seven knots, and you are trying to do all of this, you do not have a lot of time," remembered Aubrey Bassett, who worked on some of Shell Oil's earliest offshore seismic crews. "Two hundred feet goes by in a hurry and you are just back there wildly putting all of this stuff together." Sometimes this meant that the wrong charge was detonated (Bassett n.d.).

The early years of offshore development also saw some spectacular mobile drilling vessel disasters. During 1955–1957, four major vessels overturned with the loss of 13 lives. The worst was the capsizing of the Golden Meadow Drilling company's *Mister K* off the South Pass of the Mississippi River in April 1957, in which nine lives were lost. Operators blamed human error for the disasters, but it was clear that these mobile drilling vessels, especially jack-ups like *Mr. Gus*, which capsized two weeks before the *Mister K* off of Texas's Padre Island, had design flaws (Calvert 1957). Billy Pugh, a young boat captain hired to ferry crews to *Mr. Gus* was not convinced of that vessel's seaworthiness when he attended its christening. He said: "The thing was built in two pieces. It was latched together with some 2-inch cables and 20-inch pipe. I had been at sea long enough to know that it wouldn't even get out of the mouth of the Sabine Pass …. The president of Bethlehem Steel got up and made a speech that night, saying 'we have conquered the sea with this jack-up barge.' I said, 'Oh man, he hadn't been to sea much." After the death of the two Halliburton employees, Jimmy Storm, a partner in Glasscock Drilling, called Pugh up in the middle of the night to design a better solution. This led to the development of the Billy Pugh Personnel Transfer Net, which became standard in offshore operations in the Gulf and around the world (Pugh n.d.).

Drilling was the most dangerous work offshore, and the most fearsome problem for drilling operations was the blowout. Unlike on land, blowouts could mean complete disaster on isolated offshore barges and platforms. Modern blowout prevention systems received special attention early on from offshore operators, but the loss of well control was still an inevitable fact of life in the Gulf, leading to fires, explosions, casualties, property damage, and pollution. The most common cause of blowouts in the Gulf was in exploratory drilling that encountered high-pressured and undetected shallow natural gas. In 1959–1960, following the mobile rig disasters, were many dramatic blowouts in both the shallow and deeper waters of the Gulf. The most tragic one occurred on a CATC group (Continental, Atlantic Refining, Tidewater, and Cities Service) platform in the West Delta, which exploded in October 1958, killing seven and seriously injuring the remaining 29 workers who had to escape the flame-engulfed structure by jumping 50 to 60-feet in the water (Calvert 1959).

One can make the case that the relatively dangerous and hazardous nature of offshore operations was inherent in the adjustment from taking land-based technologies, equipment, and practices into the marine environment. Almost everything had to be redesigned and rethought. Marine engineering and construction advanced by improvisation and trial-and-error, and error could be harmful to the environment and debilitating or fatal to workers. In the first decades after World War II, booming demand for petroleum products in the United States made growth a top priority. Safe processes and designs either did not exist or remained untested ideas in the minds of researchers. Facilities engineering was a novel concept. Platforms were often stick-built with equipment squeezed or slapped together on the deck with little concern for worker safety . Crew quarters, for example, could be placed right next to a compressor building (Arnold n.d.). Workers were trained and drilled about safe operating practices, but they were really not trained to manage safety or manage change in safe ways. Said one retiree: “older guys could tell you, you know, ‘watch this’ or ‘watch that’ but there was nobody watching you and telling you, ‘you had better do this,’ or ‘you had better do that (Viater n.d.).

The result was that safety took a back seat to growth and productivity. “We talked safety but we were really not that much into safety,” said Lou Trosclair, longtime Shell Oil employee and manager. “Of course, we tried not to hurt anybody, don’t get me wrong—I mean, we were not barbaric or anything—but it seemed like the work had to be done and you did it as fast as you could.” Cliff Hernandez, another Shell veteran, had a more frank assessment: “When I first started working, they didn’t care whether they killed you or not! In other words, ‘we are going to get it done regardless.’ There was no suing like people are suing now. Back then, if you got hurt, they just pushed you to the side and put somebody else in. I mean, a lot of people got hurt and did not get paid for it. Crippled” (Viater n.d.; Hernandez n.d.)

Oil, drilling, and service companies did not completely disregard safety and environmental protection, but they had near autonomy in defining what words like “safe” and “clean” meant. Companies learned from the series of mishaps, blowouts and fatalities of the late 1950s, and they continued to improve drilling, blowout prevention, and production technology.[1] Overall, however, little really changed in the industry’s approach to safety or in government regulation or oversight to insure greater safety or protection of the environment.[2] Between 1958 and 1960, the USGS issued OCS orders 2–5, requiring procedures for drilling, plugging and abandoning wells, determining well producibility, and installing subsurface safety devices, or “storm chokes.” In 1958 and 1960, the Offshore Operators Committee, however, was able to dilute Order 5 to permit waivers on requirements for storm chokes (USGS 1954–1966). Most significantly, the orders did not have any test requirements. Companies had to have certain equipment, but they did not have to test it to see if it worked (Arnold n.d).

Furthermore, the USGS did not inspect installations on a regular basis. Enforcement was lax. State and federal regulatory bodies were underfunded and understaffed. Some supervisors were political appointees, and even those with the appropriate training and competence often had neither the requisite experience in the oil business nor a grasp of its changing technological capabilities. As one consulting geologist observed in the late 1960s, “Each oil well has its own personality, is completely different than the next and has its own problems …. It takes good experienced personnel to understand the situation and to cope with it. If an “employee doesn’t know a ‘cat-head’ from a ‘bull-plug,’” he continued, “how can they be expected to enforce these rules and regulations?” Too often on drilling structures, he complained, one found inexperienced supervisors, employees who overlooked rules and regulations, the purpose of which they did not understand, and sometimes orders from bosses to cut corners, all of which created conditions for

[1] The CATC disaster led to safety precautions when welding was done on OCS platforms.

[2] In July 1959, the USGS issued an order requiring facility inspectors, for the first time, to make a report for the files of what facility they inspected and what deficiency they noted or action taken. “To keep such reports realistic, an inspection is defined as an official, critical, close examination at the wellhead or lease facility.” USGS. 1959. Monthly Engineering Reports. Gulf Coast Region. Volume 131. July.

an “explosive situation.” “Disaster might not strike the first time, but it will come!” (Etson 1970).

Disaster struck often in the 1960s—blowouts (22 deaths on the *C.P. Baker* catamaran drilling vessel in 1964), helicopter crashes (11 in one crash in 1966), freighters colliding into platforms, among other accidents[3]—but not until 1969–1970 did industry and government finally get religion on safety issues. This was due, of course, first to the January 1969 blowout at Union Oil’s Platform A-21 in the Santa Barbara Channel, which spilled 50,000 to 70,000 barrels of oil, catalyzed the national environmental movement, and set the stage for the passage of the National Environmental Policy Act (NEPA). These developments created a new and potentially hostile climate for Gulf Coast operators whose practices in the past had rarely been examined or challenged.

As the industry protested and resisted a new stringent set of OCS regulations handed down by Interior Secretary Walter Hickel in August 1969, disaster struck operators in the Gulf. In February 1970, Chevron’s Platform C on Main Pass block 41 blew out and caught fire. Oil pollution from that blowout postponed a federal lease sale, damaged wildlife, and drew a $31.5 million suit against the company by Louisiana oyster fisherman and a $70 million suit from the shrimp fishermen. A U.S. District Court also fined Chevron $1 million for failing to maintain storm chokes and other required safety, the first prosecution under the 1953 Outer Continental Shelf Lands Act, and the Justice Department proceeded to obtain judgments against other major oil and gas companies for similar violations (Reifel 1976). And then in December, Shell Oil Company suffered a major blowout on a giant platform in the Bay Marchand area, killing four men and injuring more than 30 others. It took 136 days to bring eleven wild wells under control, at a cost of $30 million.

These events changed industry and government mindsets on safety issues and committed industry to improving safety technologies and designs. Public expectations on safety and the environment had already shifted massively, and these catastrophic blowouts, with all the national media attention and legal and political fallout from them, forced the most radical changes to operating practices in the U.S. offshore industry’s history. The government regulatory program was expanded and strengthened. Most OCS orders and leasing and operating regulations were rewritten, mandating the installation of more sophisticated safety hardware and shutdown systems. Orders now specified minimum requirements for wellhead controls and testing procedures. The USGS tripled its number of inspectors and engineers, introduced a more standardized inspection program, and stopped using industry-furnished transportation for inspection purposes (Standley 1972).

The new approach to safety, however, was not something the federal government foisted on an uncooperative industry. In fact, the Offshore Operators Committee and the API Offshore Safety

[3] In September 1966, the USGS reported that a Louisiana Air National Guard jet narrowly missed an ODECO rig in crashing in the West Delta area. “Add another hazard to the Pandora’s box of problems associated with offshore operations! wrote the USGS Monthly Engineering Report from the Gulf Coast Region. USGS. 1966. Monthly engineering reports. Gulf Coast Region. Volume 159. September.

and Anti-Pollution Equipment Committee worked closely with the USGS not only in advising changes in the OCS orders but in drafting, in a period of about six months, a new set of API "recommended practice documents" for the selection, installation, and testing of various kinds of safety devices (Arnold et al. 1989). As Ken Arnold, a former facilities engineer for Shell and founder of Paragon Engineering, put it: "We changed in a period of very few years and got most people to buy into it. Then, the operating people had to maintain them, which was important, and the suppliers started to supply better gizmos, better three-way valves, better sensors, and we learned how to incorporate these sensors into designs in ways that they actually worked and did not give false signals" (Arnold n.d.). The industry effort proved that sometimes the best way to get industry to change its behavior is not regulation so much as it is the threat of regulation.

The offshore oil industry's safety record in the Gulf improved significantly after the introduction of new regulations and practices. Both the incidence and rate of fatalities and injuries in the OCS declined. Although the total number of drilling man-hours reported for the OCS increased from 26 million to 105 million between 1962 and 1977, the accident frequency for the same period declined from 14.9 to 9.3 accidents per 100 man-years. In other words, there was a fourfold increase in exposure-hours, but a 38 percent decrease in accident frequency (Committee 1981). During the 1970s and 1980s, the industry did not achieve a significant reduction in blowout frequency, largely because of serious limitations in methods for controlling shallow gas influxes. However, there was a sharp decline in the number of catastrophic blowouts and a significantly lower number of casualties and fatalities (Danenberger 1993).

To be sure, accidents and casualties continued. In the late 1980s, several industry accidents increased scrutiny of safety in the industry. However, by most accounts, these events did not reflect a problem with technology or noncompliance with industry safety standards, but had more to do with human error stemming from inadequate training and supervision, rote reliance on regulations, and generally poor operating practices. As had always been the case, most accidents involved entry-level workers. Contributing to this problem was the increasing turnover rate in the offshore labor market, the growing use of contract personnel, and the emergence of smaller, independent operators without the necessary organizational structure for managing safety. According to Peter Velez, manager of regulatory affairs for Shell Offshore in the early 1998, during the first 40 years of the offshore industry, "80% of the efforts to improve safety and the environment were focused on equipment design, operational considerations, and prescriptive regulations," whereas today "80% of the accidents and injuries are due to human error" (Velez 1998).

This does not mean that workers are to blame for their own injuries. The point is that the industry in the early 1970s, pressured by larger changes in society and prompted by their own failures, took unprecedented steps to bring greater safety into technology, process, and design, and that as offshore technology and organization has become increasingly complex, the challenge has been to improve the so-called "human" side of the business to keep up with the technological side.

References

Arnold, K. n.d. Interview.

Arnold, K.E. P.S. Kosezela, and J.C. Viles. 1989. Improving safety of production operations in U.S. OCS. Proceedings, Twenty-first Annual Offshore Technology Conference, May 1–4, Houston, Texas, OTC Paper 6079.

Bassett, A. n.d. Interview.

Calvert, J.W. 1957. The Mobile rig disasters. World Petroleum. (June):30–33.

Calvert, J. W. 1959. Disaster of Platform 'E.' World Petroleum. (January):42–49.

Committee on Assessment of Safety of OCS Activities. 1981. Safety and offshore oil. Washington, DC: National Academy Press, 134.

Danenberger, E.P. 1993. Outer Continental Shelf drilling blowouts, 1971–1991. Proceedings, Twenty-fifth Annual Offshore Technology Conference, May 3–6, Houston, Texas, May, OTC 7248.

Donhaiser, J.N. 1995. Offshore fire and safety protection. Paper presented to the API Offshore Operating Symposium, Southwestern District, Production Division, Houston, Texas, March.

Etson, N.R. to President Nixon. 1970. RG 57, Central Classified Files, 1968–1974, Box 71, March 18.

Hernandez, C. n.d. Interview.

Houston Chronicle. 2004. Copter tragedy 'just shattering,' rise in Gulf accident raises industry concern. March 25.

Paine, S. n.d. Interview.

Pugh, B. n.d. Interview.

Reifel, M.D. 1976. Offshore blowouts and fires. In: ETA Offshore Seminars, Inc. The Technology of Offshore Drilling, Completion and Production. Tulsa: The Petroleum Publishing Company. Pp. 239–57.

Standley, E.W. Interior Liaison Representative to Jack W. Boller, Assistant Executive Secretary, Marine Board, National Academy of Engineering 1972. RG 48. Records of the Secretary of Interior, Central Reports. Gulf Coast Region. Classified Files, 1969–1972, Box 136, Part 13. February 15.

USGS. 1954–1966. Monthly Engineering Reports Volumes 109–160. Record Group 57, Records of the U.S. Geological Survey, Conservation Division, Oil and Gas Leasing Branch, National Archives and Records Administration (NARA), College Park, MD.

Velez, P. 1998. Safety and environment protection: a collaborative approach. MMS Today. 8(3):5.

Viater, K. n.d. Interview.

Written, J.H. n.d. Interview.

Ty Priest is an independent scholar and partner in History International, LLC, a consulting firm specializing in corporate histories. He received his Ph.D. in history from the University of Wisconsin-Madison and has taught at Middlebury College and the University of Houston. A specialist in the history of the oil and gas industry, he is the co-author, with Joseph Pratt and Christopher Castaneda, of Offshore *Pioneers: Brown & Root and the History of Offshore Oil and Gas* and the author of a forthcoming history of the Shell Company. He is currently researching the history of oil and gas exploration in the Gulf of Mexico.

WOMEN IN THE GULF OF MEXICO OFFSHORE OIL AND GAS INDUSTRY: OVERLOOKED BUT NOT FORGOTTEN

Diane Austin, Bureau of Applied Research in Anthropology, University of Arizona

Introduction

In 1901, oil was discovered in Jennings, Louisiana. Decades later, in 1947, the industry successfully moved offshore into the Gulf of Mexico (GOM). From those beginnings to now, the oil and gas industry in southern Louisiana has undergone significant changes—in machinery, processes, and work culture. Yet, despite numerous apparent differences in their circumstances as oilfield wives and as workers, the experiences women describe over the years are remarkably similar.

In general, U.S. women entered the workforce in significant numbers during World War II, were displaced from most jobs when men returned from the war in large numbers, and then returned to out-of-the-home workplaces during the 1970s and 1980s. In the 1980s and 1990s, dramatic changes in U.S. corporations and society reshaped the work-family patterns that had been established in previous decades, and by the end of the 20th century, economic distress, amid the downsizing of government and the restructuring of corporations, again brought attention to questions of women and work.

In contrast to many other industries, the U.S. oil industry has severely restricted women's participation. Even during World War II, when many jobs were opened to women, work on rigs and platforms was confined to men. Men working offshore recalled the frustration of being kept home from the war because their jobs were deemed critical to national security. Situated in the U.S. South, where the cultural images of both "woman as homemaker" and as "lady" remain powerful in defining the proper role for a woman as wife and mother (Middleton-Keirn and Howsden-Eller 1986; Mathews 1989; Dillman 1989), women seeking employment in the offshore oil and gas industry have faced significant challenges.

When the doors to offshore employment in all sectors were finally opened in the 1970s, some women took the chance to earn higher pay. Many of these women pioneers met resistance and even hostility. Those who persevered watched many others come and go. During the downturn of the 1980s, both men and women workers with little seniority were laid off or had their hours reduced. By the mid-1990s, when activity picked up again, it did so at a time of significant industry restructuring when the total number of workers had been reduced. Even into the 21st century there are few women working on rigs and platforms or in fabrication and shipyards, the most visible signs of the industry in the GOM region. Yet, despite their apparent absence, women contribute to the industry in numerous ways.

Women and the Offshore Industry

Within what has become an international offshore oil and gas industry, the GOM has been distinguished by its "cowboy" culture.[1] Reliable figures on the offshore workforce are hard to obtain—though petroleum companies fill some positions themselves, they rely on a large array of contract companies to supply seismograph crews, drillers, cooks, truckers, divers, mechanics, and a multitude of other people necessary for finding, reaching, and producing oil and gas from the U.S. Outer Continental Shelf. Throughout this vast industrial landscape, and largely invisible, are substantial numbers of women. These women support the industry in their roles as blue-, pink-, and white-collar workers, and as relatives of men who work offshore (Austin 2005).

The move offshore began when rigs were erected first on pilings and then on barges in the marshes and lakes of southern Louisiana. For many oil companies, the initial transition from land to water was gradual. Nevertheless, the move into the GOM initiated a significant change in the lifestyle patterns of oilfield workers. No longer were workers required to physically move their homes and families to the sites of exploration and production. For the first time, some oilfield families could settle down in one community while the worker commuted to and from ports and docks to be transported to rigs and platforms. In addition, people already living in the Gulf region could take jobs that would enable them to remain in their native communities. Under these circumstances, two groups of women came together—migrants from places like Texas and Oklahoma with a history in the oilfields and locals exposed to the industry for the first time. The all-male culture of the onshore oil industry was transferred offshore. The concentrated scheduling of offshore work (7 days on and 7 days off, 14 and 14, or combinations such as 21 and 7) meant that workers were absent from home for long periods of time. Thus, wives continued to have significant responsibility for managing nearly all aspects of the household and to face potential isolation; like their predecessors who moved from place to place, women used their social networks to get by (e.g., Schrag-James 2002).

At the same time, and though largely hidden, women were to do more than manage households in the new industry. As relatives of men who worked in the industry, they have helped perform the tasks required of employees. In addition, women have held their own jobs, onshore in both typical "pink-collar" jobs and nontraditional "blue-collar" jobs, and offshore as well. The industry received a significant boost at the end of World War II when men and equipment became available in southern Louisiana. Women, too, who had gained skills in wartime employment in factories and shipyards, could put those to work. They filled clerical and secretarial positions for oil companies and those that provided service to them. As the onshore infrastructure for the offshore industry grew, many small businesses were formed, and women played a critical role in creating many of these. Thus, long before the 1970s when oil and gas companies were forced by federal civil rights laws to begin hiring women in offshore jobs, women were intimately involved with the industry. Yet, as the offshore industry developed, even

[1] Movies like *Giant*, *Hell Fighter* or *Thunder Bay,* and books like *Louisiana Blue*, characterize the oil field as the new Wild West. Scholars working in the North Sea and Canada have argued that workers from the Gulf of Mexico brought with them a cowboy culture that was highly resistant to change (e.g., Lewis, Porter, and Shrimpton 1988, Røyrvik 2000).

in support sectors such as supply boats that evolved locally, the distinction between men's and women's work and the separation of youth from adults was reinforced.

The routes by which women have come to the industry and their experiences in it are many. They have been motivated by good wages, familiarity, confronting stereotypes, and the pursuit of challenging and interesting work. For some, the work has provided freedom and opportunities not otherwise available. For others, it has simply been a mechanism for survival. Though women's support had been critical to small and large companies for decades, the forced entry of females into specific nontraditional jobs in the 1970s generally was not welcome. Coming in the wake of other personnel changes, their entry challenged the all-male work culture that had prevailed throughout the oil and gas industry for more than 50 years and marked a period of transition in workforce culture.

Through their attitudes and behaviors, individual women have been able to influence their acceptance or rejection at their workplaces, and organizations such as Desk and Derrick Clubs offered them some support. However, despite the successes, the numbers and position of women in the industry have changed little over the past 30 years. Through this period, the U.S. trend toward greater workforce participation by women has been thwarted by both stereotypes of Southern women and of oilfield workers.

References

Austin, D.E. 2005. The offshore oil and gas industry in southern Louisiana: Impact on women's lives. Research in Economic Anthropology. Forthcoming.

Dillman, C.M. 1989. Southern women: In continuity or change? In: Mathews, H.F., ed. Women in the South: An Anthropological Perspective. Athens: The University of Georgia Press. Pp. 8–17.

Lewis, J., M. Porter, and M. Shrimpton. 1988. Women, Work and Family in the British, Canadian and Norwegian Offshore Oilfields. London: Macmillan.

Mathews, H.F. 1989. Introduction: What does it mean to be a woman in the South today? In: Mathews, H.F., ed. Women in the South: An Anthropological Perspective. Athens: The University of Georgia Press. Pp. 1–7.

Middleton-Keirn, S. and J. Howsden-Eller. 1986. Reconstructing femininity: The woman professional in the South. In: Mathews, H.F., ed. Women in the South: An Anthropological Perspective. Athens: The University of Georgia Press. Pp. 57–70.

Røyrvik, E. 2000. Cowboys and rebels in the North Sea. (Summary of Smith-Solbakken, M. 1997. Offshore Workers: History of Cowboys and Rebels. Nr. 17. NTNU: Historisk Institutt.) Gemini, an online publication of Norges Teknisk-Naturvitenskapelige Universitet (NTNU). *http://www.ntnu.no/gemini/2000-01e/13.html*.

Schrag-James, J. 2002. Offshore employment as lifestyle and culture: Work and family in New Iberia. In: Austin, D.E. and T.R. McGuire, eds. Social and Economic Impacts of OCS Activities on Individuals and Families: Volume 2: Case Studies of Morgan City and New Iberia, Louisiana. Report prepared for the Gulf of Mexico Region of the Minerals Management Service. Pp. 5–56.

Diane E. Austin is an assistant research anthropologist in the University of Arizona's Bureau of Applied Research in Anthropology (BARA). She specializes in the development of community-based participatory research methodologies and coordinates BARA's internship program. Her major interests include environmental anthropology; social impact assessment; environmental justice; community development; and research methods and analysis. She began studying the impacts of the offshore oil and gas industry on southern Louisiana in 1996.

USING ORAL HISTORY TO UNDERSTAND IMPACTS ON COMMUNITIES

Tom McGuire and Diane Austin,
Bureau of Applied Research in Anthropology, University of Arizona

Although researchers have documented the social impacts of the offshore oil and gas industry on workers, families, and communities in the late 20^{th} century (Austin et al. 2002, Austin and McGuire 2002), documentation of impacts over the industry's nearly 60-year history is sparse. Given the lack of written documentation, oral history provides a mechanism for obtaining information about the early industry and its effects on southern Louisiana.

In addition, oral history is particularly effective in uncovering the meaning that those who were affected attributed to impacts and in providing opportunities for many voices and perspectives to be represented. By gathering the stories of a diverse sample of workers, family members, and community leaders whose lives were directly affected by this industry, we acknowledge that there is no single story or interpretation of what happened.

One important benefit of the collection of oral histories is the opportunity we have to understand community response to OCS development. Differential impacts of the industry on southern Louisiana communities can be attributed to 1) the community's history and political economy; 2) the sociocultural context within which the community evolved; 3) the natural features that define the community; 4) the footprint of industrial activity; and 5) the duration of that activity.

Five Communities

- New Iberia
- Morgan City
- Houma
- Golden Meadow
- Venice

New Iberia

- —Sweetest, oiliest, saltiest, hottest; land tied up in agriculture
- —Spanish, French, Senegambian slaves, Acadians
- —Located along Bayou Teche, water access via Vermillion Bay and Intracoastal Canal
- —Port of Iberia
- —Offshore from 1970s to present

Harold Dugas, "My parents were born and raised around this area, in southwest Louisiana, in this parish here. My daddy was a sugarcane farmer …. The last junior and senior year of high school, daddy had to pull me out of school for six weeks to help him on the farm …. I had no concept of the oil—I just didn't know hardly anything about it …. All we knew was sugarcane farming with the little schooling we had…."

Morgan City

- —Railroad brings commerce; lumber industry, shrimping
- —Cosmopolitan
- —Located on Tiger Island, water access via Atchafalaya River and Bayou Boeuf
- —Bulkheads along the bayou
- —Oil discovered in marshes in 1920s; World War II; first offshore well in 1947

Pete Rogers "These companies had been exploring, and there was quite a number of oilfields. When I worked for this timber company, we pulled timber with a pull boat in back of White Castle, and Shell Oil Company at that time—I think it was back in the early 30s—Shell had a field in back of White Castle, and the oil was loaded in wooden barges."

Houma

- —Oyster Capital; agriculture, fishing, trapping
- —Acadian base with large influx due to oil industry
- —Convergence of five bayous at Houma
- —Ideal land base for inshore development
- —First well drilled onshore in 1928; World War II; oil service industries dominate

Annie Weaver "At one time this was the oyster capital of Louisiana and before we came, they had something they called 'turtle camps' down on the bayou and people got turtles, I guess to eat. And then of course we have always had the cane …. We were looked down on at first. I went to a coffee at one of the elderly ladies' in my neighborhood and she said, 'Please don't tell anybody you are with the oil field.'"

Golden Meadow

- —Only incorporated town in South Lafourche; fishing, trapping
- —Populated by Acadians with Houma Indians segregated in lower Golden Meadow
- —Bayou Lafourche
- —Shipyards, offshore vessel companies; Port Fourchon established in 1960
- —Oil rigs throughout town in 1930s

Chester Cheramie, "When the [trapping] season's over you split what you make. So all the time you never had any money… So until you started in the oil field back in the late 30s, that's when people started having a little money because they would come here and they'd spud into the oil well…. So a lot of these people would get a $200–300 dollar check a month. That was a lot of money for those people because they did not have nothing before."

Venice

- —Trapping, citrus, oyster fishing
- —Croatians
- —Mississippi River
- —"The Jump"
- —Oil discovered in the mid-1930s; companies established camps

Myrtle Phillips, “At one point and time before I was ever born, it was all fresh water. Then you know eventually the salt water came in and killed, there were cypress trees on both sides of the bayou and all they’ve got now is the stumps. When the tide goes real low you can see the stumps.”

Summary

- Each community experienced the oil and gas industry uniquely
- Collective memories of conditions, attitudes, and events contribute to our understanding of the industry and its impacts
- Interviewees introduce numerous themes and topics for further study

References

Austin, D.E., K. Coelho, A. Gardner, R. Higgins, T.R. McGuire. 2002. Social and Economic Impacts of OCS Activities on Individuals and Families: Volume 1. Report prepared by the University of Arizona, Bureau of Applied Research in Anthropology. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico Region. New Orleans, LA OCS Study MMS 2002-022.

Austin, D.E. and T.R. McGuire, eds. 2002. Social and Economic Impacts of OCS Activities on Individuals and Families: Volume 2: Case Studies of Morgan City and New Iberia, Louisiana. Report prepared by the University of Arizona, Bureau of Applied Research in Anthropology. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico Region. New Orleans, LA OCS Study MMS 2002-023.

Tom McGuire received his Ph.D. in anthropology from the University of Arizona and is currently an associate research anthropologist in the Bureau of Applied Research Anthropology (BARA) at the University of Arizona. In addition to his research on the historical development and social impact of the oil and gas industry along the Gulf of Mexico, Dr. McGuire has conducted work on the fisheries of the Gulf of California, Native American water rights and resource use in the Southwest, and cattle reaching on the Ft. Apache Reservation in Arizona.

Diane E. Austin is an assistant research anthropologist in the University of Arizona’s Bureau of Applied Research in Anthropology (BARA). She specializes in the development of community-based participatory research methodologies and coordinates BARA’s internship program. Her major interests include environmental anthropology; social impact assessment; environmental justice; community development; and research methods and analysis. She began studying the impacts of the offshore oil and gas industry on southern Louisiana in 1996.

SESSION 2A

ACOUSTICS IN THE MARINE ENVIRONMENT

Chair: **Bill Lang, Minerals Management Service**

Co-Chair: **Ron Brinkman, Minerals Management Service**

CALIBRATION AND ANALYSIS OF SEISMIC AIRGUN DATA FROM AN EARS BUOY

Joal J. Newcomb and William M. Sanders,
Naval Research Laboratory
James M. Stephens, Christopher D. Walker, Benjamin Brack, and
Grayson H. Rayborn, University of Southern Mississippi
Natalia A. Sidorovskaia and Arslan M. Tashmukhambetov,
University of Louisiana at Lafayette
George E. Ioup, Juliette W. Ioup, and Sean R. Chapin,
University of New Orleans

Abstract

In the summer of 2003, during the Sperm Whale Seismic Study (SWSS), two Environmental Acoustic Recording Systems (EARS) buoys were deployed in the northern Gulf of Mexico (GOM) by the Littoral Acoustic Demonstration Center (LADC), an Office of Naval Research-funded consortium consisting of the University of New Orleans, the University of Southern Mississippi, the Naval Research Laboratory, and the University of Louisiana at Lafayette. The buoys were co-located and recorded ambient noise and seismic airgun array shots up to approximately 25 kHz. The gains and hydrophone sensitivities were set such that one EARS buoy could record the seismic shots without clipping and the other could record ambient noise. The *M/V Kondor* towed an airgun array on linear tracks with horizontal closest points of approach to the buoy of 0, 500, 1000, 2000, and 5000 m. Experimental data are available for a wide range of horizontal distances (up to 7 km) and arrival angles. The raw data were calibrated in post processing using the EARS system parameters to produce calibrated pressure time series for each shot. These data are analyzed in both the time and frequency domains. Maximum pressures for each shot as well as sound exposure levels (pressure squared integrated over time for 200 ms in this case) for the shots on the first three tracks are presented. Also presented is a spectrogram analysis for a fixed window length in terms of shot number rather than time. The maximum time-domain peak pressure recorded was 200 dB re 1 μPa when the array was 736 m from the buoy. The maximum sound exposure level was 177 dB sec re 1 μPa^2 sec

Arrival times for direct path, reflected path and critically refracted events from the series of five parallel survey lines are discussed. Near uniform sound speed in the survey area allowed for classification of first-break and secondary arrivals as direct arrival and either reflected or refracted path arrival, respectively, using simple propagation geometries. Beyond a certain horizontal range (approximately 4.5 km), the critically refracted arrival overtook the reflected arrival. In the survey line farthest from the recording buoy (approximately a 5 km closest point of approach), the refracted arrival arrives prior to the seafloor reflection in every shot record and actually begins to precede the direct arrival. These data allow for estimates of the critical angle and sound propagation speed in the seafloor sediment layer.

The identification of different types of arrivals (direct pulse, surface ghost, bottom reflected, etc.) and evaluation of their frequency content depending on the azimuth angles, emission angles, and distance to the array for the subsequent numerical studies are discussed. The numerical modeling of the recorded temporal arrivals from a broadband (10–25,000 Hz) two-dimensional seismic exploration array (the *M/V Kondor* 31-gun, 3,590 cubic-inch array) by the standard underwater acoustic parabolic equation model RAM (Range-dependent Acoustic Model) subject to the actual propagation conditions in the northern GOM is presented. The comparison of the recorded arrival patterns with the expected ones due to the waveguide propagation is given. The complexity of propagation and source models required to predict the identified arrivals are discussed. (This work was supported by the Industry Research Funders Coalition.)

Introduction

The Littoral Acoustic Demonstration Center (LADC) is an Office of Naval Research-funded consortium consisting of the University of New Orleans, the University of Southern Mississippi, the Naval Research Laboratory, and the University of Louisiana at Lafayette. LADC deployed two Environmental Acoustic Recording System (EARS) buoys in the northern GOM during June 2003 (see Figure 2A.1) in conjunction with the Sperm Whale Seismic Study (SWSS). The objective was to obtain calibrated sound pressure levels in an effort to understand the spatial character of seismic airgun emissions. EARS buoys (developed by the Naval Oceanographic Office) are autonomous, self-recording buoys capable, in this configuration, of more than 19 days continuous recording of a single channel at a 78.125 kHz sampling rate. The two buoys were co-located on the same mooring (see Figure 2A.2) near Green’s Canyon in the Northern GOM. One buoy (labeled E3) was designed to record ambient noise and the other (labeled AG) designed to record airgun emissions without clipping the data. The hydrophone of each buoy was approximately 250m from the bottom in a water depth of about 983m. Only the data from the AG EARS buoy will be discussed in this paper.

The *M/V Kondor* towed a seismic airgun array on five parallel linear tracks with horizontal closest points of approach to the EARS buoy position of 0, 500, 1000, 2000, and 5000m (see Figure 2A.3). These tracks provide a wide range of arrival angles and horizontal distances (up to 7 km, see Table 2A.1 (Fontana 2003) from the airgun to the EARS buoys.

Table 2A.1. Airgun calibration lines.

Line Number	Lateral Offset	Emission Angles	Horizontal Range
1 (0.2)	0 m	80° – 6°- 80°	4800m – 63m
2 (500.0)	500 m	81° – 31°- 81°	4900m – 860m
3 (1000.0)	1000 m	82° – 53°- 82°	5200m – 1250m
4 (2000.0)	2000 m	82° – 70°- 82°	5300m – 2100m
5 (5000.0)	5000 m	84° – 82°- 84°	7000m – 5050m

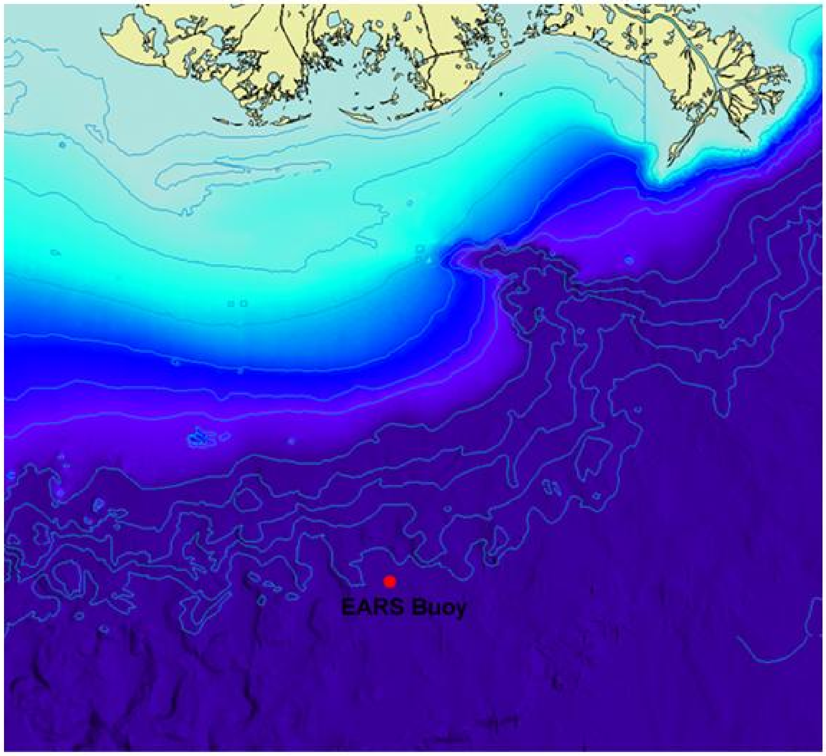


Figure 2A.1. Chart of Northern Gulf of Mexico indicating the position of the EARS buoys near Green's Canyon.

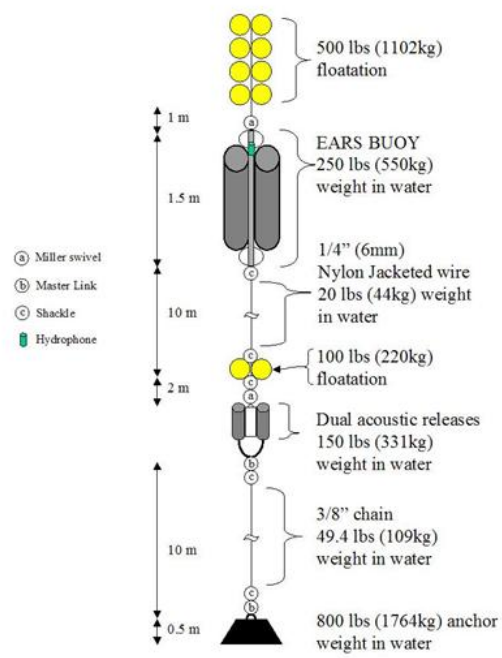


Figure 2A.2. Illustration of the mooring showing the two co-located EARS buoys.

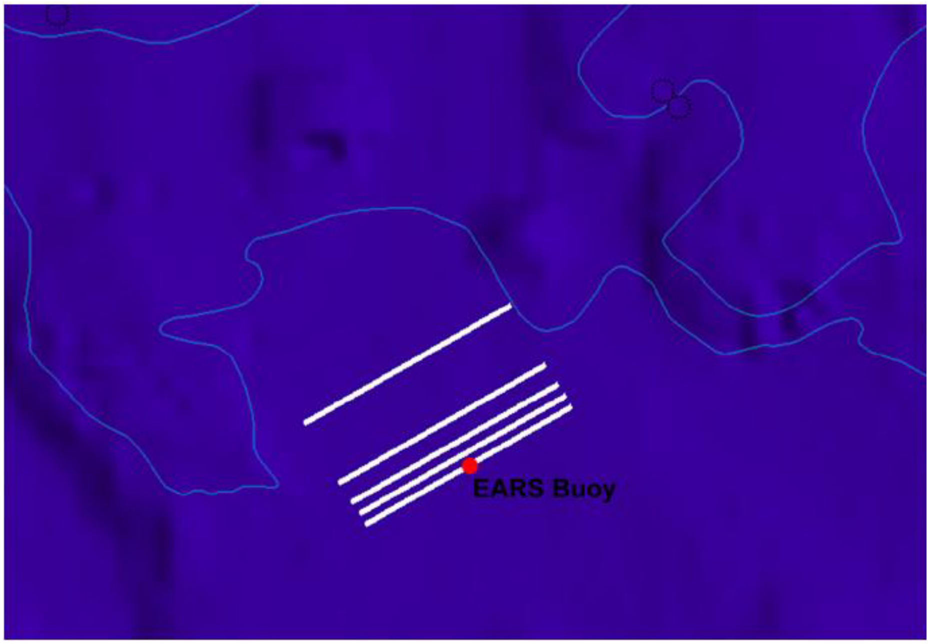


Figure 2A.3. Illustration of the tracks of the M/V KONDOR in relation to the EARS buoy position.

Calibrations

To report absolute sound pressure levels, it is important that the equipment calibrations be fully understood. Two methods of calibration were used for the AG EARS buoy. The first method involves injecting a single narrowband sine wave (CW) into the electronics downstream of the hydrophone. The input voltage of the injected CW signal is compared to the output voltage. This is repeated for many different frequencies to obtain the transfer function of the equipment across a broad frequency band. This method is often called a frequency domain solution.

The other method injects a very temporally short (4.7µsec wide) signal into the electronics downstream of the hydrophone. The characteristics of this "impulse" are such that a very wide band of frequencies are represented. The output was recorded and supplied the impulse response of the equipment. This is often called the time domain solution. Theoretically, the impulse response of the equipment and the transfer function of the equipment are equivalent. A comparison of the two methods for the AG yielded the same results between 6 Hz and 25 kHz. For ease of calculation all final calibrations were performed using the frequency domain solution. The hydrophones were new and calibrated at the manufacturer.

Figure 2A.4 is an illustration of the data from shot 248 along the 0 m offset line. Shot 248 is near the closet point of approach (CPA) to the EARS buoy. Figure 2A.4 illustrates only 200 ms of data corresponding to the "direct" arrivals. The upper plot is the raw data in Volts and the bottom plot is the same data in µPa after all the calibrations have been applied. The EARS response is nearly flat from 6 Hz to 25 kHz so that the two plots have very little differences except in units.

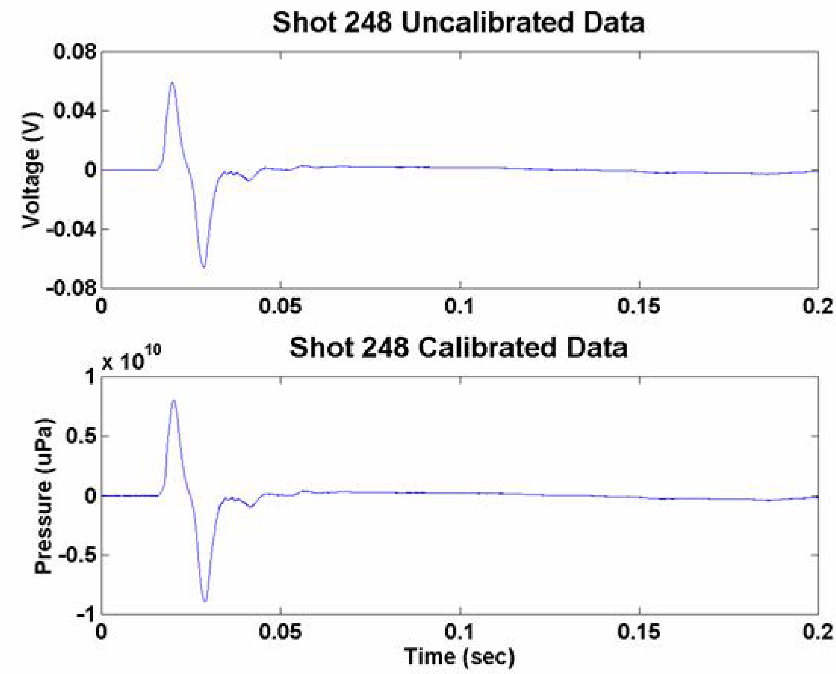


Figure 2A.4. Plots of data from Shot 248 on the 0m offset line near the point of closest approach to the EARS buoy illustrating the shot before and after calibrations have been applied.

Airgun Calibration Data Analysis

Three approaches are used initially to analyze airgun calibration data.

1. The simplest is the maximum instantaneous airgun pressure for each shot at a given range, azimuth, and depth. This measure is important but it does not give signal duration or energy transfer.
2. The second is the Sound Exposure Level (SEL), the sum of the squared pressures multiplied by the sampling interval for a given time window, which includes the effects of signal duration. A 200 ms window is used because there seems to be a consensus developing that this is the appropriate integration time for sperm whale hearing.
3. The third is the sound pressure density spectrum, which gives the distribution of intensity over frequency.

The plots in Figure 2A.5 show the maximum peak pressures in dB re 1 μPa versus shot number for each of the five lines. If instead of a single peak pressure we had used the peak-to-peak difference, these numbers would be increased by less than 3 dB. Although one might be tempted to make isopleths, i.e., contours of constant pressure, based on these data, it is not possible to do so. It must be remembered that these measurements are in three dimensions, not two, and they are far too sparse to determine contours. These contours can be determined by modeling, however, and the measurements can be used to validate the models.

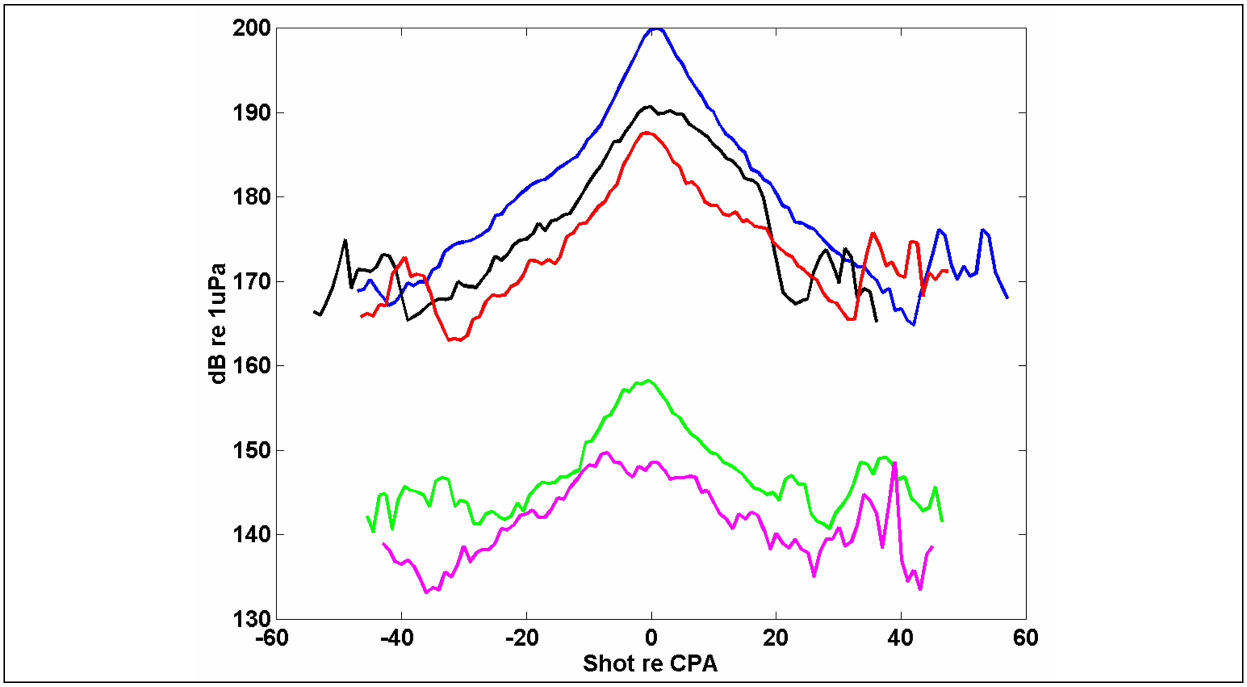


Figure 2A.5. Maximum pressures in dB re 1 μPa versus shot number for each of the five lines.

Figure 2A.6 is a graph of the voltage recorded for the shot of CPA for Line 1. The sound exposure level in dB sec re 1 μPa^2 sec for a 200ms window slid over the shot is shown in Figure 2A.7. The maximum SEL for every shot in Lines 1, 2, and 3 (in red, blue, and green, respectively) is shown in Figure 2A.8, plotted versus shot number. The gaps occur during ship turns. For some analyses, SEL is given for 90% of the total SEL. This is done when it is difficult to distinguish where the airgun shot starts and finishes relative to the background ambient noise. For the AG EARS buoy, the signal-to-noise ratio is high enough that background ambient noise does not contribute to the SEL. Therefore 100% of the SEL calculated over the 200 ms window can be used (Madsen 2005).

Finally, Figure 2A.9 contains what can be regarded as a spectrogram, except that the horizontal axis is shot number rather than time. The sound pressure density spectrum level in dB re 1 μPa^2/Hz is shown for all calibration shots sequentially along each of the five lines, one line after the other. There are a total of 587 shots (including the shots made while the ship was turning between lines). The window for each shot is 1.28 sec. The frequency to 25 kHz is shown on the vertical axis, and the line number on the horizontal axis. The intensity is indicated by the color bar, ranging from 60 to 160 dB. Very faint intensity lines can be seen at regular intervals at 18 kHz. These are caused by the ship's echosounder.

One-third octave bands are close to reflecting the way that animal hearing integrates sound. Therefore this analysis is important. This calculation and appropriate normalization are currently in process.

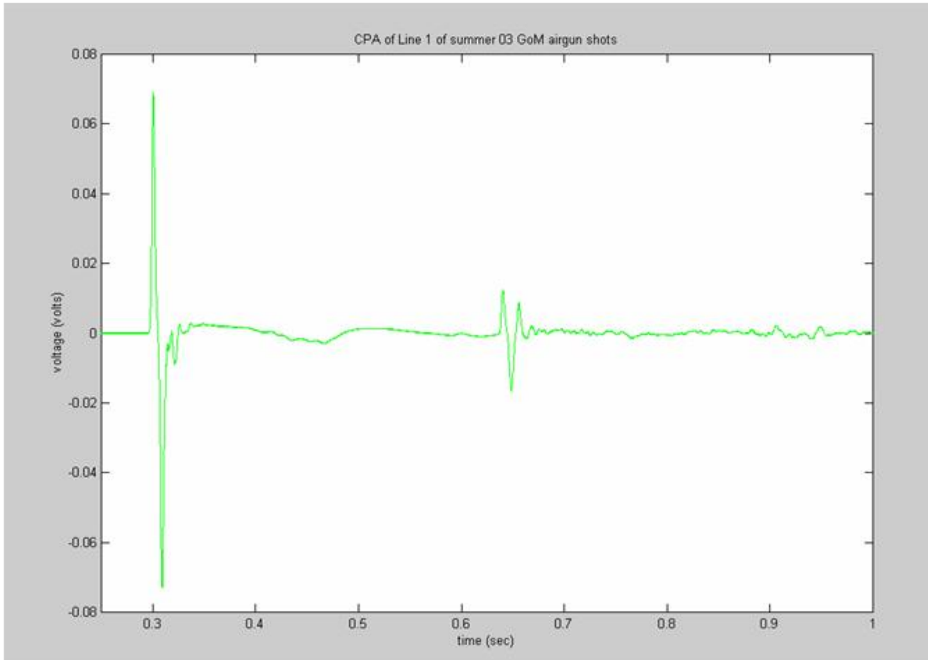


Figure 2A.6. Voltage versus time for the shot of the closest point of approach for Line 1.

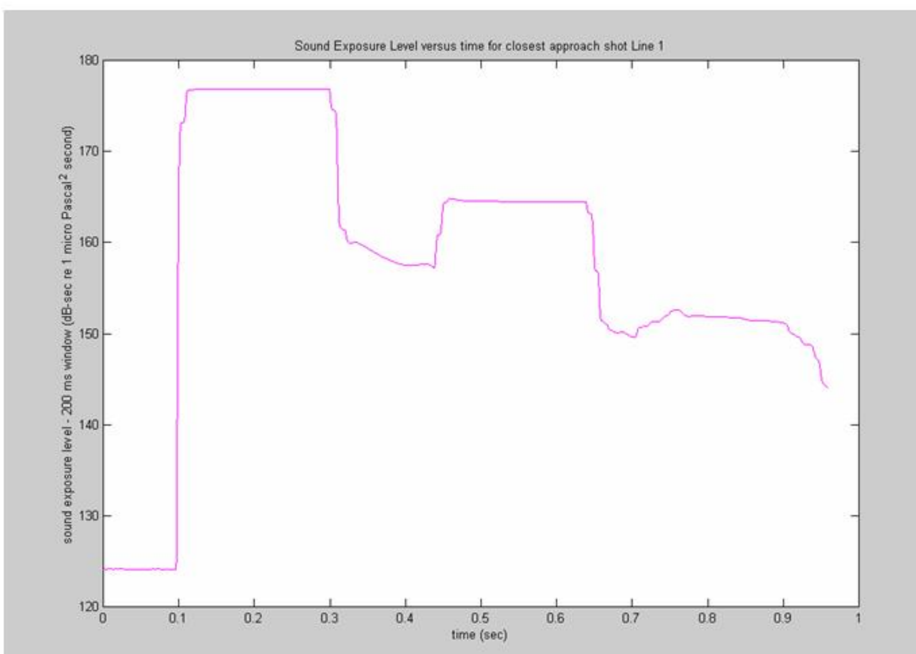


Figure 2A.7. Sound Exposure Level in dB sec re 1 μPa^2 sec for a 200 ms sliding window for the shot of the closest point of approach for Line 1 as shown in Figure 2A.6.

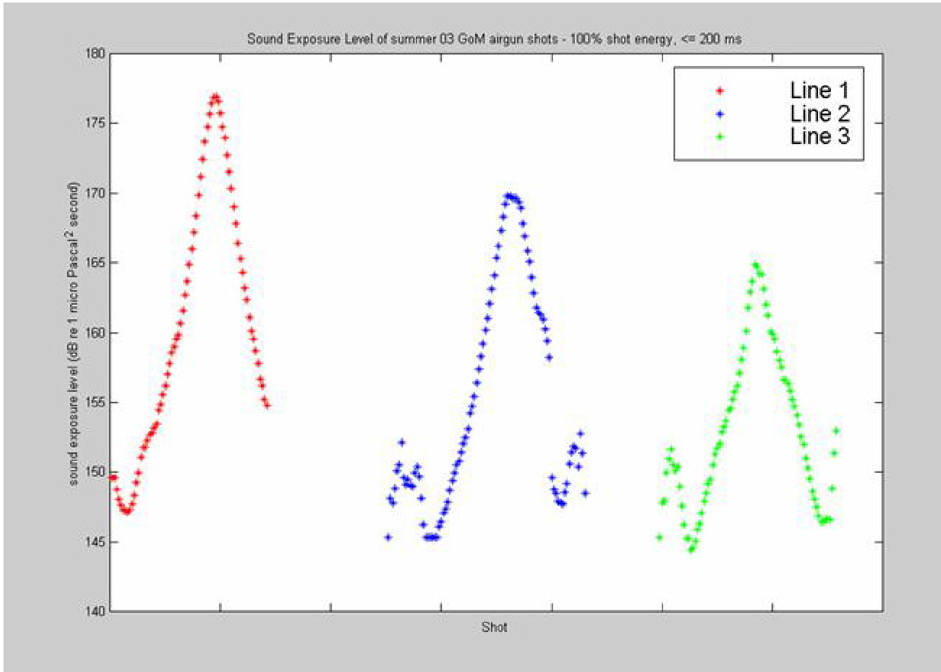


Figure 2A.8. Maximum Sound Exposure Levels over a 200 ms window for each shot on Lines 1, 2, and 3, in dB sec re 1 μPa^2 sec.

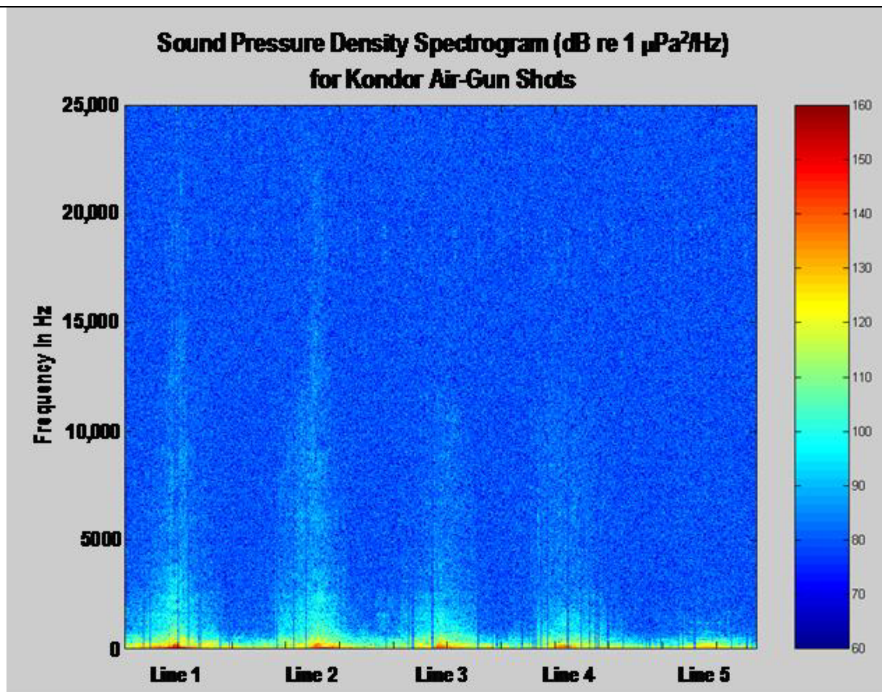


Figure 2A.9. Sound pressure density level spectrogram of airgun shots, but with shot number on the horizontal axis rather than time. Plot shows intensity by color for 0 to 25 kHz for each shot number sequentially along each line. The intensity scale goes from 60 to 160 dB for sound pressure density level given in dB re 1 μPa^2/Hz.

Arrival Time Analysis

Assuming a constant sound speed in the water column, both direct and reflected arrivals exhibit hyperbolic moveout: the arrival time vs. horizontal range (offset) curve is a hyperbola in each case. At some critical distance, Xc, the refracted arrival begins to appear. The refracted ray precedes the reflected array for all offsets greater than Xc, and will—in principle—eventually overtake the direct ray. The arrival time vs. offset curve for the refracted ray is a straight line, with sound propagation speed in the seafloor layer appearing as the inverse slope. This expected behavior is depicted in Figure 2A.10. If distinct arrival events can be recognized in the time series, a plot of arrival time vs. horizontal offset can be used to determine the onset of refracted arrival, as well as estimate the critical angle and sound speed in the seafloor layer.

A plot of the second event arrival vs. offset exhibits hyperbolic character for small offsets, as this event, presumably, is the reflected path arrival, but will flatten out at offsets equal to or greater than X_c. At this distance the refracted arrival overtakes the reflected energy and follows a linear relationship with horizontal offset. An example is seen in Figure 2A.11. To make the deviation from hyperbolic moveout more apparent, we plot the difference in first arrival (first break) and second arrival times vs. offset. When the first break corresponds to the direct arrival, and the second arrival is the reflected signal arrival, the difference plot asymptotically approaches a horizontal line. With the appearance of refracted energy in the second arrival, the difference plot will drop sharply from the expected asymptotic behavior. This effect is clearly seen in Figure 2A.12, at an offset of approximately 4,500 m. In all the data this effect—attributed to the appearance of the refracted wave—manifests itself at 4,500 m, which we take as our estimate of X_c.

From elementary geometry, the critical angle can be determined from X_c,

$$\theta_c = \tan^{-1}\left(\frac{X_c}{d+h}\right). \quad (1)$$

The quantities d and h are the heights of the seismic source and hydrophone above the seafloor, respectively. The sound speed in the seafloor layer, u, may now be determined as

$$u = \frac{c}{\sin\theta_c}, \quad (2)$$

where c is the sound speed (assumed constant) in the water column. In the experiment, d = 983 m, and h = 250 m. If the (nearly constant) sound speed in the water column is taken as 1,500 m/s, the resulting value for u is approximately 1,550 m/s.

The large offset portion of the second arrival vs. offset plot should, in principle, provide a second means to determine the speed in the seafloor layer; it is the reciprocal of the slope of this linear portion. Linear regression on the data yielded results that were not self-consistent, which we interpret to be due to the small number of data points for offsets larger than X_c. Additionally, in one of the survey lines the CPA was greater than 4,500 m, so the second arrival should have exhibited a linear relationship with offset and, indeed, should have overtaken the direct arrival at some point. Analysis of this line was problematical; however, apparently the discrete arrival events could not be identified and separated as easily as might have been hoped.

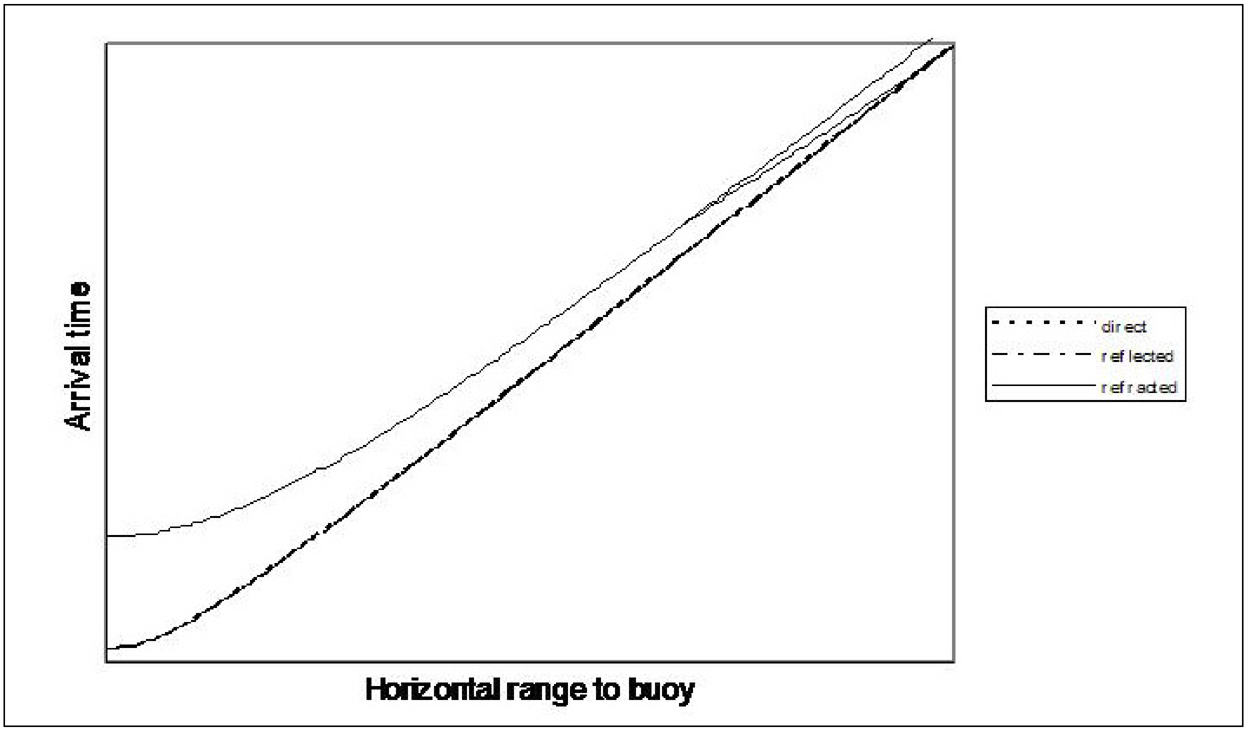


Figure 2A.10. Expected arrival time behavior for direct, reflected, and refracted energy.

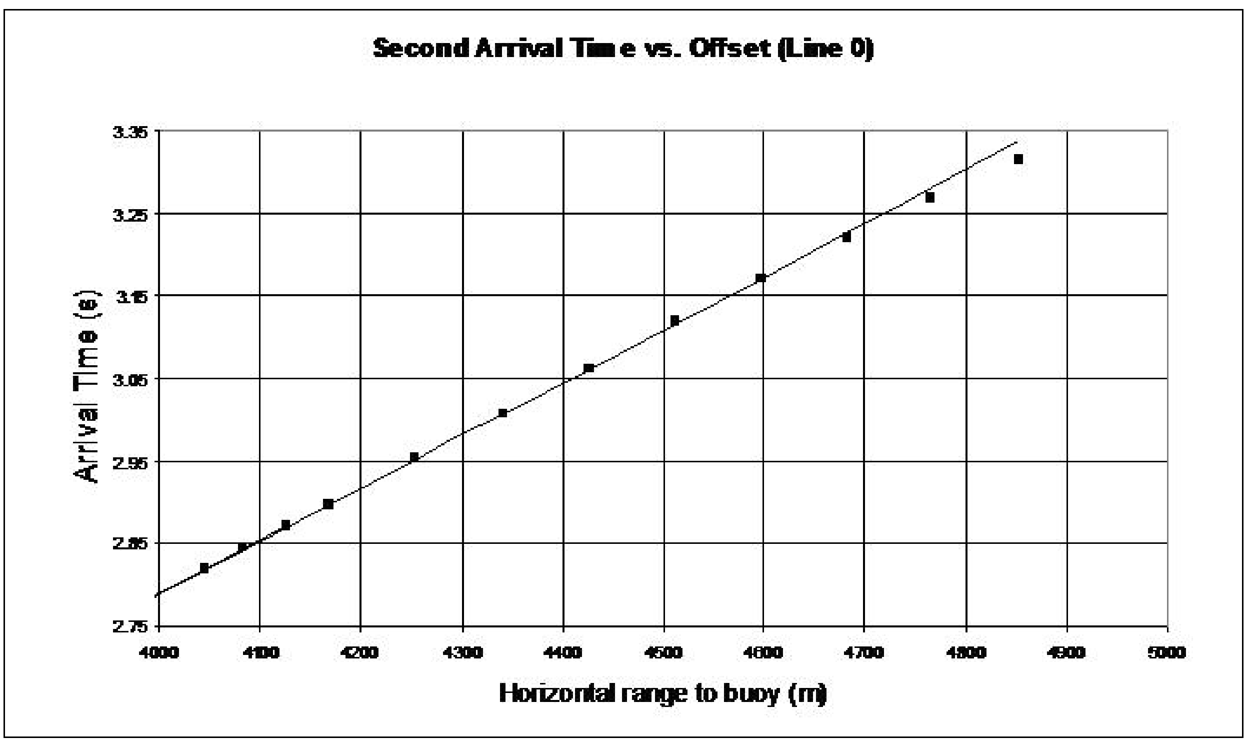


Figure 2A.11. Flattening of second arrival at large offsets, indicating refracted arrival overtaking reflected energy.

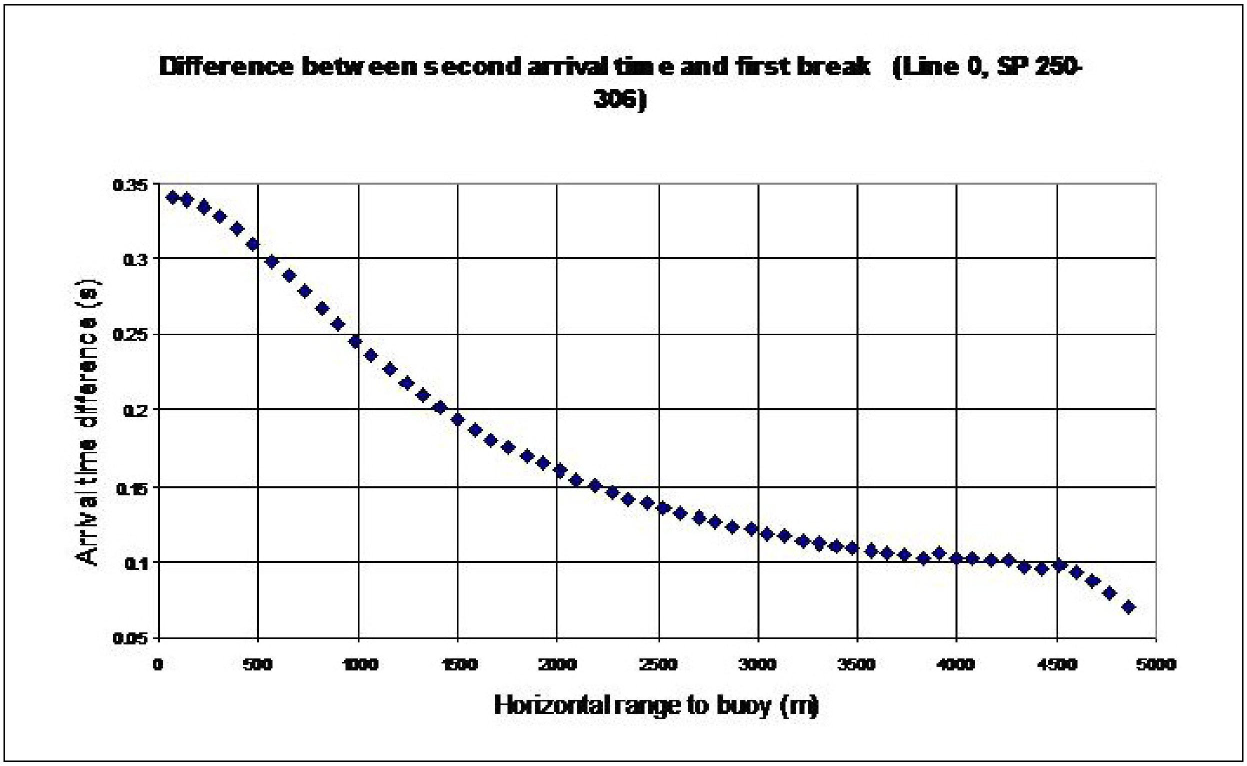


Figure 2A.12. Difference between second and first arrival vs. horizontal range (offset). Dip at approximately 4500 m is a deviation from the expected asymptotic behavior when second arrival corresponds to reflected path.

Acoustic Energy Propagation Modeling

Two main objectives of the acoustic propagation modeling of the LADC calibration experiment were 1) the generation of a three-dimensional acoustic energy distribution in the oceanic volume of interest based on the successful fit of the modeled data to the EARS recordings and 2) the prediction of three-dimensional acoustic energy distribution variations due to anticipated changes in the geographical position of a future survey, ocean environmental conditions, and source configuration without conducting additional costly calibration experiments.

The propagation modeling workflow is illustrated on Figure 2A.13. Source frequency or temporal signature, source-receiver geometry, and oceanic waveguide model (bathymetry, sound speed profile, bottom layering) are inputs into propagation model, which is basically a wave equation solver. The simulated acoustic signature at the EARS location as an output of the propagation code is compared to the experimental one. If an adequate fit is achieved, then the primary objectives can be addressed by changing the input parameters and analyzing the simulated output. Otherwise, the accuracy of the inputs should be adjusted, and the modeling should be repeated.

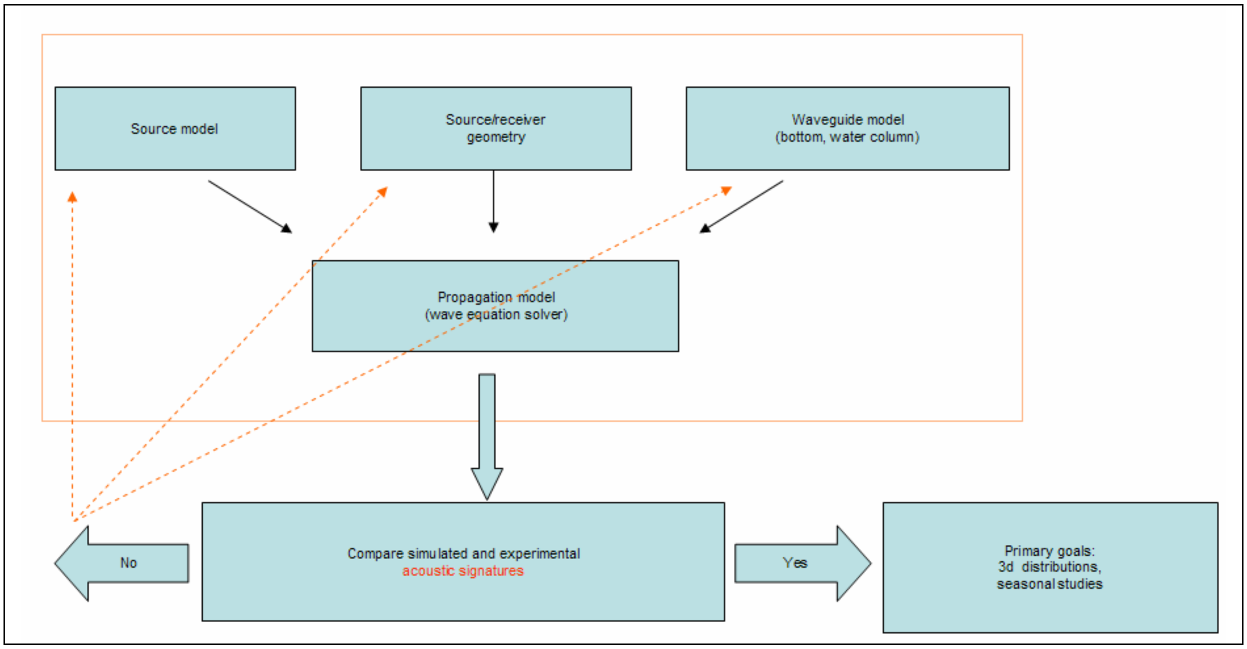


Figure 2A.13. The propagation modeling workflow.

The standard underwater acoustic model RAM (Range-dependent Acoustic Model) (Collins 1993) was used to simulate the acoustic signature at the EARS location. The code was modified to generate the response from a broadband multi-source seismic array. To describe the source-receiver geometry, a spherical coordinate system was utilized. The origin of the system is in the center of the seismic array. The EARS position is described by the vertical angle Θ, the horizontal angle ϕ, and the horizontal range, which represents the projection of the direct distance from the center of the array to the hydrophone into the horizontal plane (see Figure 2A.14).

The water column waveguide model used in the simulations was constructed from the experimental data of pressure, salinity, and temperature of the water collected by XBT casts performed concurrently with the experiment. The bottom model based on an historical database consists of three layers: a 10 m deep layer of soft silty-clay, a 1 km deep layer of sand, and a rock foundation (Hamilton 1980). The waveguide model is presented in Figure 2A.15. According to the constructed sound speed profile in the water column, the seasonal surface duct is apparent in the first 10 m of water. The surface duct should generate a unique series of early acoustic arrivals (precursors) at the receiver position as indicated in previous studies (Monjo and DeFerrari 1993, Sidorovskaia 2004). The effects of the energy redistribution in the water column from the directional seismic source due to a seasonal surface duct are under study and will be addressed in future publications.

The frequency domain representation of the transfer function (Green's function) generated by RAM for two different shot points is presented in Figure 2A.16. Each color line corresponds to the individual transfer function from a particular airgun to the EARS buoy. The seismic exploration array consists of 31 spaced or single airguns with volumes ranging from 20 to

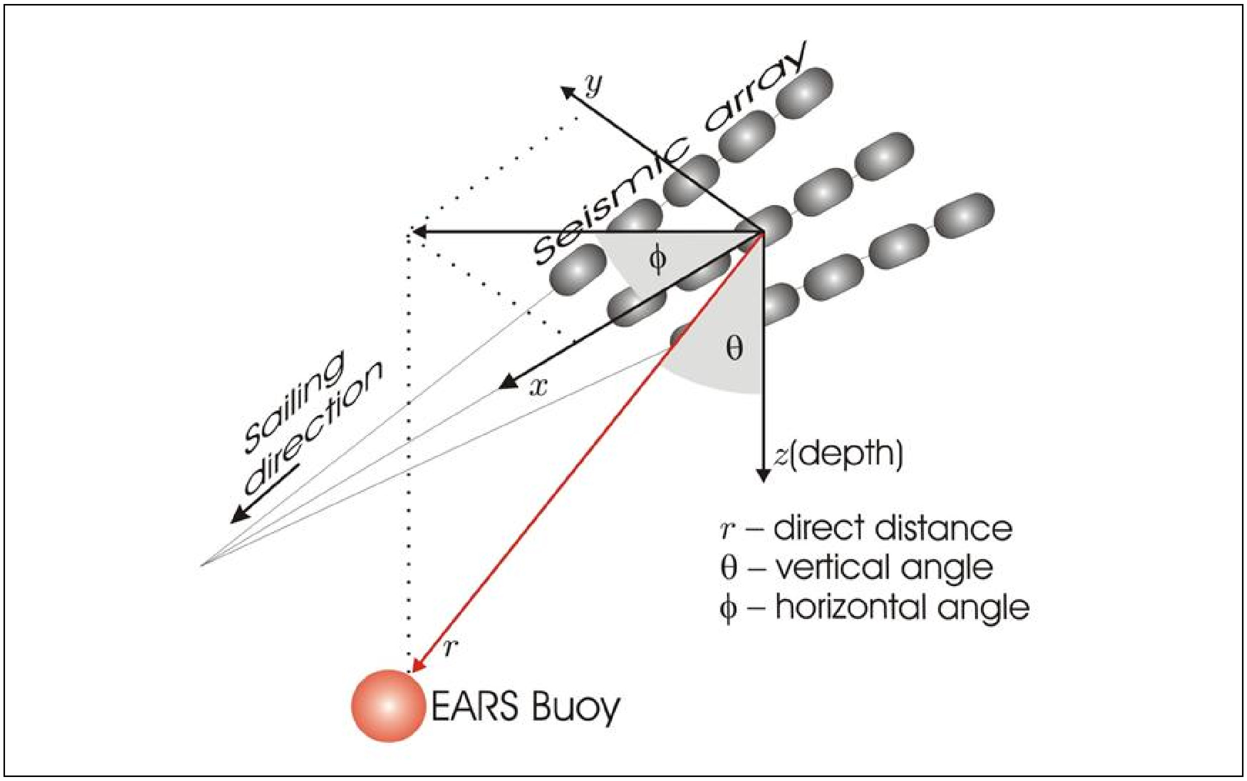


Figure 2A.14. Array-buoy coordination system.

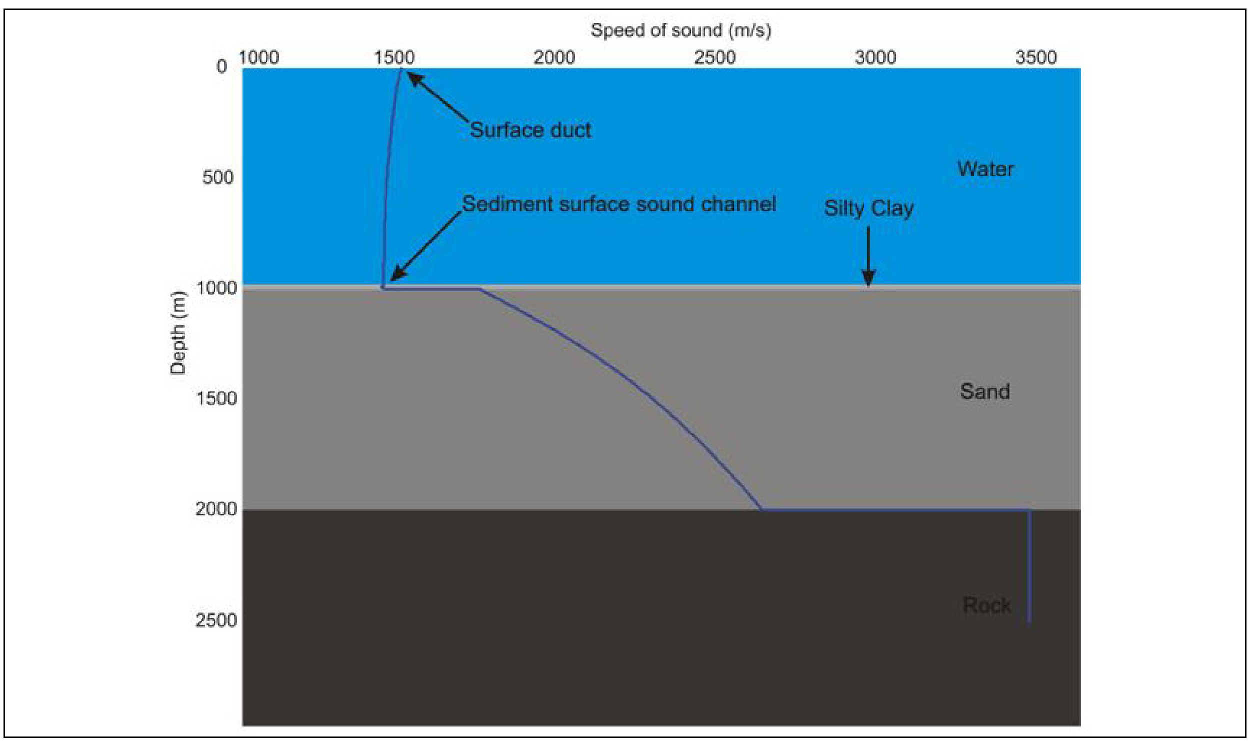


Figure 2A.15. Waveguide model.

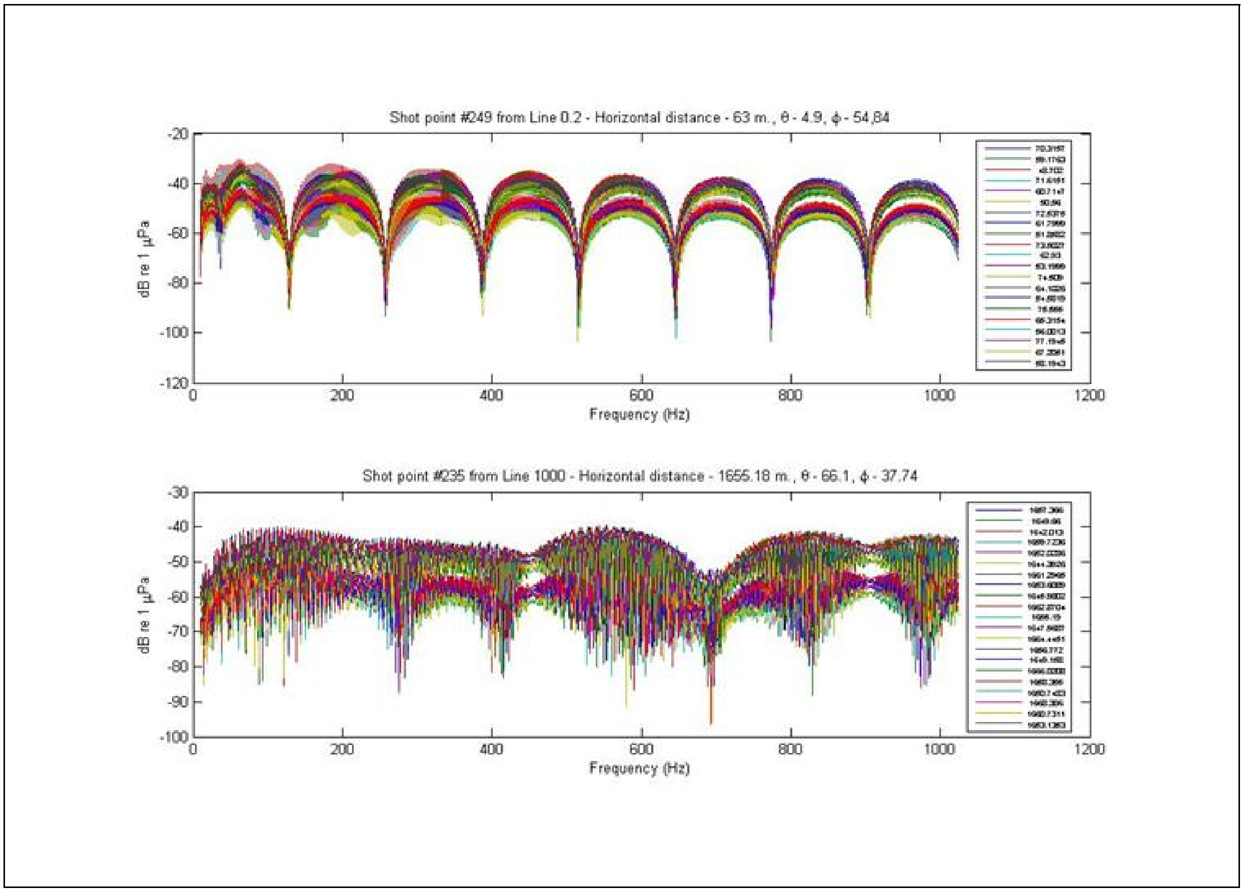


Figure 2A.16. Green's function generated by RAM.

250 cubic inches, giving a total volume of 3,950 cubic inches. The difference in the individual source powers corresponds to the variation in sound pressure density spectral levels. The low-frequency interference structure in the Green's function is due to the surface reflection. The fine structure of the transfer function is determined by the first bottom reflection and multiples.

The measured seismic exploration array signature in the frequency domain is modeled by the sum of the products of the transfer, $G_i(f)$, and source, $S_i(f)$, functions for each airgun:

$$p_{EARS}(f) = \sum_{i(airguns)} G_i(f) \cdot S_i(f) \quad . \qquad (3)$$

Figure 2A.17 shows the comparison of the experimental and modeled signatures for two different array positions relative to the EARS buoy. For this plot, the frequency signatures of the individual airguns are modeled as flat over the entire frequency band of interest (10-1000 Hz). It is obvious from the comparison that this model reflects the actual airgun design only in the lower part of the spectrum (up to 250 Hz) where satisfactory agreement is reached. The experimental spectra indicate faster attenuation of the high frequencies than modeled ones.

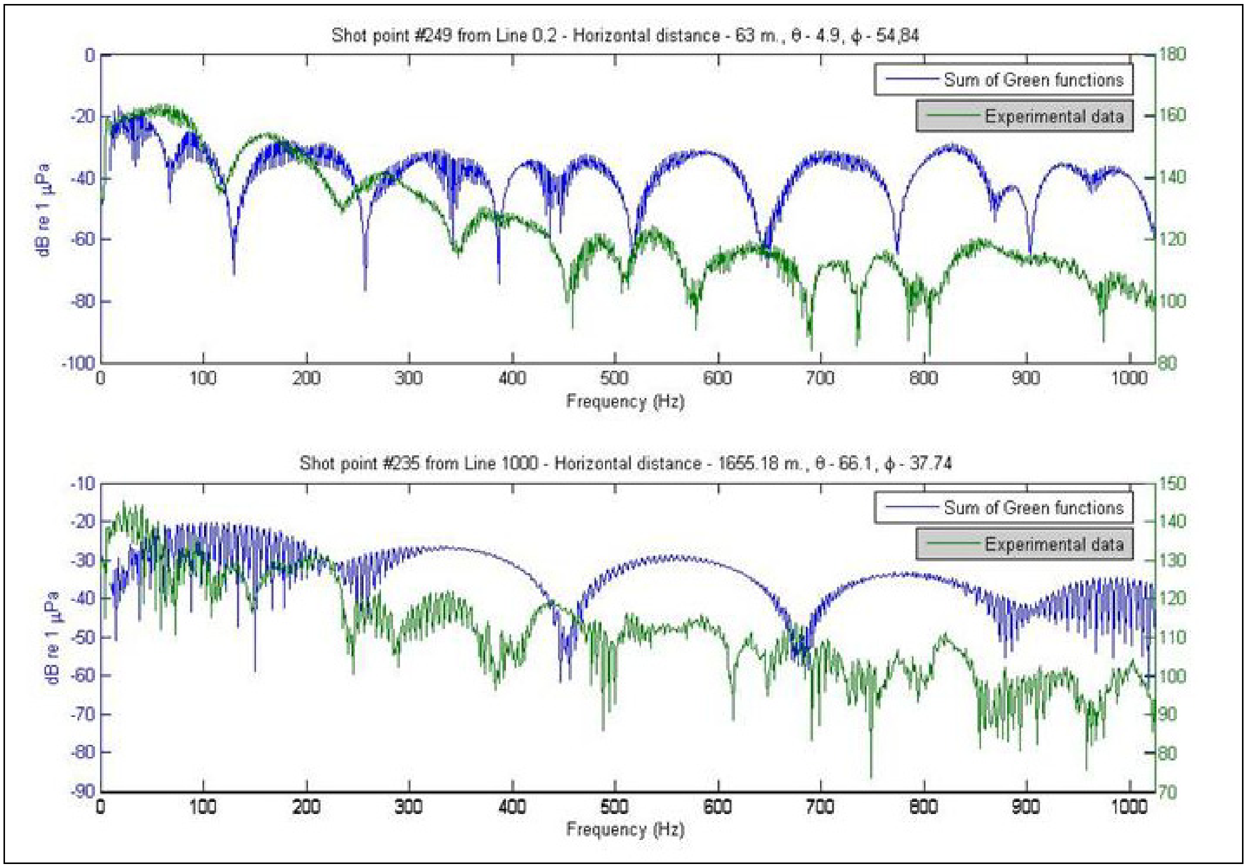


Figure 2A.17. Model output versus experimental data.

The modeling has demonstrated that a more advanced signature of the individual sources should be implemented to account for the high-frequency attenuation (Ziolkowski 1970). Once a better match is achieved for the high-frequency components, three-dimensional acoustic energy distribution maps will be generated.

Acknowledgments

This research was supported by the Industry Research Funding Coalition.

References

Collins, M.D. 1993. A split-step Pade solution for parabolic equation method. Journal of the Acoustic Society of America. 93:1736–1742.

Fontana, P. 2003. Private communication.

Hamilton, E.L. 1980. Geoacoustic modeling of the sea floor. Journal of the Acoustic Society of America. 68(5):1313–1340.

Madsen, P. 2005. Private communication.

Monjo, C.L. and H.A. DeFerrari. 1994. Analysis of pulse propagation in a bottom-limited sound channel with a surface duct. Journal of the Acoustic Society of America. 95:3129–3148.

Sidorovskaia**,** N. 2004. Systematic studies of pulse propagation in ducted oceanic waveguides in normal mode representation. The European Physical Journal, Applied Physics 25(2):113–131.

Ziolkowski, A. 1970. A method for calculating the output pressure waveform from an air-gun. Geophysical Journal of the Royal Astronomical Society 21:137–161.

Joal J. Newcomb received a B.S. degree in physics and mathematics from Southwestern Oklahoma State University, an M.S. in atomic physics from Kansas State University, and a Ph.D. in experimental atomic physics from Kansas State University. He is currently a research physicist in the Acoustics, Simulations, Measurements & Tactics Branch of the Naval Research Laboratory at the John C. Stennis Space Center, Mississippi. Dr. Newcomb was the chief scientist of OUTPOST SUNRISE, a major acoustic measurement program, and has been principal investigator of several projects to study underwater ambient noise, broadband and narrowband signal propagation, and basin reverberation. Dr. Newcomb is an internationally recognized expert in underwater ambient noise and shipping noise.

William M. Sanders has conducted research in underwater acoustics at the Naval Research laboratory since 1998. His areas of specialty are ambient noise, propagation modeling, data fusion and signal processing. He earned his Ph.D. from the University of Miami in 1998 in applied marine physics. He conducted research in underwater acoustics and signal processing for private industry between 1985 and 1992. He is a member of the Acoustical Society of America.

James M. Stephens is a research faculty member of the Department of Physics and Astronomy at the University of Southern Mississippi (USM). Dr. Stephens holds a B.S. from Rice University, a Master's degree from the University of Southern Mississippi, and a Ph.D. from the Georgia Institute of Technology, all in physics. Prior to joining USM, he was employed by WesternGeco in Houston as a project geophysicist and processing geophysicist. Dr. Stephens attended Rice University on an NROTC scholarship, and served as an officer in the United States Navy for nine years, including a tour at the Naval Oceanographic Office, located on the National Space Technology Laboratories (now Stennis Space Center), Mississippi.

Christopher D. Walker received a B.S. in physics in 2002 from the University of Southern Mississippi. He is pursuing a graduate degree at the University of Southern Mississippi where he is also employed as a full-time staff research scientist. His research experience includes laser spectroscopy, signal processing, acoustics, modeling, simulation, and visualization.

Benjamin Brack earned a B.S. in physics from University of Southern Mississippi and worked at the USM Signal Research Center studying seismic airgun emissions and whale vocalizations.

Grayson H. Rayborn received a B.S. in physics from the Rensselaer Polytechnic Institute and a Ph. D. in physics from the University of Florida. After a year on the faculty of Old Dominion University he joined the physics faculty of the University of Southern Mississippi where, except for a sabbatical year at the University of Nebraska, he remained until he retired from the faculty as Professor of Physics and Astronomy. He continues to pursue his research interests in signal processing, experimental atomic physics, and underwater acoustics as Professor *Emeritus* at the University of Southern Mississippi Signal Research Center.

Natalia A. Sidorovskaia received a M.S. in radiophysics from the Gorky (presently Nizhny Novgorod) State University, an M.S. in physics from the University of New Orleans, and a Ph.D. in engineering and applied science from the University of New Orleans. After a two-year career in the oil industry with Landmark Graphics Corporation, Halliburton Company, she joined the Department of Physics, University of Louisiana at Lafayette where she is now an Assistant Professor. Her research interests include numerical modeling of sound propagation through oceanic waveguides; theoretical methods in scattering from objects; depth imaging techniques in seismic signal processing; seismic data management; methods of presentation and processing of deterministic and random signals, including the adaptive processing of highly noisy experimental data; methods of solutions of hydrophysical inverse problems (noise source imaging, ocean acoustic tomography).

Arslan M. Tashmukhambetov received his B.S. degree in plasma physics from the Kazakh State University, and he is now a physics graduate student at the University of Louisiana at Lafayette. His research interests include digital signal processing, computational acoustics, solid state physics, and plasma physics.

George E. Ioup received an S.B. in physics from the Massachusetts Institute of Technology and a Ph.D. in physics from the University of Florida. After one-year appointments as a postdoctoral fellow at the University of Connecticut and as an assistant professor of physics at the U. S. Coast Guard Academy, he joined the Department of Physics, University of New Orleans (UNO). He is now University Research Professor of Physics and Geophysics. He currently serves as Director of UNO at Stennis Space Center and has been president of the Southeastern Geophysical Society (SGS). His research interests include acoustic, geophysical, and aerospace signal analysis and processing; deconvolution, mathematical digital filtering, and spectral estimation; Fourier and wavelet transforms; higher order correlations and spectra; underwater acoustics; modeling and simulation; and computational physics.

Juliette W. Ioup received a B.S. and M.S. in physics from the University of Florida and a Ph.D. in physics from the University of Connecticut. She has been a professor of physics at Xavier University of Louisiana, a geophysicist data processor at Texaco in New Orleans, and is presently a professor of physics, geophysics, and electrical engineering at the University of New

Orleans. Her research interests include geophysical, acoustic, and aerospace signal analysis and processing; deconvolution, mathematical digital filtering, spectral estimation; Fourier and wavelet transforms; neural networks; higher order correlations and spectra; underwater acoustics; modeling and simulation; and computational physics. She is a Fellow of the Acoustical Society of America and a member of ASA, SEG, AGU, IEEE, APS, AWIS, and SGS.

Sean R. Chapin received a BS in Physics from Western Michigan University. After working as a research scientist in the Scientific Research Laboratory at Ford Motor Company, he obtained an MS in Applied Physics from the University of New Orleans (UNO). He is currently a physicist at the Naval Surface Warfare Center in Dahlgren, Virginia and is concurrently working on a PhD in Engineering and Applied Science from UNO. His research interests include underwater acoustics, radar, electro-optic sensors, modeling and simulation, signal and image processing, and track processing.

BOTTOM-MOORED HYDROPHONE MEASUREMENTS OF AMBIENT NOISE DURING STORMS IN THE GULF OF MEXICO

Joal J. Newcomb, Naval Research Laboratory
Mark Snyder and Wesley R. Hillstrom, Naval Oceanographic Office
Ralph Goodman, University of Southern Mississippi

Abstract

The Littoral Acoustic Demonstration Center (LADC) deployed three Environmental Acoustic Recording System (EARS) buoys in the northern Gulf of Mexico (GOM) during the summer of 2002 (LADC 02). The hydrophone of each buoy was approximately 50m from the bottom in water depths of 645m to 1,034m. During LADC 02, Tropical Storm Isidore and Hurricane Lili passed within approximately 73nmi and 116nmi, respectively, west of the EARS buoys. The proximity of these storm systems to the EARS buoys, in conjunction with wind speed data from three nearby NDBC weather buoys, allows for the direct comparison of underwater ambient noise levels with high wind speeds. These results are compared to the G.M. Wenz (Wenz 1962) spectra at frequencies from 1 kHz to 5.5 kHz. Anomalously high levels of ambient noise may be due to banding effects of the storms. Results of the ambient noise analysis will be presented. (Research supported by ONR).

Introduction

The Littoral Acoustic Demonstration Center (LADC) is an Office of Naval Research-funded consortium consisting of the University of New Orleans, the University of Southern Mississippi, the Naval Research Laboratory, and the University of Louisiana at Lafayette. LADC deployed three Environmental Acoustic Recording System (EARS) buoys in the northern GOM during the summer of 2002 (LADC 02) to study ambient noise and marine mammals. The LADC EARS buoy (developed by the Naval Oceanographic Office) is an autonomous, self-recording buoy capable of more than 66 days continuous recording of a single channel at an 11.7 kHz sampling rate. The hydrophone of each buoy was approximately 50m from the bottom in water depths of 1,034m to 645m along an upslope track. The buoys were labeled EARS 1 (deepest), EARS 2, and EARS 3 (shallowest). Oceanographic data (CTD and XBT data) were obtained during each deployment along a longer upslope track and along a cross slope track centered at EARS 1. Bottom information for these tracks was obtained during LADC 01 (summer of 2001) from side-scan sonar data.

During LADC 02, Tropical Storm Isidore and Hurricane Lili passed within approximately 73nmi and 116nmi, respectively, west of the EARS buoys. The proximity of these storm systems to the EARS buoys, in conjunction with wind speed data from three nearby National Data Buoy Center (NDBC) weather buoys (see Figure 2A.18), allows for the direct comparison of underwater ambient noise levels with high wind speeds.

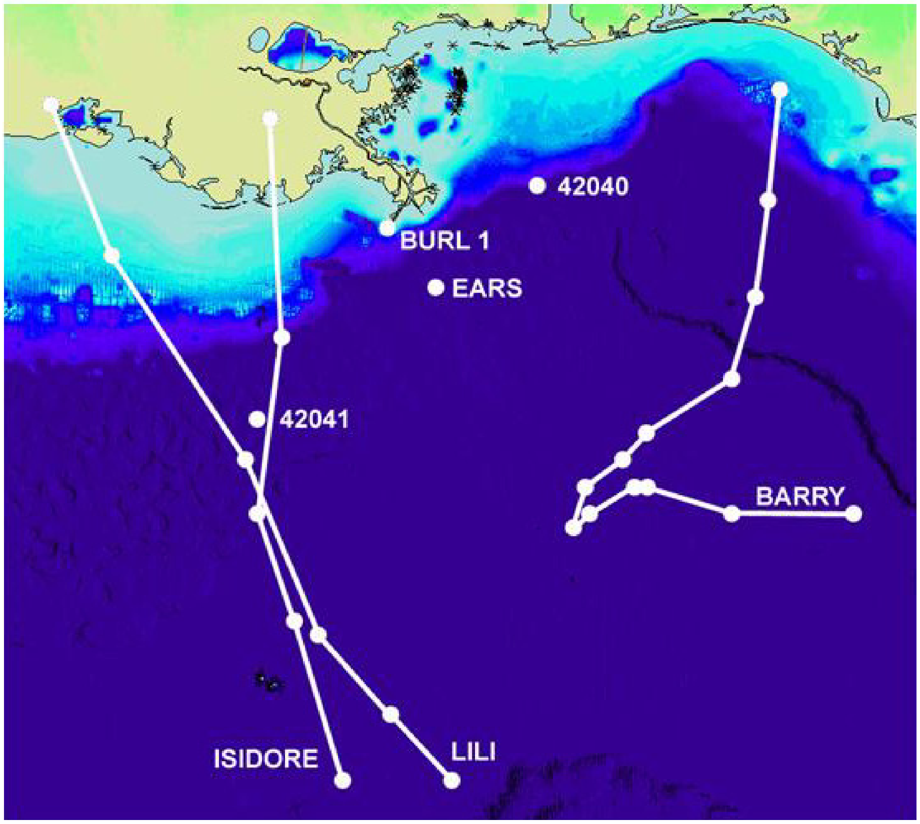


Figure2A.18. Chart of storm system tracks during the summer of 2001 and 2002 relative to the EARS deployment site and the NDBC weather buoys.

Ambient Noise Results

The storm systems' tracks were obtained from positional data published by the National Hurricane Center (NHC) indicated by the solid circles connected with straight lines in Figure 2A.18. Wind speed estimates at the EARS location were obtained from an examination of wind speed and wave height measurement data obtained from the NDBC weather buoys. Ambient noise results were obtained from a spectral analysis of the EARS raw acoustic data.

Hurricane Lili at closest approach passed about 116nmi west of the EARS buoys. All three NDBC buoys were used to estimate wind speed for each time period except for the time period where Hurricane Lili passed very close to NDBC buoy 42041.

Figure 2A.19 illustrates the ambient noise results for Hurricane Lili for EARS 1 from 1 kHz to 5.5 kHz. The closely grouped spectra are the noise levels for the time periods corresponding to published positions of Hurricane Lili and represent estimated wind speeds of 20 to 47kts. The much lower-level spectrum represents the results for a time period during which there were no storm systems in the GOM and is presented only for comparison. As expected, when Hurricane

Lili approached EARS 1, the wind speeds increased and the corresponding noise levels increased. Superimposed upon these results are the Wenz curves for Beaufort Wind Forces (BWF) of 5 and 8 (solid black lines) and the projected upper limit of prevailing noise. As can be seen from Figure 2A.18, the measured spectra agree well with the slope and levels of the BWF 8 curve for wind speeds of 34kt to 40kt. Results from the EARS 3 buoy have overall higher spectral levels, but otherwise are very similar.

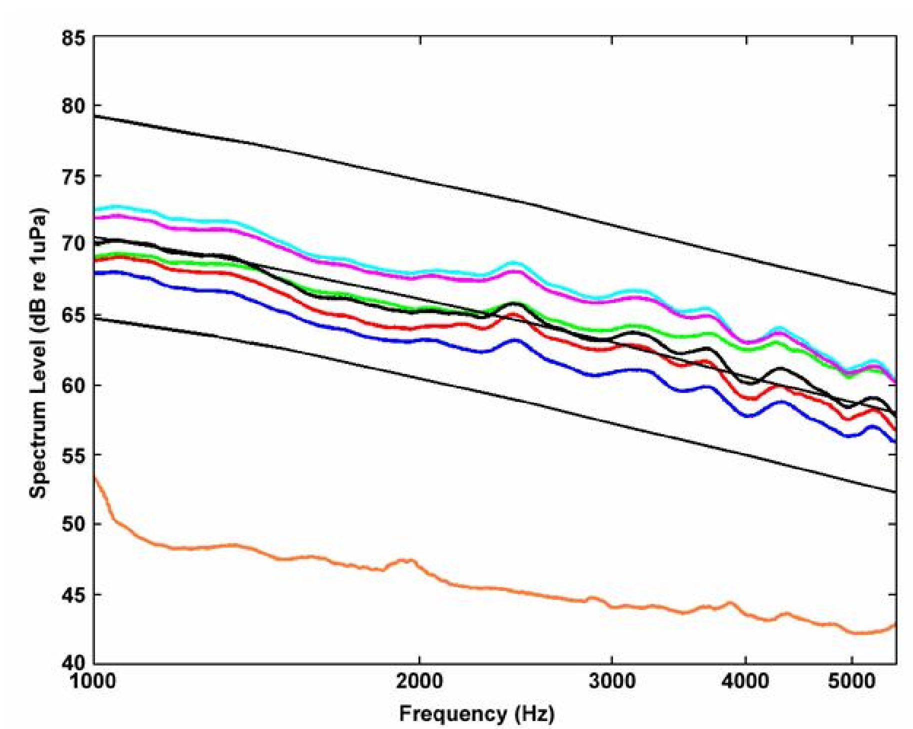


Figure 2A.19. Illustration of the ambient noise results for EARS 1 during Hurricane Lili.

Tropical Storm Isidore was less organized and weaker than Hurricane Lili. She was also a very large storm geographically. As can be seen from Figure 2A.18, TS Isidore passed approximately 43nmi closer to the EARS buoys than Hurricane Lili at closest approach (73nmi west of EARS buoys). Consequently, the spectrum levels for TS Isidore are about the same as the spectrum levels for Hurricane Lili. All three NDBC buoys were used to estimate wind speed for each time period except for the time period where TS Isidore passed very close to NDBC buoy 42041.

Figure 2A.20 illustrates the ambient noise results for TS Isidore from 1 kHz to 5.5 kHz for EARS 3. The closely grouped spectra correspond to the published positions of TS Isidore and represent estimated wind speeds of 21 to 55kt. The much lower level spectrum represents the results for a time period during which there were no storm systems in the GOM and is for comparison only. As expected, and similarly to the results for Hurricane Lili, when TS Isidore approached EARS 3, the wind speeds increased and the corresponding noise levels increased.

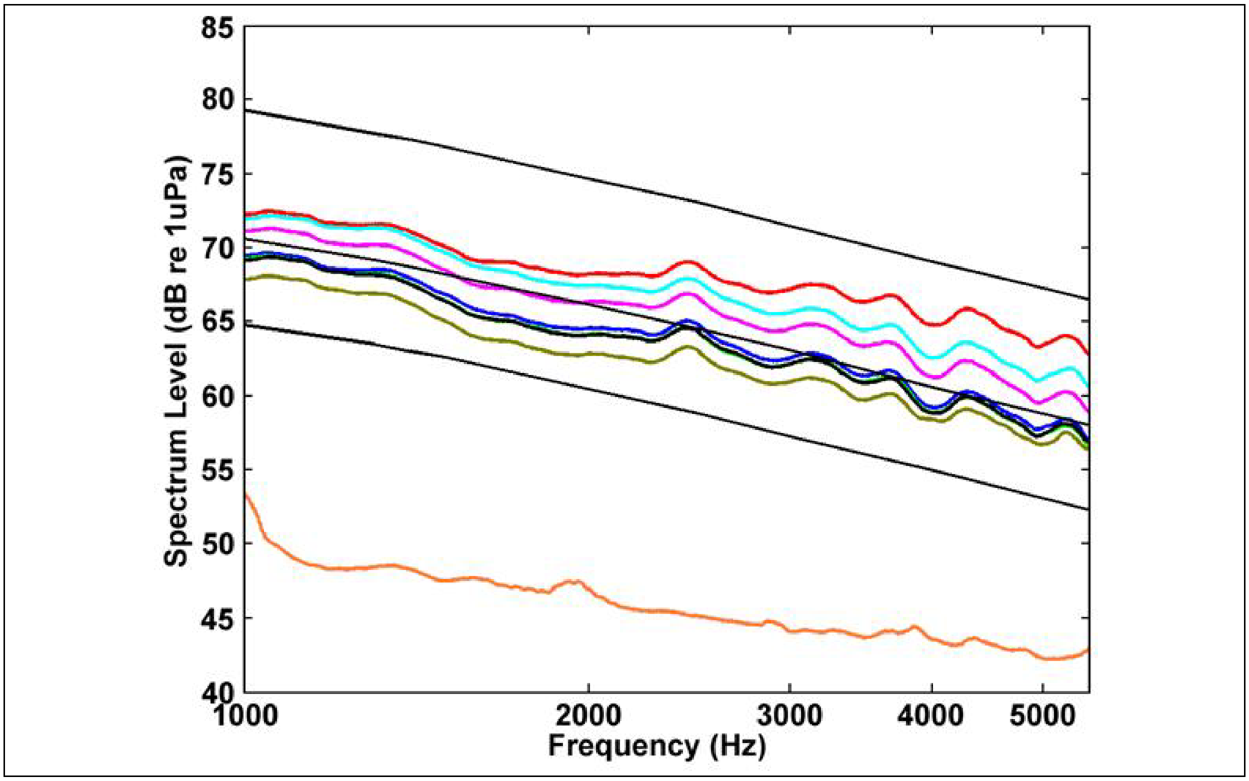


Figure 2A.20. Illustration of the ambient noise results for EARS 1 during Tropical Storm Isidore.

There were some anomalous time periods during TS Isidore where the noise levels were much higher than those expected from the wind speed estimates (e.g., upper red curve in Figure 2A.20). In those cases, acoustic data from 30 minutes before or after the original time period yielded results in line with wind speed estimates.

Superimposed upon the results for TS Isidore are the Wenz curves for Beaufort Wind Forces (BWF) of 5 and 8 (solid black lines) and the projected upper limit of prevailing noise. As can be seen from Figure 2A.20, the measured spectra agree well with the slope and levels of the BWF 8 curve for wind speeds of 34kt to 40kt, the sole exception being the anomaly noted previously.

It is postulated that these anomalies might be due to the banding nature of tropical storm systems. Figure 2A.21 is a composite satellite photograph of TS Isidore clearly illustrating two major bands of the storm. In these bands, localized severe weather conditions are common (e.g., rain squalls, high wind speeds, tornadoes, etc.).

If the anomalously high ambient noise levels were due to banding effects, it would be expected that they occurred periodically throughout the passage of the storm. Figure 2A.23 is a spectrogram of the ambient noise for a 24-hour period during TS Isidore. There are four broadband regions of high-level ambient noise starting near hour 12. Examined closely, these four bands do not have the characteristic scalloping associated with shipping noise. Further, they lack the low-frequency content and have more high-frequency content than the noise from a

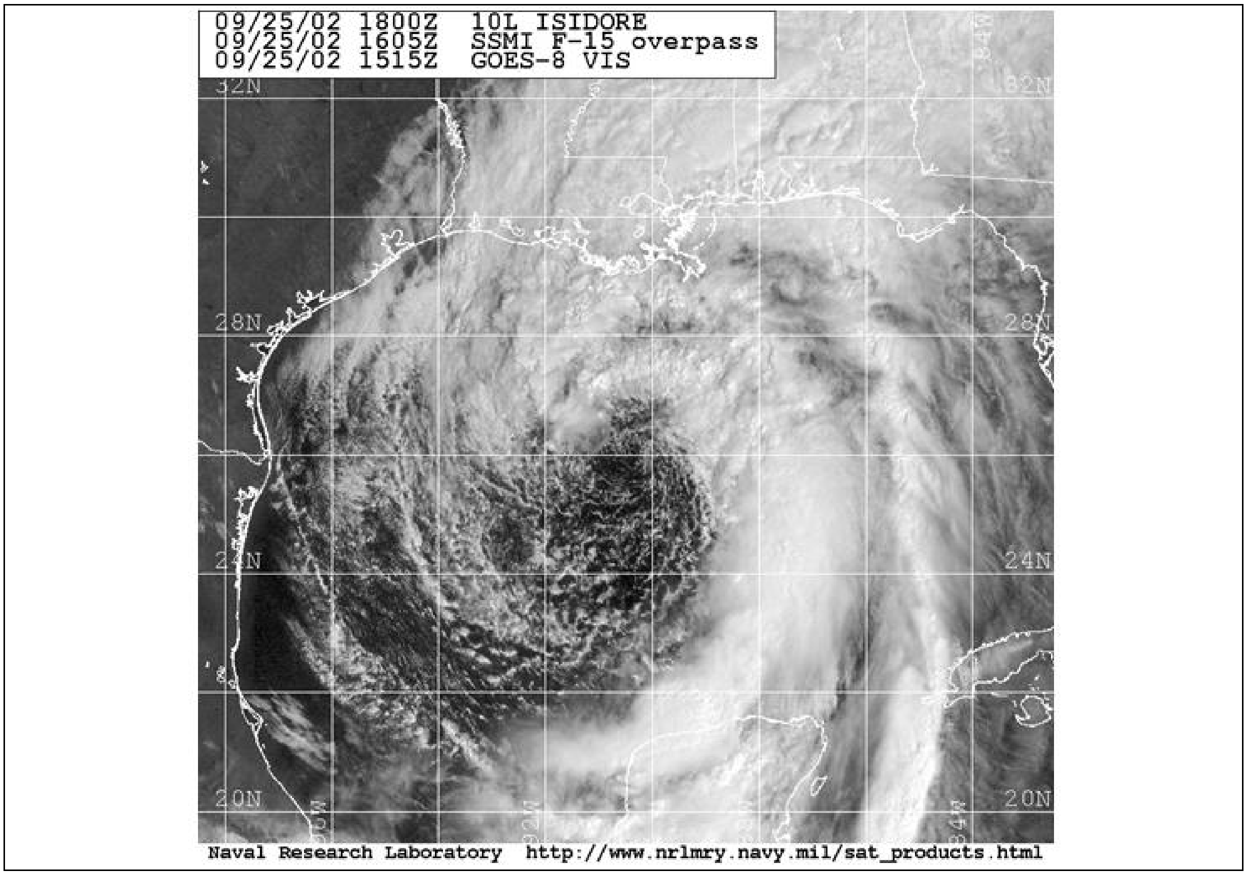


Figure 2A.21. Satellite image of Tropical Storm Isidore illustrating banding.

passing ship (e.g., high-level noise seen near hour 3, Figure 2A.22). An aural examination of the four broadband regions reveals no indication of shipping noise.

Figure 2A.23 is an illustration of a six-minute average of the ambient noise during the first of the four bands of high level noise near hour 12 (upper data curve) and during a time period that does not contain a band (lower data curve). The ambient noise levels are superimposed upon the Wenz curves for BWF 5 and 8 and the upper limit of prevailing wind noise. As can be seen from Figure 2A.23, the measured spectrum for the lower data curve agrees well with the slope and levels of the BWF 5 and 8 Wenz curves. The higher-level data is well above the BWF 8 Wenz curve and in fact is above the upper limit of prevailing wind noise.

Also in Figure 2A.23 are the curves representing the noise levels expected from heavy and moderately heavy precipitation. The high-level data clearly agree well with the Wenz curve for heavy precipitation for frequencies below about 1,500Hz. Above 1,500Hz the data diverge from the heavy precipitation curve and fall off in a manner similar to the Wenz wind curves although at highly elevated levels. This would seem to indicate that the noise is some combination of noise due to wind and rain.

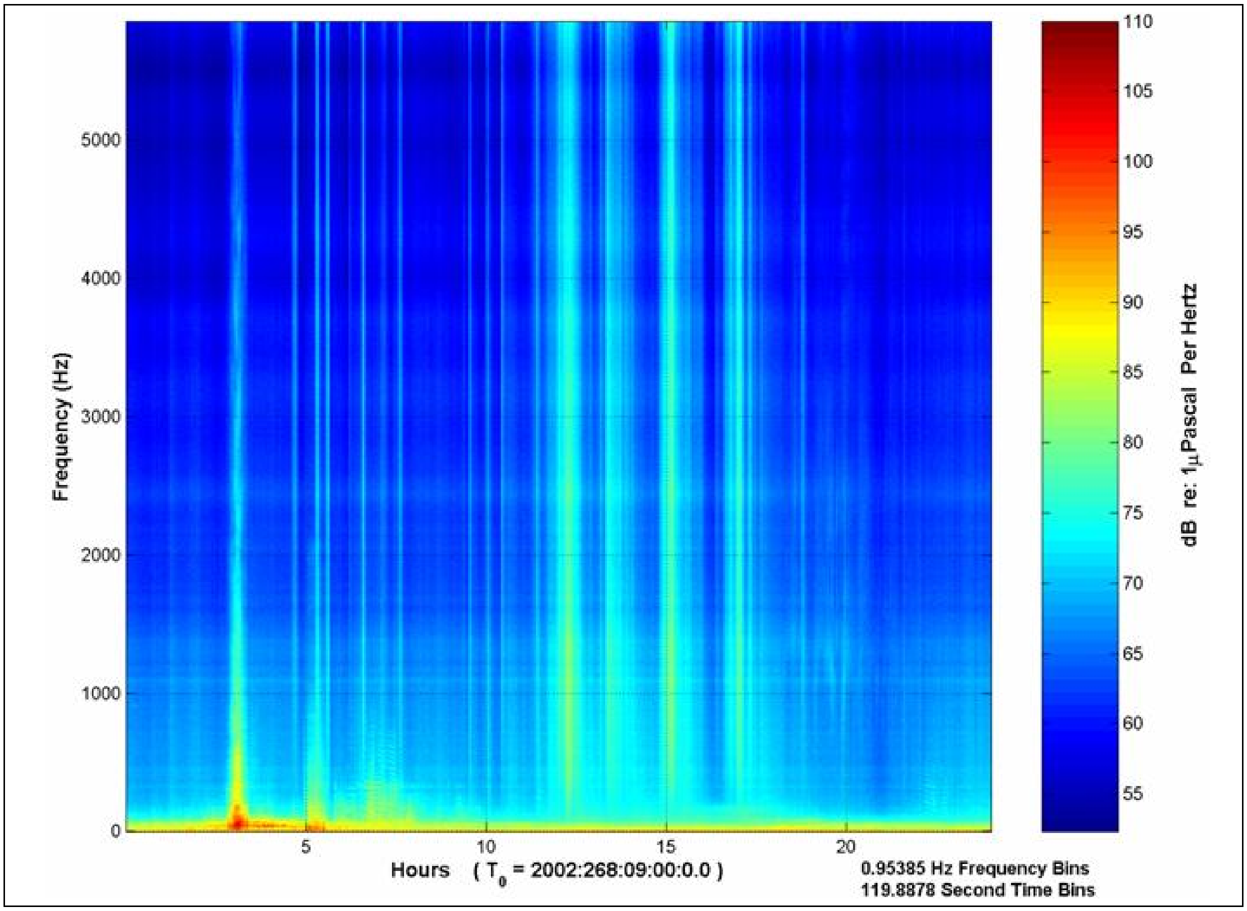


Figure 2A.22. Spectrogram of the ambient noise results for EARS 1 during Tropical Storm Isidore illustrating effects of banding.

Jeffrey Nystuen at APL Washington has developed a mathematical relationship between rainfall amounts and recorded noise levels (Nystuen 2001). Table 2A.2. displays the rainfall amounts for the four bands based on the average noise levels of the bands. Rainfall amounts are displayed in mm/hour and in in/hour.

Table 2A.2. Average noise levels for bands of TS Isidore compared to calculated rainfall amounts.

Band	Average Noise SPL (dB)	Rain Rate (mm/hour)	Rain Rate (in/hour)
1	70.7	68.8	2.71
2	69.6	58.4	2.30
3	72.8	94.2	3.71
4	71.4	76.4	3.01

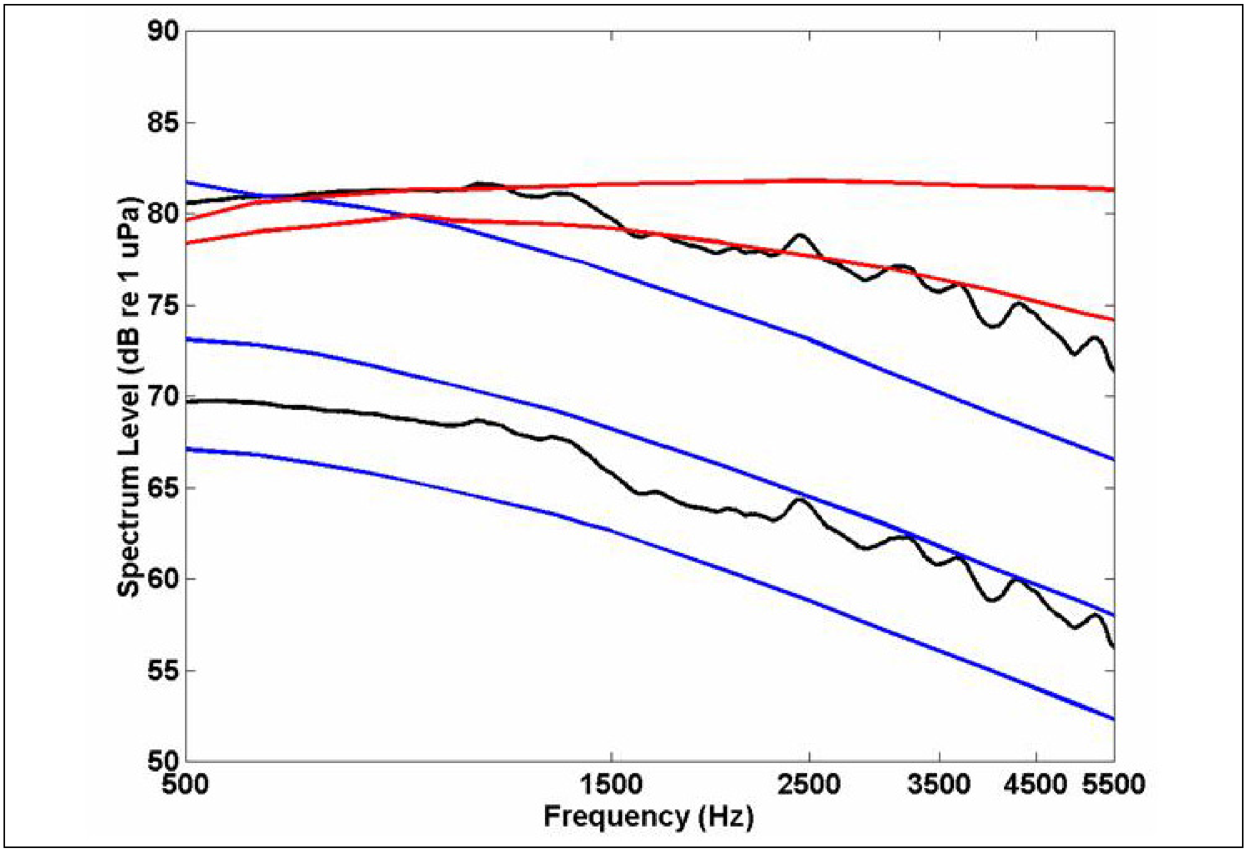


Figure 2A.23. Illustration of the ambient noise results for EARS 1 during Tropical Storm Isidore (black) compared to Wenz curves (blue) and rain curves (red).

Summary

Ambient noise results in the frequency range of 1 kHz to 5 kHz from the LADC 2002 experiment during Hurricane Lili and TS Isidore, with notable exceptions, are in good agreement with expected wind trends. They also agree well with the Wenz curves. The exceptions can be attributed to banding effects of the storms and are at least partially due to heavy precipitation.

Acknowledgments

This research was supported by ONR Program Element 62435N.

References

Nystuen, J.A. 2001. Listening to raindrops from underwater: An acoustic disdrometer. Journal of Atmospheric Ocean Technology 18:1640–1657.

Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. Journal of the Acoustic Society of America 34:1936.

Joal J. Newcomb received a B.S. degree in physics and mathematics from Southwestern Oklahoma State University, an M.S. in atomic physics from Kansas State University, and a Ph.D. in experimental atomic physics from Kansas State University. He is currently a research physicist in the Acoustics, Simulations, Measurements & Tactics Branch of the Naval Research Laboratory at the John C. Stennis Space Center, Mississippi. Dr. Newcomb was the chief scientist of OUTPOST SUNRISE, a major acoustic measurement program, and has been principal investigator of several projects to study underwater ambient noise, broadband and narrowband signal propagation, and basin reverberation. Dr. Newcomb is an internationally recognized expert in underwater ambient noise and shipping noise.

Mark Snyder received a B.S. degree in physics from the University of Illinois and an M.S. in physics from the University of New Orleans, where he is currently a Ph.D. candidate. He has worked as a geophysicist for Shell Oil Company in New Orleans. For the past twenty years he has worked as an oceanographer/physicist for the Naval Oceanographic Office (NAVOCEANO). He currently works in the Ocean Projects Department at NAVOCEANO.

Wesley R. Hillstrom received a B.S. degree in geology from Wayne State University, Detroit, and an M.S. degree in marine science from the University of Southern Mississippi. Since 1979 he has been a geophysicist with the Naval Oceanographic Office, currently involved in underwater acoustics with the Undersea Warfare Division. Mr. Hillstrom is a member of the American Geophysical Union, the Marine Technological Society, the Mississippi Academy of Sciences and Sigma Xi.

Ralph R. Goodman received B.S. degrees in mathematics and physics, an M.S. degree in physics, and a Ph.D. in theoretical physics from the University of Michigan. His specialties in physics are solid-state physics and underwater acoustics. Dr. Goodman has served as Professor of Physics at Colorado State University, Associate Director of the Naval Research Laboratory, Director of the Naval Ocean Research and Development Activity, Director of NATO's SACLANT Research Centre, Director of NCPA, and Professor of Acoustics at Pennsylvania State University. He is currently a Research Professor at the University of Southern Mississippi.

ANALYSIS OF BOTTOM-MOORED HYDROPHONE MEASUREMENTS OF GULF OF MEXICO SPERM WHALE PHONATIONS

George E. Ioup and Juliette W. Ioup, University of New Orleans
Natalia A. Sidorovskaia, University of Louisiana at Lafayette
Rachel T. Walker, Stan A. Kuczaj, Christopher D. Walker, Grayson H. Rayborn, and Benjamin Brack, University of Southern Mississippi
Andrew Wright, University of Wales, Bangor
Joal Newcomb and Robert Fisher, Naval Research Laboratory – Stennis Space Center

Abstract

The Littoral Acoustic Demonstration Center (LADC) is an Office of Naval Research-funded consortium consisting of the University of New Orleans, the University of Southern Mississippi, the Naval Research Laboratory, and the University of Louisiana at Lafayette. LADC deployed three Environmental Acoustic Recording System (EARS) buoys in the northern Gulf of Mexico (GOM) during the summers of 2001 (LADC01) and 2002 (LADC02) to study ambient noise and marine mammals. The LADC EARS buoy (developed by the Naval Oceanographic Office) is an autonomous, self-recording buoy capable of 36 days (summer 2001) or 66 days (summer 2002) of continuous recording of a single channel at an 11.7 kHz sampling rate (bandwidth to 5859 Hz). The hydrophone of each buoy was approximately 50m from the bottom in water depths of about 1,000m (EARS1), 800m (EARS2), and 600m (EARS3) along an upslope track.

This paper contains recent analysis results for the sperm whale phonations measured on these LADC EARS buoys. The three topics treated and the four sections pertaining to the first topic, are as follow:

1. Identification of individual sperm whales from their clicks
   a) Acoustic properties of sperm whale clicks as a basis for individual whale identification
   b) Propagation modeling for sperm whale phonations
   c) Quantitative studies of the null pattern similarity in sperm whale phonations
   d) Self-organizing maps for sperm whale identification
2. Effects of passing vessels on sperm whales
3. Automated detection of sperm whale clicks

Spectrograms of LADC northern GOM data containing sperm whale click codas strongly suggest that regularly spaced clicks in a coda have a spectral pattern that persists across all the clicks in that coda. These patterns are most simply described as nulls which persist across the successive click spectra in a coda and which vary from coda to coda. A conclusion is that each coda originates from a single whale and that all codas with similar properties come from the same whale.

Each sperm whale click can contain several separate pulses, i.e., peaks in the plot of click pressure versus time. It is quite possible that the spacing and other properties of the component pulses of a click could lead to the patterns observed in the click spectra. It is also possible that the patterns could be due to the interference of multiple arrivals at the hydrophone from a single click, due to reflections from the top and/or the bottom of the water column. These arrivals must be spaced within four msec of each other since that is the duration of these clicks. Propagation modeling is used to show that it is unlikely that the patterns in the spectra are due to the interference of multiple arrivals.

All the individual click plots of pressure versus time for a single coda have similar character, which can be different from the character of the clicks in other codas. This suggests that a classification of individual sperm whales could be done based on the pressure versus time plots of a coda as well as based on the click spectra of a coda.

Although echolocation clicks may seem to be less likely candidates for identifying individual whales due to the highly directional nature of these clicks, the results of Mohl et al. (2003) are analyzed to show that these clicks might also be used in identification.

Attempts to match by eye spectral plots of different codas to associate them with individuals make it clear that automated quantitative methods are needed. The first method given is based on a similarity measure which evaluates numerically how alike two click spectra are. This method is applied to both coda click spectra and echolocation click spectra. The echolocation click spectra studied have an even greater similarity to each other than the coda click spectra considered. The similarity function analysis distinguished about 15 similar echolocation clicks in the time interval of 10 sec. The average click production rate is estimated as one click per second, which is consistent with the reported rate for deep sperm whale dives. Two similar null-pattern coda events are identified at the mid-buoy with a separation time of about 40 sec.

The data used for the self-organizing map analysis consist of three sequential minutes recorded by LADC01 on the EARS2 buoy. These three minutes are selected because they contain 43 sperm whale codas. Self-organizing maps (SOMs) are used to compare and classify the time series, the magnitudes of the Fourier transforms, and the wavelet transforms of each coda in order to determine how many whales are present, assuming that similar coda clicks would be produced by the same whale. The results show that SOMs can be used to classify underwater acoustic signals from sperm whales. For the 43 codas tested, SOMs of the time series data and wavelet transform coefficients agree for all 43 codas. The SOMs of the Fourier transform magnitudes agree with them for 40 codas. The time series and wavelet transform SOMs indicate that four whales are present while the Fourier SOM has five whales. All SOMs show that the whale in class 1 vocalizes much more than the others.

Five weeks of continuous acoustic recording from the summer of 2001 (LADC01) are examined to assess the potential impact of vessel noise on sperm whale diving behavior. Sperm whale acoustic activity is defined by the number of clicks detected in Ishmael (version 1.0; Mellinger 2001). A noise event is defined as a period during which a broadband spectrum noise level of ≥

65 dB re: 1μPa, normalized to 1 Hz bands, across frequencies of 2-5.5 kHz, is achieved. Only noise events that are confirmed to be related to vessel traffic are used for analysis.

Boat noise events were significantly more likely to occur at the EARS 1 site when compared to either the EARS 2 or the EARS 3 site, and there was a significant difference in the average duration of boat noise at the three buoys. Sperm whale acoustic activity was then compared for the periods 1, 5, and 15 minutes before and after each boat noise event. At the EARS 1 site, significant sign tests revealed sperm whale acoustic activity decreased after noise events for the 5- and 15-minute comparisons, but not for the 1-minute periods. There was also no significant difference in sperm whale activity at the EARS 2 and EARS 3 sites for any of the time samples.

Similar control comparisons are made to determine whether there are any differences in sperm whale acoustic activity before and after a period approximately equal to the average duration of recorded noise events (15 minutes) that contain no boat noise. Sign tests indicate no change in sperm whale activity for 1, 5, or 15 minutes before and after non-noise events at any site, suggesting noise was a possible factor for change in sperm whale acoustic behavior at the EARS 1 location. It should be noted that the criteria for classification as a boat noise event is arbitrary and may not accurately reflect levels or frequencies that could elicit responses in sperm whales.

The background noise on the LADC01 buoys tends to vary slowly compared to the abrupt changes in level due to clicks from sperm whales. The discrete derivative or finite difference of the time series seems is a good method of filtering the data for click detection. When the level rises above a threshold value, a possible click is detected. After using the discrete derivative to filter the data, standard pulse detection techniques are applied to locate and count sperm whale clicks in the data.

Introduction

The Littoral Acoustic Demonstration Center (LADC) is an Office of Naval Research-funded consortium consisting of the University of New Orleans, the University of Southern Mississippi, the Naval Research Laboratory, and the University of Louisiana at Lafayette. LADC deployed three Environmental Acoustic Recording System (EARS) buoys in the northern (GOM) during the summers of 2001 (LADC01) and 2002 (LADC02) to study ambient noise and marine mammals. The LADC EARS buoy (developed by the Naval Oceanographic Office) is an autonomous, self-recording buoy capable of 36 days (summer 2001) or 66 days (summer 2002) of continuous recording of a single channel at an 11.7 kHz sampling rate (bandwidth to 5859 Hz). The hydrophone of each buoy was approximately 50m from the bottom in water depths of about 1,000m, 800m, and 600m along an upslope track. The buoys were labeled EARS 1 (deepest), EARS 2, and EARS 3 (shallowest). Oceanographic data (CTD and XBT data) were obtained during each deployment along a longer upslope track (from 1100m to 200m depth) and along a cross slope track centered at EARS 1. Bottom information for these tracks was obtained during LADC 01 from chirp sonar data (Turgut et al. 2002). Figure 2A.24 shows the upslope and cross slope survey tracks. The whale symbols in the figure represent sperm whale sightings. Note that the buoys were deployed in the region of the greatest number of sightings.

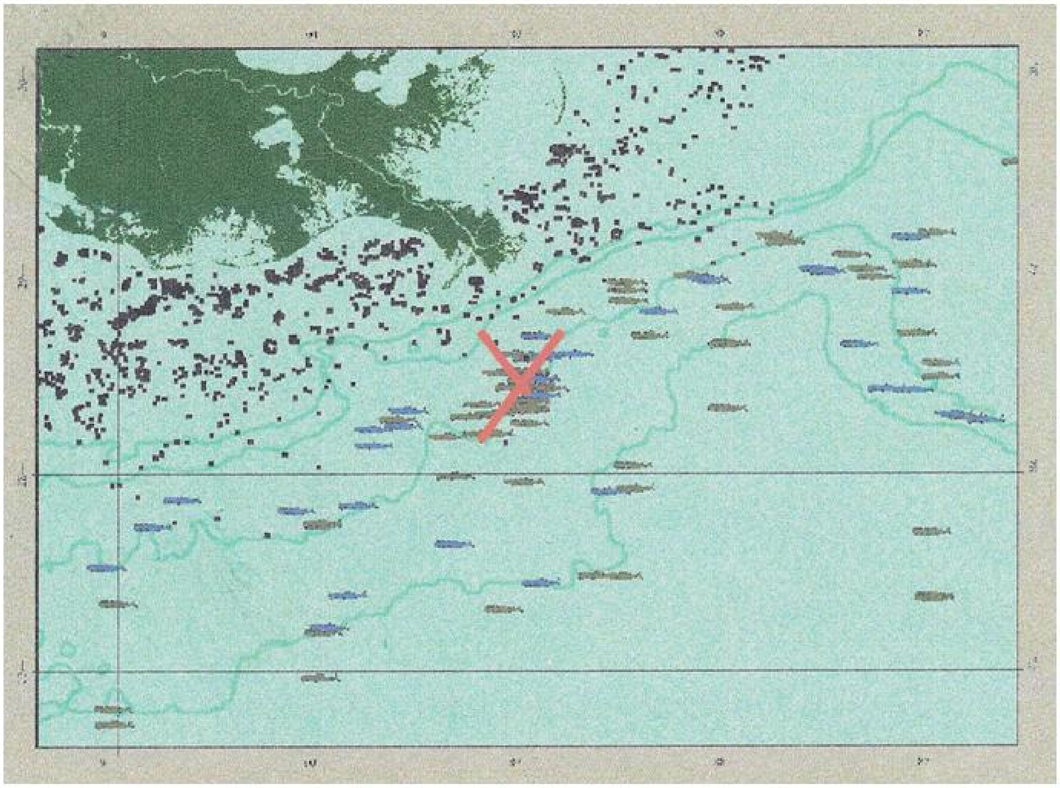


Figure 2A.24. Map shows whale symbols at sperm whale sightings and black dots for oil platforms. Cross slope and upslope tracks for LADC01 and LADC02 are shown in red. Upslope track ends at the 200m contour. Cross slope track is at the 1000m contour. Hydrophones are placed at the 600m, 800m, and 1,000m contours. Oceanographic surveys were done along the upslope and cross slope lines.

This paper contains recent analysis results for the sperm whale phonations measured on these LADC EARS buoys. The three topics treated and the four sections pertaining to the first topic are as follow:

1. Identification of individual sperm whales from their clicks
   a) Acoustic properties of sperm whale clicks as a basis for individual whale identification
   b) Propagation modeling for sperm whale phonations
   c) Quantitative studies of the null pattern similarity in sperm whale phonations
   d) Self-organizing maps for sperm whale identification
2. Effects of passing vessels on sperm whales
3. Automated detection of sperm whale clicks

As stated, Topic A is treated in four sections. In the first, the possibility of acoustically identifying individual sperm whales from the properties of their clicks is discussed. This approach requires that click properties not be primarily due to effects of acoustic propagation through the water column. The second section presents acoustic propagation modeling to illustrate the effects of propagation. The third section is devoted to a similarity technique that associates sperm whale clicks from a single individual. Finally for this part of the analysis, the fourth section describes the use self-organizing maps to group the codas from individual whales. The fifth section addresses the second topic and explores the effects of shipping noise on sperm whale click rates. The sixth section is for the third topic and presents a computational automated sperm whale click detector.

Identifying Individual Sperm Whales from the Acoustic Properties of Their Clicks

Spectrograms of LADC northern GOM data containing sperm whale click groups strongly suggest that regularly spaced clicks in a group have a spectral pattern that persists across all the clicks in that group. These patterns are most simply described as nulls that persist across the successive click spectra in a group. A preliminary conclusion is that each group of clicks originates from a single whale and all groups with similar properties come from the same whale. In this and the following three sections, this idea is developed. Preliminary analysis has been presented at a meeting of the Acoustical Society of America (Ioup et al. 2004).

In Figures 2A.25(a)–(d), the first four 4-second spectrograms are shown from one minute of data under consideration. The minute was taken from the data measured by the EARS 2 buoy in LADC01 and is very rich in groups of sperm whale clicks. The top graph shows the voltage versus time. The voltage is proportional to the pressure measured by the hydrophone. The middle spectrogram goes from zero to 5,859 Hz, showing the full spectrum of the recorded data. The bottom figure displays only from zero to 1,000 Hz. It shows the strong ambient noise at low frequencies, mainly occurring below 100 Hz except in Figure 2A.25(c). Between 8.5 and 9.5 seconds, the red part of the spectra goes above 200 Hz due to an airgun shot 67 miles away.

From the middle plot in each of the Figures 2A.25(a)–(d), one can see the groups of clicks referred to earlier and the null patterns that persist across the groups of clicks. These patterns vary from being quite striking to being subtle and not as consistent across the clicks in a group. An important point to note is that the null patterns change from group to group. It is the existence of these null patterns that strongly suggests the possibility of identifying individual whales.

Zimmer (2004) has analyzed similar data from LADC EARS buoys in the Mediterranean Sea. He believes that the groups of clicks are sperm whale codas used for communication and generally emitted by the whales in the top 100m of the water column. A group of clicks is therefore referred to as a coda in the remainder of this discussion.

Norris and Harvey (1972), Gordon (1981), and Mohl et al. (2003) discuss the time structure of individual sperm whale clicks. Each click can contain several separate pulses (peaks in the plot of click pressure versus time). It is possible that spacing and other properties of the component pulses of a click could lead to the patterns observed in the click spectra. Dougherty (1999) has investigated techniques for identifying sperm whales acoustically from the properties of their clicks. It is possible that the patterns could be due to interference of multiple arrivals at the hydrophone from a single click, due to reflections from the top and/or bottom of the water column.

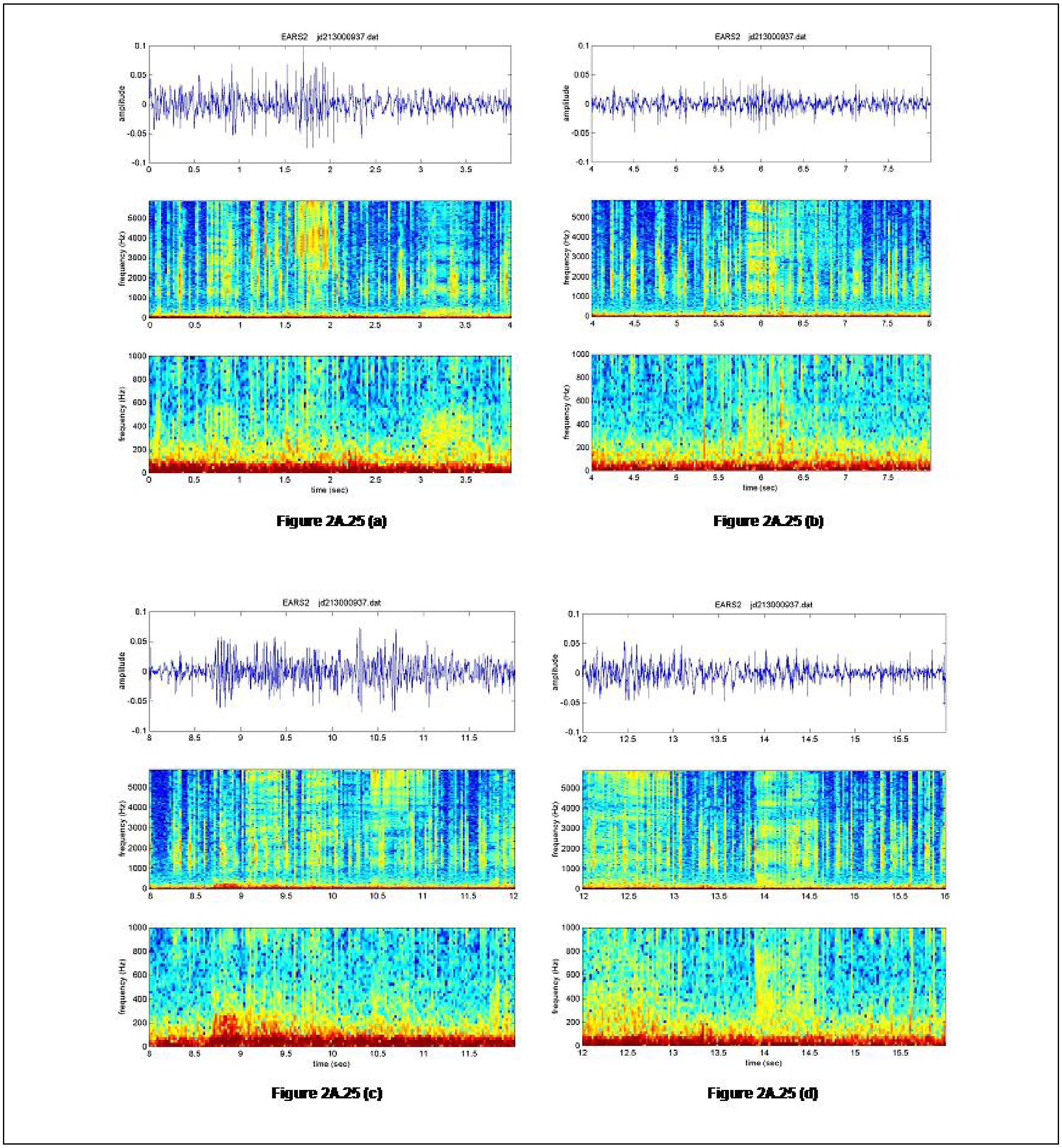


Figure 2A.25. 800m mooring data extracted from a 60sec segment beginning at Julian Day 213, Zulu 0 hr, 9 min, 37 sec. Figures. 2A.25 (a) – (d) each give four seconds of data. They give sequentially the first four 4-sec segments of data for the 60 sec of data being investigated. In each, the top plot is the voltage (proportional to pressure) amplitude versus time. The middle and bottom graphs of (a) – (d) are spectrograms. All frequencies up to 5859Hz are shown in the middle graphs and frequencies up to 1,000Hz are shown in the bottom graphs. Broadband transform lines in the middle graphs are sperm whale clicks and closely spaced clicks are codas. The red peak in the bottom graph of (c) is the seismic airgun. Since it is 107km away from the EARS buoy, significant reverberation is present.

To gain insight into these possibilities, it is helpful to examine the voltage (pressure) amplitude versus time plots for the clicks within a coda. Figures 2A.26(a) and (b) show the click amplitude versus time for the clicks in two different codas, respectively. The voltage amplitudes of each click of a coda are offset by a different constant so they can all be observed on one plot. There are two important details to note in Figure 2A.26. The first is that most of the significant amplitude for each click occurs within 4 msec. This means that if different propagation path arrivals are to interfere to give the spectral patterns, they must arrive within 4 msec of each other. This subject is explored in detail in the next section.

The second important detail is that all the click plots of amplitude versus time for a single coda have similar character, which is different from the character of the clicks of the other coda, as is manifest in the contrast between the click plots of Figure 2A.26(a) and those of Figure 2A.26(b). This suggests that a classification of individual sperm whales could be done based on the pressure versus time plots of a coda as well as based on the click spectra of a coda. This is discussed in the section on self-organizing maps.

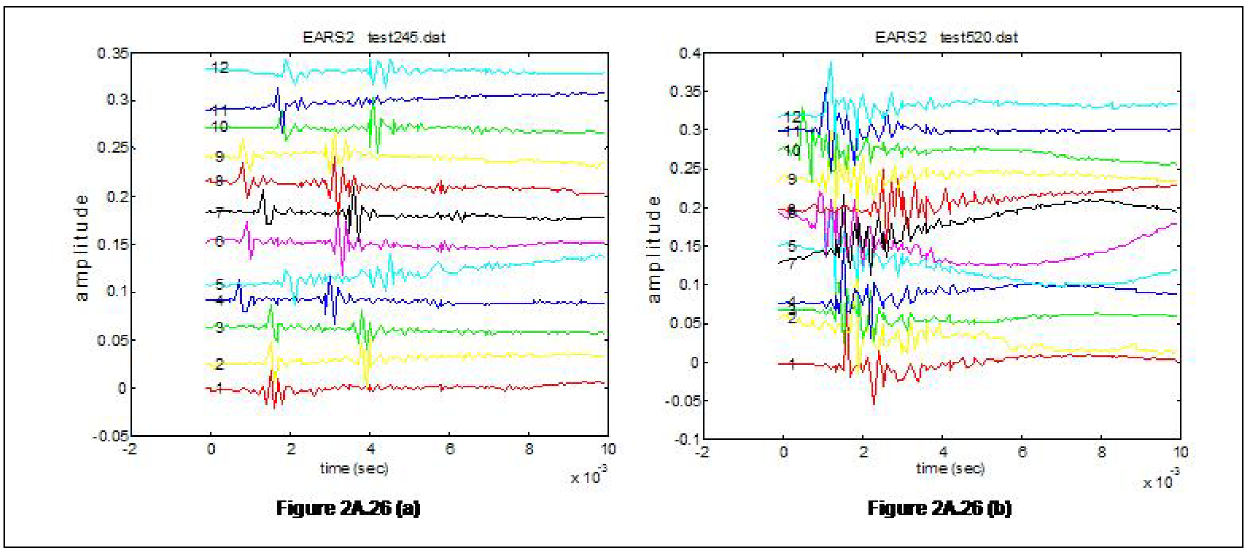


Figure 2A.26. Voltage amplitude versus time plots for all the clicks in one coda (a), and in another coda (b). Voltage in each click is offset for clarity.

To gain a clearer picture of the spectral similarity of the clicks within a coda, it is helpful to over-plot the magnitude of the Fourier spectrum of each of the clicks of a single coda. In the minute of interest there are 15 codas. Figures 2A.27(a)–(c) show all 15, with five codas to a figure. Most of the codas show fair to excellent consistency among the individual click spectra of a coda. There are a very few outliers, which presumably are due to another whale clicking while the coda was in progress. These can easily be edited out. One can look at the fifteen coda plots to try to pick pairs by eye that could belong to the same whale. Figures 2A.28(a)–(c) give the results. In Figure 2A.28(a) the overplotted click spectra of two different codas, chosen because of their click spectra similarity, are shown in the top and bottom plots, respectively. These two coda click spectral overplots very closely resemble each other. If this method is valid, it can be concluded

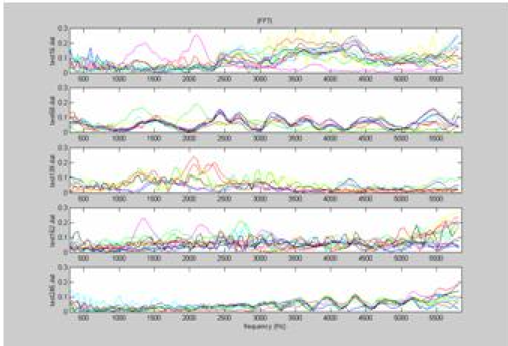


Figure 2A.27 (a)

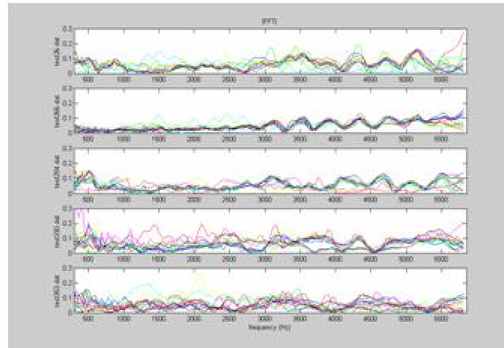


Figure 2A.27 (b)

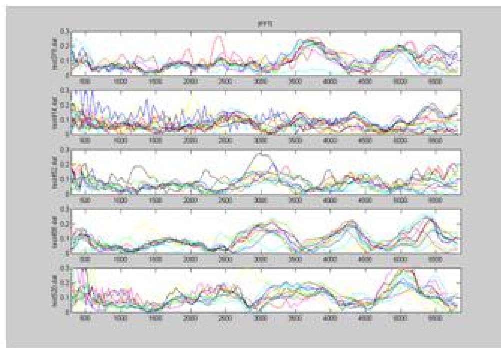


Figure 2A.27 (c)

Figure 2A.27. Each graph is an overplot of the Fourier magnitude spectra for all the clicks in one coda. Five different codas are shown in each of (a), (b), and (c).

with little doubt that these codas came from the same whale. The next pair selected, shown in Figure 2A.28(b), are similar to each other but the resemblance is not as striking as the first pair. These two codas probably come from the same whale, but the conclusion is reached with less confidence. Finally, the pair shown in Figure 2A.28(c) is selected. For this pair there is even less confidence that the pair of codas came from the same individual. It is a reasonable assumption that human qualitative judgments are not the best way to do these pairings. Automated, quantitative methods are needed. Two possible methods are discussed in the third and fourth sections of this paper, on similarity analysis and on self-organizing maps, respectively.

Thus far the discussion has focused on communication clicks within codas. These clicks may be somewhat omni-directional, to serve the communication function. Echolocation clicks, in contrast, are known to be highly directional, as discussed by Mohl et al. (2003) and the references cited therein. The dominant p1 peak (pulse) is much stronger than the other peaks on-axis, and the on-axis p1 peak is much stronger than all the peaks of a click measured significantly off-axis. Figure 2A.29 of Mohl et al. is an important one. It shows the spectra of over 100 successive p1 pulses of an echolocating whale versus click number. The frequencies go to 25 kHz. Presumably because of the directionality of the clicks, the spectra vary markedly from click to click. This suggests that it might be difficult to identify whales by their echolocation clicks. This was assumed to be the case until the similarity analysis indicated otherwise.

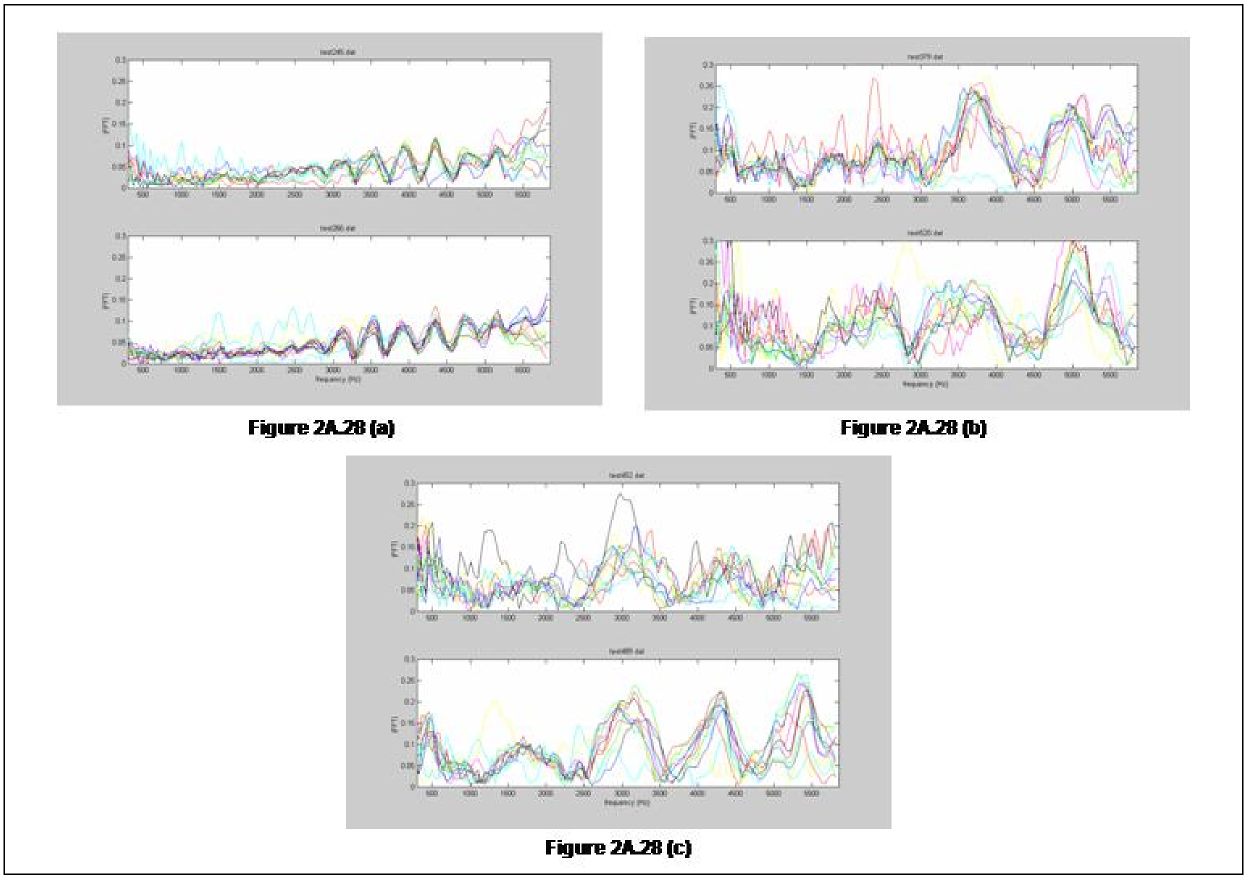


Figure 1A.28. Three pairs of overplotted spectra of clicks within a coda, one in each of (a), (b), and (c). Each pair could be from the same whale; i.e., (a), (b), and (c) each show a pair of codas from a different whale.

Closer inspection of Figure 2A.29 of Mohl et al. gives insight into why it might also be possible to use the echolocation clicks to identify individual whales acoustically. For the somewhat off-axis clicks (the first 102 clicks of the 108 in the figure), the click-to-click changes are all happening above about 5 kHz. Since the EARS data only go to 5,859 Hz, the current analysis is only considering the part of the spectrum which is distinctive and fairly robust against changes in direction as long as the click is somewhat off-axis. A preliminary suggestion then is to filter somewhat off-axis echolocation clicks down to a 5 to 6 kHz upper limit (if higher frequencies have been measured) before using them for acoustic identification of individuals. The on-axis p1 pulses (the last 6 of the series of 108 in Mohl et al. Figure 2A.29, also shown in Mohl et al. Figure 2A.32, labeled p1) do have spectra which are different in character from the of-axis p1 spectra, even below 5,000 Hz, and not as distinctive. These clicks may or may not be useful for identifying individuals. In any case, the similarity analysis of the third section of this paper is applied to both coda and echolocation clicks.

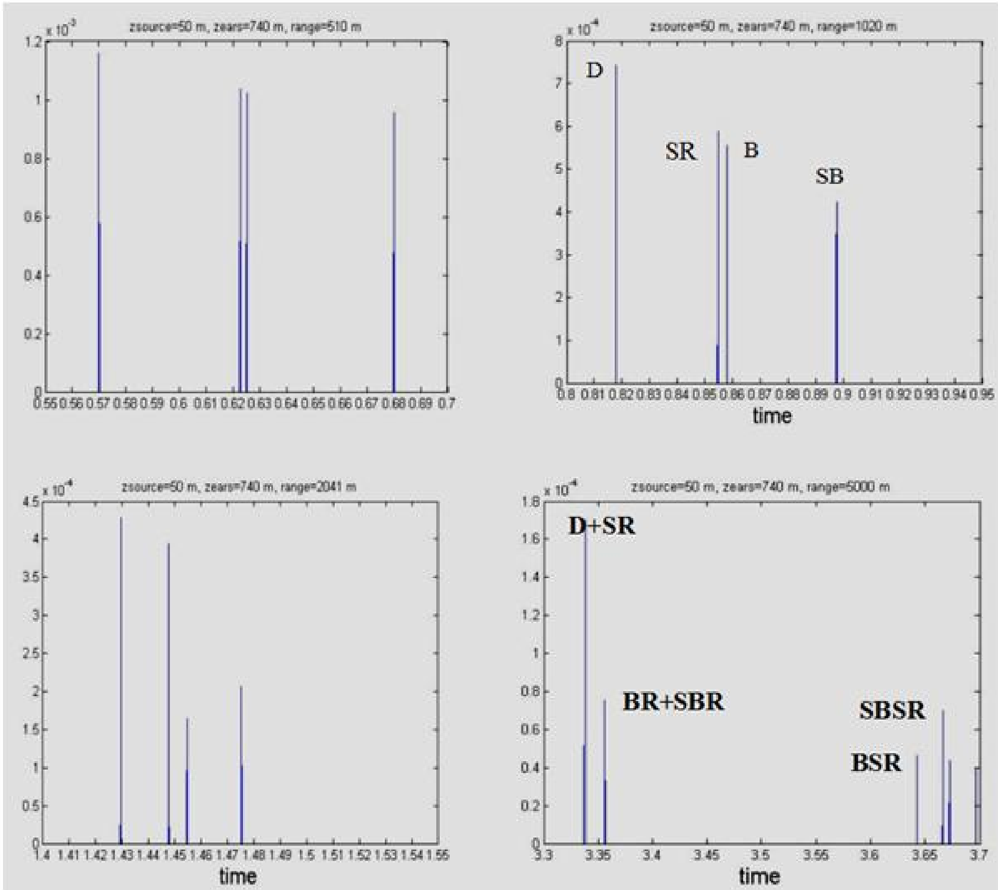


Figure 2A.29. Temporal structure of arrivals on the 740 m deep EARS buoy for the mammal depth of 50 m and the ranges of 510, 1020, 2041, 5000 m from the receiving buoy.

Propagation Modeling for Sperm Whale Phonations

At this point, a reasonable question to ask is whether the spectral interference structure is caused by propagation effects and could be utilized for localization of a sperm whale, or if it is caused by the particular features of a whale phonation apparatus and could be an attribute for the individualization of sperm whales. This section addresses this question.

The environmental parameters measured during the experiment (sound speed profile in the water column, bottom properties) were input in the ray-propagation model Bellhop to generate the time sequence of direct and reflected arrivals for different hypothetical mammal locations (*http://www.hlsresearch.com/oalib/Rays/*; Sidorovskaia et al. 2004). Figure 2A.29 shows the temporal structure of arrivals on the 740 m deep EARS2 hydrophone for a mammal depth of 50 m, where coda signals can be produced. The horizontal ranges to the EARS buoy are 510, 1020, 2041, and 5000 m, respectively. It can be seen from the presented plots that the delay between the direct and first reflected (Surface Reflected, SR) arrivals varies from 50 msec to 18 msec for ranges from 500 to 2,000 m, with a train duration of the first four arrivals between 100 msec to 45 msec at the 740 m deep EARS hydrophone. The direct and surface reflected arrivals are overlapping for the range of 5,000 m. The bottom reflected arrivals are significantly attenuated for smaller grazing angles (ranges > 2,000 m). The next set of simulation results (Figure 2A.30) is produced for a mammal depth of 400 m which would correspond to the temporal structure of direct and reflected arrivals from an animal descending to foraging depths. In the mid-depth echolocation clicks the separation between the direct and first reflected arrival (Bottom Reflected, BR) varies from 40 msec to 10 msec for ranges from 500 to 5,000 m. The direct and bottom reflected arrivals do not overlap up to 5 km in range. The bottom reflected arrivals are significantly attenuated for smaller grazing angles (range > 1,000 m). Another foraging depth (about 700 m deep source location) echolocation signal temporal structure was previously simulated (Sidorovskaia et al. 2004) and also supports the conclusions stated in the next paragraph.

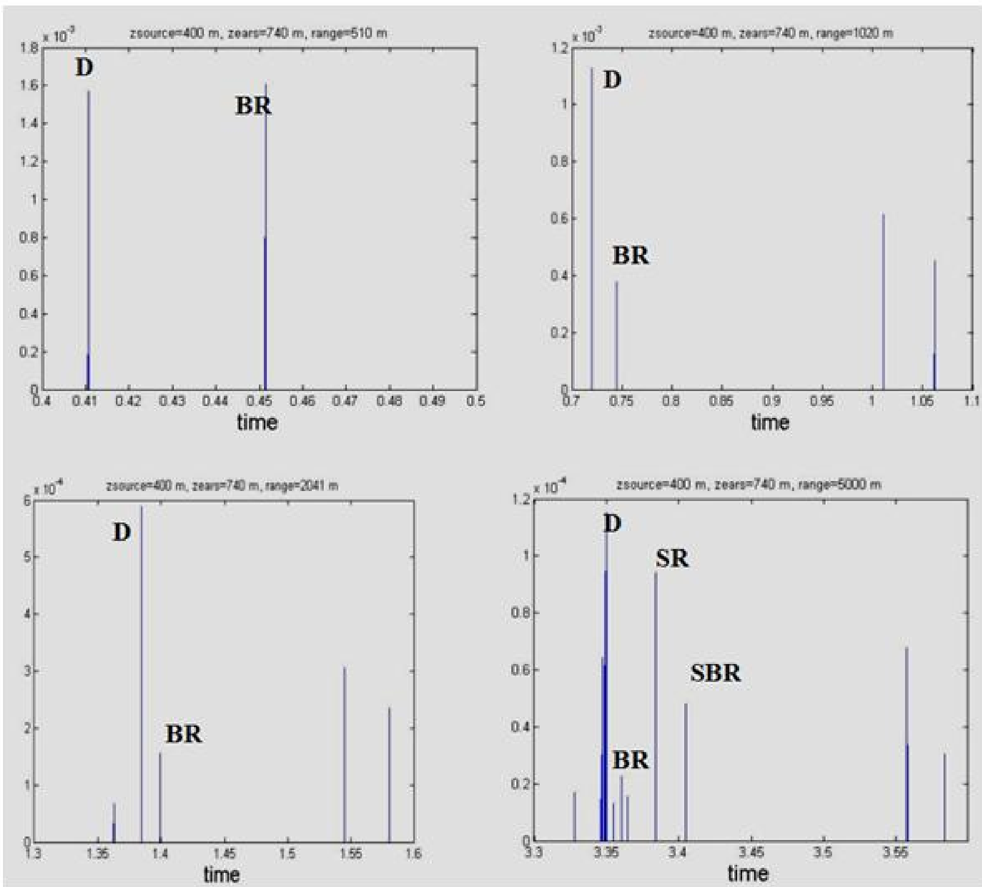


Figure 2A.30. Temporal structure of arrivals on the 740 m deep EARS buoy for the mammal depth of 400 m and the ranges of 510, 1020, 2041, 5000 m from the receiving buoy.

Thus, propagation modeling suggests that the null pattern structure for the short-time click spectra (4 msec) and relatively close positioning of an animal could be interpreted as being due to distinct features of a mammal phonation apparatus for any type of phonations (clicks, short-range clicks, and clicks within codas). Independent algorithms are needed for sperm whale individualization based on the acoustic signature from single hydrophone recordings to confirm the hypothesis that the null pattern or other features could be efficient tools in sperm whale acoustic individualization. The research on this topic is now in progress, and some of the results are discussed below.

Quantitative Studies of the Null Pattern Similarity in Sperm Whale Phonations

As the first step in developing automatic tools for associating sperm whale clicks with similar null patterns, a similarity analysis algorithm was implemented. Figure 2A.31 shows 1-second fragment of the LADC data rich in the sperm whale phonations with 4-msec window spectrograms on the right for all three buoys (the 1,000 m contour EARS1 buoy is on the top). Two types of phonation events can be distinguished in these data sets: the communication, "coda-like" event on the middle buoy and regular echolocation clicks on the shallow buoy. The arrows on Figure 2A.31 identify two clicks from two different events whose spectra were taken to be reference spectra, $s_{ref}(f_i)$. One minute of data for all three buoys was processed to find clicks with identical or similar null patterns. The similarity function is introduced as:

$$SIM = 1 - \frac{\vec{S} \bullet \vec{R}}{\|\vec{S}\| \cdot \|\vec{R}\|}; \ \vec{S} = \{|s(f_i)|\}, \vec{R} = \{|s_{ref}(f_i)|\} \quad , \qquad (1)$$

where $\vec{R}$ is a multi-dimensional (frequencies treated as independent dimensions) vector containing the amplitudes of spectral components present in the reference spectrum, $\vec{S}$ is a vector of amplitudes of the instant 4-msec windowed spectrum from 60 seconds of data, $\bullet$ is the scalar product of two vectors. If two spectra have a similar null pattern, the normalized scalar product of two vectors will be close to one. The thresholds for identifying two phonation events as having a similar null pattern were set to be a 1% difference from one in the scalar product for echolocation clicks and to be 5% for codas. The results of the analysis are shown in Figure 2A.32. The right-hand graphs are the temporal histograms of the number of clicks that were identified as having similar null patterns. The similarity function analysis distinguished about 15 similar echolocation clicks in the time interval of 10 seconds. The histogram statistics represents the mix of direct and reflected arrivals (refer to Figure 2A.32(a)). The average click production rate could be estimated as 1 click per second, which is consistent with the reported rate for deep sperm whale dives (Goold and Jones, 1995). The absence of other picks could be speculatively attributed to the high directionality of the echolocation clicks (Mohl et al. 2003). Two similar null-pattern coda events are identified at the mid-buoy with a separation time of about 40 seconds (refer to Figure 2a.32(b)). Presumably, the communication signals are omni-directional; consequently, we could identify the same animal at a later time. There are also some coda-like events on the deep buoy with the same null pattern as the reference one that requires more detailed analysis. In conclusion, the similarity function is shown to be an efficient quantitative algorithm to single out similar null pattern clicks.

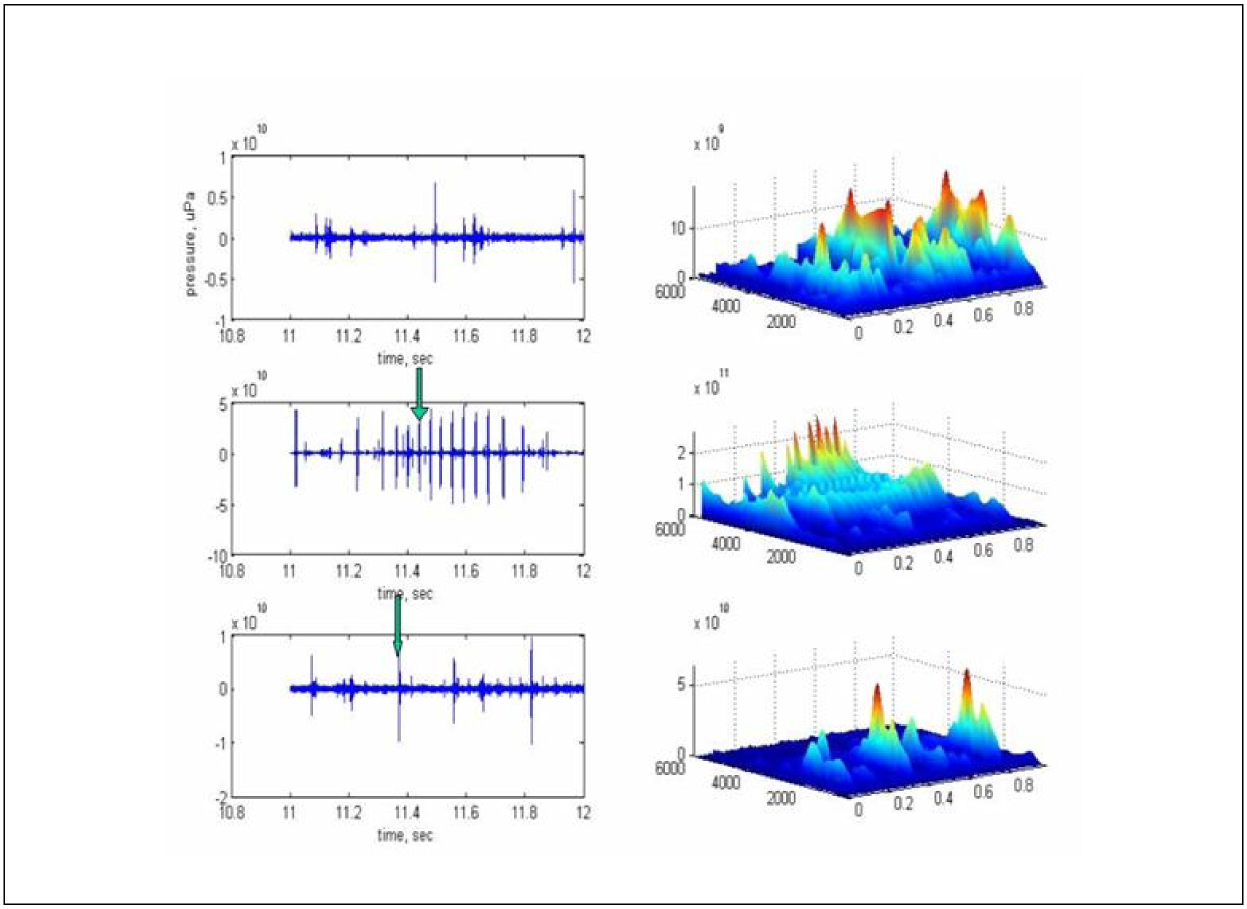


Figure 2A.31. 1-second fragment of the LADC data rich in the sperm whale phonations with the 4-msec window spectrograms on the right for all three buoys (the 1000 m contour buoy is on the top).

Self-Organizing Maps for Sperm Whale Identification

Self-Organizing Maps

A self-organizing map (SOM) is the "result of a nonparametric regression process that is mainly used to represent high-dimensional, nonlinearly related data items in an illustrative, often two-dimensional display, and to perform unsupervised classification and clustering" (Kohonen, 1997).

The inputs to a SOM, the features or attributes, may be numerical values or binary (1's and 0's indicating the presence or absence of a particular feature or attribute). The weight values may be initialized as all zeros, all ones, selected data values, random numbers, or other values relevant to the particular data set. Each feature set is presented to the SOM, and the "distance" from each node computed. The distance can be the Euclidian distance of each data set from each node in the one- or two-dimensional weight matrix. The minimum distance determines the winning node. The winning node and the nodes in a specified neighborhood of the winner are updated by

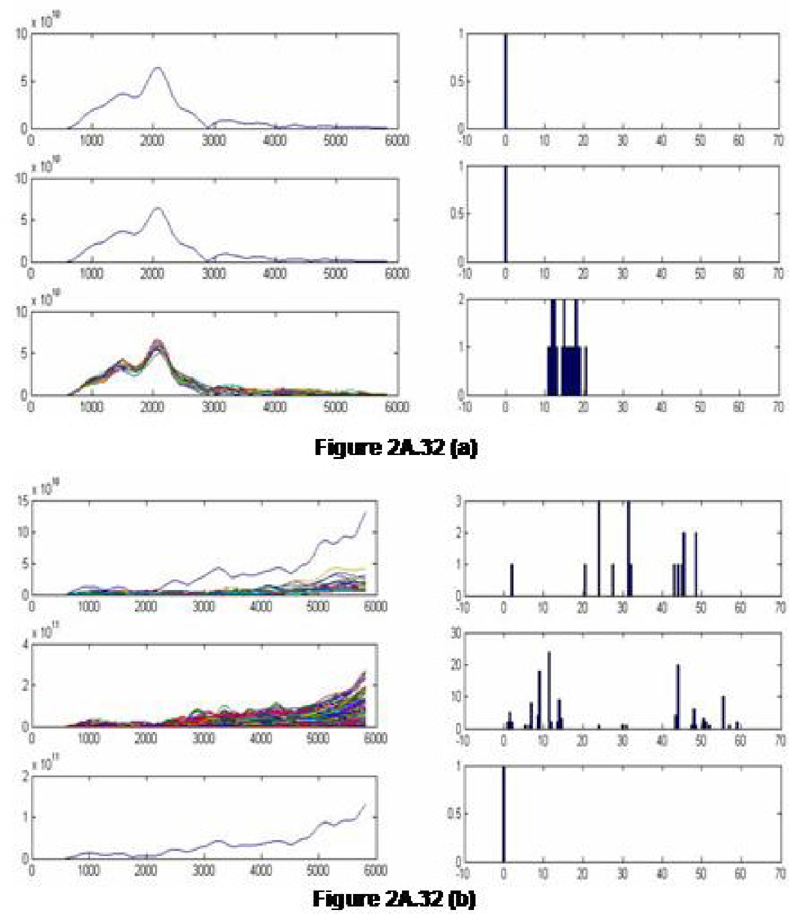


Figure 2A.32. Similarity analysis results for: (a) echolocation clicks, (b) communication signals.

increasing their weights. The amount of the update and the neighborhood size decrease with the number of iterations. Repeated presentations of the input data sets train the weight matrix so that one node (or some few adjacent nodes) is most responsive to a particular input. This node determines the classification of the output.

Figure 2A.33 is a two-dimensional plot illustrating the use of a SOM. In the upper left diagram, two groups of blue points are easily separated by the human eye. All the initial "centers" for the SOM are chosen to be at the origin and are marked with red circles. The upper right plot shows the results after one iteration. One red "center" has moved to the middle of the plot, and the remaining two are still at the origin. After two iterations, shown in the lower left plot, one red "center" is located at the center of the upper group of blue points and the other at the center of the lower group of blue points. There is no change after three iterations, shown in the lower right. There were only two groups of blue points, so the initial third red center was not needed and has not moved from the origin.

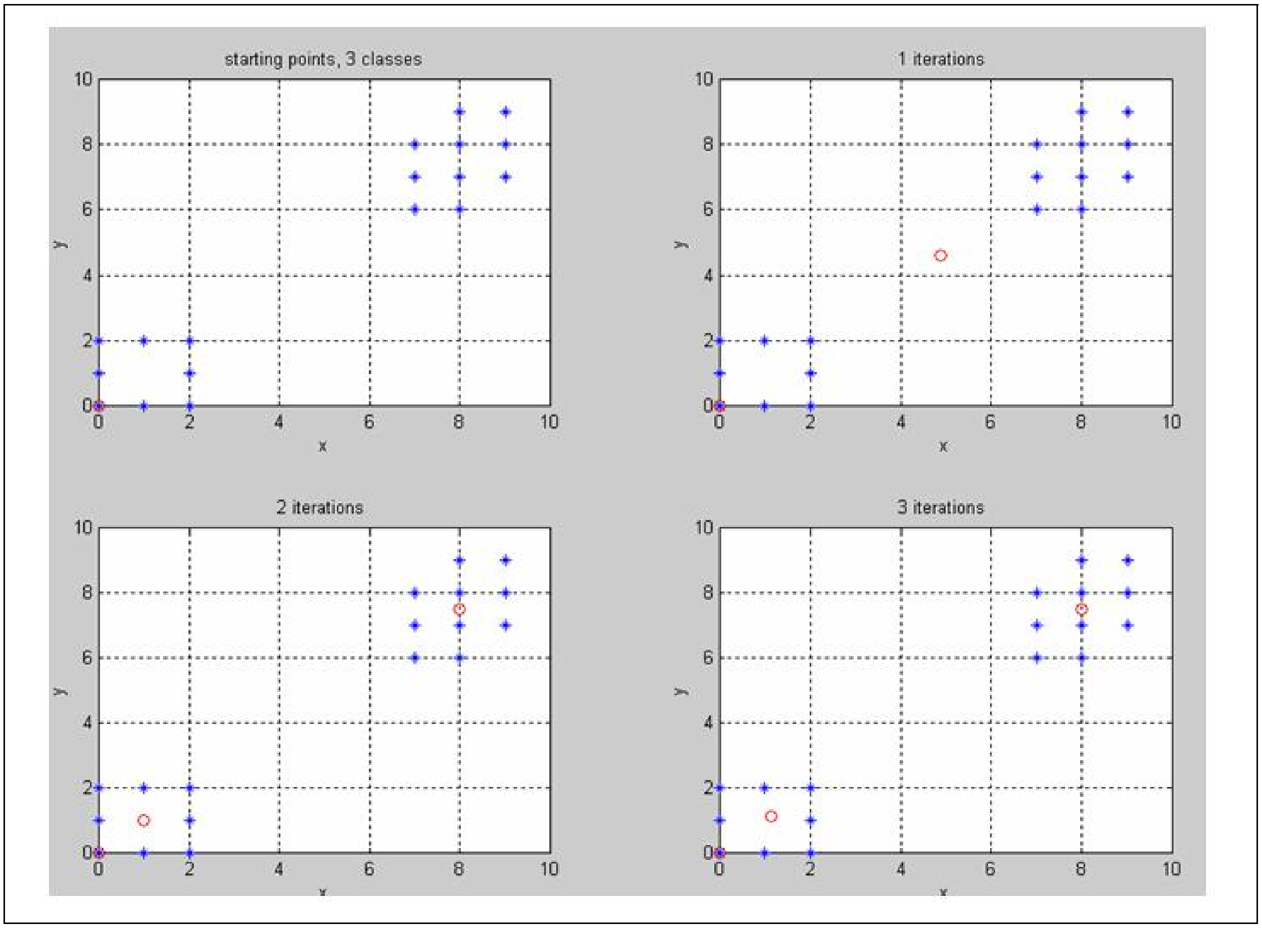


Figure 2A.33. SOM example.

SOMs are used here for classification of underwater acoustic signals that contain sequences of clicks made by sperm whales (Ioup and Ioup 2004). A one-dimensional SOM with numerical inputs is used to separate the signals into classes with similar properties, and results are presented in both graphical and tabular form.

Underwater Acoustic Data

The data used here consist of three sequential minutes recorded by LADC01 on one of three EARS buoys (EARS2) in the northern Gulf of Mexico during the summer of 2001. These three minutes were selected from more than three months of data (more than one month on each buoy) because there were many instances of sperm whale clicks.

Figure 2A.34 shows the middle minute of data referred to in the first section of this paper. The top plot gives the signal amplitude versus time in seconds. The middle plot is the spectrogram of this time series, with the frequency axis vertical. Frequencies up to 5,859 Hz are shown. The bottom plot is the same with frequencies shown only up to 1,000 Hz. The large amplitude red "lumps" at the low frequencies are a seismic airgun conducting a survey 67 miles away from the

EARS buoy. Frequencies below 300 Hz will be filtered out for the subsequent processing. The broadband clicks of the sperm whales can be seen well, both single isolated clicks and in groups called codas. The codas will be used in the research described in this section.

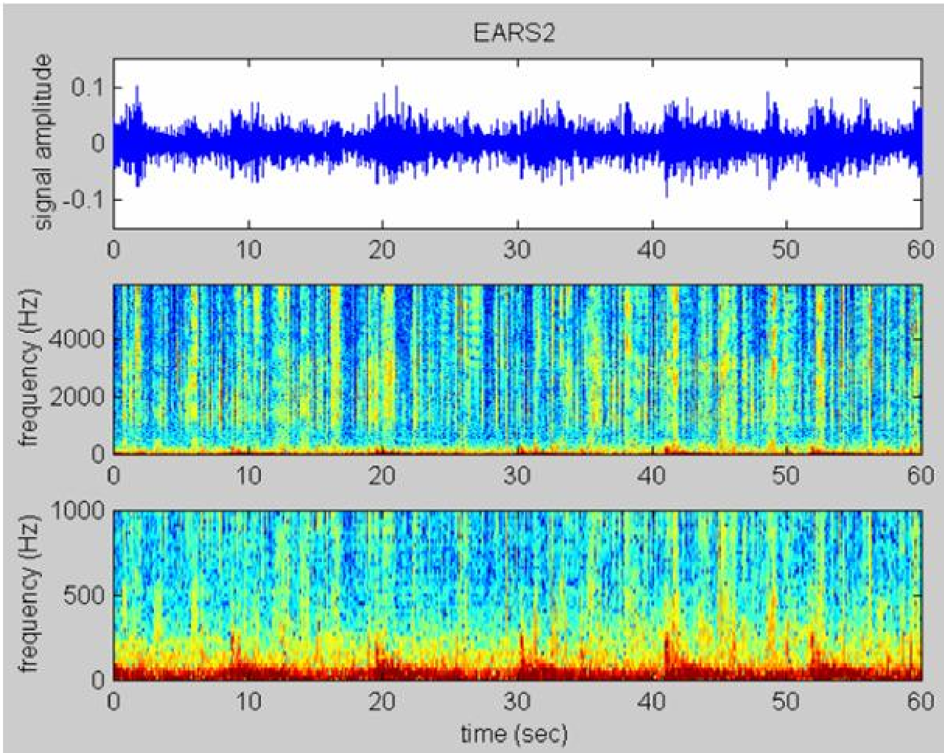


Figure 2A.34. Top: Time series data for one minute. Middle and Bottom: Spectrogram of data.

Codas are usually used for communication when the whales are near the ocean surface. Since each coda could be assumed to be made by one whale, only the short times (about 0.6 sec) for each coda were selected out of each minute for processing. There were 43 codas in the three minutes, each containing from three to 15 clicks. Self-organizing maps are used to compare the time series, the Fourier transforms, and the wavelet transforms of each coda in order to determine how many whales are present, assuming that similar coda clicks would be produced by the same whale.

Four representative codas are shown in Figure 2A.35. The time axis is horizontal to the right and the amplitude is shown vertically. Each click in the coda is displaced slightly into the page according to the time it was emitted during the coda.

The discrete Fourier transform (DFT) is computed using a Fast Fourier Transform (FFT) algorithm (Bracewell 2000).

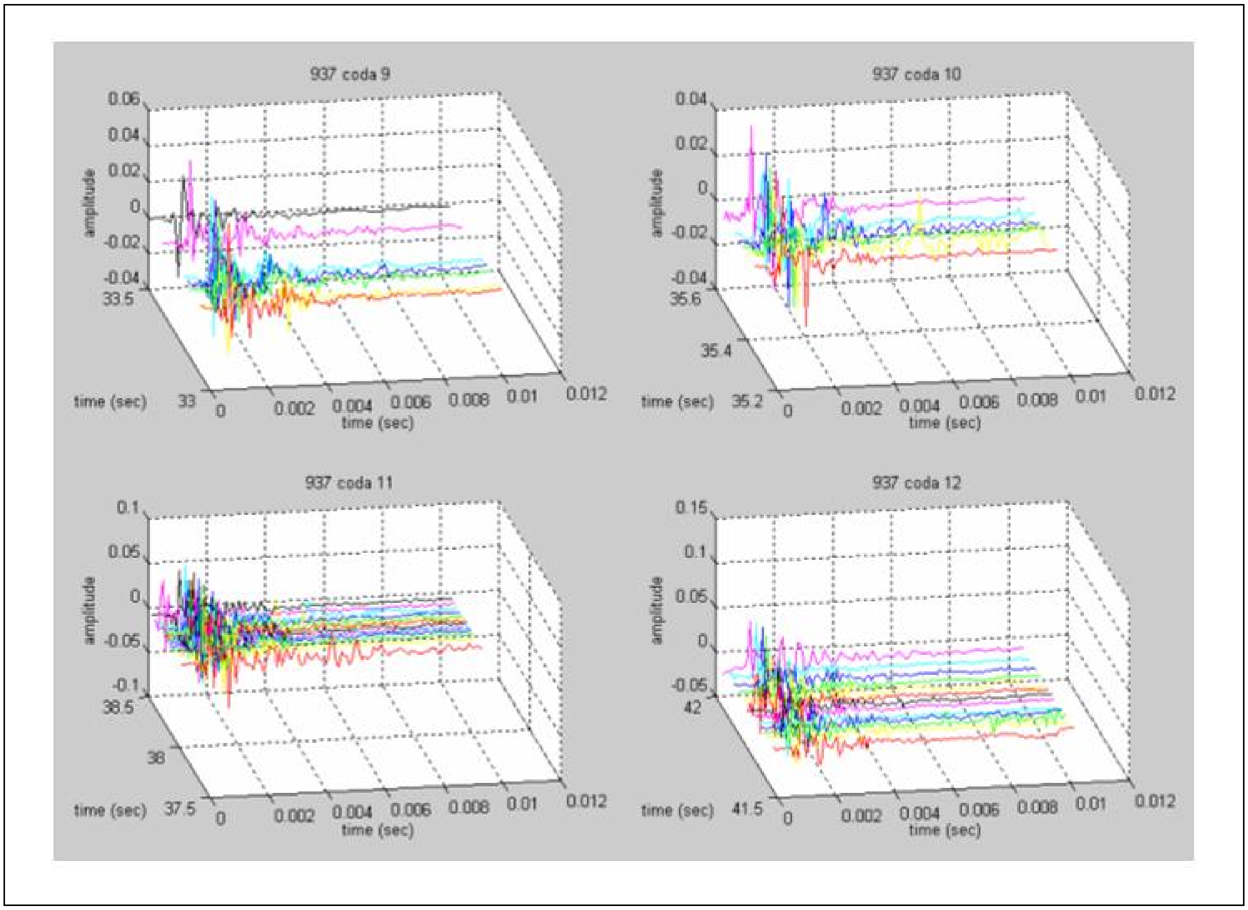


Figure 2A.35. Four representative codas.

Wavelet Transforms

Any function y(x) may be expanded in a linear combination of basis functions

$$y(x) = \Sigma\, a_{sk}\, w_{sk}(x)\,, \qquad (2)$$

where the a_{sk} are the amplitudes of the individual basis functions $w_{sk}(x)$ which have mathematically desirable features (Daubechies 1992; Strang and Nguyen 1996; Mallat 1998). The two parameters s and k describe the scaling and shifting of the mother wavelet. The discrete wavelet transform (DWT) is used in the same fashion as the DFT.

The choice of the wavelet to use is data dependent. The most common wavelet families are the Daubechies (including the Haar wavelet), coiflet, biorthogonal, symmetric, Morlet, and Mexican hat, although there are many more. Wavelets used here include the haar, db4, sym4, coif2, bior6.8, which produced identical classes; and bior2.2, bior3.9, which had classes similar to the others. All were at level one using the MATLAB DWT function.

Results

Trace editing was performed by hand to remove clicks from each coda that were obviously much different from the rest. These extraneous clicks were probably individual clicks from another whale received during the time that the coda was recorded.

The self-organizing map procedure was used to find a representative click from each coda. Five iterations were performed. The result obtained is the same as the average of the clicks in that coda.

The 43 representative clicks (one from each coda) were collected together. Figure 2A.36 shows the time series in the top plot, the magnitude of the Fourier transform coefficients in the middle plot, and the wavelet transform coefficients using a Daubechies db4 wavelet in the bottom plot. Each representative click is displaced slightly along the axis into the paper and plotted with a different color to distinguish it. The DFT coefficients were lowpass filtered at 300 Hz to remove low-frequency noise such as the airgun signals.

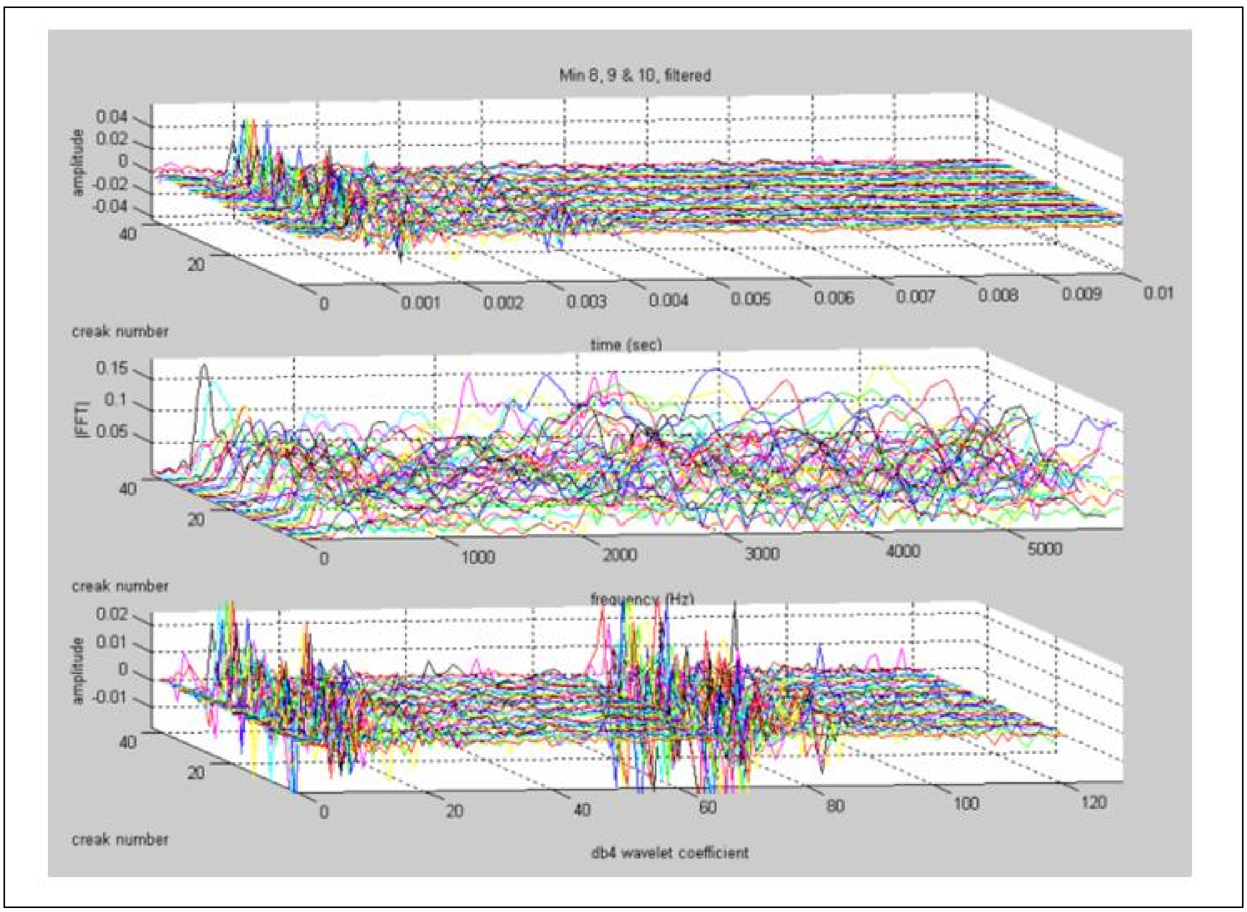


Figure 2A.36. Top: 43 representative clicks, 1 per coda. Middle: FFT amplitude, and Bottom: Wavelet transform, of data shown at top.

The self-organizing mapping procedure was applied to each of the three groups of signals. The order of presentation did not matter since identical results were produced using either the first or the last signal as the initial input. Twenty iterations were used (forty for the FFT). Six to twenty-five classes were allowed in different trials.

Figure 2A.37 shows results obtained with the time series. There are six possible classes (whales). Signals from each class are plotted together, using the colors from the previous figure. It can be seen that only the first four classes are populated, indicating that there are probably four whales present. The whale in class 1 vocalizes much more than the others.

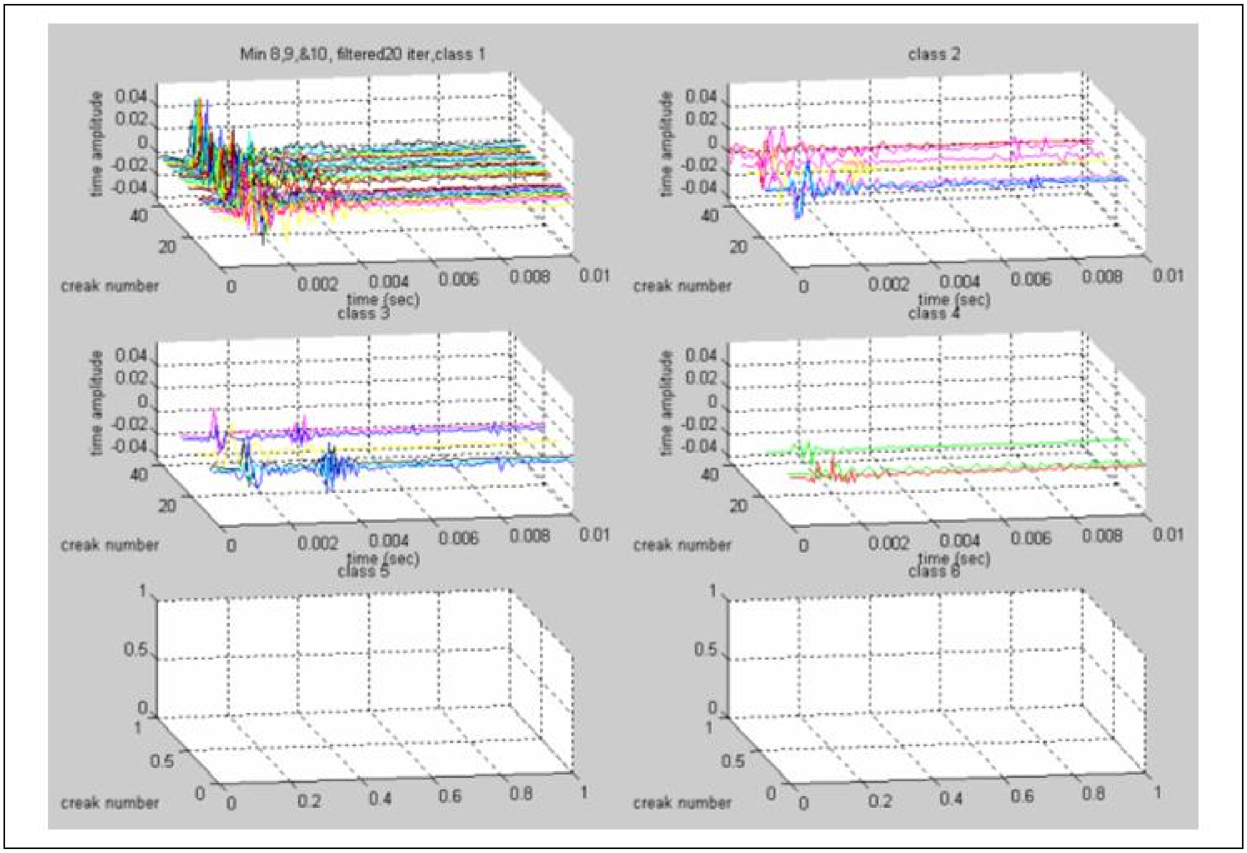


Figure 2A.37. SOM classes using time series data.

Figure 2A.38 presents the results using the SOM with the Fourier transform magnitudes. Five classes contain signals, and although the colors seem to indicate a large disagreement with the classes of the time series, there are only three codas differing, as will be shown below with the table of classes (Table 2A.3).

Figure 2A.39 presents the results using the db4 wavelet transform coefficients. It can be seen that the signals are sorted into the same four classes as they were using the time series.

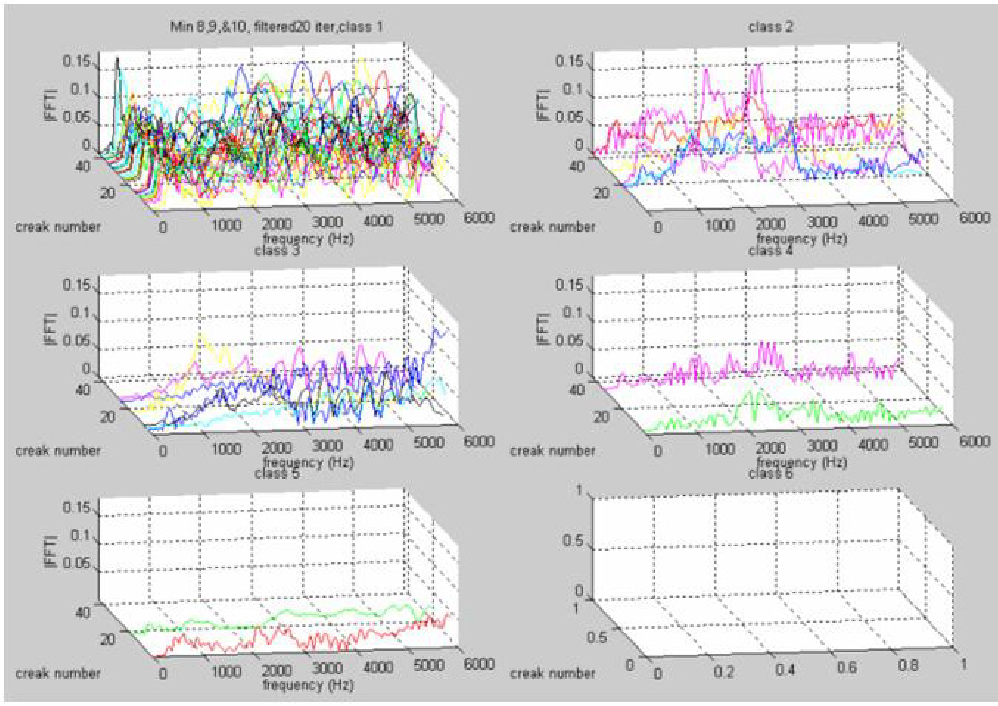


Figure 2A.38. SOM classes using FFT amplitude data.

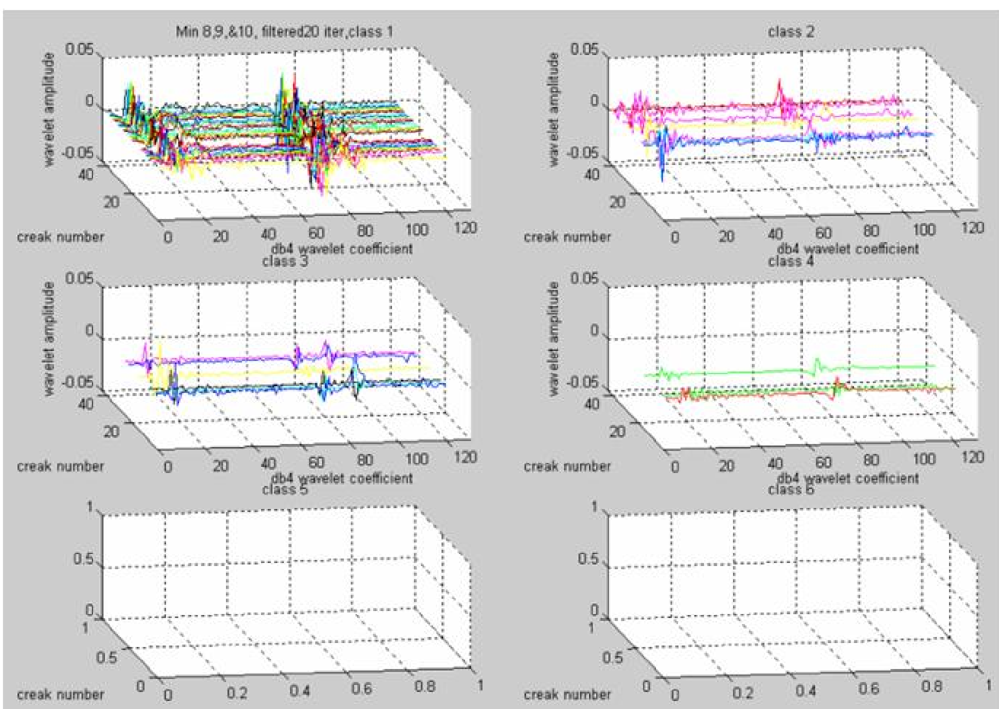


Figure 2A.39. SOM classes using db4 wavelet transform data.

Table 2A.3 shows the data set number and the class for each of the codas for each of the three inputs. In general, there is excellent agreement. The time series and the DWT coefficient inputs give results that agree on classes for all 43 codas. The Fourier transform magnitudes give results that agree for 40 codas. The three which disagree are marked with an asterisk.

Table 2A.3. Data set number and the class for each of the codas for each of the three inputs.

Set	Time	FFT	DWT	Set	Time	FFT	DWT
* 1	4	5	4	23	1	1	1
2	1	1	1	24	1	1	1
3	4	4	4	25	3	3	3
4	3	3	3	26	1	1	1
5	3	3	3	27	3	3	3
6	1	1	1	28	1	1	1
7	3	3	3	29	1	1	1
8	1	1	1	30	2	2	2
9	1	1	1	31	1	1	1
10	1	1	1	32	1	1	1
11	1	1	1	33	1	1	1
12	1	1	1	34	2	4	2
13	1	1	1	35	1	1	1
14	1	1	1	36	1	1	1
15	1	1	1	37	1	1	1
16	3	3	3	38	1	1	1
* 17	4	5	4	39	1	1	1
18	2	2	2	40	1	1	1
19	2	2	2	41	2	2	2
20	2	2	2	42	1	1	1
21	1	1	1	43	2	2	2
22	1	1	1				

Conclusions

This study has shown that self-organizing maps can be used to classify underwater acoustic signals from sperm whales. For the 43 codas tested here, the time series data and wavelet transform coefficients agree for all 43 codas. Fourier transform magnitudes agree with them for 40 codas. This data set is small, however. Furthermore, other features (including but not limited to the interpulse interval) should be included in the SOM procedure.

Reactions of Sperm Whales to Passing Vessels as Determined Through Remote Acoustic Recordings

Five weeks of continuous acoustic recording from the summer of 2001 (LADC01) were examined to assess the potential impact of vessel noise on sperm whale diving behavior. Sperm whale acoustic activity was defined by the number of clicks detected in Ishmael (version 1.0; Mellinger 2001). A noise event was defined as a period during which a broadband spectrum noise level of ≥ 65 dB re: 1μPa, normalized to 1 Hz bands, across frequencies of 2–5.5 kHz, was achieved. Only noise events that were confirmed to be related to vessel traffic were used for analysis. Other events were excluded, such as if the threshold was exceeded by sound produced by sperm whales.

There were 171 boat noise events identified at EARS 1, 103 at EARS 2, and 113 at EARS 3. Boat noise events were significantly more likely to occur at the EARS 1 site when compared to either the EARS 2 site, $\chi^2 = 16.87$, $p < 0.01$, or the EARS 3 site, $\chi^2 = 11.84$, $p < 0.01$. There was a significant difference in the average duration of boat noise at the three buoys (one-way ANOVA, $F = 5.866$, $p < 0.05$). Sperm whale acoustic activity was then compared for the periods 1, 5, and 15 minutes before and after each boat noise event. At the EARS 1 site, significant sign tests revealed that sperm whale acoustic activity decreased after noise events for the 5- and 15-minute comparisons ($Z = -0.2069$, $p = 0.039$; $Z = -2.625$, $p = 0.009$), but not for the 1-minute periods. There was also no significant difference in sperm whale activity at the EARS 2 and the EARS 3 site for any of the time samples.

Similar control comparisons were made to determine if there were any differences in sperm whale acoustic activity before and after a period approximately equal to the average duration of recorded noise events (15 minutes) that contained no boat noise. Sign tests indicated no change in sperm whale activity for 1, 5, or 15 minutes before and after non-noise events at any site, suggesting noise was a possible factor for change in sperm whale acoustic behavior at the EARS 1 location. An additional comparison was then made at this site, contrasting the clicks detected in 5-minute periods before and after the noise event that was separated from the event by 20 minutes (*i.e.*, the period 25-20 minutes prior to event onset was compared to the period 20–25 minutes after event conclusion). A significant sign test revealed that there continued to be a reduced level of clicks detected as long as 25 minutes after noise events at EARS 1.

Estimates of the number of whales present proved to be largely inaccurate when determined using our detection criteria in Ishmael. Instead the five minutes periods before and after each vessel noise event at each EARS site were manually examined, and coded to reflect the number of whales contributing to the clicks recorded. They were coded as 0 for no sperm whale activity, 1 for one whale, or 2 for more than one whale. A significant decrease in the perceived number of whales was observed after noise events at EARS 1, indicating fewer whales producing clicks ($Z = -3.40$, $p = 0.001$), but this was not the case at either the EARS 2 or EARS 3 sites.

In conclusion, the most noise events related to vessels were detected at the EARS 1 location, which was also the site at which the events were typically longest in duration. Additionally, there were fewer clicks, and whales, detected after boat noise events at the EARS 1 site, with effects lasting at least 25 minutes after the conclusion of an event. It should be noted, however, that the criteria for classification as a boat noise event was arbitrary and may not accurately reflect levels or frequencies that could elicit responses in sperm whales. Consequently, further analysis of this data, and data from LADC02, are needed to investigate the possibility of effects similar to those observed at EARS 1 at either the EARS 2 or EARS 3 sites, using different noise event criteria. Additional work is also required to determine if the effects currently seen at EARS 1 are acoustically mediated. Finally, additional analyses may potentially be able to differentiate between whale movement and changes in their acoustic behavior.

Automated Detection of Clicks

The LADC data from 2001 are digitally sampled recordings of the ambient noise of the northern GOM. The background tends to vary slowly compared to the abrupt changes in level due to clicks from sperm whales. The discrete derivative or finite difference as given in Equation (3) of the time series seems to be a good method of filtering the data for click detection.

$$f'(x) = f(x+1) - f(x) \tag{3}$$

Figure 2A.40 shows a sample of data with a click embedded in a slowly varying background. Figure 2A.41 is the discrete derivative of the data in Figure 2A.40, the first step in the automated click detection algorithm. When the level rises above a threshold value, a possible click is detected. After using the discrete derivative to filter the data, standard pulse detection techniques may be applied to locate and count sperm whale clicks in the data.

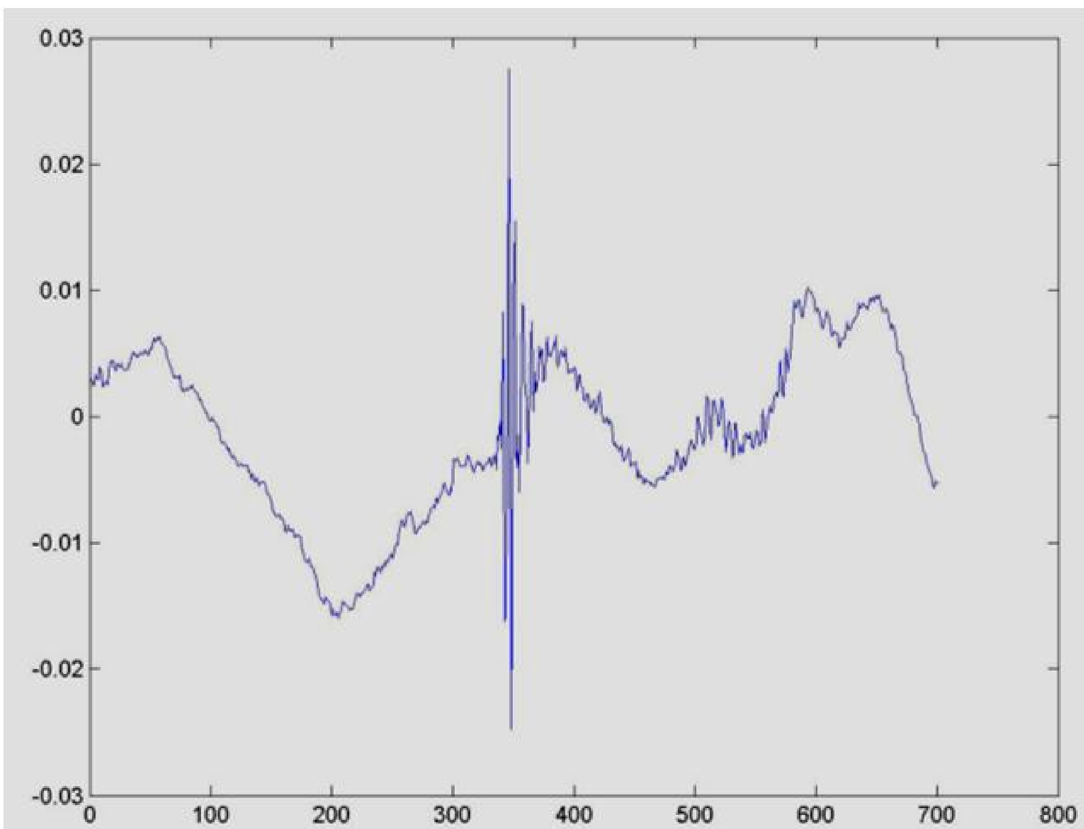


Figure 2A.40. A sample of data with a click embedded in a slowly varying background.

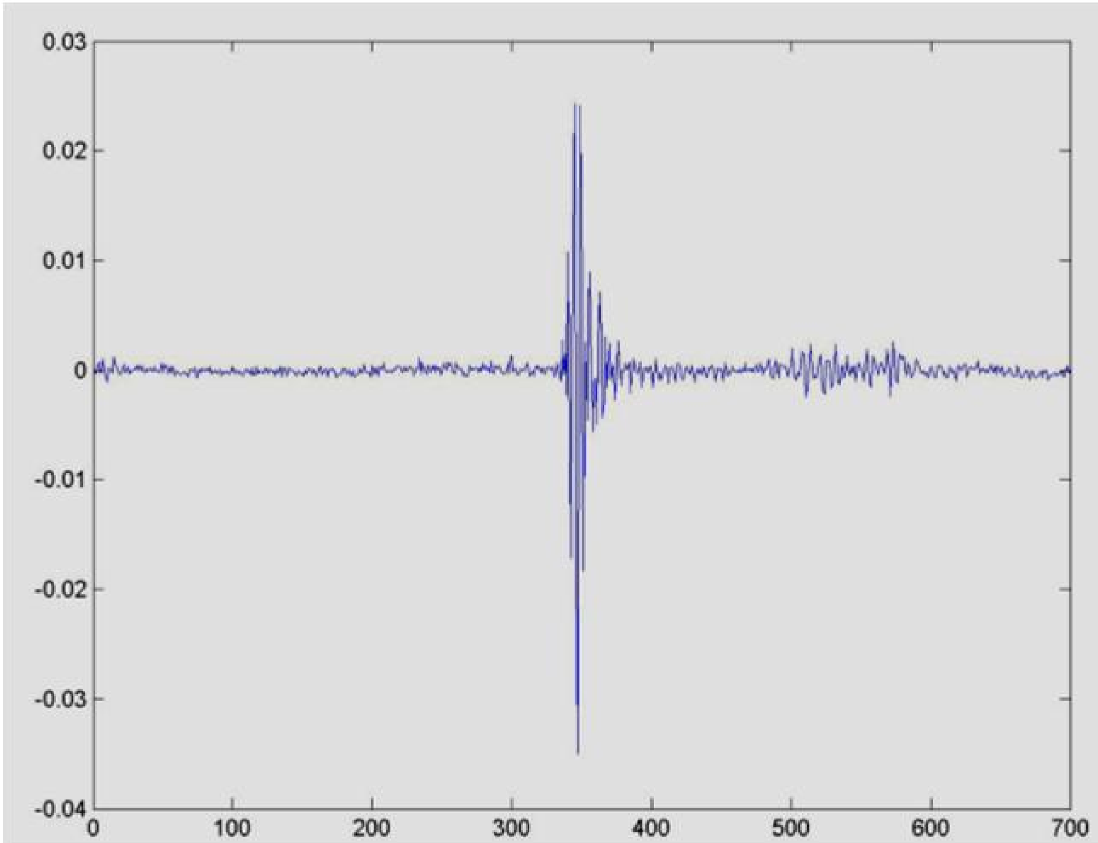


Figure 2A.41. The discrete derivative of the data in Figure 2A.40, the first step in the automated click detection algorithm.

Acknowledgments

The authors gratefully acknowledge support from the Office of Naval Research, PE #62435N, Program Officer Dr. Mel Briscoe. They also greatly appreciate the development of the EARS buoy and other technical support by the scientists and engineers of the Naval Oceanographic Office. They are indebted to many experts in sperm whale acoustics for helpful discussions.

References

Bracewell, R.N. 2000. The Fourier Transform and Its Applications, 3rd edition. New York: McGraw-Hill.

Daubechies, I. 1992. Ten Lectures on Wavelets. Philadelphia: Siam.

Dougherty, A.M. 1999. Acoustic Identification of Individual Sperm Whales (*Physeter macrocephalus*). M.S. Thesis, University of Washington. 52 pp.

Goold, J.C. and S.E. Jones. 1995. Time and frequency domain characteristics of sperm whale clicks. Journal of the Acoustical Society of America 98(3):1279–1291.

Gordon, J.C. 1991. Evaluation of a method for determining the length of sperm whales from their vocalizations. Journal of Zoology 224:301–314.

http://www.hlsresearch.com/oalib/Rays/

Ioup, G.E., J.W. Ioup, J.P. Larue, N.A. Sidorovskaia, S.A. Kuczaj, G.H. Rayborn, and C.D. Walker. 2004. Spectrogram analysis of low- to mid-frequency marine mammal clicks. Presented at the Acoustical Society of America, New York, 24–28 May and abstracted in Journal of the Acoustical Society of America 115:2556.

Ioup, J.W. and G.E. Ioup. 2004. Sperm whale identification using self organizing maps. Presented at the Acoustical Society of America, New York, 24–28 May and abstracted in Journal of the Acoustical Society of America 115:2556.

Kohonen, T. 1995. Self-Organizing Maps, 2nd edition. Berlin: Springer Series in Information Sciences. 426 pp.

Mallat, S. 1998. A Wavelet Tour of Signal Processing. San Diego: Academic Press.

Mellinger, D.K. 2001. Ishmael 1.0 User's Guide, Technical Report OAR-PMEL-120, available from NOAA/PMEL, 7600 Sand Point Way NE, Seattle, WA 98115-6349.

Mohl, B., M. Wahlberg, P.T. Madsen, A. Heerfordt, and A. Lund. 2003. The monopulsed nature of sperm whale clicks. Journal of the Acoustical Society of America 114:1143–1154.

Norris, K.S. and G.W. Harvey. 1972. A theory for the function of the spermaceti organ of the sperm whale. NASA SP-262:397–417.

Sidorovskaia, N.A., G.E. Ioup, J.W. Ioup, and J.W. Caruthers. 2004. Acoustic propagation studies for sperm whale phonation analysis during LADC experiments. High-frequency Ocean Acoustics, M.B. Porter, M. Siderius, W.A. Kuperman, eds. AIP Conference Proceedings 288–295.

Strang, G. and T. Nguyen. 1996. Wavelets and Filter Banks. Wellesley, MA: Wellesley-Cambridge Press.

Turgut, A., M. McCord, J. Newcomb, and R. Fisher. 2002. Chirp sonar sediment characterization at the northern Gulf of Mexico Littoral Acoustic Demonstration Center experimental site. Proceedings, MTS/IEEE OCEANS2002 Conference. Pp. 2248–2252.

Zimmer, W. 2004. Personal communication. NATO SACLANT Undersea Research Center, La Spezia (SP), Italy.

George E. Ioup received an S.B. in physics from the Massachusetts Institute of Technology and a Ph.D. in physics from the University of Florida. After one-year appointments as a postdoctoral fellow at the University of Connecticut and as an assistant professor of physics at the U. S. Coast Guard Academy, he joined the Department of Physics, University of New Orleans (UNO). He is now University Research Professor of Physics and Geophysics. He currently serves as Director of UNO at Stennis Space Center and has been president of the Southeastern Geophysical Society (SGS). His research interests include acoustic, geophysical, and aerospace signal analysis and processing; deconvolution, mathematical digital filtering, and spectral estimation; Fourier and wavelet transforms; higher order correlations and spectra; underwater acoustics; modeling and simulation; and computational physics.

Juliette W. Ioup received a B.S. and M.S. in physics from the University of Florida and a Ph.D. in physics from the University of Connecticut. She has been a professor of physics at Xavier University of Louisiana, a geophysicist data processor at Texaco in New Orleans, and is presently a professor of physics, geophysics, and electrical engineering at the University of New Orleans. Her research interests include geophysical, acoustic, and aerospace signal analysis and processing; deconvolution, mathematical digital filtering, spectral estimation; Fourier and wavelet transforms; neural networks; higher order correlations and spectra; underwater acoustics; modeling and simulation; and computational physics. She is a Fellow of the Acoustical Society of America and a member of ASA, SEG, AGU, IEEE, APS, AWIS, and SGS.

Natalia A. Sidorovskaia received a MS in radiophysics from the Gorky (presently Nizhny Novgorod) State University, a MS in physics from the University of New Orleans, and a Ph.D. in Engineering and Applied Science from the University of New Orleans. After a two year career in the oil industry with Landmark Graphics Corporation, Halliburton Company, she joined the Department of Physics, University of Louisiana at Lafayette where she is now an Assistant Professor. She has published more than 20 scientific publications including contributions to two books on ocean acoustics. She received two Bill Good Awards from the Physics faculty of the University of New Orleans in recognition of outstanding research in Physics and a Distinguished Graduate Research Award at the Doctoral Level from the University of New Orleans. She was selected to be published in the 14th Edition of "Who's Who in the World". Her research interests include numerical modeling of sound propagation through oceanic waveguides; theoretical methods in scattering from objects; depth imaging techniques in seismic signal processing; seismic data management; methods of presentation and processing of deterministic and random signals, including the adaptive processing of highly noisy experimental data; methods of solutions of hydrophysical inverse problems (noise source imaging, ocean acoustic tomography). She is a member of ASA, SEG, SGS, and Sigma Pi Sigma National Physics Honor Society.

Rachel T. Walker received her M.S. in biology in 2001 from the University of Southern Mississippi where she is completing her Ph.D. in experimental psychology. She is also a visiting

faculty member of the Psychology Department at the University of Southern Mississippi. She is a member of several professional organizations including the American Psychological Society, the American Psychological Association, the Society of Marine Mammalogy and the Comparative Cognition Society.
Stan Kuczaj received his B.A. in psychology in 1972 from the University of Texas at Austin and his a Ph.D. in child psychology in 1976 from the University of Minnesota. After serving as professor and chair for the Department of Psychology at Southern Methodist University, he joined the Department of Psychology as professor and chair at the University of Southern Mississippi in 1996. He currently serves as an associate editor of the British Journal of Developmental Psychology and First Language. He is a founding fellow of the American Psychological Society, a founding member of the Comparative Cognition Society and a fellow of the American Psychological Association. He is also a member of numerous professional organizations, including the Acoustical Society of America, the Animal Behavior Society, and the Society of Marine Mammalogy.

Christopher D. Walker received a B.S. in physics in 2002 from the University of Southern Mississippi, where he is currently pursuing a graduate degree. He is also employed as a full-time staff research scientist. His research experience includes laser spectroscopy, signal processing, acoustics, modeling, simulation, and visualization.

Grayson H. Rayborn received a B.S. in physics from the Rensselaer Polytechnic Institute and a Ph. D. in physics from the University of Florida. After a year on the faculty of Old Dominion University he joined the physics faculty of the University of Southern Mississippi where, except for a sabbatical year at the University of Nebraska, he remained until he retired from the faculty as Professor of Physics and Astronomy. He continues to pursue his research interests in signal processing, experimental atomic physics, and underwater acoustics as Professor Emeritus at the University of Southern Mississippi Signal Research Center.

Benjamin Brack earned a B.S. in physics from USM and worked at the USM Signal Research Center studying seismic airgun emissions and whale vocalizations.

Andrew J. Wright received a B.Sc. in marine biology in 1997 from the University of Newcastle-Upon-Tyne and then joined a variety of research and rehabilitation programs, working with a range of animals from bat fish and sea turtles, to manatees and pygmy sperm whales. He completed a M.Sc. in 2004 in marine mammal science from the University of Wales, Bangor, undertaking research at the University of Southern Mississippi in Hattiesburg for his thesis on "The Effects of a Tropical Storm on the Use of Clicks by Sperm Whales in the Northern Gulf of Mexico." Currently on a short-term contract with the Marine Mammal Commission, his research interests include bioacoustics and behavioral ecology. Andrew is a member of the SMM, ECS, ABS and SCB.

Joal J. Newcomb received a B.S. degree in physics and mathematics from Southwestern Oklahoma State University, an M.S. in atomic physics from Kansas State University, and a Ph.D. in experimental atomic physics from Kansas State University. He is currently a research physicist in the Acoustics, Simulations, Measurements & Tactics Branch of the Naval Research Laboratory at the John C. Stennis Space Center, Mississippi. Dr. Newcomb was the chief scientist of OUTPOST SUNRISE, a major acoustic measurement program, and has been principal investigator of several projects to study underwater ambient noise, broadband and narrowband signal propagation, and basin reverberation. Dr. Newcomb is an internationally recognized expert in underwater ambient noise and shipping noise.

Robert A. Fisher received a B.S. degree in biology from Jacksonville University in 1974 and an M.S. degree in marine science from the University of South Florida in 1979. He is an oceanographer in the Acoustic Simulations, Measurements and Tactics Branch at the Naval Research Laboratory, Stennis Space Center, MS. While at NRL, he has conducted research in biological volume reverberation, arctic acoustics and oceanography, and shallow water oceanography. Volume reverberation work focused on understanding changes in swimbladder volumes of midwater fishes that undergo vertical migrations. Arctic studies concentrated on measuring and understanding environmental acoustic parameters of under-ice propagation and ambient noise in major arctic environments. Cooperative arctic research with the Defence Research Establishment Pacific, Canada, resulted in a multi-year environmental acoustic site selection and characterization for the Spinnaker project. He currently conducts and interprets oceanographic measurements made in support of acoustic studies in shallow water and is a member of NRL's Scientific Dive Team.

AIR-GUN ARRAY CALIBRATION STUDIES IN THE GULF OF MEXICO

Jack Caldwell,
International Association of Geophysical Contractors, Houston, Texas

The oil and gas industry in general and the seismic contractors in particular have known for many years what their air-gun arrays emit, in the frequency band from approximately 3 Hz to approximately 800 to 900 Hz. As interest in the issue of ocean noise and marine mammals has grown, so has the interest in finding out what the air-gun arrays emit at frequencies above 900 Hz or so. Making quality measurements for frequencies between 1,000 Hz and 25,000 Hz and higher is difficult, requiring specialized recording equipment and software systems, as well as in-field measurement hardware. The calibration of the in-field sensors, as well as the recording equipment, is a necessary step in making these quality measurements and is a step not trivially done. This paper presents the overall results from one of three air-gun array experiments conducted during the Summer of 2003 in the Gulf of Mexico (GOM) where broad-band (~ 10 Hz–25,000 Hz) data were collected. Related papers presented in these Proceedings are those by Newcomb et al., Tolstoy and Diebold, and Madsen.

Questions about air-gun array outputs fundamentally involve 1) the received pressure levels, and 2) the received energy levels, at different distances from the array, at different emission angles (angles measured from the vertical), and for different azimuths (different map directions from the source), for different frequency bands. To answer these questions, two experiments were conducted using an air-gun array representative of those routinely used by the oil and gas industry, the *M/V Kondor* 31-gun, 3,590-cubic-inch array. One experiment used the SPAR buoy from Lamont-Doherty Earth Observatory as the in-water recording hardware, and the measurements were made in the Mississippi Canyon area along the continental slope where water depths ranged from about 1,000 meters to around 820 meters. The SPAR buoy was free to move with the currents and did. Some results from this experiment are presented in the paper by Tolstoy and Diebold. A D-tag (see Madsen) was also attached to the SPAR buoy, the intent being to compare the output of the SPAR buoy system to the D-tag system. The second experiment was conducted in the Green Canyon area, using an Environmental Acoustic Recording System (EARS) buoy deployed by the Littoral Acoustic Demonstration Center (LADC). (See Newcomb et al. for details not presented in this paper.)

It was hoped, when the SPAR buoy and the EARS buoy experiments were designed and carried out, that the following questions would be answered:

1. What pressure levels, and energy levels, are generated in different frequency bands between 10 Hz and 25 kHz?
2. What frequencies are dominant in the waves emitted at different angles from the vertical up to the horizontal, and in particular, those waves traveling mostly vertically versus those traveling mostly horizontally, and what are the pressure levels and energy levels in those frequency bands?

3. In conjunction with (2), how do the pressure and energy levels vary with azimuth from the array?
4. Given that there are non-uniform velocity structures in the water column, and in the sediments beneath the seafloor, at what offset does the refracted wave come in earlier than the direct water-borne wave?
5. How do the responses of the three different systems (the SPAR buoy, the D-tag, and the EARS buoy) compare to each other?

Environmental conditions put limits on the usefulness of the SPAR buoy and D-tag data, so quantitative information about the horizontally traveling waves was not obtained during these experiments. The EARS buoy data did provide, however, quantitative information about the waves traveling vertically (0º) to those waves traveling at emission angles up to about 20º below horizontal (an emission angle of 70º - emission angles [Θ] are measured with respect to vertical, as indicated in Figure 2A.44a). That information is summarized here, but further analysis is needed to provide more in-depth information about those waves.

For the EARS buoy experiment, the anchored hydrophone was located in 990 meters of water and positioned 251 meters above the seafloor. Figure 2A.42 indicates the geometry of the five source lines with respect to the location of the EARS buoy. Figure 2A.43 shows the geometry of the hydrophone with respect to a source passing directly overhead. In actuality, the source line passing closest to the hydrophone was offset 200 meters (see Newcomb et al. for more details).

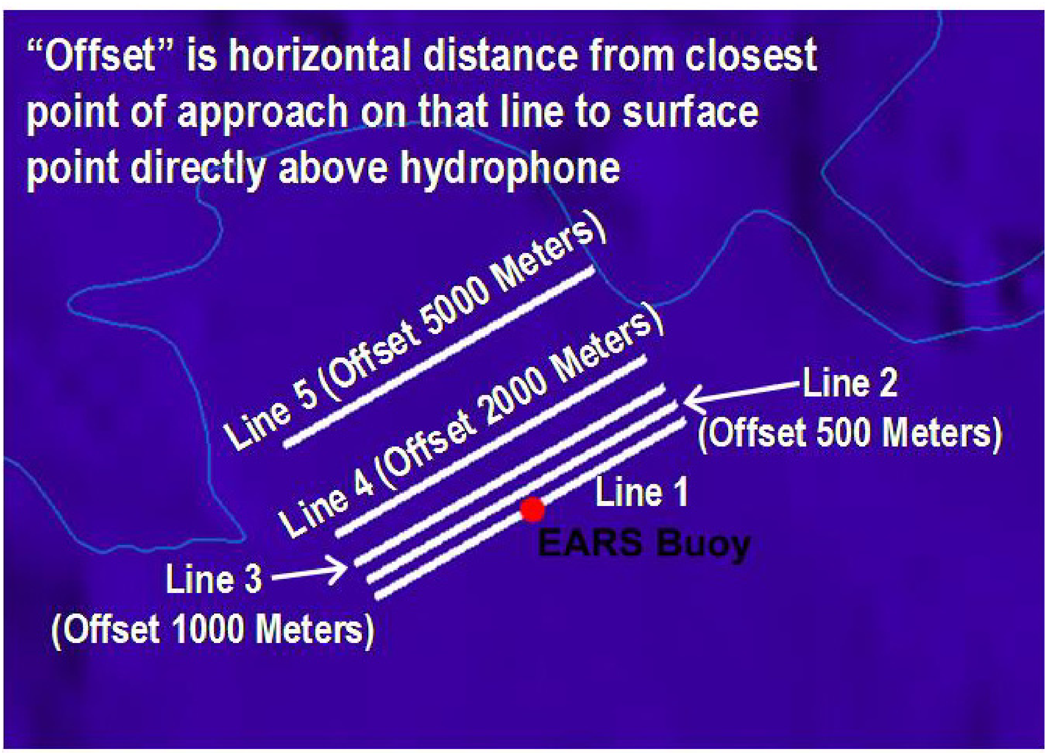


Figure 2A.42. EARS Buoy shot line geometry.

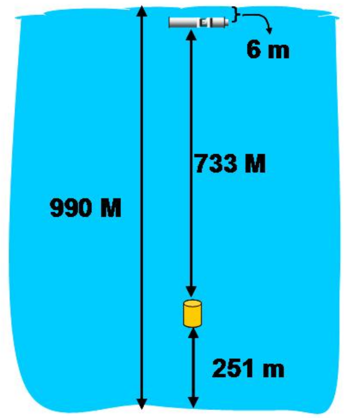


Figure 2A.43. Hydrophone geometry.

Figure 2A.46 illustrates a typical record of an air-gun pulse that was recorded nearly vertically 736 meters above the EARS-buoy hydrophone. Air-gun arrays are constructed so that the output is focused downward, and consequently, upward, as well. This leads to a strong peak, followed immediately by a very similar-looking trough that is the reflection of the peak from the air-water interface (Figure 2A.44b shows a cartoon of a ray diagram where the white ray creates the strong peak, and the two red rays create the trough). That is labeled the "first break" in Figure 2A.46. The second major event is the "seafloor reflection." The cartoon of Figure 2A.45 shows how it occurs: the white ray represents the first break arrival, and the red rays represent the pulse from the air-gun array traversing the water column, reflecting off the seafloor, and being received at the hydrophone (for simplicity, the detail of the first break division into the rays contributing to the peak and trough are omitted, so only a single white ray indicating the first break arrival is shown). The last identified event on the record in Figure 2A.46 is the energy from the 18 kHz echosounder. This record is known as a "time domain" record since it depicts the amplitude of pressure along the vertical axis versus time along the horizontal axis (although in this display, only the relative amplitude is shown, rather than the absolute amplitude).

The same record can be viewed in the "frequency domain," where amplitude per Hertz is shown along the vertical axis, and frequency is displayed along the horizontal axis (Figure 2A.47). In this figure, absolute amplitude per Hertz is displayed on the vertical axis, and the duration of the signal that is used in the analysis is 100 milliseconds beginning just before the arrival of the first break energy. Reference to Figure 2A.46 will demonstrate that 100 milliseconds will include all of the high amplitudes associated with the first break energy. Figure 2A.47 shows that the maximum amplitude of approximately 158 dB/Hz re 1 µPa occurs very close to 62 Hz, and that an amplitude of about 107 dB/Hz re 1 µPa occurs close to 1,000 Hz. The salient point here is that the high pressures in an air-gun pulse occur in the 10-100 Hz frequency band, and the pressure levels drop quite rapidly with increasing frequencies. Generally, a 30 to 50 dB drop in amplitude is observed between 100 Hz and 1,000 Hz for the shot records acquired in the EARS buoy experiment. The amplitudes continue to drop between 1,000 Hz out to around 8,000 Hz or so where the noise floor of the recording system is reached.

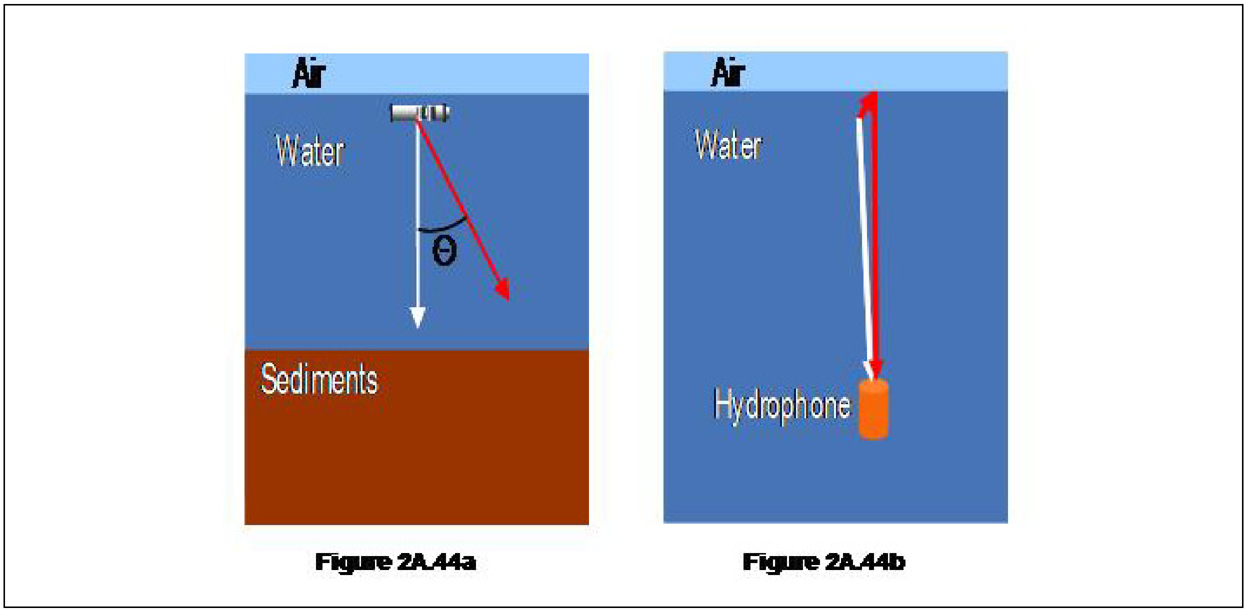


Figure 2A.44. An emission angle of 70º is shown in Figure 2A.44a. Figure 2A.44b represents a ray diagram where the white ray creates the strong peak, and the two red rays create the trough

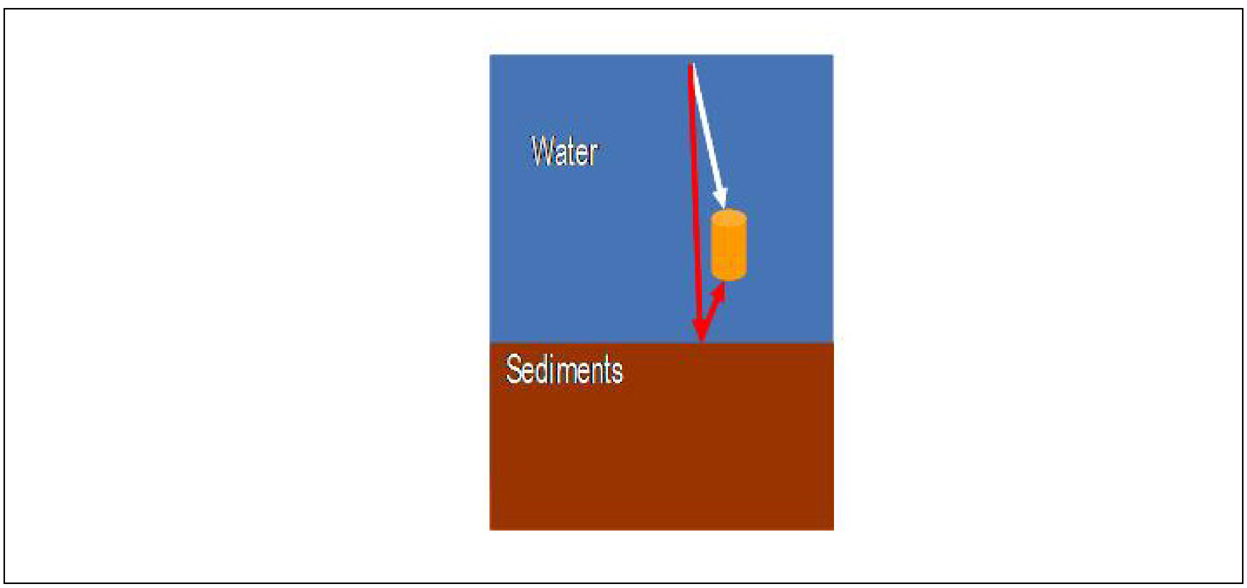


Figure 2A.45. The white ray represents the first break arrival, and the red rays represent the pulse from the air-gun array traversing the water column, reflecting off the seafloor, and being received at the hydrophone

Figure 2A.48 shows sound pressure density (sound pressure squared per Hertz) versus frequency and makes it clearer that there is no energy at levels higher than 80 dB re 1 µPa from the air-gun array in the vertical lobe of the radiation pattern at frequencies higher than 4,000 Hz at a distance of 736 meters from the hydrophone. Figure 2A.48 is an analysis from a single shot record.

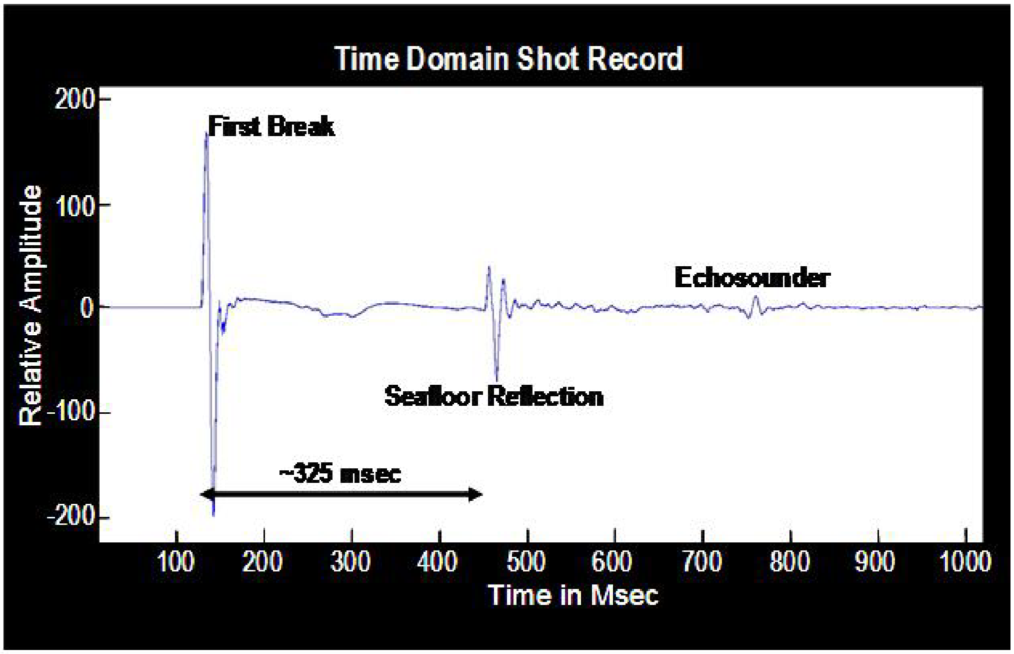


Figure 2A.46. Time domain shot record 736 meters away (mostly above) from hydrophone.

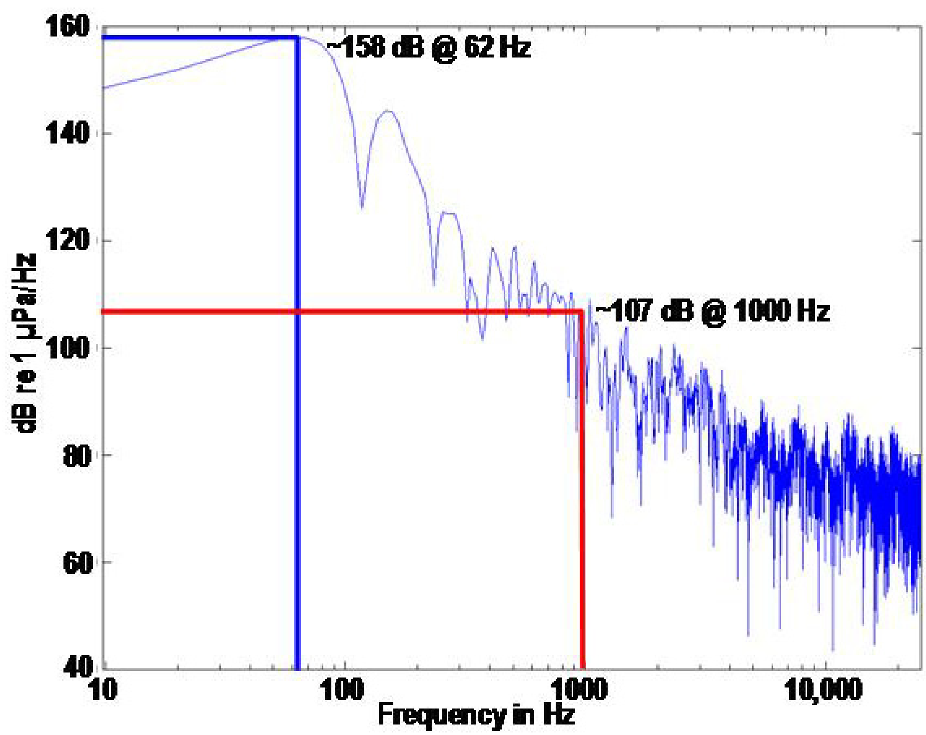


Figure 2A.47. Sound pressure/Hz versus frequency. Note rapid drop-off above 100 Hz.

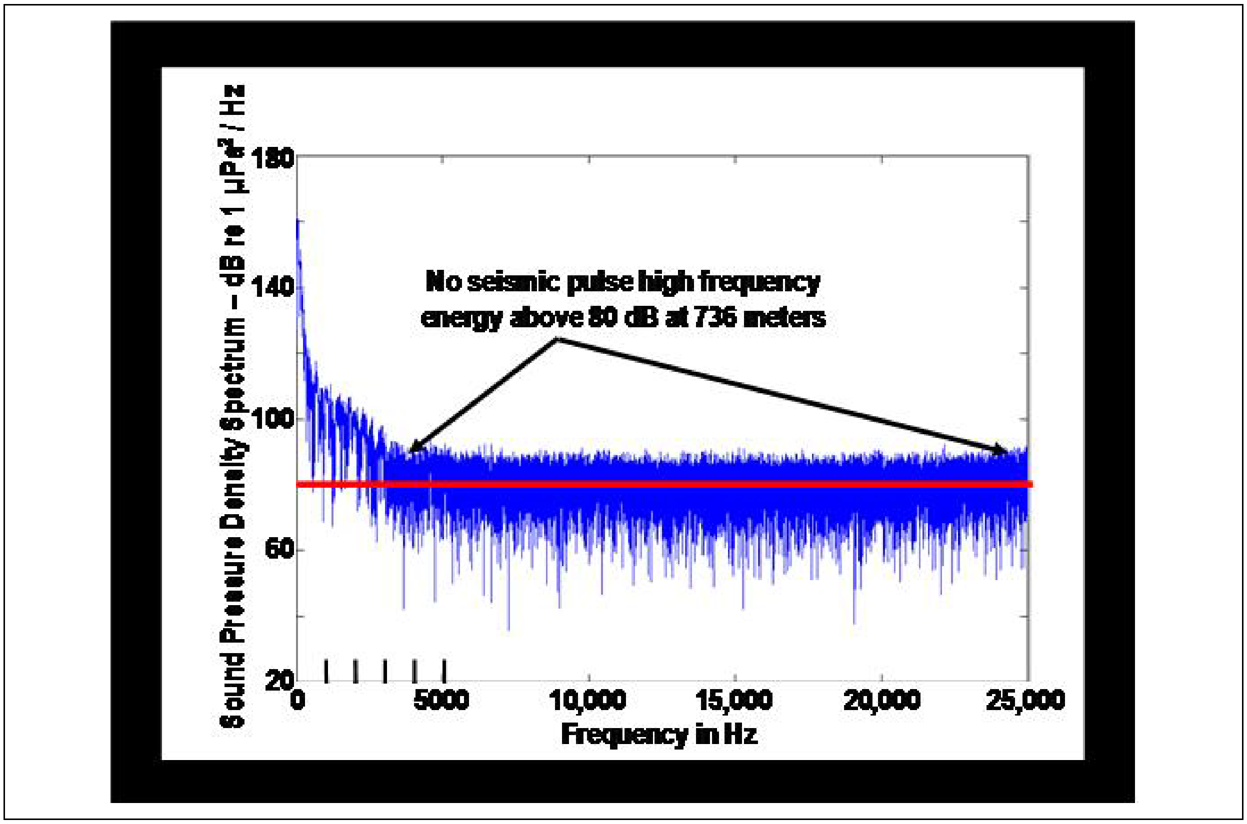


Figure 2A.48. Sound pressure density spectrum.

Figure 2A.49 is a more inclusive look at the EARS buoy data because it includes all of the shot records that were recorded in the EARS buoy project. This figure is a spectrogram: frequency is plotted on the vertical axis, shot record is implied along the horizontal axis, and color indicates sound pressure density (pressure squared per Hertz), an entity related to amplitude, and the color scale is indicated on the right side of the plot. There are about 100 shot records associated with each of the five source lines acquired in the EARS buoy project, and the records associated with each line are indicated along the horizontal axis. A window of 1.28 seconds was taken for each shot record, and the window began about 50 milliseconds before the first break.

Figure 2A.49 shows how the pressure levels increase as the source moves first towards the hydrophone for each line, and then away from the hydrophone, so you get a mound-like appearance along the horizontal axis: Line 1 is the left-most group of traces on the plot, and the left-most trace will be the farthest trace to the southwest of the hydrophone, and then each subsequent trace to the right will be closer and closer to the hydrophone until the source is essentially directly over the phone, and then the source begins to move away from the phone to the northeast, until the end of Line 1 is reached. Then the traces of Line 2 begin, etc.

All of the reds and yellows in Figure 2A.49 occur at less than 1/10 of the way up to 5,000 Hz, so below 500 Hz. The pale greens are gone by about 1/5 of the way to 5,000 Hz, which is 50 dB down at 1,000 Hz (dark red is 160 dB, pale green is 110 dB). The pale blue (60 to 70 dB below the levels at the peak frequencies) in Figure 2A.49 is broadly distributed across all five lines for frequencies below 4,500 Hz. The pale blue occurs for narrowing groups of shots up to around 23,000 Hz for Lines 1 and 2, the two lines that go almost directly over the hydrophone. The pale blue is also visible in regular tick marks parading across the plot at around 18,000 Hz: this is the signal from the echosounder and is not present in the analysis window on all of the shot records.

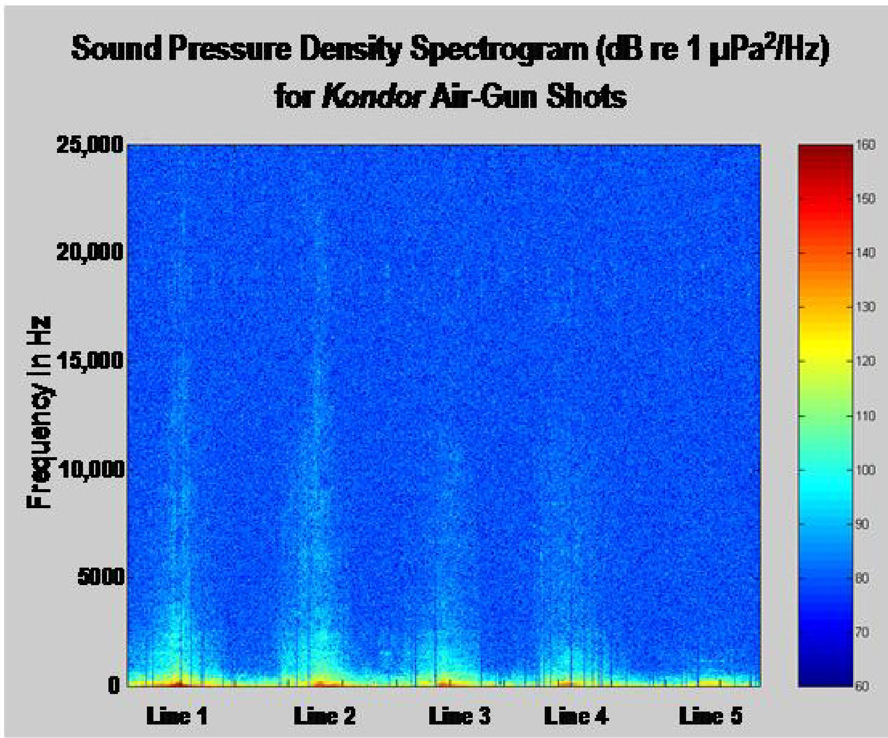


Figure 2A.49. Sound pressure density spectrogram. See text for description.

The calibration studies done using the *M/V Kondor* in the GOM taught us a number of lessons.

1. Efforts to measure sound from acoustic sources should be careful to address the following areas to ensure the quality of the recorded measurements:
   a) Recording system characteristics, such as dynamic range and frequency response
   b) Uncertainties associated with the position of receivers relative to the source
   c) Physical properties of the environment where the data are acquired.
2. The amplitude spectrum of the *M/V Kondor* air-gun array, while relatively flat between 10 and 100 Hz, has a peak at around 62 Hz, and the output levels are 30 to 50 dB lower at 1,000 Hz than the levels at 100 Hz, for distances 736 meters and greater to the receiver, and for emission angles between 0º and ~70º.

3. The output levels continue to decline from 1,000 Hz to 5,000 Hz, where the levels are 60 to 70 dB lower than the levels at 100 Hz, for distances 736 meters and greater to the receiver, and for emission angles between 0º and ~70º.
4. The EARS buoy dataset provides detailed information on the output that a standard industry air-gun array emits at vertical and sub-vertical emission angles.
5. Results show that, for odontocetes, current mitigation exclusion zones are conservative with respect to potential for physical impacts from high frequency emissions from industry seismic surveys

A well-documented, broad-band (10 Hz to 25,000 Hz), and precisely acquired data set with horizontally propagating waves is still needed by the oil and gas industry. Additionally, the vertical and sub-vertical output of an industry array, over the same broad bandwidth, needs to be measured at a distance of around 200 meters. Collaborative efforts will continue with other research groups to make optimum use of existing data and limited resources.

I would like to acknowledge the support of several groups and individuals who made this project and its results possible: the Industry Research Funders Coalition, Littoral Acoustic Demonstration Center (LADC), International Association of Geophysical Contractors (IAGC), SWSS, Lamont-Doherty Earth Observatory (L-DEO), and Woods Hole Oceanographic Institution (WHOI); Joal Newcomb, George & Juliette Ioup, Jim Stephens, Greyson Rayborn, and Natalia Sidorovskaia (all from LADC), Mike Jenkerson, Rodger Melton, and Andy Wigton (all from ExxonMobil), Phil Fontana (Veritas DGC), Chip Gill (IAGC), Bill Lang (MMS), John Diebold and Maya Tolstoy (both from L-DEO), and Mark Johnson (WHOI).

Jack Caldwell, a geophysical consultant, has been in the oil and gas industry as a technically-oriented geoscientist for 27 years. He received a B.S. in mathematics from Davidson College and a Ph.D. in geophysics from Cornell University. He worked two and a half years in research for Texaco, almost seven years in various positions for Marathon Oil, and 15 years in numerous technical and managerial positions for Schlumberger. Since 1996, he has spent extracurricular time involved with the issue of sound in the ocean and its effect on marine mammals. He has organized several industry workshops on this issue, and has written several articles to help the oil and gas industry better understand this issue's different aspects. He served on the U.S. National Research Council of the National Academy of Sciences Committee on Potential Impacts of Ambient Noise in the Oceans on Marine Mammals that published its report entitled *Ocean Noise and Marine Mammals* in 2003. He was awarded the U.S. Minerals Management Service Corporate Leadership award in 2000 for his work on this issue, and in 2002 was awarded lifetime membership in the Society of Exploration Geophysicists largely as a result of his efforts to get the oil and gas industry more involved in addressing this issue.

MANTA: THE MARINE ANIMAL TRACKING APPARATUS

Thomas F. Norris, Marine & Environmental Sciences Division,
Science Applications International Corp.

ABSTRACT

MANTA is a marine animal tracking and data-telemetry system which integrates acoustic transponder, underwater modem, data-logging, GPS, and VHF telemetry technologies. This system differs from existing tag-based, marine animal tracking technologies in that it incorporates several complementary technologies allowing tagged marine animals to be tracked underwater in real-time, three-dimensionally and at very high spatial resolution (i.e. +/- a few meters). The primary application of MANTA is detailed real-time monitoring and data-collection of animal movements, behaviors (including vocalizations), and physiology, as well as for collection of oceanographic data directly from tagged marine vertebrates (e.g. whales, pinnipeds, elasmobranchs, sea turtles etc.). Location information is processed in real-time on a "surface station" located onboard a tracking vessel. Location data includes the animal's latitude, longitude, and depth (+/- 1m) and can be updated every few seconds. Standard VHF telemetry allows animals to be tracked while at the surface and when they are beyond the tracking range of the acoustic system. In addition, data can be collected from up to six sensors (e.g. accelerometer, thermistor, etc.) that can be integrated on the tag. Furthermore, data from the MANTA tag can be acoustically telemetered (at limited bit-rates) to the surface via an underwater modem and/or logged internally on FLASH memory modules. The current version of the tag has an integrated accelerometer (to derive pitch & roll). A prototype acoustic "event detector" also has been developed, and improvements to processing and data-storage capabilities are planned. Examples are provided of data collected from test deployments on blue whales in Monterey Bay, California (work funded by ONR).

SESSION 2B

NORTHERN GULF OF MEXICO CONTINENTAL SLOPE HABITAT AND BENTHIC ECOLOGY STUDY RESULTS, PART II

Chair: **Greg Boland, Minerals Management Service**

Co-Chair: **James Sinclair, Minerals Management Service**

DGoMB MEIOFAUNA STUDIES

Jeff Baguley and Paul Montagna, Texas A&M University
Wonchoel Lee, Hanyang University, Seoul, Korea

Meiofauna are ubiquitous in deep-sea soft sediments and exhibit high abundance compared to larger-sized invertebrates (e.g., macrofauna). The northern Gulf of Mexico (NGOM) deep sea is characterized by topographical contrasts, with the flat topography of the Florida slope followed by the precipitous depth increase of the Florida escarpment; the complex Texas/Louisiana slope with numerous basins and knolls; and numerous canyon features such as the Mississippi Trough and DeSoto Canyon. To better understand the distribution of meiofauna and how they respond to topographic, geochemical and physical forcing in the NGOM, meiofauna abundance and environmental variables were analyzed in a hypothesis-based univariate and multivariate design.

Meiofauna abundance is significantly related to water depth but also exhibits significant longitudinal differences resulting from proximity to Mississippi River outflow. Canyon features in proximity of Mississippi River outflow were found to greatly enhance meiofauna abundance. The Florida Escarpment interacts with Mississippi River inflow and the Loop Current to enhance meiofauna abundance at stations lying directly above and below the escarpment. Multivariate comparisons of meiofauna abundance with environmental variables reveal a strong Mississippi River influence. River outflow alters local sediment characteristics and interacts with loop current eddies and dynamic slope topography to increase POM flux in the northeastern region, thus creating areas of higher than normal meiofauna abundance.

Harpacticoida (Copepoda) are the second most abundant taxon within the meiofauna and an important component of deep-sea meiofaunal communities. However, regional species pools, processes structuring communities on various scales, and distributions of organisms in response to topographic, geochemical, and physical oceanographic forcing is largely unknown for deep-sea environments. The NGOM is a dynamic environment with complex continental shelf topography and longitudinal gradients of water column primary production due to Mississippi River outflow. Harpacticoid copepod community structure was analyzed at 43 stations in the NGOM deep sea to test regional and bathymetric patters of diversity. Harpacticoid copepod diversity is significantly related to depth and longitude. Most stations have unique species compositions, suggesting high regional (2,700 species) and global (10^5 - 10^6 species) diversity by extrapolation. Although highest diversity, in terms of expected number of species (rarefraction), is found at approximately 1,200 meters, average taxonomic and average phylogenetic diversity continue to increase with depth, indicating greater morphological or functional diversity. Multivariate analysis reveals significant inverse relationships between diversity and POM flux, which are confirmed by a significant region-scale depth and longitude differences. However, within- versus between-station variability suggests an interaction between small and region-scale processes maintaining high diversity.

Meiofauna exhibit high biomass in deep-sea soft sediments, compared to larger invertebrates (e.g. macro- and megafauna), and play an important role in the global carbon cycle. However, deep-sea meiofauna community function (grazing, respiration, etc.) has only been sparsely investigated. In the present study, meiofauna biomass was calculated at 51 stations using a newly developed, semi-automated, digital microphotographic method, and meiofauna mass-dependent respiration was estimated at 51 stations using an allometric power law. Strong relationships exist between biomass and meiofauna community respiration with depth. Highest biomass and respiration occurred in the proximity of high particulate organic matter flux where surface currents interact with Mississippi River inflow complex slope topography. Allometric estimates indicate that meiofauna require 7% of their biomass per day to meet their metabolic energy budget and are therefore not food limited with respect to sediment bacterial biomass. Meiofauna account for 10-25% of whole sediment community respiration indicating their importance in global biogeochemical cycles.

Jeffrey Baguley received his Ph.D. in December 2004 from the University of Texas at Austin. He is now a research assistant professor in the Baruch Institute for Marine and Coastal Sciences at the University of South Carolina, Columbia campus. Dr. Baguley's main research interests are in the field of meiofauna ecology, but more specifically, harpacticoid copepod ecology, deep-sea diversity, meiofauna community energetics, and harpacticoid molecular population structure.

Paul Montagna, Ph.D., is a Research Professor at the University of Texas at Austin, Marine Science Institute and Project Coordinator for the proposed Texas National Estuarine Research Reserve. He has more than 30 years' experience as a benthic ecologist.

Wonchoel Lee, Ph.D., is an associate professor in the Department of Life Sciences, Hanyang University, Seoul, Korea. He is a professional taxonomist specializing in the order of the Harpacticoida (Copepoda) and has published descriptions of several new species and genera.

DGoMB MACROFAUNA

G. Fain Hubbard and Gilbert T. Rowe, Texas A&M University

Nearly 175,000 macrofauna specimens were found, predominantly composed of polychaetes (64,627; 37.3%). Extraordinary numbers of amphipods occurring at MT1, MT2, and MT3 skewed their relative abundance (34,385; 19.8%). Harpacticoids, tanaidaceans, bivalves, ostracods, aplacophoran mollusks, and cumaceans followed in that order.

The faunal groups that were further identified as close to species level as possible were the polychaeta, amphipoda, tanaidacea, bivalvia, isopoda, aplacophora, and cumacea. These accounted for 126,505 specimens representing 504 genera and 968 species.

Macrofaunal density by transect and depth are shown for the combined cruises. Density decreases with depth with infrequent inconsistencies, e.g., NB4, 5 < B1; GKF < WC12.

Macrofaunal Shannon-Wiener Diversity ($\log_2$) was quite uniform throughout both transect and depth, with appreciable reduction only on the abyssal plain.

Expected number of species for a macrofauna population of 180 individuals [$E(S_{180})$] was also remarkably uniform with certain notable exceptions: Mississippi Trough stations MT1 and MT2, the High Productivity (HP) station, Green Knoll Furrows (GKF), and Sigsbee Abyssal Plain stations S1, S2, and S3 were all quite low. The graph of expected number of species (N=180) plotted versus depth yielded a hyperbolic curve with an apex occurring around 1,500 m.

Macrofaunal similarity was demonstrated on a map with different colored circles on a dendrogram with the same similarity zones denoted by the same colors and by transect versus depth with "fence" diagrams, all illustrating the shifting of grouping by depth as well as some east-west component.

Polychaete densities were shown by transect and depth and illustrate the same general decrease with depth pattern as the macrofauna as a whole. Polychaete Shannon-Wiener diversity showed a somewhat more evident decrease with depth than did the macrofauna as a whole. The expected number of species (N=100) appeared to decrease steadily with depth, with any maximum occurring above the depth of the samples. Similarity was again illustrated by map and by transect/depth "fence" diagram, again demonstrating grouping by depth with some east-west influence.

Amphipod densities were uniformly low at all stations except MT1 and MT2 and slightly at C7. The photograph of the sea floor near MT1 shows a shag carpet appearance due to the presence of thousands of amphipod tubes on and in the surface. Station bathymetry shows the vicinity of the core samples and the photography and the apparent homogeneity of the area. Amphipod expected number of species (N=5) for the 49 stations at which amphipods were found show a slight apex about 800 m. Amphipod similarity map and transect/depth “fence” diagram show grouping by depth with slightly more erratic east-west confusion. Individual stations not grouping with any others were MT1, S39, and S3.

Bivalve densities, while rather low at most stations, showed remarkable abundances at stations MT1, MT2, HP, GKF, and S5. Expected numbers of species (N=50) showed an apparent peak at about 1,500 m. Bivalve similarity by map and transect/depth “fence” diagram show a grouping trend with depth with some east-west influence.

Isopod densities follow the trend of the macrofauna in general with exceptionally high values at stations BH, S35, S36, S3, and S5. Expected numbers of species (N=20) showed an apparent peak at about 1,750 m. Isopod similarity by map and transect/depth “fence” diagram show a grouping trend with depth with little east-west influence.

Bottom photography of stations S2, with the lowest macrofaunal populations on the abyssal plain, and S5, with the highest, shows the great similarity in the overt appearance of the two.

Aplacophoran mollusk densities followed the trend of the macrofauna in general with exceptionally high values at stations MT2, MT3, and S35. Expected numbers of species (N=5) showed a slight peak at about 1,100 m. Aplacophoran similarity by map and transect/depth “fence” diagram show a grouping primarily by depth with some clutter caused by the relatively small number of organisms overall and independent stations at S41 and S43.

Cumacean densities followed the macrofauna in general with exceptionally high values at stations MT2, MT3, and S35. Expected numbers of species (N=5) showed no peak low R^2 of 0.34. Cumacean similarity by map and transect/depth “fence” diagram showed grouping by depth, erratic influence by the relatively small number of organisms overall, and independent stations at RW4, RW5, S1, GKF, C14 and MT6.

Harpacticoid densities exhibited exceptionally high values at C12, S5, MT3, S35, S36, S37, and perhaps S38. Expected numbers of species (N=185) showed no obvious peak below the shelf. The Harpacticoid similarity map showed a grouping trend with depth with little east-west influence.

Expected number of species diagrams (N=5) for amphipoda, aplacophora, isopoda, and cumacea illustrate that the greater the number of stations (49 or 51 rather than 29 or 22) the greater reliability of the R^2 values for the graph curves (0.66 or 0.72 rather than 0.32 or 0.34, respectively). Expected number of species values for bivalvia, ($E(S_{50})$ with N=48 and R^2=0.68 and harpacticoidea, $E(S_{180})$ with N=43 and R^2-0.22, seem to indicate that neither the number of stations represented nor the population maximum of the estimate may have that much effect. Expected number of species for polychaeta at $E(S_{50})$ with N=50 and R^2=0.61 and $E(S_{100})$ with N=50 and R^2=0.71 seem to indicate that given the same number of stations, estimations based on higher population sizes are more reliable. This may also show that comparing between populations of different taxa and between different population sizes of the same taxa may be like comparing oranges and bananas.

Conclusions derived from this study:

1. Density, diversity, and numbers of species decrease and species change with depth;
2. Faunal composition differs east and west of DeSoto Canyon;
3. Upper Mississippi Trough fauna are unique in species and density;
4. Western fauna are similar to basin/non-basin as well as to central fauna; and
5. Basin and non-basin stations differ only by depth.

Dr. G. Fain Hubbard obtained his Ph.D. from Texas A&M University, College Station. He is now a Faculty Lecturer at Texas A&M University, Galveston.

Dr. Gilbert T. Rowe completed his B.S. in zoology and M.S. in oceanography at Texas A&M before going to Duke for a Ph.D. in zoology. That was followed by 11 years as a research scientist at WHOI and eight years as a research scientist at the Brookhaven National Lab on Long Island. In 1987 he returned to Texas A&M to become Head of the Oceanography Department. He transferred to the Galveston campus in 2002 as Head of Marine Biology. Since 1999 he has been the Program Manager of the MMS Deep Gulf of Mexico Benthos project (DGoMB), now nearing completion.

NORTHERN GULF OF MEXICO CONTINENTAL SLOPE HABITAT AND BENTHIC ECOLOGY STUDY RESULTS: MEGAFAUNA

Mary K. Wicksten, Department of Biology, Texas A&M University

Megafaunal invertebrates, with a size greater than 10 mm, include sponges (phylum Porifera), sea anemones and their relatives (Cnidaria), various larger worms, mollusks, crustaceans and echinoderms. Feeding modes range from passive filtration to active predation; metabolic levels range from sluggish to rapid. Species may be solitary or colonial.

During the DGoMB study, megafaunal invertebrates were taken by trawl and weighed and sorted on ship. Final identification was made in the laboratory. At least 185 species were taken. Species richness was greatest at site S35 (De Soto Canyon). Other species-rich sites were C4, MT5, S38 and S41. Species diversity was highest at Site MT6 (Mississippi Trough) followed by site MT5. Lowest species diversity was at sites on the upper slope (MT1, S42, S43 and S44), basins (B1, B2 and B3) and sites dominated by small sponges (NB4 and S37).

Biomass was highest at sites in the De Soto Canyon (S35, S37, S38 and S41) and also MT3. Much of the biomass was due to wet weight of holothuroids. Single heavy animals, such as large squid or crabs, were not included in the biomass per site. The greatest number of individuals was at S37 (1,612 individuals, mostly small sponges). Other sites with more than 300 individuals were MT1, MT5, MT6, NB5 and S38. The mussel *Amygdalum politum* was more abundant in canyon sites than elsewhere, but other records suggest that the mussel is not confined to canyons.

Crustaceans were more diverse and abundant in the De Soto Canyon than in the Mississippi Trough. A more detailed study of zoogeography of decapods in the Gulf of Mexico suggests that the De Soto Canyon has the most diverse decapod fauna (63 species out of 129 total species). The northeastern and eastern Gulf of Mexico has a more diverse decapod fauna, including the golden crab *Chaceon fenneri,* than other parts of the Gulf. Ten species, supposedly endemic to the Gulf, are rare and may have been overlooked elsewhere. The Gulf is particularly rich in craylets, *Munidopsis* spp, with 25 species. The fauna of the Straits of Florida is distinct and should not be considered to be part of that of the Gulf. Most of the megafauna ranges from the Gulf of Mexico into the Caribbean and western Atlantic.

Mary Wicksten received her B.A. in Biology from Humboldt State College, California in 1970 and her M.A. in 1972. She received her Ph.D. from the University of Southern California in 1977 and spent three years of further study there before coming to Texas A&M University in 1980. She is a professor in the Department of Biology. An active diver and field biologist, she has participated in numerous research cruises in the Gulf of Mexico and eastern Pacific. She is a specialist on decapod crustaceans, having published over 100 papers in refereed journals and having described 34 new species.

MACROBENTHIC COMMUNITY STRUCTURE AND TOTAL SEDIMENT RESPIRATION AT COLD SEEPS IN THE NORTHERN GULF OF MEXICO

Clifton C. Nunnally, Texas A&M University, Galveston

Cold seeps in the Gulf of Mexico (GOM) have been intensely studied since they were first described by Paull et al. (1984) and Kennicutt et al. (1985), but little of the ecology has focused on associated sediment infauna. Structural and functional characteristics of benthic macrofaunal communities were studied to gain a better understanding of the broader influence of cold seeps in the northern Gulf of Mexico (NGOM). Density of macrofauna at seeps does not decrease with depth and proves to be greater than at most any other site surveyed. Diversity has shown to increase with water depth in the benthos (Hessler and Sanders 1967; Sanders 1968). Two seeps, Garden Banks 425 (GB 425) and Green Canyon 234 (GC 234) exhibit decreased diversity when compared to sites within a similar depth range. Sediment community oxygen consumption, determined using *in situ* benthic flux chambers, exhibited much higher rates of SCOC than from the continental shelf and slope away from seeps, suggesting a supplemented supply of carbon to the benthos.

H_{07}: Proximity to organic input causes bioenhancement.

Stations: Bush Hill

Cold seeps in the GOM provide an additional source of carbon to benthic fauna communities that are typified by high biomass and low diversity (Brooks et al. 1987, Agard et al. 1993). The larger megafauna that inhabit cold hydrocarbon seeps (tube worms, clams and mussels) utilize endosymbiotic bacteria to mediate methane and petroleum (Aharon 2000, Brooks 1987, Sassen et al. 1993). This symbiotic relationship thus only occurs near seeping fluids and limits the spatial extent of the vent community (Aharon 2000, Hecker 1985). Bioenhancement is not limited to the megafauna and bacteria; benthic infauna were also affected by the additional food found at cold seeps.

Sediment cores taken from GOM cold seeps were higher in abundance of macrofauna and exhibited lower diversity (Nunnally 2003). The mean abundance of macrofauna found at the cold seeps, Garden Banks 425 and Green Canyon 234, was 28,774 individuals per square meter (N/m^2). The mean abundance of DGoMB sites within similar depth ranges (200–1,000 meters) was significantly less at 8,883 individuals per square meter. The diversity of taxonomic groups at these seeps was also lower than similar DGoMB stations, a mean of ten groups at seeps compared to 21 groups. The mean Shannon-Weiner index of diversity (H’) for cold seeps was 1.355 and 1.790 for DGoMB stations, a significant difference. The only community attribute measured in which cold seeps and DGoMB stations did not differ significantly was Eveness, where cold seeps had a value of 0.635 and DGoMB stations has a value of 0.584.

The Bush Hill station was added during the field program to specifically test the hypothesis of organic input by cold seeps. It is located two kilometers from a large cold seep known as Bush Hill. The macrofauna community at the Bush Hill station showed no differences from the other sites tested. Bush Hill had mean values of 4,006 N/m^2, 19 taxa groups, an H' of 1.8880 and an Evenness of 0.6379. These values of macrofauna community structure did not vary significantly from the other DGoMB stations studied. The low abundance and high diversity of taxonomic groups indicated that at two kilometers distance from an active seep, the benthos shows no recognizable bioenhancement within the macrofauna.

Enhancement of the benthos by cold hydrocarbon seeps in the GOM appears to be a localized on the scale of five meters or less from the seepage a fluids. Cold seeps do concentrate a significantly large biomass reservoir in the midst of a low biomass habitat. Diversity at such seep sites is diminished due to the competition for resources. This competition for an excess of food in a food-limited environment assures that little of the labile carbon ever leaves the vicinity of a cold seep.

Descriptive statistics are shown in Table 2B.1.

Table 2B.1. Mean values of macrofauna abundance, taxa groups, H' (Shannon-Weiner), and evenness for DGoMB study stations (non-seep) and SETTI stations (seep).

	TYPE	Mean	Std. Deviation	N
Taxa Groups	*non-seep*	21	4.2	92
	seep	10	0.5	4
Abundance (N/m^2)	*non-seep*	8883	5616	92
	seep	28774	9738	4
H'	*non-seep*	1.80	.3054	92
	seep	1.35	.0354	4
Eveness	*non-seep*	.584	.0936	92
	seep	.635	.0071	4

References

Agard, J., J. Gobin, and R. Warwick. 1993. Analysis of marine macrobenthic community structure in relation to pollution, natural oil seepage and seasonal disturbance in a tropical environment (Trinidad, West Indies). Marine Ecology Progress Series 92:233–243.

Aharon, P. 2000. Microbial processes and products fueled by hydrocarbons in submarine seeps. In: Riding, R. and S. Awaramik, eds. Microbial Sediments. Berlin: Springer –Verlag. Pp. 270-281.

Brooks, J., M. Kennicutt, C. Fisher, S. Macko, K. Cole, J. Childress, R. Bidigare, and R. Vetter. 1987. Deep-sea hydrocarbon seep communities: Evidence for energy and nutritional carbon sources. Science 238:1138–1142.

Hecker, B. 1985. Fauna from a cold sulfur-seep in the Gulf of Mexico: Comparison with hydrothermal vent communities and evolutionary implications. Biological Society of Washington 6:465–473.

Hessler, R. and H. Sanders. 1967. Faunal diversity in the deep-sea. Deep-Sea Research 14:65–78.

Kennicutt II, M.C., J. Brooks, R. Bidigare, R. Fay, T. Wade, and T. McDonald. 1985. Vent-type taxa in a hydrocarbon seep region on the Louisiana slope. Nature 317:351–352.

Nunnally, C. 2003. Macrobenthic community structure and total sediment respiration at cold hydrocarbon seeps in the northwestern Gulf of Mexico. M.S. Thesis, Dept. of Oceanography, Texas A&M University. 44 pp.

Paull, C., B. Hecker, R. Commeau, R. Freeman-Lynde, C. Neumann, W. Corso, S. Golubic, J. Hook, E. Sikes, and J. Curray. 1984. Biological communities at the Florida Escarpment resemble hydrothermal vent type taxa. Science 226:965–967.

Sanders, H. 1968. Marine benthic diversity: A comparative study. The American Naturalist 102: 243–282.

Sassen, R., H. Roberts, P. Aharon, J. Larkin, E. Chin, and R. Carney. 1993. Chemosynthetic bacterial mats at cold hydrocarbon seeps, Gulf of Mexico continental slope. Organic Geochemistry 20:77–89.

Clifton C. Nunnally is a Graduate Teaching Assistant at Texas A&M University at Galveston and is currently pursuing a Ph.D. in biological oceanography. He obtained his B.S. in biology from Abilene Christian University in 1998 and M.S. in oceanography from Texas A&M University in 2003. His thesis title was "Macrobenthic Community Structure and Total Sediment Respiration at Cold Hydrocarbon Seeps in the Northern Gulf of Mexico."

NORTHERN GULF OF MEXICO CONTINENTAL SLOPE HABITAT AND BENTHIC ECOLOGY STUDY RESULTS PART II: MEXICAN COMPONENT

Elva Escobar-Briones,
Universidad Nacional Autónoma de México,
Instituto de Ciencias del Mar y Limnología

Introduction

The tropical oceanic environments have been recognized as geographic locations that have low primary productivity, have reduced phytoplankton biomass characterized by small sizes and display a low seasonality that leads to efficient energy transfer in the water column and hence a low export of biogenic carbon to the abyssal plain benthic communities. The expected distribution pattern of the abundance and biomass should display low variability at the large scale and a large variability at the local scale. The ability to recognize the factors that act as the main promoters of change in the natural environment can help to establish the baseline levels and distinguish man induced changes on the seafloor from those naturally occurring. It can help as well to understand how both interact and can magnify and act over the biological communities. The present study has as main objective to describe the density, biomass, and taxonomic richness patterns that characterize the benthic communities in the Gulf of Mexico exemplified by the studies carried out by UNAM in the abyssal southwestern Gulf of Mexico. The results from the study of specimens collected in the scavenger traps, of the assemblage composition of megafaunal, macrofaunal and meiofaunal components, and the composition and characterization of POC in the offshore habitats are addressed in this document.

Results from Scavenger Traps

Abundance and Growth

A total of 128 specimens of the amphipod *Eurythenes gryllus* (Crustacea: Amphipoda: Lyssianassidae) were collected at six sampling sites in the abyssal plain of the central Gulf of Mexico, 26 in June of 1997; 60 in June and 47 in August of 2002. The total length and the biomass in *E. gryllus* in the Gulf of Mexico was $W = 0.0232L^{2.87}$. The elemental composition of the amphipod's muscle tissue varied from 40.7 to 47.1% C and 11.9 to 15.5% N. The C/N ratio ranged from 3.02 to 3.47. Potential diet sources included carcasses and plant debris. The elemental composition in these materials ranged between 41.31 and 49.83%C and 12.97 to 17.21%N and 41.81 to 67.25%C and 1.25 to 2.58%N. The conceptual model proposed includes three boxes, a detritus/carcass box, the scavenger standing stock and the biomass of potential predators on the amphipods. Arrows arrive to the detritus/carcass box from the water column and connect with the scavenger standing stock box, the arrow that pulses the carcass availability will be interlinked with the water column productivity and pelagic food web length displayed in a separate water column section. The potential diet arrives from the pelagic system as recorded by their isotopic signature that ranges between $\delta^{13}C$ –24-64 to 21.98 o/oo. The C sources that contribute to the scavenger diet are a mixture of exported demersal carcasses and autochtonous materials in the sediment. These results suggest that the geographical variability of the abundance in the scavenger amphipods is a response to food availability and that the growth patterns and population structure are similar to those of other abyssal scavenger populations.

Mitochondrial 16S rRNA Sequences

The molecular characterization of the amphipods considered specimens of three locations on the abyssal plain of the Gulf of Mexico and tested isolation from the Atlantic populations in the Gulf of Mexico. The sequences determined of the mitochondrial 16S rRNA gene showed small differences when compared with the corresponding sequences from other *Eurythenes* amphipods of the Atlantic Ocean (3.6 to 3.9%) and Pacific Ocean (4.0 to 4.1%). Larger differences were recorded (4.2 to 9.5%) in sequences for specimens from shallower sites (<500m), e.g. in seamounts from the Pacific Ocean. The largest differences (18%) were observed when the sequence was compared with that of *Eurythenes sp*. from the Tongue of the Ocean, whose sequences suggest a different species. The differences with the external genus *Abyssorchomene* were 25%, suggesting that the abyssal scavenger amphipods of the *E. gryllus* species in the Gulf of Mexico still maintain a continuous genetic flow with the north Atlantic amphipod populations. Their predominant swimming behavior allows the populations to move horizontally along the abyssal water masses in the region. This study concluded that in spite of the morphological differences found a similar genetic composition to the populations from the Northern Atlantic exists, suggesting connectivity through the deeper passages between the Western Atlantic and the Caribbean and the latter through the Yucatan Channel with the deep Gulf of Mexico.

Assemblage Composition of Megafaunal Components

The Megafaunal Database

A total of 1,583 specimens were captured in the database using the BIÓTICA 4.1 software. The Biótica information System (Biótica ©) is curatorial, nomenclatural, geographical, bibliographical, and ecological in nature. Biótica © was developed by the Mexican conservation agency (CONABIO) in a modular form to assist, reliably and simply, in the capture and updating of the data. This software helps link the information from the databases to information managed for diverse applications (images, sounds, web pages, spreadsheets, genetic databases). The version 4.1 was used to create the database for the deep-sea megafauna and was divided into nine modules (Database, Directory, Nomenclatural, Curatorial, Ecology, Georeferenciation, Bibliography, Tools and Help). The catalogs included in Biótica © are the names of biological groups up to genus or species, the names of authors of taxons, the information of the collections and institutions, the states and municipalities according to INEGI for Mexico, the priority hydrological, marine and land regions of Mexico, according to CONABIO, the catalogues that can be related to the sample and are personalized by the user such as types of vegetation, forms of nutrition, forms of life, habits, etc., the catalogue of population parameters that can be personalized by the user, and the nomenclatural types.

The records and information of 92 families, 133 genera, 147 identified species and two infraspecies of megafaunal components can be consulted through the dynamic reports that can be constructed by the user-defined format according to the needs of researches, students and managers. The database includes 55 records with size information of the specimens and form.

The input for a each species includes the full scientific name, the taxonomic category, relations among taxons (synonymy, etc.) and common name, in addition to the physical and environmental factors and references. All megafaunal specimens have been physically located in six national collections (Table 2B.2) and each specimen is identified by a reference code provided by the collection curators. A total of 352 maps were produced and included in the database to display the occurrence of each species in the different regions of the southwest Gulf of Mexico.

Table 2B.2. Number of species/ records of deep sea specimens from the Gulf of Mexico, including DGoMB-JSSD cruises, deposited in the Mexican National Collections and included in CONABIO database.

Collection Code	Collection Name	Institution Code	Institution Name	No. of species/ records	No. of specimens
CNCR	Colección Nacional de Crustáceos (Crustacea)	IBUNAM	Departamento de Zoología, Instituto de Biología, UNAM	160	561
CNMO	Colección Nacional de Moluscos (Mollusks)	IBUNAM	Departamento de Zoología, Instituto de Biología, UNAM	29	72
CNP	Colección Nacional de Peces (Fish)	IBUNAM	Departamento de Zoología, Instituto de Biología, UNAM	73	260
ICML	Colección Nacional de Equinodermos Mexicanos "Dra. María Elena Caso Muñoz" (Echinoderms)	ICML	Instituto de Ciencias del Mar y Limnología, UNAM, Unidad Distrito Federal	45	486
ICML	Colección Nacional del Phylum Porifera "Gerardo Green" (Sponges)	ICML	Instituto de Ciencias del Mar y Limnología, UNAM, Unidad Distrito Federal	17	40
ICML-CMP	Colección de Mar Profundo (other invertebrates)	ICML	Instituto de Ciencias del Mar y Limnología, UNAM, Unidad Distrito Federal	28	164

The connection of the system to the database is made every time information is included; the configuration of fields allows introduction of new records to the data. The software Biótica © can be used both in a single-user environment as well as in a multi-user environment (network).

Distribution Patterns of Species Richness, Abundance, and Diversity of the Fish

The distribution pattern, abundance, diversity, and species richness of fishes that belong both to the classes Actinopteriyii and Chondrichthyes collected in trawls in the central and southwest Gulf of Mexico are reported here. The results obtained showed increasing diversity values at mid depth on the continental slope and decreased to the abyssal plain. This pattern has been previously recorded for the northern Gulf of Mexico (NGOM) and North Atlantic (Merrett and Haedrich 1997). The largest diversity and evenness values (H'= 2.90 to3.55; J'= 0.58 to 0.66) were recorded in stations from the upper slope (548m depth) in contrast to the lowest values (H' = 0.43 to 2.27; J'= 0.12 to 0.41) recorded in the abyssal plain (3725m depth). These larger values are related to the high species richness (98 species).

The three geographic regions show different values of diversity; the highest values occur in the Campeche Bank (H' = 3.64; J'= 0.56) with a total of 101 species.

Distribution Patterns of Species Richness, Abundance, and Diversity of Mollusks

The species composition and richness and abundance of mollusks of the classes Bivalvia, Gastropoda and Scaphopoda were analyzed in samples from cruises (SIGSBEE IV in 2001, SIGSBEE V in 2002, SIGSBEE VI in 2003 and DGoMB-JSSD in 2002) in the southwest Gulf of Mexico. The samples were collected on the continental shelf, the upper continental slope, and the abyssal plain and a total of 56 species were identified in 486 specimens. The largest abundance was recorded in class Gastropoda (43 specimens) grouped in 19 specimens on the continental shelf, 29 in the upper continental slope. Gastropods were absent in the abyssal plain samples and were replaced by eight species from class Bivalvia. The largest diversity values were recorded in the upper continental slope (H' = 2.52) correlated to the increasing number of species. The diversity values of the abyssal plain samples responded to the large evenness values (J' = 0.84). The lowest diversity and evenness values occurred in the continental shelf (H' = 1.99; J' = 0.68). A canonical correspondence analysis (Figure 2B.1) allowed us to recognize that 16% of the distribution patterns of the mollusk species are attributed to depth while 20.5% of the species have an affinity to specific geographic regions (Bank of Campeche, Mexican Ridges, and the Sigsbee abyssal plain). Only 6.9% of the species are related to both factors, depth and geographic region as described by the environmental factors from the bottom water mass and the sediment.

Variability of Species Composition, Richness, and Abundance in the Macrocrustacean

The first deep-sea specimens collected in the abyssal plain of the Gulf of Mexico and deposited in Mexican formal collections belong to the joint collaborative effort between UNAM and Texas A&M. Previous work on deep-sea crustaceans carried out by Mexican researchers date back to the mid 1980s and are related to the abundance and composition (Soto et al. 1999); the biology of the isopod *Bathynomus giganteus* (Barradas-Ortiz et al. 2003); the description of new species and records by Vázquez-Bader and Gracia (1994) and Gómez-Ponce and Gracia (2003); and the shrimp fishery and incidental discards with records of *Chaceon quinquidens* by Navarrete del Proo and Gracia (1996), Arreguín et al. (1997), and Gómez-Ponce and Gracia (2003). All studies include records solely from the continental shelf and slope, none from deeper habitats.

The objective of the study was to describe the species composition of the macrocrustacean assemblage collected by bottom-trawl gear during the DGoMB-JSSD cruises in the Sigsbee abyssal plain and compare with ongoing sampling in the outer continental shelf and upper slope at cruises SIGSBEE.5, 6 and 7 in the western and southwestern sectors of Gulf of Mexico.

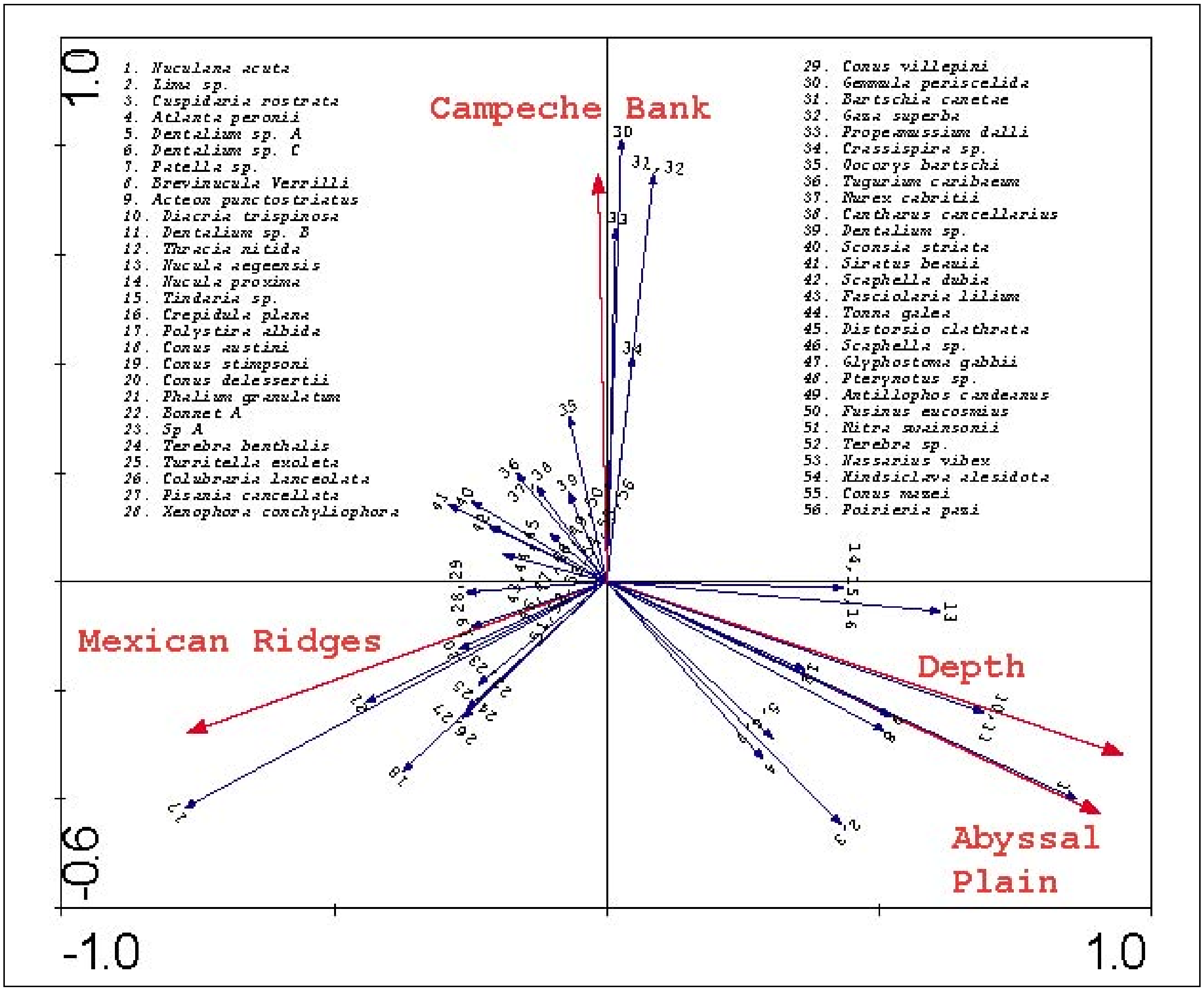


Figure 2B.1. Biplot of the canonical correspondence analysis with the distribution patterns of the mollusk species by depth and geographic region.

At all cruises the samples were collected with bottom-trawling gear (OTSB otter trawl) with the following specification: 12m length, 9m width, 2.5 inches mesh size, cod-end. Each trawl lasted 25 minutes of bottom contact, at speeds that varied from 1.3 to 3.5 knots, covering distances from 1.85 to 7.49 km. The samples collected on the outer continental shelf and upper slope in the Mexican Ridges and Campeche Bank regions were collected onboard UNAM's R/V *Justo Sierra* in cruises SIGSBEE.5 (6 stations, June 2002), SIGSBEE.6 (5 stations, July 2003) and SIGSBEE.7 (5 stations, June 2004). The samples collected in the abyssal plain (5 stations, August 2002) were collected in the DGoMB-JSSD cruise onboard the R/V *Gyre*. The specimens were fixed in ethanol, identified to species level where possible, counted and deposited in the National Crustacean Collection, and the records inserted in the Biotica information system with an identification catalog number. The ecological indexes were determined using the Biodiversity–Pro.5 software, the similarity between the different sampling sites based in the species composition. Its presence and absence was determined by the Bray Curtis similarity index using average single linkage to classify the assemblage and display the results as a dendrogram.

A total of 107 species of macrocrustacea was identified belonging to the orders Lophogastrida, Isopoda and Decapoda. The species were group into 39 families. The largest number of species and abundance occurred in the upper continental slope (61 species; 793 specimens). The shrimps of the infraorder Caridea were highly diversified with 12 species and 142 specimens occurring mostly in the slope and abyssal plain with 13 species and 19 specimens. The largest species richness was recorded in the upper slope. The region with the largest number of species was the Campeche Bank (CB) with 48 species. Several species co-occur in two of the three regions, none occur in all three geographical regions or depth zones.

The abundance followed a similar trend with depth as the species richness; the largest abundance was recorded in the upper continental slope. The region with the largest abundance was the CB where the group with the largest abundance was attributed to the superfamily Penaeoidea. Densities in the abyssal plain were low, with 1,002 ind km^{-2}, in comparison with the shallower sites and contributed to the largest diversity values (H= 3.27). The most frequent species were *Nephropsis rosea* and *Bathyplax thypla* followed by the scavenger isopod *Bathynomus giganteus*.

The H´ values were as low as 0.42 (Sta. E1 SIGSBEE.5) the trend increasing with depth characterized the area of study. The species had a low abundance and this even pattern contributed to the large evenness values recorded with increasing depth where the largest values (J´= 0.822) occurred in the abyssal plain in contrast to those that occur in the slope (J´= 0.487) and the outer continental shelf (J´= 0.325). The evenness is the factor that defines the pattern observed in the diversity in the crustacean assemblage.

Assemblage Composition of Macrofaunal Components

The Abyssal Macrofauna

The objective of the macrofaunal sampling was to establish the variability in the large scale of stations located in the abyssal plain in the central Gulf of Mexico. The information obtained provides a list of the taxonomic groups and abundances found in each of five replicates at each sampling station during SIGSBEE.6 cruise at which additionally environmental factors were measured such as dissolved oxygen, temperature, pH, salinity of the bottom water mass, chlorophyll in a six-water column strata, depth, sediment grain size, elemental organic carbon and nitrogen, and pigment concentration in the superficial sediment. Samples were collected for this purpose from every latitude and longitude within a grid at depths below 3000m in the central Gulf of Mexico (Figure 2B.2), the maximum depth in the basin being 3,850m.

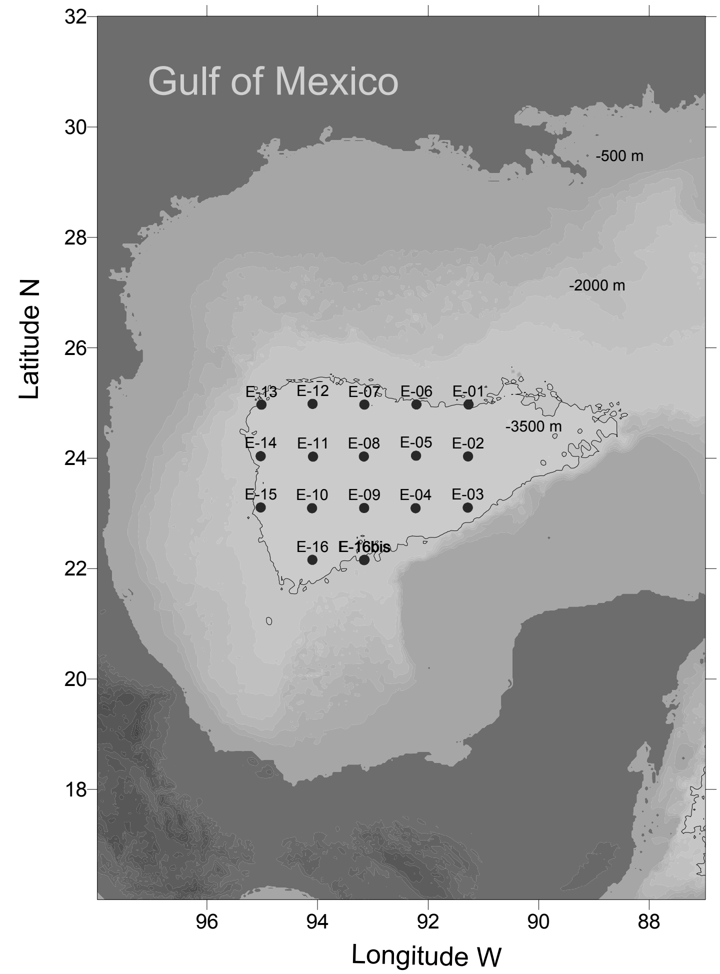


Figure 2B.2. The area of study and the sampling stations located at 3,000m or more in the Sigsbee abyssal plain.

The average values for both the taxonomic richness and abundance of the stations (n=5) sorted show a large variability both within station as well between station. The larger values can be found on the northwest section of the grid in contrast with the stations located in the southeast corner of the grid. A parallel sampling program provided insight on the effect of canyons on the macrobenthic community composition and density.

The Campeche Canyon. The macrofaunal samples collected from the Campeche canyon in the southwestern Gulf of Mexico were sampled along the main axis of the canyon to answer the question whether canyons are different and are affected by different processes. A total of 20 taxa were grouped in ten phyla, 12 classes, one subclass, two suborders and six orders. The polychaete and nematode worms were dominant components in the canyon in contrast with the shallower habitats where polychaete worms were abundant. A diminishing trend with increasing depth and distance from the coast was recorded. The hydroids contributed significantly. The biomass values near the head of the canyon reached values of 27.44 mg $C.m^{-2}$. The distribution patterns of both the density and biomass values are defined in the Campeche canyon by the content of organic carbon and nitrogen in sediment in addition to depth and distance from the coast.

The Amphipod Diversity

As part of the macrofauna the amphipod Crustacea from the Gulf of Mexico have been reported for diverse habitats recording a total of 101 benthic species. The results of this study increased this value to 275 species that were grouped into 146 genera, 53 families and 4 suborders. The order Gammaridea contributed 73% (200 species), the Hyperiidea contributed 21% of the total number of species in the basin and species from the families Caprellidea and Ingolfiellidea contributed jointly a 6%. Most of the gammarid amphipods that occur in the Gulf of Mexico are, together with the caprellid and ingolfiellid amphipods benthic dwellers (79%). Of the gammaridean families the most diversified, were the Corophiidae-Ischyroceridae (24 species), Ampeliscidae (13 species), Lysianassidae (12 species), Colomastigidae (11 species) and Melitidae (8 species). In contrast, the suborder Caprellidea was poorly diversified and each recorded amphipod family in the Gulf of Mexico was represented by one, or at most two species. The largest number of records occurred in shallower habitats (75% of the records). In contrast, the outer continental shelf, the continental margin and upper slope displayed a low number of records (5%). Species from these depth zones remain gaps in our knowledge of amphipods in the region. Results from samples collected in the Sigsbee and DGoMB cruises recognized the families Ampeliscidae, Phoxocephalidae, Corophiidae and Caprellidae as dominant components of the amphipod assemblage off Tamaulipas and in the Campeche Bay, which host differences in species richness and with density that are significant (Kruskal-Wallis $H = 18.19$, $p = 0.0027$; $H = 30.26$, $p = 0.0001$). Gammarid amphipods of the genus *Pseudharpinia* sp, *Podocerus* sp and *Stenothoe* sp. and the Caprellidae *Caprella* sp, *Caprella danilevskii* and *Caprella equilibra* are distributed in a depth range of 2,001 to 3,700 m. The species *Deutella* sp, *Hemiaegina minuta*, *Paracaprella pusilla*, *Byblis* sp, *Hourstonius tortugae*, *Apocorophium simile*, *Monocorophium insidiosum*, *Ericthonius* sp, *Concarnes* sp, *Concarnes concavus*, *Halice* sp, *Syrrhoe* sp y *Protohaustorius* sp., *Caprella penantis*, *Apocorophium acutum*, *Ericthonius brasiliensis*, *Stenothoe gallensis* and *Monocorophium acherusicum* occur in the abyssal plain. Other species have a wider distribution range.

The northern and eastern sectors of the Gulf of Mexico have been studied intensively and have accounted for 73% of the total number of amphipod records, in contrast to the 27% of records corresponding to the southern and western sectors. Probably the southeastern and southwestern sectors are the least explored with fewer records. The identification of the different families of amphipods that inhabit the deep-sea central region was composed by a large number of yet undescribed genera and species and will contribute to the amphipod diversity in the Gulf of Mexico in the near future.

Assemblage Composition of Meiofaunal Components

The deep-sea benthic community in tropical latitudes responds to the oligotrophic condition of the primary production in the water column with lower abundances and smaller body sizes that approximate the sediment grain size, making the process of sorting specimens difficult (Duplisea and Dgras 1999). The meiofauna constitutes food supply for higher trophic levels (Longhurst and Pauly 1987) and limited in motility responds to short-term effects caused by sea-floor disturbances (deBovée et al. 1990, Coull and Chandler 1992). Studies of the flux of materials and energy in benthic communities have recognized the importance of the sediment fauna in the use of detritus transported to the seafloor (Rowe et al. 1990). The meiofaunal biomass in the NGOM is larger than that of the macrofauna (Pequegnat et al. 1990). This pattern is the reverse of that occurring in higher latitudes (Gray 1981). We compared two sorting methods, the manual and centrifuge density gradient, for meiofaunal samples of sediments from the abyssal plain (3,720 to 3,830 m) to define whether sorting methods had an effect on the distribution patterns of deep-sea meiofaunal samples. Community structure factors (taxonomic composition, abundance, and biomass) allowed us to recognize differences between the two sorting methods. The manual sorting method produced more taxonomic groups and larger abundance and biomass values than the centrifuge sorting method. The biomass values recorded with the manual sorting method were larger in abyssal plain samples 26.75 $mgC.m^{-2}$, than the samples sorted with the centrifuge method, which contained on average 1.85 $mgC.m^{-2}$. The results obtained from the two sorting methods suggest that distribution patterns of deep-sea meiofaunal samples can be a result of the sorting method chosen.

Composition and Characterization of POC

The geochemical characterization of the particulate organic carbon (POC) was determined through the analysis of relative abundances of stable isotopic carbon ratios ($\delta^{13}C_{VPDB}$). Scanning electron microscope images (SEM) helped to interpret and confirm the composition and some of the resulting signatures. The sampling strategy included the offshore waters of Tamaulipas with stations located on the abyssal plain and on the continental slope and the Campeche canyon with samples from six depth levels in the water column in the mixed layer, the top of thermocline, the deep chlorophyll maximum, the bottom of thermocline, below the thermocline, and the bottom water mass. The $\delta^{13}C_{VPDB}$ POC values in the three depth zones ranged from -25.39 to -20.95‰ and were identified within the range of values of marine phytoplankton (-18.00 to -30.5‰). The POC in the Campeche canyon showed significant differences (p=0.01) with the offshore stations. Differences were recorded among levels in the water column with ^{13}C enriched with increasing depth. Major differences occurred between the maximum chlorophyll level and the bottom water mass. The differences in isotopic composition were related to the changing phytoplankton assemblages both from one location to another, among regions and with depth. The depleted values recorded with increasing depth were attributed to a larger proportion of suspended refractory material and to the residence time of the organic particles in the water column.

The SEM images confirmed that coccolithophore species characterized the offshore samples. Diatoms of genera *Bacteriastrum* and *Chaetoceros* dominated the samples collected on the continental slope. Diatoms of genus *Nitzchia* and *Thalassiosira*, as well as some species of dinoflagellates of genus *Oxytoxum, Dinophysis* and *Ceratium* characterized the POC samples from the Campeche canyon. The size of most particles ranged between 5 and 50µm.

Acknowledgments

Grants: Deep Gulf of Mexico Benthos Study(DGoMBS) – Joint US/Mexico Studies of the Sigsbee Deep (JSSD) MMS Contract 1435-01-99-CT-30991 TAMU; PAPIIT IN224503; IN211200; CONABIO BE013, SEP-CONACyT 2002 Code 40158; CONACyT G-27777B and CONACYT-G35442-T

Colleagues and student collaborators to the study of specimens collected in the scavenger traps: E. Nájera Hillman, P. Acuña, F. Alvarez; the assemblage composition of megafaunal: A.B. Jiménez Brito, H. Espinoza, L. Alvarez, E. Naranjo; A. Gaytán, J.L. Villalobos; the macrofaunal components: I.P. Plaza, E.L. Estrada, I. Winfield; the meiofaunal components: C. Díaz, P. Legendre; composition and characterization of POC in the offshore habitats: M. González. Institutional support ICML and the crew of UNAM's R/V *Justo Sierra*.

References

Arreguín, F., L. Schultz-Ruiz, A. Gracia, J. Sánchez-Chávez, and T. Alarcón-Fuentes. 1997. Las Pesquerías de Camarón de alta mar: explotación, dinámica y evaluación. In: Flores-Hernández, D., P. Sánchez-Gil, J.C. Seijo, and F. Arreguín-Sánchez, eds. Análisis y Diagnóstico de los Recursos Pesqueros Críticos del Golfo de México. EPOMEX Serie científica 7:145–172.

Barradas-Ortiz, C., P. Briones-Fourzán, and E. Lozano-Álvarez. 2003. Seasonal reproduction and feeding ecology of giant isopods, *Bathynomus giganteus*, from the continental slope of the Yucatán Península. Deep Sea Research I. 50:495–513.

Coull B.C. and T. Chandler. 1992. Pollution and meiofauna: Field, laboratory and mesocosm studies. Oceanography Marine Biology Annual Review 30:191–271.

de Bovée, F., D.G. Laurence, and J. Soyer. 1990. Quantitative distribution of deep-sea meiobenthos in the northwestern Mediterranean Gulf of Lions. Continental Shelf Research 10:1123–1145.

Duplisea, D.E. and A. Drgas. 1999. Sensitivity of a benthic, metazoa biomass size spectrm to differences in sediment granulometry. Marine Ecology Progressive Series 177:73–81.

Gómez-Ponce, M.A. and A. Gracia. 2003. Distribution and abundance of larvae and adults of *Solenocera* (Decapoda, Solenoceridae) in the southwestern Gulf of Mexico. Crustaceana 76(6):681–698.

Gray, J.S. 1981. The ecology of marine sediments. Cambridge Studies in Modern Biology 2. Cambridge University Press.

Longhurst, A.R. and D. Pauly. 1987. Ecology of tropical oceans. In: Biological Communities of Tropical Oceans. Academic Press, Inc. USA. Pp. 62–104.

Merrett, N.R. and R.L. Haedrich. 1997. Deep-sea Demersal Fish and Fisheries. New York: Chapman and Hall.

Navarrete del Proo, A. and A. Gracia. 1996. La pesquería de camarón en Alta Mar. Golfo de México y Caribe Mexicano. In: Instituto Nacional de la Pesca, SEMARNAP. Pesquerías relevantes de México, XXX Aniversario del INP. México, Tomo 1:29–63.

Pequegnat, W.E., B.J. Gallaway, and L.H. Pequegnat. 1990. Aspects of the ecology of the deep-water fauna of the Gulf of Mexico. American Zoology 30:45–64.

Rowe, G.T., M. Sibuet, J. Deming, J. Tietjen, and A. Khripounoff. 1990. Organic carbon turnover time in deep-sea benthos. Progressive Oceanography 24:141–160

Soto, L.A., S. Manickchand-Hileman, E. Flores, and S. Licea. 1999. Processes that promote decapod diversity and abundance on the upper continental slope of the SW Gulf of Mexico. In: Von Vaupel Klein, J.C. and F.R. Shram, eds. The Biodiversity Crisis and Crustacea. Rotterdam: A.A. Balkema. Pp. 385–400.

Vázquez-Bader, A. and A. Gracia. 1994. Macroinvertebrados bénticos de la plataforma continental del suroeste del Golfo de México. Instituto de Biología UNAM. Publicación especial 12:1–113.

Elva G. Escobar-Briones has been a Professor with the Institute of Marine Sciences and Limnology (ICML) of the National Autonomous University of Mexico (UNAM) since 1993. Dr. Escobar-Briones received an undergraduate degree in biology from the Metropolitan Autonomous University (UAM) in 1981, completed a master's degree in fisheries and ocean sciences at UNAM in 1984 and defended a doctoral dissertation in biological oceanography in 1987, also from UNAM, on the structure and function of benthic communities in the southwestern Gulf of Mexico. Dr. Escobar-Briones has been recognized on the study of the biology of benthic communities with some 55 peer-reviewed articles and over 50 reports and articles on related topics co-authored with both Mexican students and colleagues and international collaborators. Dr. Escobar-Briones has been the Head of the Academic Unit in Coastal and Ocean Systems since 1999 and is active teaching graduate and undergraduate levels at UNAM and coordinates the research program in deep-sea benthos of the southwestern Gulf of Mexico at ICML UNAM, program that is financed by UNAM's program PAPIIT and the Mexican funding agency CONACyT. This project has been carried out in collaboration with Texas A&M University.

DEEP GULF OF MEXICO BENTHOS: SUMMARY AND SYNTHESIS

Gilbert T. Rowe, Texas A&M University

The DGoMB project can claim several firsts. Maps can be constructed of individual species distributions, recurrent groups (zones), species diversity for the entire northern Gulf of Mexico, (NGOM) from the outer margin of the continental shelf out across the abyssal plain, from Mexico to Florida. There is no other area of the deep ocean where such maps can be drawn. Features of community structure can now be correlated with dynamic processes, such as sediment community oxygen consumption. Nine different recurrent groups can be identified in the macrofauna, based on percent species shared between sites. Four of these are related to depth but overlap in depth with several other "zones " that occur on the Florida slope or a canyon. The most dynamic sites are the upper Mississippi Trough, located just off the Mississippi Delta, and the De Soto Canyon, located below a region of high surface water productivity in the northeast Gulf of Mexico. The lowest rates were found on the abyssal plain, as expected. Diversities in all groups reached a maximum on the upper continental slope at depths of 1 to 2 km. The species diversity was lower, in general, in the Mississippi Trough than at equivalent depths on the slope, because, we suggest, of an increased input of organic matter and unpredictable nature of sedimentary processes. Species richness overall, however, was higher in the Trough, we assume, due to its greater physical complexity. Standing stocks of invertebrates and fishes and SCOC all declined by about two orders of magnitude from the continental shelf to the abyssal plain, similar to other ocean margins. The decline of bacteria density with depth was less pronounced and not statistically significant. If this pattern is real, it suggests that the relative role of bacteria in the processing of organic matter is increased with depth, perhaps due to a decline in the quality of organic matter as depth and distance from shore increase. The standing stock information has been coupled with the SCOC data to construct foodweb carbon budgets for two end-member sites: the head of the Mississippi Trough and the abyssal plain. This allows a comparison of how organic matter is cycled among the living components at the high and low extremes in standing stocks and carbon cycling. The foodweb budgets, in terms of stocks and fluxes between stocks at steady state, have been put into a dynamic simulation that illustrates how each stock responds to variations in carbon input from the water column. The model allows experiments to be performed that portray how carbon is cycled at radically different levels of input. Recommendations for future work include 1) model validation experiments, 2) studies of deep corals, and 3) studies of the steep Florida, Sigsbee and Campeche escarpments.

Dr. Gilbert T. Rowe completed his B.S. in zoology and M.S. in oceanography at Texas A&M and his Ph.D. in zoology at Duke. That was followed by 11 years as a research scientist at WHOI and eight years as a research scientist at the Brookhaven National Lab on Long Island. In 1987 he returned to Texas A&M to become Head of the Oceanography Department. He transferred to the Galveston campus in 2002 as Head of Marine Biology. Since 1999 he has been the Program Manager of MMS Deep Gulf of Mexico Benthos project (DGoMB), now nearing completion.

SESSION 2C

SOCIOECONOMIC STUDIES

Chair: **Asha Luthra, Minerals Management Service**

Co-Chair: **Kristen Strellec, Minerals Management Service**

SOCIOECONOMIC RESEARCH ISSUES FOR THE GULF OF MEXICO OCS REGION

Harry Luton, Minerals Management Service

Background

The Gulf of Mexico Region Workshop on Socioeconomic Research Issues, held in New Orleans in February 2004, is a sequel to a workshop held a decade before, but its story begins earlier still. The nationwide OCS leasing program was established in the late 1970s, and the social impact assessment (SIA) methods federal agencies were applying at that time to energy developments stimulated little consideration of the socioeconomic consequences of the Gulf's offshore industry.

These SIA methods were developed for new projects in rural areas and assumed that projects would increase labor demand, causing in-migration which would lead to other social problems. In the Gulf, the industry was large and long-lived and projects were without noticeable demographic effects. Thus, the industry had few socioeconomic consequences that were relevant to the assessment methods that were being applied.

The trauma of the 1980s oil price collapse convinced people in the Gulf of the relevance of the industry's socioeconomic effects. MMS began holding ITM workshops and funding several small studies addressing the bust. In 1992, the National Research Council reviewed the MMS Studies Program and noted that the lack of socioeconomic research in the Gulf was unfortunate since the Gulf's history made it a "natural laboratory" for studying OCS socioeconomic effects. That same year, the Gulf Region, building on the natural laboratory idea, held its first socioeconomic agenda-setting workshop from which a robust set of socioeconomic studies emerged.

Workshop Objectives

Over the next decade, some 35 studies that flowed from this workshop were completed, and 20 are still ongoing. The 2004 Workshop on Socioeconomic Research Issues was held in response to this wide-ranging research. Studies were at a juncture; the vision of the last decade was concluding and MMS wanted advice on how to build on it. MMS provided participants with descriptions of past studies, a critique of SIA based on labor demand and demographic change, a history of offshore oil development, and a list of challenges facing Gulf socioeconomic assessment including:

1. The lack of an unaffected baseline uncomplicated by regional and national trends;
2. A situation where the main effect of OCS leasing is to maintain the status quo;
3. An enormous affected area (coastal counties of all Gulf states);
4. A multiplicity of industries that find, extract, process, and market petroleum; and,
5. A problem with locating local effects prior to local development plans.

Workshop Organization and Breakout Groups

This workshop included a half-day introductory plenary session, one and one-half day breakout groups, and a half-day plenary session to share results. MMS identified some people for each breakout to ensure a mix of local, academic, and industry expertise. Groups brainstormed, categorized and identified topics, and developed study proposals. Breakout groups included:

1. Industry trends and dynamics, chaired by Kristen Strellec and Diana Olien,
2. Community-level impacts, chaired by Asha Luthra and Barbara Wallace, and
3. Cultural impacts, chaired by Kimberley Cook and Dianne Austin.

Industry Trends Breakout

Generally, SIA focuses on the construction industry as the cause of other effects. By contrast, GOMR studies emphasize characteristics of the petroleum industry itself. This focus began with economic modeling and attempts to regionalize effects in the Gulf. A study of sour gas in Alabama, particularly, highlighted the importance of variability in industry demand, by showing significant differences between it and the Gulf offshore industry average.

The industry session developed many study ideas that exhibited two basic themes: First, the group emphasized the need to develop a good picture of each major industry sector, its size, distribution, labor force, internal dynamics, etc. Related to this was the priority need for better data on all sectors and the suggested development of a set of variables to monitor the industry. The second theme was the need to understand industry activity in the Gulf of Mexico (GOM) within a larger global context.

Community Impacts Breakout

The Family Study greatly influenced Gulf SIA by using industry sectors in the analysis of social impacts. Since sectors make different demands on labor, host communities, and the environment, they also have different socioeconomic consequences. Because sector dynamics differ, each sector's effects are changing in different ways. While past SIA used demography to drive change, the Gulf stresses differential effects of industry dynamics.

Two themes run through the group's study ideas that will likely inform future research. First, while SIA looks at rural landscapes, oil support activities occur in urban areas. Houston is a successful oil boomtown, New Orleans a declining one. The group emphasized the analysis of urban effects and a city's effects on surrounding rural areas. Second, the group suggested typologizing adaptations to the oil industry—the types of relationships between government, communities and/or individuals and industry, and the possible outcomes inherent in these relationships.

Cultural Impacts Breakout

SIA seldom addresses culture and, when it does, it usually focuses on attitudes (e.g., toward risks or the environment). Cultural questions interest agency staff but are generally too off-topic or ideological (e.g., "Cajun oil-field yard art" or "oil wealth as a symbol of corruption"). We addressed cultural impacts to see how the topic might be developed.

Participants emphasized current difficulties with defining culture groups, noting that, while individuals may still self-identify as Cajuns or Yugoslavians, the localized social and economic distinctions that existed 50 years ago have largely disappeared. They noted that some recently immigrated groups (e.g., Vietnamese) are national rather than cultural groups. Participants suggested alternatives to culture groups including populations of large geographic areas (e.g., "southwest Louisiana" or "Cajun country") and membership in occupational, religious, and other types of groups. Participants explored the use of geographical areas for sociocultural analysis, suggesting the importance of formal, data-intensive methods in defining areas. Participants also explored the use of industry sectors in the analysis of cultural effects. Since the move from shallow to deepwater affects various industry sectors differently, this move affects various workforces and host communities differently. All breakout sessions emphasized land loss issues.

Conclusions

The workshop confirmed the importance of industry sectors as a driver of effects and as an organizing principle of analysis. Various methods and significant studies effort will be employed to describe, measure, and project the industry. All three breakout groups emphasized the differential social and economic consequences of various parts of the oil industry. Thus, some MMS research will focus on particular sectors or on communities dominated by them. However, many industry consequences have diffuse and/or aggregate causes unrelated to a particular sector. Therefore, a standard list of SIA effects (e.g., labor demand, demography, fiscal, infrastructure, etc.) will also direct future plans.

All three breakout groups raised complex issues regarding geographic variation in industry activities and their OCS effects. This problem, too, will be addressed as a component of the industry sector and SIA foci, and through case studies of particular places. Participants suggested that this geographic variation might be defined in terms of variable boundaries or epicenters. Participants noted that similar difficulties inherent in identifying OCS effects in urban areas also needed to be addressed.

While the workshop breakouts distinguished between the sociological and anthropological, immediate studies planning will not. Instead, cultural effects will be addressed by expanding goals and methodologies of particular studies. For example, a standard SIA study of education would include fiscal and demographic impacts. Cultural effects might be addressed including questions of educational content (e.g., school-to-work or job training programs).

The workshop addressed all the challenges we identified except one: the problem of linking sale effects to industry effects remains a basic challenge to SIA of the OCS leasing program.

Harry Luton was born in Michigan. He received his undergraduate degree from the University of Michigan, a Masters from the University of Pennsylvania, and his doctorate from the University of Michigan. Since 1982, he has worked in MMS's environmental assessment branch, first in Alaska, then Headquarters and, for the last nine years, the Gulf of Mexico OCS Region.

DEMOGRAPHIC CONSEQUENCES OF THE OFFSHORE PETROLEUM INDUSTRY

John Petterson, Impact Assessment Inc.
Roger M. Olien, University of Texas-Permian Basin
F. Carson Mencken, Baylor University

Project Goal

Develop a systematic understanding of the GOMR petroleum industry's demographic effects, the distribution of these effects, their causes, their changing trends, and the differences between onshore and offshore activities.

Project Objectives

1. To provide a coherent description of such changes in demographic effects through time and the reasons behind these changes through the analysis of a coherent set of research questions developed from the study objectives;
2. To provide a general understanding of the industry's demographic effects and causes of those effects over time. As the industry and society have evolved, these effects have changed. For example, while early onshore hydrocarbon discoveries often led to localized "boomtowns," the recent large discoveries in deepwater have not;
3. To provide a general understanding of variation (state and sub-state) in those effects and the causes of this variation. For example, the demographic consequences of the 1980s oil price collapse were different for Texas than for Louisiana. MMS seeks a coherent description of the reasons behind such variation; and
4. To provide a differentiated and well documented data system that would allow a continuous monitoring of demographic changes in the future.

Research Team

- John S. Petterson, Ph.D., Anthropologist, PI
- Carson Mencken, Ph.D., Sociologist, Co-PI
- Roger Olien, Ph.D., Oil Historian; Co-PI
- Michael Irvin, Ph.D., Demographer, Co-PI
- Charles Tolbert, Ph.D., Sociologist, Co-PI

Quality Review Board

- Joachim Singelmann, Ph.D., Sociologist
- Norval D. Glenn, Ph.D., Historical Demographer
- Richard Forstall, Ph.D., Demographer
- Joseph Pratt, Ph.D., Historian

Research Objectives

Objective 1

Describe and analyze the petroleum industry's demographic consequences. Sections I, II, and IV in the demographic analysis meet this criteria. In Section I, we describe total and contextual population trends for each decade between 1900 and 2000. In Sections II and IV we disaggregate population growth trends between different levels of geography, from macro (national) to micro (county/parish). In Section IV we propose a more robust attempt (e.g. regression models) to link micro-level demographic changes since 1950 to direct and indirect changes in the petroleum industry. In Section IV we also propose to analyze the journey-to-work patterns in Texas and Louisiana coastal areas prior to, during, and following the growth and decline periods in the petroleum industry.

Objective 2

Describe and analyze differences between offshore and onshore industries. Section III, the spatial clustering analysis of county/parish unique population effects, will be useful in this objective. Working from the assumption that onshore and offshore activities did not occur in the same time or place (particularly in Texas), the spatial analysis will help to differentiate the unique effects of these two processes by locating the clusters of petroleum-related demographic changes in both time and space.

Objective 3

We describe and analyze the short- and long-term demographic effects of the industry's volatility in Texas and Louisiana. The first three sections of the proposed demographic analysis address some component of this objective. Section I describes demographic change over time, Section II helps to identify the factors and conditions that affect the magnitude of change by examining population dynamics within each decade (1950–2000) and by locating the impact of local unique characteristics on decade-specific demographic change. Section III is a formal test of spatial distribution and clustering of these effects in Texas and Louisiana. The off-shore petroleum industry is not randomly distributed throughout these two states. This analysis will better locate time and place effects.

Objective 4

Describe and analyze the consequences that the industry has had on the demographic characteristics of the Louisiana and Texas workforce. The shift-share analysis in Section II will provide valuable insight into the effects of population change related to the petroleum industry on the composition of the states and communities. It allows us to document growth and/or decline in sex/age/race/ethnicity specific populations. The analysis of journey-to-work patterns for 1960–2000 will demonstrate how changes in the petroleum industry affected county/parish level commuter patterns.

Objective 5

Describe and analyze current demographic effects. The analysis in Sections I and II for the 1990s will provide an understanding of how the changes in the petroleum industry after the bust of the

1980s affected the demographic structure of petroleum industry communities as reflected in the 2000 Census.

Objective 6

Provide a framework that can be used for ongoing monitoring of demographic change. The shift-share is an analytical tool that can both describe what has happened in the past and make future projections about demographic composition and change. The multilevel modeling can be used as a guide to the relative importance of different spatial levels (nation, state, CZ, county/parish, place).

Research Design

Multi-Level Demographic Analysis Plan

We divide the demographic analysis into four sections. Each section provides a unique analysis to describe and understand population change in size and composition from 1900 to 2000. Each section progressively moves toward providing a better link between the petroleum industry and population dynamics at different levels of geography.

Levels of Geography Defined

We perform demographic analysis at multiple levels of geography. Local and regional population change is not independent of state, regional, and national trends. Any endeavor to understand demographic change at the local level must take the macro-level processes into account. The definitions of national and state are clear. We incorporate other levels of analysis: regional, which we define as the five Gulf of Mexico (GOM) states; sub-state, which we define as Commuter Zones (CZs) based on commute to work patterns, and local, which we define as county/parish. We will use the place as a level of geography and explore trends at this level in limited context. We prefer using CZs as a sub-state geographical unit because they represent a more substantively meaningful sub-division. They are based on journey-to-work patterns.

The first analysis is a descriptive account of demographic change for multiple levels of geography. A descriptive analysis provides a base-line understanding of when and where population change took place, and how local patterns in the geographic areas of interest correlate with and deviate from national, state, and regional trends. We perform the descriptive analysis for all decades between 1900 and 2000. However, there are more detailed data available, particularly regarding age, race, ethnicity and sex breakdowns, from 1950 forward.

I. Description of Population Change 1900–2000

   In this section we describe general population trends for each decade between 1900 and 2000 at multiple levels of geography:

   a) the national level,

   b) the regional level (defined as all GOM states),

c) the state level (Louisiana, Texas, and Florida for comparison),

d) the commuter zone level (sub-state level), and

e) the county/parish level (local level—includes all counties/parishes in Louisiana, Texas, and Florida for comparison).

At each level, we provide

a) The population change for each decade between 1900 and 2000

b) A detailed description for age/sex/race/ethnicity composition and change for each decade between 1950 and 2000

There are approximately 400 places in the Texas and Louisiana coastal counties/parishes along the GOM. We provide demographic descriptive statistics for those coastal places for years in which data are available.

We are particularly interested in the GOM coastal economy counties/ parishes. These are defined by whether or not the county/parish is in a labor market area that borders the GOM. We expect that these counties/parishes are embedded within economies that are the most off-shore petroleum industry-intensive. To better understand the effects of the off-shore petroleum industry, we compare population change in this cluster of counties/parishes to other counties/parishes within these states. In Texas and Louisiana these counties and parishes include:

a) Texas counties: Aransas, Austin, Brazoria, Brooks, Calhoun, Cameron, Chambers, Duval, Fort Bend, Galveston, Hardin, Harris, Jackson, Jasper, Jefferson, Jim Wells, Kenedy, Kleberg, Liberty, Madagorda, Montgomery, Newton, Nueces, Orange, Polk, Refugio, San Jacinto, San Patrico, Tyler, Victoria, Waller, Washington, Willacy.

b) Louisiana parishes: Allen, Assumption, Beauregard, Calcasieu, Cameron, Iberia, Jefferson, Jefferson Davis, Lafourche, Orleans, Plaquemines, St. Bernard, St. Charles, St. James, St. John the Baptist, St. Mary, St. Tammany, Terrebonne, Vermilion, Vernon.

II. Demographic Shift-Share Analysis of Population Growth

In this section we plan to use demographic shift-share analysis to make multiple comparisons of population growth rates (by age, race, ethnicity, sex). Demographic changes at the local level are not independent of transformations at higher levels of analysis. Since 1920, western economies have undergone industrial transformations from agriculture to manufacturing and subsequently from manufacturing to services

(Singelmann 1978). Each of these transformations has had an impact on key demographic variables (family size, residency patterns/mobility, fertility, etc.). These national trends are independent of changes in the petroleum industry during the same time period. Therefore, to understand the effects of the petroleum industry on sub-national levels (i.e. state, county), we must separate local demographic changes from those that occur as a result of national shifts in the primary mode of production (agriculture to manufacturing to services). Demographic shift-share analysis provides a multi-level analysis and attributes demographic change in a local area to three sources 1) local population change associated with overall population growth or decline in the region (usually defined as a state, group of states or nation), 2) local population change associated with the interaction between regional growth and the specific demographic composition in a local area (the share of demographic change associated with the local mix of age/race/sex/ethnicity groups), and 3) patterns of demographic change not shared with the larger state or region, that are attributed to the unique conditions of each locality (shift)—the 'unique effect' of each locality. The advantage of this method is that it specifies multi-level/micro-macro links between local population growth and larger demographic patterns. It will also provide to us, for each decade between 1950 and 2000, an assessment of the population growth (by age, race, ethnicity, sex) that a) is due to the national growth rate, b) is due to the demographic composition of a local area associated with national patterns of growth and decline, c) that which is due to the unique conditions of the local area, such as the industry structure of the local area.

a) National vs. State Level Shift-Share Analysis: This analysis will differentiate state population growth (by age, race, ethnicity, sex) into state-level growth that is due to national growth rates, that which is due to the demographic composition of the state, and that which is due to the unique conditions of the state. This analysis will be performed for each decade between 1950 and 2000 and include the 48 contiguous states. One benefit of this analysis to the overall project is that the shift component will identify the 'unique effects' for the states in question (Louisiana, Texas) or the population growth in these states during each decade that is attributable to the unique conditions of the state. This analysis will be performed for each decade between 1950 and 2000. If the petroleum industry had a unique effect on the population dynamics of Louisiana and Texas at the state level, then these effects should manifest during some of the decades under consideration (most likely the 1970s and 1980s).

b) County/Parish vs. National Level Shift-Share Analysis: This analysis will differentiate county/parish population growth (by age, race, ethnicity, sex) into county/parish level growth that is due to national growth rates, that which is due to the demographic composition of the county/parish, and that which is due to the unique conditions of the counties/parishes. One benefit of this analysis to the overall project is that the shift component will identify the 'unique effects' for the counties/parishes in the study area. We expect that the petroleum industry counties/parishes have different demographic change patterns in different time periods than other counties/parishes. This analysis will be performed for each decade between 1950 and 2000. The magnitude and character of these unique effects is expected to vary across time and space in ways associated with activity levels of the petroleum industry.

c) Commuter Zones vs. State Level Shift-Share Analysis: This analysis will differentiate sub-state (commuter zones) regional population change (by age, race, ethnicity, sex) into population change that is due to state growth rates, that which is due to the demographic composition of the commuter zone, and that which is due to the unique conditions of the commuter zone. This analysis will be performed for each decade between 1950 and 2000 and will identify regional effects within Texas and Louisiana.

d) County/Parish vs. State Level Shift-Share Analysis: This analysis will differentiate county population growth in Texas (by age, race, ethnicity, sex) and parish population growth in Louisiana into county/parish level growth that is due to state growth rates, that is due to the demographic composition of the county/parish, and that is due to the unique conditions of the counties/parishes. This analysis will be performed for each decade between 1950 and 2000. The shift component can be of further use to understand the spatial distribution of population change (in size and composition) within Texas and Louisiana.

e) Place Effects: We also propose to decompose for those places in the coastal counties/parishes in Texas and Louisiana demographic change between 1970 and 2000 at the place level. We intend to analyze the shift-component 'unique effect' using hierarchical linear modeling (see below).

f) Petroleum Industry Effects: Based on previous research we have a good sense of the time and place where the components of the petroleum industry were located, including those industries directly related to oil and gas exploration/production, and those industries indirectly connected to oil and gas production (e.g. fabrication of oil field equipment in the Houston, Lafayette, and Beaumont regions, petroleum refining in Lake Charles region). At the county/parish level, we descriptively and statistically compare the 'unique effect' total population and age/race/ethnicity/sex-specific population growth. The population change due to the 'unique effect' of local counties/parishes relates directly to issues of migration. A negative shift value indicates potential county out-migration, while a positive shift value indicates possible in-migration. Furthermore, a positive shift effect for age/race/ethnicity/sex-specific population growth indicates positive in-migration of a particular social group. The in-migration is attributed to the unique characteristics of the county/parish.

At the county, CZ, and state level we will calculate, map, and describe the 'unique effect' of total population change, as well as age/race/ethnic/sex-specific change for each decade between 1950 and 2000. This will allow us examine the effect of local unique characteristics on age/race/ethnicity/sex-specific population change. This will allow us to explore the role of the petroleum industry on contextual (i.e. age/race/sex-specific) population dynamics, with important implications for population migration and retention. Furthermore, by knowing the time line of the petroleum industry growth and decline periods, we can use the shift-share analysis comparison of state vs. national population growth to explore the impact of the petroleum industry (and the effects of petroleum industry counties/parishes) on state population dynamics.

III. County/Parish Level Spatial Clustering Analysis

The shift component of the shift-share analysis will generate a 'unique effect' of population growth (by age, race, ethnicity, sex) for each of the decades between 1950 and 2000. This unique effect represents the population change in the county/parish that is due to the unique characteristics of that county/parish. We propose to use a local indicator of spatial autocorrelation (LISA) statistics (particularly Moran's I and Geary's C) to examine (and map) spatial clustering in the county/parish 'unique effects' for each of the decades between 1950 and 2000. The off-shore petroleum industry is not randomly distributed throughout these two states. If the boom-and-bust pattern in the petroleum industry had an effect on the population composition of the counties/parishes, then we should see time-specific spatial clustering of county/parish population change that is attributable to the unique characteristics of the county/parish. Furthermore, working from the assumption that onshore and offshore activities did not occur in the same time or place, the spatial analysis will help to differentiate the unique effects of these two processes.

IV. Regression Analysis with the Unique Shift Effect

While the shift-share analysis provides data to perform interesting descriptive analysis, we also employ pooled time-series cross-sectional regression models within each decade between 1950 and 2000 to better understand the role of the petroleum industry in explaining the county/parish 'unique effect' population growth in Louisiana and Texas counties/parishes. We treat the county/parish population growth 'unique effect' as a dependent variable in a regression model, while including inter-census industry employment growth measures in mining, manufacturing, construction, services, and unique institutional structures of each area (associations, third places, churches) as predictors, along with standard socioeconomic control measures (previous decade population change, age composition, education measures, income measures). The pooled time-series cross-sectional approach permits us to decompose change into temporal and spatial components.

This analysis will tell us, over time, which industry sectors (if any) are most responsible for the county/parish 'unique effect' total population growth, and age, race, ethnic, sex-specific population growth. Furthermore, in order to address the issue of what conditions demographic impacts have led to the kinds of problems hypothesized by customary social impact assessment, we perform further regression analysis. In the second set of regression models we utilize the 'unique effect' population growth during each decade as an independent variable to predict standard county/parish level measures of socioeconomic conditions (poverty rates, median and per capita income levels, female-headed households, and crime rates) at the end of each decade.

We also propose in our Section IV regression analysis to employ the new class of multilevel statistical models known as hierarchical linear modeling (Raudenbush and Bryk 2002). The lowest level (level one) of the model would be specified as attributes of places nested within counties and parishes. The second level would be characteristics of the counties themselves. Like other regression approaches, these models permit us to assess the effects of level-one (places) on the unique demographic effects derived in the shift-share analysis. Unlike other approaches, the hierarchical models also permit us to make sound statistical assessments of the effects of second-level (and other higher-order) effects. Moreover, this multilevel modeling approach allows for cross-level interaction effects which reveal how the attributes of counties affect place-level relationships. We might find at the first level, for example, that places with large mining labor force components exhibit more out-migration than other places (a positive relationship between mining employment and net out-migration). However, it is conceivable that a second-level measure of civic climate (e.g., per capita churches or per capita associations) has an attenuating cross-level effect on the place-level relationship between employment and migration. Simply put, counties with more civic institutions show less of a relationship between mining employment and out-migration. In statistical terms, the cross-level coefficient reduces the positive first-level coefficient. Since multilevel time-series estimators are not well developed, we propose to develop cross-sectional models for years in which place-level data are available.

a) Coastal Commuter Zone Analysis: We propose to analyze changes in the coastal Commuter Zones between 1960 and 2000. We will compare the journey-to-work patterns in the 1980 CZs to the 1970 and 1960 journey-to-work patterns in the Texas and Louisiana coastal CZs. This analysis will provide an assessment of how the growth period in the petroleum industry affected the journey-to-work patterns in these coastal areas. We will also compare the 1980 journey-to-work patterns to the 1990 and 2000 journey-to-work patterns in the coastal CZs. This analysis will inform how the downturn in the petroleum industry affected the journey-to-work patterns in coastal areas along the GOM.

b) Data Source: The data for this project come from two primary sources. Demographic and socioeconomic condition, institutional data are from the decennial census for each decade between 1900 and 2000. From 1950 to 2000, detail age/race/ethnicity/sex data are available at the county/parish level. Prior to 1950, more general measures of population and composition are available. Industry employment data are from the BEA Regional Economic Information Systems.

References

Raudenbush, S.W. and A.S. Bryk. 2002. Hierarchical Linear Models: Applications and Data Analysis Methods. Second Edition. Newbury Park, CA: Sage.

Singelmann, J. 1978. From Agriculture to Services: The Transformation of Industrial Employment. Beverly Hills CA: Sage Publications.

John Petterson has served as the PI on about 20 prior MMS socioeconomic studies—in the GOMR, in Alaska, and the Atlantic. He has also led the impact assessments of the proposed high-level nuclear waste repositories at Hanford, Washington, and then later, at Yucca Mountain, Nevada. He was also the PI for the state of Alaska socioeconomic impact assessment of the Exxon Valdez oil spill, as well as studies of the Shetlands Islands, La Coruña, Spain, and Genoa, Italy oil spills, as well as the sinking of the P-36 deepwater oil platform off the coast of Brazil. He is also conducting the follow-up study of the Exxon Valdez oil spill for the Alaska MMS office.

Roger M. Olien earned his Ph.D. in history and political science from Brown University in 1973 and is regarded among the leading U.S. historians with respect to the history and evolution of oil development in the U.S. He is currently the J. Conrad Dunagan Professor of Regional and Business History at the University of Texas-Permian Basin. The present study focuses on questions that have been central to his professional career. Dr. Olien has written several of the seminal historical works on oil development, including Oil Booms: Social Change in Five Texas Towns (1982), Wildcatters: Texas Independent Oil Men (1986), Life in the Oil Fields (1986), Easy Money: Oil Men and Investors During the Jazz Age (1990), Oil and Ideology: The Cultural Creation of the American Petroleum Industry (2000), Oil in Texas: The Gusher Age, 1895-1945 (2002), and Black Gold: The Petroleum Industry in Texas (2003), and Oil in Texas: The Mature Age, 1945 to the Present (2004).

F. Carson Mencken earned his Ph.D. in sociology at Louisiana State University and is an associate professor of sociology and anthropology at Baylor University. Dr. Mencken specializes in the sociology of regional processes in primary sector economies—that is, economies with significant concentrations of agriculture and/or mining (coal and oil/natural gas). In addition to advancing the conceptual issues of regional processes, Dr. Mencken has extensive experience and expertise performing spatial analysis (over time) on county and labor market area data. Dr. Mencken has published 11 articles on this topic in peer-reviewed journals in the last five years, and recently completed the analysis of labor market analyses for coastal LMAs in the five GOM states on the MMS projects entitled Effects on Local Human Communities Of OCS Mineral Extraction in Frontier Areas and Deepwater Program: Benefits and Burdens of OCS Activities on Selected Communities and Public Institutions.

ENVIRONMENTAL JUSTICE IN SOUTHEAST LOUISIANA: A COMPARATIVE PERSPECTIVE

Scott A. Hemmerling and Craig E. Colten, Louisiana State University

This project employs a geographic perspective to compare the relative degree of environmental justice impacts found in different sectors of the vertically integrated oil extraction and processing industry. In particular, it builds upon methods recently developed to investigate environmental justice concerns associated with outer continental shelf (OCS) oil and gas extraction (Hemmerling and Colten 2003). Given its offshore location, OCS presents few potential impacts at the extraction site; points of potential impacts lie, instead, along transportation corridors (surface or pipeline) or proximate to service-related industries. Further reducing impacts is the low population density in the Louisiana coastal zone, where wetlands inhibit urbanization and many workers and their families live far from the actual embarkation sites. Moreover, minority and low-income families are not heavily concentrated near nodes of activity associated with the extraction industry. Populations living nearby face a range of potential impacts—explosions, accidental releases on site, transportation related releases, or fires.

Our methodology allows us to compare findings across these different sectors and develop generalizations about levels of relative risk to low-income and minority populations. We incorporate toxicity values into the new hazardscape models and are thus able to develop a relative comparison between the different types of facilities. When we use a cumulative hazardscape weighted by toxicity, we are able to compare all facilities in our entire study area on a single sliding scale. For federal agencies, such as MMS, such a methodology will allow researchers to more effectively gauge, classify, and possibly ameliorate, instances of environmental injustice.

The current research explores the environmental justice implications in three individual case study parishes, each focusing on one particular aspect of the petrochemical industry. The intent is to compare the environmental impacts of extensive onshore and offshore oil and gas development in three Louisiana coastal parishes and to examine any socioeconomic inequality patterns in their distributions. The chosen parishes all represent different stages of historical petroleum development in Louisiana. Lafourche Parish, for example, is a coastal Louisiana parish that serves as the primary land-based supply center for the majority of the Outer Continental Shelf (OCS) oil activity occurring in the Gulf of Mexico (GOM). Because of its role in OCS activity, Lafourche Parish is uniquely impacted by the industry.

Jefferson Parish is a highly urbanized parish with over 455,000 residents. Its total minority population of 152,636 (33.5%) closely mirrors the state proportion (35%). Studies have shown a greater concentration of environmental inequity in urban locations, and it is essential to consider one such parish in coastal Louisiana for comparative purposes. Jefferson Parish's population living in poverty in 2001 (18.9%) was nearly the same as the state's percentage (18.2). Thus, Jefferson Parish has a much larger population that might be susceptible to exposure to impacts from the highly dispersed activity of oil extraction than Lafourche does. Moreover, the distribution of minorities and low-income residents in Jefferson is much higher than in Lafourche. With a total of 236 active wells in 2002, there is considerable on-shore activity in Jefferson Parish.

Like the other two parishes, St. Bernard is a coastal parish. Among its 67,000 residents, 14.5% represent a minority population and 13.2% live in poverty according to the census bureau's 2001 estimates. With two refining operations, employing over 500 workers, St. Bernard provides a good site for examining refining activity. In the case of an oil refinery, the activity is highly concentrated and the potential for exposure spatially compressed, but the degree of hazard is high due to the risk of explosion or toxic release. The minority and impoverished population for St. Bernard is similar to that of Lafourche and will enable a reasonable cross-sector comparison. The susceptible populations are highly concentrated in the areas along the natural levee, so risk is ever present in the relatively small territory occupied by human settlements.

In all, we see many differing patterns of environmental justice in our case study parishes, from the impact of shipyards and gas plants on the Houma Indian population to the locating of petroleum bulk storage in the heavily urban areas of Jefferson Parish's westbank. We have created a number of localized hazard models, geared specifically to each sector of the oil industry. But, what do these models tell us about the relative hazardousness of each sector of the oil industry? How OCS-related hazards, for example, compare to onshore and refinery-related hazards?

As would be expected, the refining district in St. Bernard Parish dominates the overall hazardscape. Nonetheless, when we explore the risk surface statistically, localized high points around Marrero, the Barataria Fields, and the gas plants in rural St. Bernard Parish still stand out, despite low relative values. Though the localized high-hazard areas in Lafourche are still significant, they are statistically much less than those in the other two regions.

Of the three sectors of the oil industry explored in this study, we found that OCS-related hazards are the most dispersed, and thus the least overtly hazardous. This is because the actual extraction sites are located far offshore, away from the parish itself. As a result, industries have fewer constraints on where to locate their facilities. While Port Fourchon, for example, is clearly the most convenient place for industry to located, relative to proximity to the offshore wells, it is also economically feasible for facilities to be located further upstream. Thus, we see shipyards located all along Bayou Lafourche, from Fourchon to Golden Meadow, up through Larose and Lockport. Petroleum bulk storage facilities are located in many communities across south Lafourche, with a larger facility in north Lafourche. In the case of some industries, such as platform and pipeline fabrication, facilities are even located in adjacent parishes, reducing the overall hazardousness of the region.

The other two sectors are much more constrained economically, geographically, and politically. In Jefferson Parish, the onshore-related infrastructure must necessarily be placed in the immediate vicinity of the oil fields. Thus we see a much greater clustering of facilities and hazardousness than in other locations. Petroleum refining requires large-scale facilities and a large labor force as well as transportation infrastructure and easy access to large amounts of water for reactive and cooling purposes. In coastal Louisiana, the potential siting locations for large refineries are extremely limited, not to mention the political incentives and disincentives involved in siting such a potentially hazardous facility.

It is the flexibility in locating new facilities that results in OCS-related infrastructure being lower on the potential hazardousness scale than both the onshore extraction and petroleum refining industries. The more dispersed the industries, the less the cumulative potential toxicity of the region. Despite these findings, it is important that agencies with oversight, such as MMS, remain vigilant and assure that no one area comes to dominate the hazardscape of the region, especially if that area is home to a disproportionately large minority or low-income populations.

References

Hemmerling, S.A. and C.E. Colten. 2003. Environmental Justice Considerations in Lafourche Parish, Louisiana. Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA OCS Study MMS 2003-038. 354 pp.

Craig E. Colten is Carl O. Sauer Professor of Geography at Louisiana State University. After completing his Ph.D. at Syracuse University in 1984, he spent a dozen years working for the Illinois Department of Natural Resources and in private-sector consulting investigating the long-term implications of hazardous wastes. In 2000, he joined LSU and has overseen research for the Minerals Management Service, U.S. Geological Survey, and the National Park Service. He recently published *An Unnatural Metropolis: Wresting New Orleans from Nature* (LSU Press, 2005).

Scott A. Hemmerling is a doctoral candidate in the Department of Geography and Anthropology at Louisiana State University. He received his B.S. in environmental studies from the State University of New York at Buffalo and his M.S. in applied urban anthropology in the College of Urban and Public Affairs at the University of New Orleans.

EFFECTS OF OIL AND NATURAL GAS PRICES AND PRODUCTION ON LOUISIANA EMPLOYMENT LEVELS: RESULTS FROM A VECTOR AUTO REGRESSION (VAR) ANALYSIS

Omowumi Iledare[2] and Williams O. Olatubi,
Louisiana State University, Center for Energy Studies

Abstract

This study finds that changes in oil and gas prices affect Louisiana employment in a statistical sense. The results indicate that negative shocks to natural gas prices, *ceteris paribus*, have a more distressing impact on Louisiana gross employment trend in the short run than equivalent shocks to oil prices in terms of elasticity estimates. The opposite is the case in the long run. However, in quantitative employment terms, the impact of an 18% positive shock to oil price (about $4.15 per Bbl) is estimated as 10,000 jobs in the short run or 26,600 jobs if the shock persists for a long period. Whereas, the quantitative impact of a 20% shock to natural gas price ($1.45 per Mcf) is estimated as 28,500 jobs in the short run or 45,600 jobs in the long run, *ceteris paribus*.

Introduction

Most boom-and-bust economic cycles in oil and natural gas rich states such as Louisiana, Texas, and Oklahoma have been linked to developments in the oil and natural gas markets, which invariably center on changes in oil and natural gas prices. As Brown and Yucel (1995) reported, such price movements in the oil and natural gas markets in the 1970s and 1980s led many to suggest that energy is “the tail that wags the dog.” Increasing energy prices may spur higher activities in the oil and gas sectors as well as sectors such as banking as investors demand more funds, which in turn leads to higher levels of demand as employment rises. On the other hand, a price that is too high may hinder the refinery and petrochemical sectors, for example, as cost of inputs rises substantially, bringing a potential loss of jobs (Scott 2002). The focus of this study on Louisiana is motivated by the role of the state in meeting U.S. oil and gas consumption needs. In this study, a time-series econometric model is developed to examine the impact of changes in crude oil prices on both the oil industries and relevant Louisiana macroeconomic aggregates. The analysis is restricted to the interactions among oil and gas prices, petroleum production from Louisiana offshore waters, and Louisiana state employment.

Theoretical Model Specification

A VAR modeling methodology is adopted in this study. In its generalized formulation, every dependent variable is modeled as a function of its immediate past values and the past values of other dependent variables in the system. Independent or exogenous variables may also be included in the system equations as explanatory variables. The general mathematical formulation of a VAR system/model usually takes the form:[3]

---

[2]Synopsis of the paper presented at the 23rd MMS Information Transfer Meeting (ITM), Kenner LA, 11–13 January 2005. The views expressed herein are those of the authors. They are not to be taken as the official view of the LSU Center for Energy Studies.

[3] See Iledare & Olatubi (2004) for a brief overview of the VAR procedure.

$$y_t = A_1 y_{t-1} + ... + A_p y_{t-p} + Bx_t + \varepsilon_t \qquad (1)$$

Where y_t is a vector of k dependent variables, x_t is a vector of m independent variables, $A_1 ... Ap$ and B are matrices of coefficients to be estimated. The term, ε_t, is a vector of innovations that may be contemporaneously correlated with each other but is not correlated with their immediate past values and other variables on the right-hand-side.

Descriptive Data Analysis

Table 2C.1 presents summary statistics of the data analyzed in the paper. The table shows that oil production appears to exhibit far less variability than gas production, and expectedly, real natural gas prices appear to show more variability than real oil prices over this period. The table also shows that gross employment levels in Louisiana display some relative stability over the study period. Nearly all the measures we examined for the E&P sector are significantly dispersed around the mean value. Again, using coefficient of variation (COV) for this comparison, we found that E&P employment level is highly dispersed with a COV of 27%. The COV for natural gas production is also high, just as the COV for natural gas prices reveal the existence of some degree of instability over the period.

Table 2C.1. Summary Statistics of Quarterly Macroeconomic and E&P Data, 1977–2000.

	Unit	Mean	Maximum	Minimum	Std. Dev.	COV
Macroeconomic Statistics						
Unemployment Rate	*%*	8.02	13.38	4.22	2.35	0.29
Total Employment	*Thousand*	1,741	1,969	1,379	133	0.08
E&P Data Statistics						
E&P Sector Employment	*Thousand*	62	100	43	17	0.27
Wellhead Gas Price	*1982$/Mcf*	3.25	8.56	1.17	1.44	0.44
Crude Oil Price	*1982$/Bbl*	31.42	42.05	21.55	4.15	0.13
State Offshore Liquid Production	*MMBbl*	6.054	8.696	3.285	1.138	0.19
State Offshore Gas Production	*Bcf*	64.301	129.114	32.300	28.824	0.45
*State Offshore Pet. Production**	*MMBOE*	16.771	30.078	9.521	5.730	0.34

* MMBbl = 6 Bcf, COV= the ratio of the standard deviation to the mean of a random variable.

The VAR Model Results

The variance decomposition results reported in Table 2C.2 were derived from estimating the system of equations in (1) for employment in combination with each resource type—oil or gas—one at a time and by using the variance decomposition procedure. The largest source of variation in employment is changes in oil price. Real oil price accounts for as much as 44% of the observed variation in employment over time. State offshore oil production accounts for no more than 2.78% over the same period. The variation in employment that was explained by autonomous oil production ranges from 0.70–2.78. In addition, 23.8–34.1% of the observed variation in employment is explained by changes in natural gas prices. However, no more than 10.6% of the observed variation in Louisiana jobs is explained by changes in autonomous natural gas production. Further statistical analyses of the results show that the effects of gas prices on employment are statistically significant over the period of estimation.

Table 2C.2. Decomposition of the variance of Louisiana employment.

Equations/Variables	Period (Years)					
	1	2	4	6	8	10
State Offshore Oil System Equations Employment						
Oil Production	0.0088	0.0070	0.0167	0.0239	0.0266	0.0278
Real Oil Price	0.2800	0.4390	0.4245	0.4183	0.4161	0.4150
State Offshore Gas System Equations Employment						
Gas Production	0.0064	0.0694	0.9500	0.1054	0.1052	0.1058
Real Gas Price	0.2381	0.3357	0.3317	0.3283	0.3283	0.3281

Economic Interpretations

Table 2C.3 shows elasticity estimates derived from estimating the system equations in (1) terms of the short- and long-run response of Louisiana employment to relative changes in oil and gas prices. As expected, long-run elasticity is generally larger than short-run because in the long run economic agents have more opportunities to adjust to changes than is possible in the short run (See column 3, Table 2C.3). The response of employment to changes in oil and gas prices is analogous and significant statistically. The corresponding quantity estimates resulting from a percentage change in prices are reported in Table 2C.4. These are restrictive or conditional equivalence of a 20 and 18% oil and gas price shocks using the 2002 oil and gas price data, respectively. According to the results reported, the number of jobs provided as a result of an oil price shock could reach 26,600. The effects of a natural gas price shock on the employment level follows a similar pattern of oil price effects. The only difference is the magnitude, which appears to indicate that, on the long-term basis, economic activities in the state benefit slightly more from a shock in oil price than from a similar shock to gas prices. The opposite appears to hold in the periods closer to the shock. For example, the difference would have been as much as 25% more jobs created as a result of oil price shock than under the gas price shock scenario in the long run.

Table 2C.3. Price elasticity of employment *.

	Short Run (SR)	**Long Run** (LR)	**Relative Size** (SR/LR)
State Offshore Oil System Equation Employment	0.04	0.10	2.5
State Offshore Gas System Equation Employment	0.05	0.08	1.6

Note: * Denote non-significance at 95%.

Table 2C.4. Quantitative estimates of the effects of maximum price 'shock' in 2002.

	Short Run (SR)	**Long Run** (LR)
State Offshore Oil System Equations Employment (Million)	0.0106	0.0266
State Offshore Gas System Equations Employment (Million)	0.0285	0.0456

Summary and Conclusions

This study examines the interrelationships between petroleum price changes and Louisiana employment conditional on the dynamics of oil and natural gas production in the state offshore waters. The empirical results show that as prices increase (assumed positive shock), more oil and natural gas are produced. To produce more oil and gas, more workers are hired. Because such price shocks often occur in boom periods in the oil and natural gas industry, competition in the labor market forces up the wage rate. In the long run, this shock may lead to a decline or even recession in the U.S. economy, which implies a reduced demand for goods and services, including oil and gas. The result of such a development is the reverse of the previous scenario—job losses.

In an overall sense, the study finds that, at least in the case of Louisiana, oil and gas prices are still important in short-term fluctuations in employment. In addition, the results indicate that while there are some differences between oil and gas prices, the pattern of effects on the economy is similar in many respects. Not withstanding this finding, it is noted that inferences from the dynamic paths of adjustment support an assertion of gas prices having a more destabilizing effect on the economy in the long run than oil prices. It is also obvious from this paper that only a sustained, relatively high positive movement in petroleum prices can have a long-lasting impact on Louisiana employment. Finally, an additional significance from the paper is that, in the absence of price movements, autonomous changes in production in state offshore waters no longer play a prominent role in Louisiana employment growth.

References

Brown, S.P.A. and M.K. Yucel. 1995. Energy prices and state economic performance. Economic Review, Federal Reserve Bank of Dallas (Second Quarter):13–23.

Iledare, O.O. and W. Olatubi. 2004. The impact of changes in crude oil prices and offshore oil production on the economic performance of U.S. coastal gulf states. The Energy Journal 25:97–113.

Scott, L. 2002. The 'Energy' Sector: Still a Giant Economic Engine for the Louisiana Economy. Louisiana Mid-Continent Oil and Gas Association, Baton Rouge, LA.

Wumi Iledare is an Associate Professor of petroleum economics and policy research at Louisiana State University's Center for Energy Studies, Baton Rouge, Louisiana. He is also an adjunct Professor of petroleum economics at Craft and Hawkins Department of Petroleum Engineering and an Associate Graduate Faculty member of the Department of Environmental Studies. Wumi holds a Ph.D. in mineral economics from West Virginia University. He is an active member of the Society of Petroleum Engineers International (SPEI) and a former council member and secretary-treasurer of the United States Association for Energy Economics (USAEE). Wumi currently serves as the editor of the *USAEE Dialogue*, a quarterly newsletter published by the USAEE.

Williams O. Olatubi is an expert in modeling regional economic impacts, particularly those associated with natural resource extraction, energy, and agriculture. Dr. Olatubi served as a post-doctoral research fellow and research associate at the Center for Energy Studies, Louisiana State University for three years. Dr. Olatubi is currently an Assistant Vice President with the Custom Modeling and Risk Analytics Group of Washington Mutual. Dr. Olatubi received his B.S. and M.Sc. in agricultural economics from the University of Ibadan, Nigeria, two M.S. degrees (environmental studies, economics), and a Ph.D. (resource economics) from the Louisiana State University.

ACCOUNTING FOR CHANGE IN THE GULF OF MEXICO ECONOMY: DEVELOPING A COMPARATIVE CONTEXT FOR REGIONAL ECONOMIC ANALYSIS AND HISTORY

Allan Pulsipher, Center for Energy Studies, Louisiana State University

Objectives

The objectives of the part of the project reported here are to

1. Facilitate analysis of cumulative socioeconomic effects that are relevant to OCS activities in the Gulf of Mexico (GOM) by providing an accessible context to disentangle the economic and demographic factors associated with economic change in the region;
2. Help compare regional with national economic experience as well as compare regional forecasts with the economic history of the region.

Method

The rate of growth in per capita personal income was allocated among the principal factors contributing to it, for each of 19 coastal parishes and 45 non-coastal parishes using the growth accounting framework developed and used by analysts at the Bureau of Economic Analysis of the U.S. Department of Commerce.[1] The period studied was from 1969 to 2000. It was divided into four cyclical phases based on behavior of personal income in Louisiana. The four periods roughly coincide with 1) the period of relatively rapid growth in petroleum exploration, production and energy price escalation that occurred from 1969 to 1980; 2) the period during which world oil prices collapsed, 1981 to 1985; 3) the recovery during 1986–1990, and 4) the period of slow but sustained growth from 1991 to 2000. The contribution of each component during each of these four periods was computed for each parish using the formula:

$$\frac{TPI}{N} = \frac{H}{J} \times \frac{E}{H} \times \frac{J}{N} \times \frac{FI}{E} \times \frac{TPI}{FI} \qquad (1)$$

where TPI is total personal income, N is total population, H is hypothetical earnings, J is the number of jobs, E is earnings, and FI is factor income (property income plus earnings). In terms of percent change, we have the following formula:

$$\begin{aligned} \textit{percent}\ \text{change}\ (\frac{TPI}{N}) &= \textit{percent}\ \text{change}\ (\frac{H}{J}) + \text{percent change}\ (\frac{E}{H}) \\ &+ \textit{percent}\ \text{change}\ (\frac{J}{N}) + \text{percent change}(\frac{FI}{E}) \\ &+ \text{percent change}(\frac{TPI}{FI}) \end{aligned} \qquad (2)$$

[1] For a review of this literature see Daniel Garnick. Accounting for regional differences in per capita income growth: An update and extension. Survey of Current Business 70(1990):29–40.

- The industry-mix (H/J) component measures the contribution to growth in per capita personal income attributable to industries paying higher wages growing faster relative to industries paying lower wages in the parish.
- The relative wage component (E/H) measures the extent to which wages in the parish increased or decreased relative to the average wage paid nation wide, with the mix of industries kept constant.
- Labor force participation (J/N) refers to changes in personal income attributable to changes in the proportion of the population that participates in the paid labor force.
- Transfer payments (TPI/FI) include social insurance, public assistance, and various other income supplements not dependent upon participation in the labor force.
- Property income (FI/E) comes from payments to individuals from interest, rent, and dividends.

The overall growth rate was allocated among these five components for each parish. A normalized standard deviation or "Z score" was calculated for each contributor in each parish based on the distribution of the value among all the parishes in the state. The means for the overall growth rate and for each of the five contributors were computed, and means for the group of 19 coastal parishes were compared to the corresponding means of the 45 non-coastal parishes for each of the four time periods. The results are summarized in Table 2C.5.

Table 2C.5. Changes in per capita personal income and its components, 1969–2000.

Period Group	Δ Personal Income/ Person	Industry Mix	Relative Wage Effect	Lab Force Part.	Transfer Payment Ratio	Property Income Ratio
1969–80						
Coastal	10.06	6.68	1.28	2.40	0.23	-0.53
Non-C	9.14	6.43	0.82	0.68	1.91	-0.70
1981-85						
Coastal	2.38	4.24	-1.96	-2.29	1.93	0.46
Non-C	4.66	4.41	-0.83	-0.04	0.82	0.30
1986-90						
Coastal	4.57	3.56	-1.09	2.33	-0.18	-0.05
Non-C	4.67	3.70	-0.47	1.16	0.19	0.09
1990-00						
Coastal	3.67	3.36	-1.10	0.91	0.47	0.05
Non-C	3.69	3.37	-1.12	1.32	0.28	-0.10
1969-00						
Coastal	6.49	5.24	-0.47	1.03	0.84	-0.16
Non-C	6.64	5.22	-0.20	0.83	0.98	-0.19

Discussion of results

I. 1969 to1980: Rising petroleum prices and production in coastal Louisiana.
   a. In retrospect, a period of exceptional improvement in both coastal and non-coastal parishes, but despite the near equivalence of their overall growth rates, the components of the growth were discernibly different in the two groups.
   b. About two-thirds of the growth was attributable to an improvement in industry mix, i.e., higher wage industries grew relative to lower wage industries, using average national wage levels to define high- and low-wage industries. This was true for both groups of parishes.
   c. The contribution of the other major factors differed significantly between the two groups:
      i. Keeping the mix of industries constant, wages increased relative to the national average in both coastal and non-coastal parishes, but they increased in coastal parishes twice as rapidly as in non-coastal parishes. The regional wage effect was small relative to industry mix improvements, however, contributing 1.28 percentage points or about 13% of the total in coastal parishes and 0.82 points or about 9% of the total in non-coastal parishes.
      ii. Change in the extent to which the population participated in the labor force contributed 2.4 percentage points to the growth rate of personal income in the coastal parishes but only 0.7 percentage points in non-coastal parishes.
      iii. Conversely, changes in transfer payments contributed 1.9 percentage points to the growth rate in non-coastal parishes but only 0.2 percentage points in coastal parishes.
   d. Thus, increases in relative regional wages, and, especially, increased labor force participation increased growth rates in coastal parishes, while transfer payments offset much more modest regional wage and labor force participation gains in non-coastal parishes.

II. 1981 to 1985: Regional repercussions of collapsing oil prices.
   a. The collapse in world oil prices reduced growth rates in both coastal and non-coastal parishes, but the drop was about twice as deep in the coastal parishes.
   b. The positive contribution of a better industry mix continued but declined among both groups of parishes and by about the same magnitude.
   c. The contributions of the other factors more or less reversed the relationships evident in the previous period of quite rapid growth.
      i. Wages declined relative to the nation in both groups of parishes, but declined twice as much in coastal parishes, where only Orleans parish experienced a small relative improvement.
      ii. Decreased labor force participation was a major factor holding down growth in coastal parishes, making a negative contribution of -2.3 percentage points relative to an overall rate of only 2.4. The decline in

non-coastal parishes was very small, only –0.04 compared to an overall rate of 4.7.

iii. Transfer payments constituted a major source of support for personal income in the coastal parishes adding 1.9 percentage points to the overall growth rate of 2.4. In non-coastal parishes the contribution was about half as large.

d. Thus, falling relative wages, and decreased labor force participation were principal avenues of adjustment to falling world oil prices in coastal parishes, their negative effects on income modified significantly by increases in transfer payment. In non-coastal parishes both the negative and positive contributors were much weaker and the overall growth rate was not quite twice as fast as it was in the coastal parishes.

III. 1986-1990: Modest recovery in coastal Louisiana

a. The recovery from the collapse of world oil prices was apparent only among the coastal parishes where the overall growth rate increased by about 90% and parity with non-coastal parishes was regained. But both groups of parishes grew at significantly slower rates than they had achieved during the boom of the 1970s.
b. Improvements in industry mix maintained their steady course but fell below levels exhibited during the bust for both coastal and non-coastal parishes.
c. Wages continued a modest decline relative to the rest of the nation in both groups of parishes.
d. Increased participation in the labor force was the principal evidence of continued recovery among the coastal parishes, adding 2.3 percentage points to the 4.6 overall growth rate. The contribution in non-coastal parishes was positive but only half as large.
e. Transfer payments did not make nearly as large a contribution as they did in the previous two periods for either group of counties.
f. Thus, the recovery from the oil price collapse was moderate at best. Few divergences from the pattern evident during the collapse are evident for the non-coastal parishes with the sizable increase in labor force participation being the principal avenue of improvement for the coastal parishes.

IV. 1991-2000: Sustained but slower growth.

a. Almost no analytically or statistically significant differences are apparent between the two groups in terms of either the total growth rates or the components of the growth.
b. The decline in the rates of growth observed in the previous two periods continued in the period.

Implications

If the contribution from changes in industry mix are regarded as an indicator of longer-term economic growth and changes in the contributions from the other components as indicators of shorter-term adjustments to the business cycle, then the stability and close equivalence of the contribution from improvements in industry mix in both the coastal and non-coastal parishes—through boom, bust and recovery periods—suggests that offshore oil and gas activities had limited if any long-term, cumulative, economic effects on residents of coastal parishes during the study period. Further, the persistent decline in regional wages relative to the nation since the 1970s boom—in both coastal and non-coastal parishes—suggests that offshore oil and gas activity does not increase wage costs for other industries in coastal parishes.

Relationships between income and population growth are discussed elsewhere in the study.

Allan G. Pulsipher is the Executive Director and Marathon Oil Company Professor of Energy Policy in the Center for Energy Studies at Louisiana State University. He has been with the Center for Energy Studies since 1990. Prior to coming to LSU, he worked as the Chief Economist for the Congressional, Monitored Retrievable Storage Review Commission (1988–89); the Chief Economist of the Tennessee Valley Authority (1980–88); a Program Officer with the Ford Foundation's Division of Resources and the Environment (1977–80); as a Senior Staff Economist with the President's Council of Economic Advisers (1973–75); and on the faculties of Southern Illinois and Texas A&M Universities. He has a B.A. from the University of Colorado and a Ph.D. from Tulane University, both in economics. He currently is working on issues created by the changing oil and gas industry, especially those affecting the offshore part of the industry. He retains an active interest in policy issues related to the storage and disposal of high-level nuclear waste and the restructuring of the electricity industry-especially as it affects the Tennessee Valley Authority.

A COLLABORATIVE INVESTIGATION OF BASELINE AND SCENARIO INFORMATION FOR ENVIRONMENTAL IMPACT STATEMENTS

David E. Dismukes, Center for Energy Studies, Louisiana State University

Introduction

The Environmental Impact Statement (EIS) process is both data-intensive and dynamic. Over the years, the depth and scope of the socioeconomic analyses included in the EIS have changed considerably, becoming both more rigorous and more detailed. This is particularly true in the examination of economic impacts and industry relationships and ties from the Gulf of Mexico (GOM) to its onshore communities. Expectations are that economic impact models will continue to become more developed and attempt to reach even greater levels of sector and geographic detail.

However, despite the increase in detail and refinement of many EIS socioeconomic analyses, there are still a large number of areas that are 1) not well understood; and/or 2) where detailed data and information is exceptionally difficult to obtain.

An example of the first problem rests with the existing MMS economic impacts models. While these models include considerable sectoral detail regarding industry expenditures, there are still areas where large percentages of offshore activities are assigned to broad industry categories (or sectors) that are intended to represent outsourcing and contracting. Where those dollars go within those contracted services category is, at this time, a black box.

The second problem (difficulty in obtaining detailed data) continues to be a source of frustration in attempting to "populate" the detailed models envisioned for EIS purposes. Much of the information needed for these models can be irregularly reported, inconsistent in scope, considered proprietary by industry, and in some instances, simply unobtainable. This quickly devolves the research project into a "scavenger hunt." Further, considerably more effort is being put into the collection of this data and information than in the actual analysis.

The goal of the Collaboratives Process is an attempt to use more reasonable methods to answer the general question of how offshore activities impact the communities of the GOM.

Project Approach and Current Activities

There are a number of options that MMS could consider to collect the baseline and scenario data and information needed for EIS purposes. One approach would be to initiate new and rigorous reporting requirements under its regulatory authority much like the Department of Energy (DOE), Federal Energy Regulatory Commission (FERC), or the Federal Communications Commission (FCC). This seems like an unlikely and unreasonable option for MMS. The second approach would be to continue the current process of scavenging for information and data and to maintain the status quo. Again, this is also an unreasonable conclusion and inefficient process for MMS. The third approach, which is the subject of this project, is to develop a more "collaborative" process for collecting and examining information associated with the offshore industry.

The collaboratives approach would be less structured and

- Is more fluid that traditional methods and takes into account the "big picture."
- Recognizes that not all trends and scenarios can be quantified explicitly.
- Is willing to accept some data limitations and rely more on professional and subject matter expert judgment.
- Sets up structure for getting the best professional judgment by collaborating with others to get specific answers to specific questions.

Conclusions

The Collaboratives Research Project is attempting to collect needed baseline and scenario information for MMS in a reasonable and practical manner. The project is moving in two concurrent tracks. First, attempting to obtain additional information on the subcontracted and outsourced activities that have bedeviled earlier analysis of the industry and its relationships with onshore communities. Second, the project is attempting to examine current informational need for MMS, and develop a process by which this information can be obtained from various subject matter experts. Hopefully, this approach will lead to more practical and efficient ways and getting answers to questions needed to be addressed in future EIS.

David E. Dismukes is the Associate Director and an Associate Professor at the Center for Energy Studies, Louisiana State University. His research interests are in the analysis of economic, statistical, and public policy issues in energy and regulated industries. He has completed several projects for MMS including the original economic impact cost models used in the MMS EIS and the deepwater infrastructure factbook and GIS database.

SESSION 1D

EFFECTS OF OIL AND GAS EXPLORATION & DEVELOPMENT AT SELECTED CONTINENTAL SLOPE SITES IN THE GULF OF MEXICO, PART I

Chair: Greg Boland, Minerals Management Service

Co-Chair: Margaret C. Metcalf, Minerals Management Service

BACKGROUND AND STUDY DESIGN

Alan D. Hart, Continental Shelf Associates, Inc.

In recent years, a remarkable increase in oil and gas exploration, development, and production has occurred in the deepwater Gulf of Mexico (GOM) (Cranswick and Regg 1997; Baud et al. 2000; Richardson et al. 2004). Over the last decade, the number of wells drilled in the deepwater Gulf has increased dramatically, with much of the activity in water depths of 450 to 1,500 m (Richardson et al. 2004). In early 2004, over one half of the active leases in the GOM were in deepwater (Richardson et al. 2004). Contributing factors to this revitalization of exploration and development in the GOM include favorable economics, the development of innovative technologies, the announcement of large deepwater discoveries, the passage of the Deep Water Royalty Relief Act, and the opportunity to lease new prospects. (Ward 2000; Richardson et al. 2004).

Deepwater operations are significantly different from conventional operations on the continental shelf because they are farther from shore, encounter different environmental conditions, are technologically more sophisticated, and may involve much higher production rates. These differences present many technical and regulatory challenges (Minerals Management Service [MMS] 2000, 2004). This study was conducted to address one challenging aspect of deepwater operations: the impacts of drilling activities on the benthic environment around wellsites. The objectives of this multi-year study, which was conducted by Continental Shelf Associates, Inc. and its subcontractors/consultants, were to assess the physical, chemical, and biological impacts of oil and gas development at selected exploration and development wellsites on the GOM continental slope. The findings from this study will assist the MMS in conducting environmental analyses, as well as developing mitigative measures and regulations specifically tailored to deepwater operations. Specific objectives were to document 1) drilling mud and cuttings accumulations; 2) physical modification/disturbance of the seabed due to anchors and their mooring systems; 3) debris accumulations; 4) physical/chemical modification of sediments; and 5) effects on benthic organisms.

Four sites were sampled during the study:

- Viosca Knoll Block 916 (VK 916) was an exploration site sampled before and after drilling of a single exploration well.
- Garden Banks Block 516 (GB 516) was an exploration/development site that was sampled once after exploration drilling and again after several development wells were drilled.
- Garden Banks Block 602 (GB 602) and Mississippi Canyon Block 292 (MC 292) were post-development sites sampled once after several exploration and development wells had been drilled.

VK 916 and GB 516 were located in water depths of about 1,000 m. MC 292 and GB 602 were located in water depths of about 1,100 m. Both water-based and synthetic-based muds (SBM) were used in the drilling of the exploration and post-development wells.

Geophysical characterizations of the sites were conducted to determine (1) the areal extent and accumulation of muds and cuttings; (2) the physical modification or disturbance of the sea bed due to impacts from anchors and their mooring systems including chains or wire ropes; and (3) the accumulation of debris attributable to oil and gas development activity. Bathymetric, side-scan sonar, and subbottom profile data were collected at each site, and these data were used to construct broad-scale images of the seafloor, which were interpreted to map possible anchor scars and accumulations of cuttings and drilling fluids. To encompass the anchor patterns for typical moored drilling units in this water depth, an area within a radius of approximately 3,000 m was surveyed at each site. Cruise 1A was conducted from 10 November 2000 to 1 January 2001 using a high-resolution deep-tow system aboard the R/V OCEAN SURVEYOR, a geophysical survey vessel. It was originally intended that all of the sites would be sampled during Cruise 1A; however, VK 916 was the only site surveyed due to extended weather delays, as well as equipment, software, and vessel problems. Cruise 2A was conducted from 24 June to 7 July 2001 at both post-development sites (GB 602 and MC 292), and a post-drilling survey was conducted at GB 516 following the completion of development drilling there. Cruise 2A was conducted aboard the M/V RIG SUPPORTER using the C&C Technologies Autonomous Underwater Vehicle (AUV), the HUGIN 3000. The post-drilling survey of the VK 916 site, Cruise 3A, was conducted from 7 to 12 August 2002, following the completion of exploration drilling there. This survey also was conducted aboard the M/V RIG SUPPORTER using the HUGIN 3000 AUV.

To assess physical/chemical modification of sediments and the effects on benthic organisms, chemical/biological sampling was conducted at each site. GB 516 and VK 916 were sampled during Cruise 1B, which was conducted from 23 October to 17 November 2000. Sampling at both post-development sites (GB 602 and MC 292) and at the GB 516 site after the completion of development drilling there was conducted during Cruise 2B (8 to 25 July 2001). Cruise 3B was a post-drilling survey of the VK 916 site following the completion of exploration drilling there and was conducted from 4 to 14 August 2002.

Each study site was defined as a circle of 500 m radius around the drilling location. This radius was selected because concentrations of synthetic based fluids (SBFs) most likely would not be detectable beyond 500 m from the discharge point, and SBF concentrations exceeding 1 ppm (an apparent threshold for biological effects; Neff et al. 2000) are most likely to occur within 300 m of the discharge point. Six circular far-field sites (or “reference areas”) also were designated for each study site. The locations of these reference areas were selected to be at 10 to 25 km away from the near-field site and at about the same depth as the near-field site. The total area of six far-field sites combined was equal to that of the near-field site, and the number of samples was allocated so that the sampling intensity was the same between the near-field site and the reference areas.

For the chemical/geological sampling, samples and data were collected with four types of equipment:

- Box core sampler (to obtain samples of sediment, microbiota, meiofauna, and macroinfauna).
- Sediment profile imaging (SPI) camera (to obtain cross-sectional images of the upper sediment column).
- Still camera on a towed/dragged sled (to obtain photographs of the seafloor and megafauna).
- Baited traps (to obtain animals for tissue analyses).

Box cores were to be collected at 12 randomly selected locations within the 500-m radius at each study site and at 12 far-field locations (two locations selected randomly within each of six far-field sites). Camera sled and SPI transects were not randomized, and the transects were conducted as drifts across each site based on prevailing currents. The still camera was programmed to take photographs at regular five-second intervals. Still photographs of the seafloor and megafauna were collected along three transects at each site and along one transect at each of three far-field sites. The SPI system was repeatedly lowered to take as many sediment profiles as possible during each transect. Sediment profile photographs were to be collected along three drift transects in the near-field and along one transect at each of three far-field sites. The baited traps were to be deployed at the two post-development sites to collect organisms for tissue analyses. For each site, eight traps were deployed in the near-field, and four traps were placed at each of two corresponding far-field sites.

References

Baud, R.D., R.H. Peterson, C. Doyle, and G.E. Richardson. 2000. Deepwater Gulf of Mexico: America's Emerging Frontier. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-022. 89 pp.

Cranswick, D. and J. Regg. 1997. Deepwater in the Gulf of Mexico: America's New Frontier. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 97-004. 43 pp.

Minerals Management Service. 2000. Gulf of Mexico Deepwater Operations and Activities: Environmental Assessment. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS EIS/EA MMS 2000-001.

Minerals Management Service. 2004. Moving into Deepwater: The Challenges of Development in the Gulf of Mexico. MMS Ocean Science 1(2):4–5. March/April 2004.

Neff, J.M., S. McKelvie, and R.C. Ayers, Jr. 2000. Environmental Impacts of Synthetic Based Drilling Fluids. Report prepared for MMS by Robert Ayers & Associates, Inc., August

2000. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-064. 118 pp.

Richardson, G.E., L.S. French, R.D. Baud, R.H. Peterson, C.D. Roark, T.M. Montgomery, E.G. Kazanis, G.M. Conner, and M.P. Gravois. 2004. Deepwater Gulf of Mexico 2004: America's Expanding Frontier. U.S. Dept. of the Interior, Minerals Management Service, New Orleans, LA. OCS Report MMS 2004-021.

Ward, E.G. 2000. Deepwater technology, Chapter 2. In: Continental Shelf Associates, Inc. Deepwater Gulf of Mexico Environmental and Socioeconomic Data Search and Literature Synthesis: Volume 1, Narrative report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-049.

Dr. Alan Hart is the Science Director of Continental Shelf Associates, Inc., located in Jupiter, Florida. He has 30 years of experience in marine environmental science, including major research programs for federal, state, and industrial clients. He has been involved in characterization and monitoring studies covering a wide range of human activities in the marine environment, including oil and gas operations, dredged material disposal, beach restoration, and sewage outfalls. Dr. Hart received his B.S. degree in zoology from Texas Tech University in 1973 and his Ph.D. Degree in biological oceanography from Texas A&M University in 1981.

GEOPHYSICAL CHARACTERIZATION OF STUDY SITES: VK916, MC292, GB602, AND GB512

Harry H. Roberts, Coastal Studies Institute, Louisiana State University

Geologic Framework

This study focuses on the effects of oil and gas exploration and development at four selected sites on the continental slope of the northern Gulf of Mexico (GOM). The study sites are located in the world's most mature deepwater hydrocarbon exploration-production province. The continental slope offshore of the northern Gulf states is also perhaps the most geologically complex continental slope in today's oceans. The shaded relief map of Figure1D.1 reflects the complexity of the slope's surface topography, a reflection of an equally complex subsurface geology.

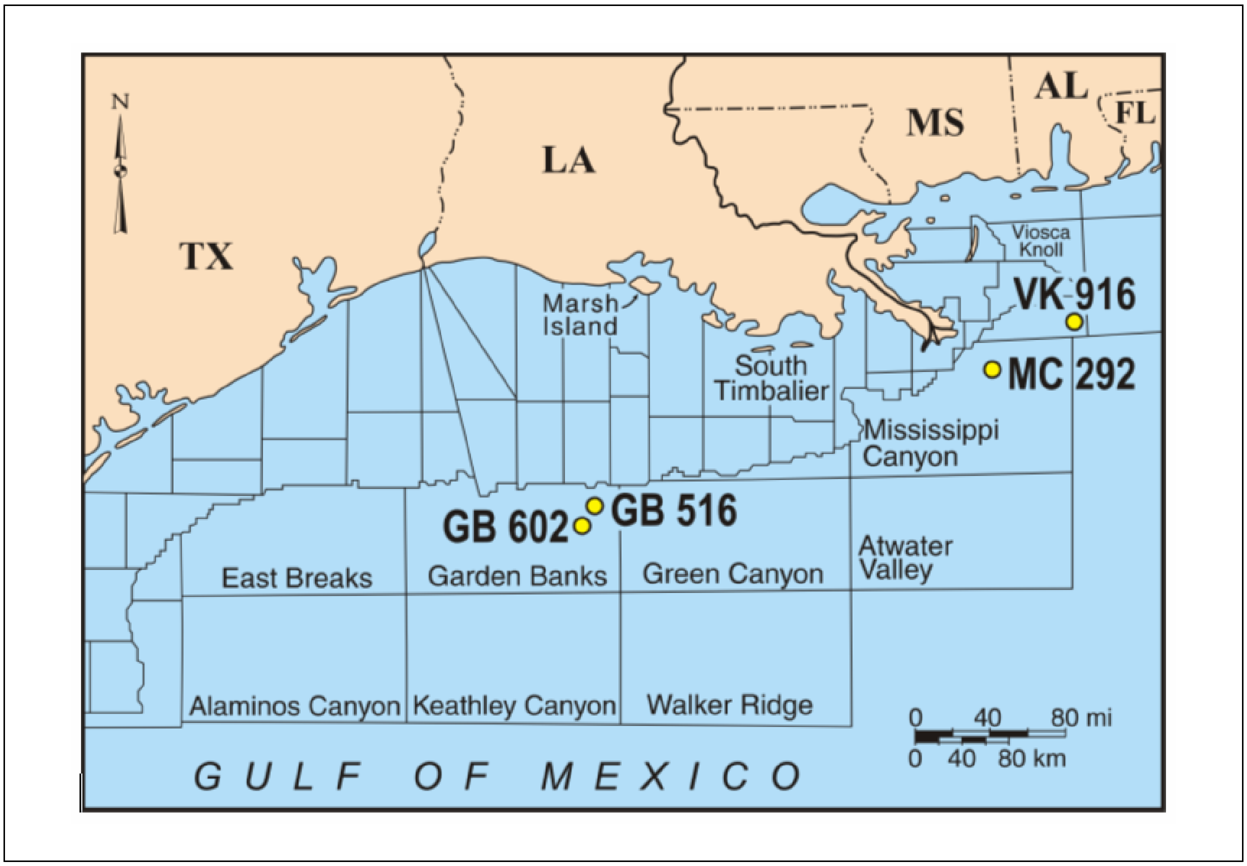


Figure 1D.1. Location map showing major lease areas of the northern Gulf of Mexico continental slope and specific sites addressed in this study.

Our present knowledge base for both the surface and subsurface geology of the northern Gulf's continental slope is largely a product of the search for and production of oil and gas. Since the late 1970s when the exploration front moved to the upper continental slope, an enormous data base of 3D-seismic, bathymetry, high resolution geohazard-scale acoustic data, and sediment core data has been compiled for deep water. These data sets confirm the geologic complexity of this province and support the idea that the slope's geologic configuration derives from the interdependency of terrigenous clastic sedimentation and salt tectonics (Humphris 1978). Research conducted in the early and mid 1990s emphasizes that variations in sedimentation rate affect the growth of salt bodies. Salt deformation in turn exerts a strong control on the locations and orientations of intraslope minibasins and associated fault networks (Talbot 1993; Vendeville and Jackson 1993; Weimer et al. 1994; Diegel et al. 1995; Rowan 1995; Rowan et al. 1995).

The northern GOM continental slope covers an area of over 120,000 km^2 and is defined by the shelf edge at roughly the 200 m isobath to the upper limit of the continental rise at an approximate depth of 2,600 to 2,750 m (Bouma and Roberts 1990). The most complex part of the basin's continental slope occurs opposite east Texas and Louisiana. In this province, regional topography is dominated by domes or knolls associated with salt in the shallow subsurface and intervening basins, as discussed above and as illustrated by Figure 1D.1. Seafloor slopes associated with these regional-scale features range from less than 1º on the dome tops and along the basin floors to over 20º on the side of domes and on basin flanks. Observable on this regional topography of domes and basins are smaller-scale geologic features that are associated with high variability in sediment type and local relief. Near-surface geology and topography of the upper continental slope in the northern GOM is highly influenced by cyclic episodes of shelf edge progradation and sediment input to deep water. In addition to filling mini-basins and mobilizing salt, sediment loading during periods of lowered sea-level activates faults. Faulting creates abrupt relief and steep slopes (some near vertical) on the modern ocean floor of the slope. Faults function as avenues of transport for fluids and gases to or near the modern seafloor. The process of fluid and gas expulsion has an important impact on the present surficial geology of the slope. Expulsion of large volumes of fluidized sediment results in the formation of mud volcanoes and mud flows (Neurauter and Roberts 1992; Kohl and Roberts 1994). Seepage and venting results in the development of highly populated communities of chemosynthetic organisms (Kennicutt et al. 1985), creation of brine pools and pock marks (McDonald et al. 1990), gas hydrate mound formation (Brooks et al. 1985), and precipitation of carbonates and other exotic minerals to form hardgrounds, chimneys, and mound-like buildups (Roberts and Aharon 1994). These various seafloor responses are all products of vertical flux of hydrocarbon gases, crude oil, and other formation fluids migrating to the ocean floor along faults.

The Mississippi River, which feeds a delta that has nearly prograded to the shelf-edge, makes a comparatively small impact on modern slope sedimentation. In response to a lack of siliciclastic sediment input during the present highstand of sea-level, a thin hemipelagic sediment unit drapes slope topography. These sediments are composed of numerous calcareous pelagic foraminifera tests in a matrix of hemipelagic clay. When studied carefully using X-ray radiography, sediments of the hemipelagic drape have a massive character, rarely display bedding, are highly bioturbated, and frequently show the effects of early diagenesis.

On the upper continental slope the hemipelagic drape is frequently missing from the tops of regional domes and knolls. Sedimentologists with experience in the GOM consider this relationship a product of dome top erosion by Loop Current intrusions directly on the slope or the impact of Loop Current eddies that transit from east-to-west along the shelf-slope break. The Loop Current can impact the seafloor to depths of nearly 1,000 m (Hamilton 1990). Dome tops on the upper continental slope within this depth range frequently exhibit seafloor erosion exposing older sediments and frequently deformed sediments. Both slumping due to oversteepening on salt dome flanks and faulting associated with salt movement frequently cause dome flank and dome top sediment deformation.

In contrast to seafloor covered with a hemipelagic drape deposit, there are vast areas of slope impacted by fluid and gas expulsion. These areas appear much more complex, both visually and on geophysical records, than the former areas.

Data Collection Schedule and Instrumentation

The data collection plan as originally drafted included the acquisition of geophysical data (side-scan sonar, subbottom profiles, and bathymetry) from four sites within the upper continental slope province of the northern GOM, Figure 1D.1. As initially planned, these data sets were to be collected with a high resolution deep-tow system. Delays associated with weather and instrumentation problems mandated a rethinking of the data collection schedule and equipment to be focused on the data collection program. Ultimately, one exploration site, Viosca Knoll Block 916 (VK 916), was completed with the deep-tow system between November 2000 and January 2001 (Cruise 1A) and resurveyed with different instrumentation in May 2002 (Cruise 3A). The other three sites—Mississippi Canyon 292 (MC 292), Garden Banks 602 (GB 602), and Garden Banks 516 (GB 516)—were surveyed in June-July 2001 (Cruise 2A). Table 1D.1 summarizes the dates of data collection, locations, and types of data collection systems used. Figure 1D.1 illustrates the general areas of the continental slope where specific sites were surveyed.

Table 1D.1. Geophysical surveys.

Cruise	Dates	Location	Survey Timing	Equipment*
1A	11–12 Nov. 2000	VK 916	Pre-drilling	Deep-Tow
	29–30 Nov. 2000	VK 916	Pre-drilling	Deep-Tow
	6 Dec. 2000	VK 916	Pre-drilling	Deep-Tow
	9–10 Dec. 2000	VK 916	Pre-drilling	Deep-Tow
	Dec. 30, 2000	VK 916	Pre-drilling	Deep-Tow (fathometer only)
	1 Jan. 2001	VK 916	Pre-drilling	Deep-Tow
2A	25–29 June 2001	MC 292	Post-drilling	AUV
	2–4 July 2001	GB 602	Post-drilling	AUV
	5–7 July 2001	GB 516	Post-drilling	AUV
3A	16–18 May 2002	VK 916	Pre-drilling	AUV

* Deep-Tow (two boats): Edgetech side-scan sonar, Edgetech subbottom profiler, ODOM deep-water echotrac (single-beam), and cesium magnetometer. AUV (HUGIN 3000): Edgetech side-scan sonar, Edgetech subbottom profiler, and Simrad EM2000 multibeam bathymetry

The pre-drilling survey at VK 916 (Cruise 1A) was the only one conducted for this project with the deep-tow system. The data collection systems in the deep-tow fish included: (a) a dual frequency EdgeTech side-scan sonar that operated at center frequencies of 120 kHz and 420 kHz, (b) an EdgeTech chirp sonar with a frequency bandwidth of 2-10 kHz, and (c) a deep-water precision depth sensor. An electro-hydraulic winch with approximately 6,400 m of cable controlled the depth of the fish above the bottom.

Although the VK 916 site was initially surveyed using a deep-tow system, it was decided that data quality would be better and data collection schedules could be met more efficiently for other sites using the C&C Technologies Autonomous Underwater Vehicle (AUV), the HUGIN 3000. The post-exploration survey of VK 916 (Cruise 3A) also used the AUV (Table 1D.1).

Results and Conclusions

Side-scan sonar and chirp sonar subbottom records were useful in mapping deposits of drilling mud and cuttings around the wellsites. A combination of a smooth seafloor (little backscatter on side-scan sonar records) and a high amplitude response at the seafloor on high resolution subbottom profiles was used to identify areas of probable drilling mud deposition. Areas where side-scan sonar showed high reflectivity extending in a radial pattern around the wellsites were interpreted as cuttings. Cuttings are derived from subsurface sediments that are much more compacted and therefore denser than surface hemipelagic sediments that drape most of the northern Gulf continental slope. When deposited over hemipelagic sediments, cuttings create an acoustic impedance difference that translates into a higher amplitude reflection on subbottom profiler records. Although the mapping conservatively identified these areas as cuttings, other processes produce high reflectance patterns on side-scan sonar records including seafloor disturbances (grooves, furrows, etc.) caused by the process of setting anchors and the dropping of sediment clumps to the seafloor from the anchor cables as they are pulled into place.

Generally, areas mapped as drilling muds were identified within about 100 m of wellsites. Areas mapped as cuttings typically extended several hundred meters from wellsites, with the greatest extent (about 1 km from the wellsite) observed at GB 602 and GB 516. Anchor scars extended to the limit of the surveyed area (about 3 km radius) around the wellsites.

Persistent cuttings and/or anchor scars from previous activities at nearby wellsites were also evident. At VK 916, cuttings and anchor scars were present from two previous wells drilled in nearby VK 872 in November to December 1998, about 3.5 years prior to Cruise 3A. At the MC 292 site, cuttings deposits and anchor scars were evident around a wellsite in the adjacent block MC 291 from drilling between August and October 1997. Within the GB 602 survey area, anchor scars and mud/cuttings were evident from three wells drilled between April and August 1996, about 5 years prior to Cruise 2A. In the GB 516 area, the mapping showed drilling deposits around a previous wellsite drilled between September 1995 and July 1996, about 5 years prior to Cruise 2A.

References

Bouma, A.H. and H.H. Roberts. 1990. Northern Gulf of Mexico continental slope. Geo-Marine Letters 10:177–187.

Brooks, J,M., M.C. Kennicutt II, R.R. Bidigare, and R.A. Fay. 1985. Hydrates, oil seepage, and chemosynthetic ecosystems on the Gulf of Mexico slope. EOS, Transactions, American Geophysical Union 66:106.

Diegel, F.A., J.F. Karlo, D.C. Schuster, R.C. Shoup, and P.R. Tauvers. 1995. Cenozoic structural evolution and tectono-stratigraphic framework of the northern Gulf Coast continental margin. In: Jackson, M.P.A., D.G. Roberts, S. Snelson, eds. Salt Tectonics: A Global Perspective. AAPG Memoir 65:109–151.

Hamilton, P. 1990. Deep currents in the Gulf of Mexico. Journal of Geophysical Research 20:1087–1104.

Humphris, Jr., C.C. 1978. Salt movement on the continental slope, northern Gulf of Mexico. In Bouma, A.H., G.T. Moore, and J.M. Coleman, eds. Framework, Facies, and Oil-trapping Characteristics of the Upper Continental Margin. American Association of Petroleum Geologists Studies in Geology 7:69–86.

Kennicutt II, M.C., J.M. Brooks, R.R. Bidigare, R.A. Fay, T.L. Wade, and T.J. McDonald. 1985. Vent-type taxa in a hydrocarbon seep region on the Louisiana slope. Nature 317:351.

Kohl, B. and H.H. Roberts. 1994. Fossil foraminifera from four active mud volcanoes in the Gulf of Mexico. Geo-Marine Letters 14:126–134.

McDonald, I.R., J.F. Rilly, II, N.L. Guinasso, Jr., J.M. Brooks, R.S. Carney, W.A. Bryant, and T.J. Bright. 1990. Chemosynthetic mussels at a brine-filled pockman in the northern Gulf of Mexico. Science 248:1096–1099.

Neurauter, T.W. and H.H. Roberts. 1992. Seismic and visual observation of seepage-related structures on the continental slope, northern Gulf of Mexico, Proceedings, Twenty-fourth Offshore Technology Conference, Houston, Texas, OTC 6850. Pp. 355–362.

Roberts, H.H. and P. Aharon. 1994. Hydrocarbon-derived carbonate buildups of the northern Gulf of Mexico continental slope: A review of submersible investigations. Geo-Marine Letters 14:135–148.

Rowan, M.G. 1995. Structural styles and evolution of allochthonous salt, central Louisiana outer shelf and upper slope. In: Jackson, M.P.A., D.G. Roberts, S. Snelson, eds. Salt Tectonics: A Global Perspective. AAPG Memoir 65:199–228.

Rowan, M.G., P. Weiner, B. McBride, P. Varnai, Z. Acosta, F. Budhijanto, R. Martinez, A. Navarro, T. Villamil, and J.C. Fidnk. 1995. Interactions between salt tectonics and sedimentation in the Louisiana Offshore: Preliminary results. In Travis C., et al., eds. SaH, Sediment, and Hydrocarbons: Gulf Coast Section. Society of Economic Paleontologists and Mineralogists Foundation, Sixteenth Annual Research Conference Proceedings. Pp. 235–244.

Talbot, C.J. 1993. Spreading of salt structures in the Gulf of Mexico. Tectonophysics 228:151–166.

Vendeville, B.C. and M.P.A. Jackson. 1993. Rates of extension and deposition determine whether growth faults or salt diapirs form. In Armentrout, J.M., R. Bloch, H.C. Olson, and B.F. Perkins, eds. Rates of Geologic Processes. Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation, Fourteenth Annual Research Conference Proceedings. Pp. 263–268.

Weimer, P., P. Varnai, Z.M. Acosta, F.M. Budhijanto, R.E. Martinez, A.F. Navarro, M.G. Rowan, B.C. McBride, and T. Villamil. 1994. Sequence stratigraphy of Neogene turbidite systems, northern Green Canyon and Ewing Bank, northern Gulf of Mexico. Gulf Coast Section Society of Economic Paleontologists and Mineralologists, Fifteenth Annual Research Conference Proceedings. Pp. 383–396.

Harry H. Roberts was for 10 years director of Coastal Studies Institute at LSU, a member of the Department of Oceanography and Coastal Sciences, and a Boyd Professor. He has had a career in marine geology that spans more than 30 years and has worked in many foreign countries as well as in the United States. Recently, he has focused his research on two areas: (a) deltaic sedimentation and processes and (b) surficial geology of the northern Gulf's continental slope. The latter research thrust has concentrated on building an understanding of the impacts of fluid and gas expulsion on the surficial geology and biology of the slope. Gas hydrates constitute one of the unusual consequences of fluid and gas migration and expulsion in deep water.

METALS, TOTAL ORGANIC CARBON AND REDOX CONDITIONS IN SEDIMENTS

John H. Trefry, Robert P. Trocine, Michelle L. McElvaine and Robert D. Rember,
Florida Institute of Technology

Introduction

As part of an MMS study of the effects of oil and gas exploration and development at selected sites on the continental slope in the Gulf of Mexico (GOM), our group at Florida Institute of Technology used several chemical parameters to help identify spatial and temporal trends in the presence of drilling discharges and in redox conditions in sediments at each site. The supporting data set is quite diverse and includes the following: (1) data for 13 metals [aluminum (Al), arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), vanadium (V) and zinc (Zn)] and total organic carbon (TOC) in sediments, (2) data for 11 metals (As, Ba, Cd, Cr, Cu, Fe, Hg, Ni, Pb, V and Zn), in *Bathynomus giganteus* (a large isopod) and *Chaceon quinquedens* (a crab), (3) sedimentation rates, (4) vertical profiles for dissolved oxygen, pH and redox potential (Eh) in sediment, and (5) data for selected redox-active chemicals in interstitial water.

The following four sites at water depths of ~1,000 m were investigated: (1) Site GB 516 (1036 m) was sampled twice, in both cases after drilling, (2) Site VK 916 (1,006 m) was sampled before and after exploratory drilling, (3) Site GB 602 (1,124 m) was sampled once post-development and (4) Site MC 292 (1,118 m) was sampled once post-development (Figure 1D.2). Results from site VK 916 provide the best perspective of pre- and post-development conditions.

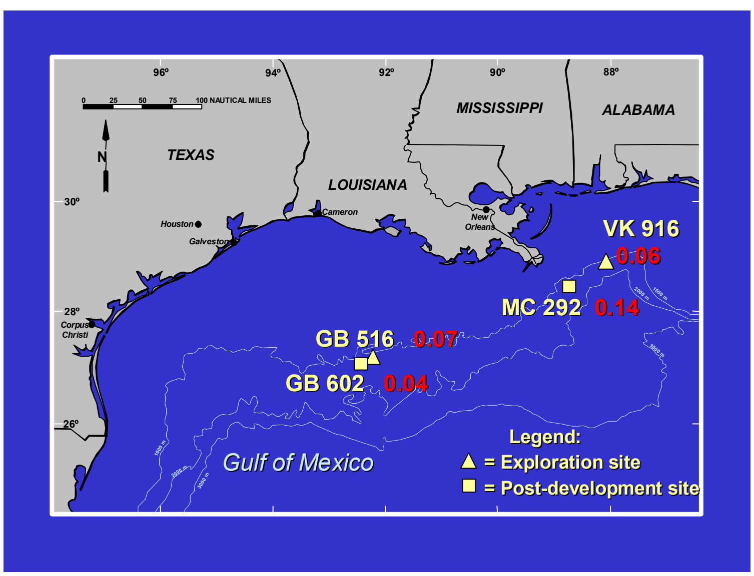


Figure 1D.2. Sampling sites in the Gulf of Mexico with background sedimentation rates in cm yr^{-1}.

Results and Discussion

Random samples were collected at multiple locations within 1,000 m of the drilling sites (near-field) and at >10km from the drilling site (far-field). Samples also were collected at a few discretionary stations sited at fixed nearfield locations.

Sedimentation rates (Figure 1D.2) based on vertical profiles for excess ^{210}Pb were 0.04 to 0.07 cm yr^{-1} for sites GB 516, GB 602 and VK 916 and higher at 0.14 cm yr^{-1} nearer the Mississippi River (site MC 292) where the ^{137}Cs profile supported results for excess ^{210}Pb. At near-field (NF) locations, maximum levels of Ba in sediment were 35% at GB 516, 17% at VK 916, 15% at GC 602 and 15% at MC 292, relative to levels of 0.1 to 0.2% at far-field (FF) stations. At site VK 916, concentrations of Ba in sediments from the NF zone increased by ~30 fold, from an average of 0.11% to 3.6%, for pre-exploration and post-exploration samples, respectively (Figure 1D.3). At site GB 516, some discharges had occurred prior to the planned pre-exploration sampling. Concentrations of Ba in sediments collected during the post-exploration phase averaged double those found during the pre-development phase, showing a continued increase in the presence of drilling residues. At sites, GB 602 and MC 292, levels of Ba in sediments at NF stations were ~60 fold and ~12 fold greater, respectively, than at FF stations. Concentrations of synthetic-based mud (SBM) did not correlate well with Ba because of differences in mud mixture, behavior after discharge and the occurrence of water-based mud (i.e., Ba and other components, but not SBM).

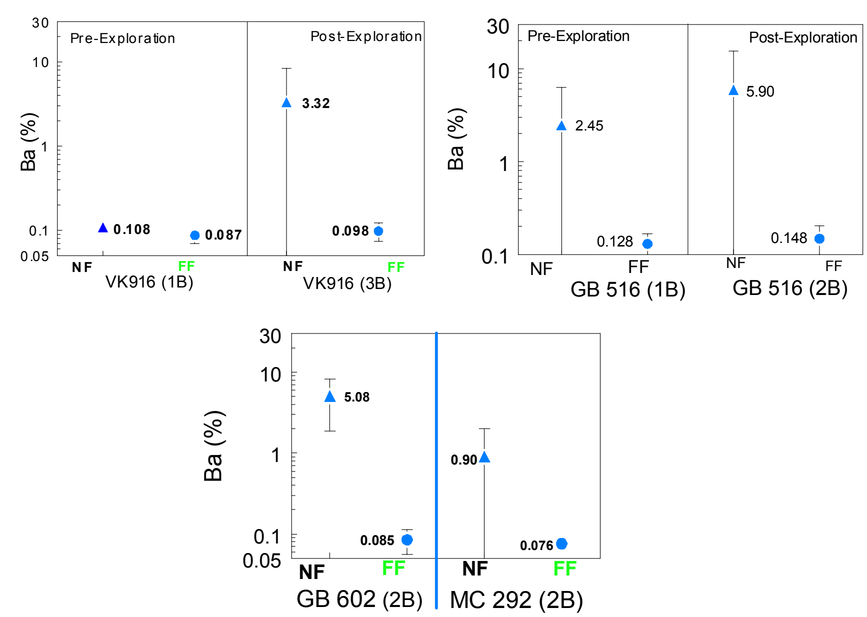


Figure 1D.3. Concentrations of Ba (markers show means and lines show standard deviations) in sediments at nearfield (NF) and farfield (FF) stations for pre-exploration and/or post-exploration surveys at sites VK 916, GB 516, GB 602 and MC 292 (notation in parentheses after site identifies cruise when sampling occurred). In some cases, the standard deviation is smaller than the marker.

Mean concentrations of Hg, Pb, As, Cd and other metals in sediments were not statistically different at NF versus FF stations at site VK 916 for pre-drilling and post-drilling expeditions. Overall, metal concentrations (excluding Ba) in the 132 NF sediments, from all four sites, were within the range of values observed for FF stations in 85 to 100% of the samples, depending on the metal considered. Several instances of elevated levels of Hg (n = 10 at > 0.15 µg/g) and Pb (n = 17 at >40 µg/g) were observed, primarily from one discretionary station (DS) at site GB 516.

Concentrations of metals in tissues from isopods (*Bathynomus giganteus*) and crabs (*Chaceon quinquedens*) showed large standard deviations and no significant differences between NF and FF samples. Concentrations of total Hg in isopods ranged from 0.6 to 15.7 µg/g (dry weight) with an average of 4.2 ± 3.9 µg/g (n = 22 from NF + FF).

Vertical profiles for dissolved oxygen in the sediment were generated at 1-mm intervals and pH and Eh were measured at 2-cm intervals. In general, concentrations of dissolved oxygen decreased to zero at shallower depths in sediment from NF sites following drilling than at FF stations. The redox potential also tended to be lower (less oxidizing, more reducing) at NF sites during post development sampling. For example, at site GB 516, dissolved oxygen could be detected to a depth of ~3.5 cm in FF sediment relative to <0.5 cm in NF sediment (Figure 1D.4). In addition, Eh levels at the FF site showed oxidizing conditions (400 mV) relative to anoxic, highly reducing conditions (-150 mV) at some NF stations (Figure 1D.4).

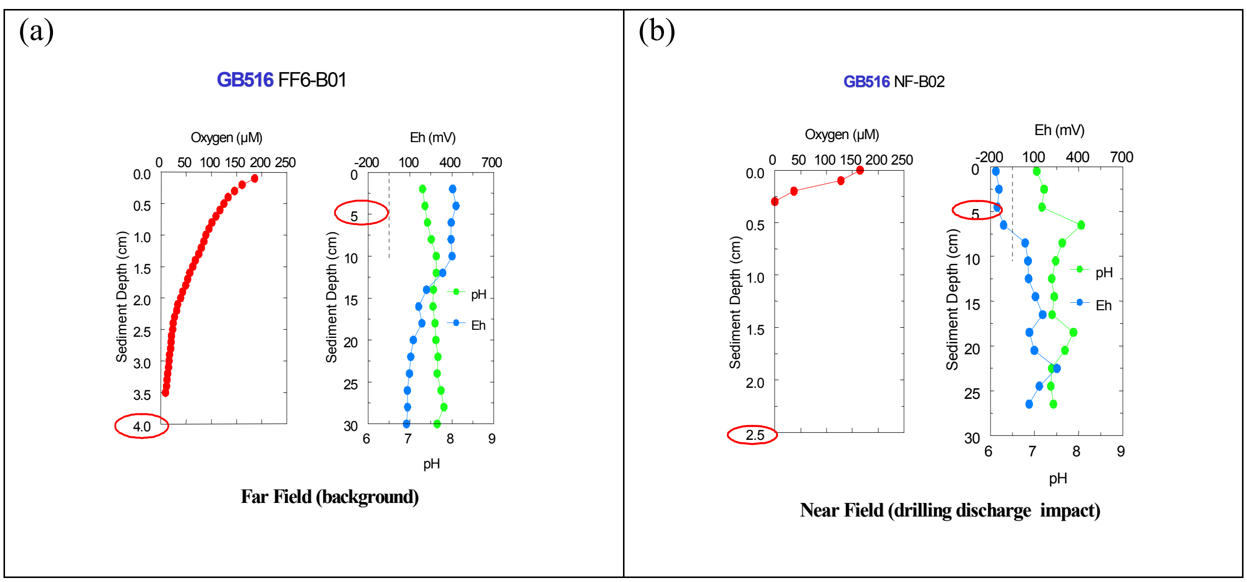


Figure 1D.4. Vertical profiles for dissolved oxygen, pH and redox potential (Eh) for (a) farfield (FF) and (b) nearfield (NF) sediments at site GB 516 where drilling discharges had occurred. Scales on oxygen profiles (4.0 and 2.5 cm) are much smaller than on the Eh profiles (30 cm).

To simplify comparisons among sites, the amount of dissolved oxygen in the sediment column was integrated as nmoles cm^{-2}. This integrated amount of dissolved oxygen in the sediment was lower at NF stations following development. For example, at site VK 916, the mean, integrated amount of oxygen in the sediment column during the pre-development sampling was statistically the same at FF and NF stations (Figure 1D.5). Following development, the mean value remained essentially the same at the FF stations and decreased by ~2 fold at NF stations and ~8 fold in sediments at discretionary stations (Figure 1D.5).

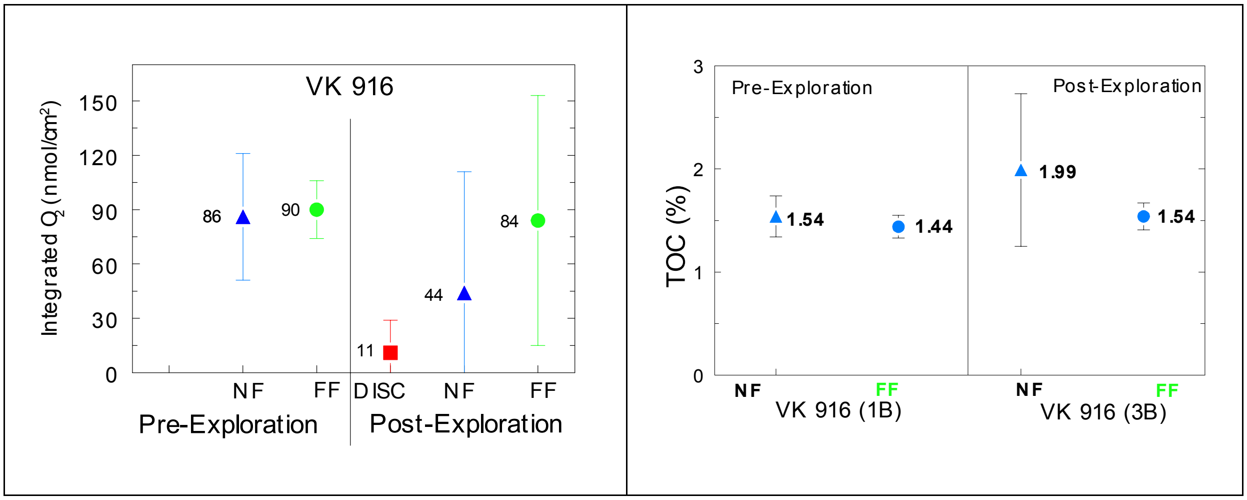


Figure 1D.5. Means and standard deviations for integrated amounts of dissolved oxygen and levels of total organic carbon (TOC) in sediments from site VK 916 for nearfield (NF), discretionary (DS) and farfield (FF) stations during pre- (cruise 1B) and post-development (cruise 3B) sampling.

At site GB 516, the amounts of integrated oxygen were ~10 fold and 7 fold lower at DS and NF stations, respectively, relative to FF stations during the post-exploration phase. During the pre-development sampling, when some discharge had occurred, only 20% lower values were observed at NF versus FF stations. The observed shift during post-development was directly related to increased amounts of drilling discharges.

Rapid deposition of several centimeters of more organic-rich material from drilling discharges at some stations in the NF zone led to an increased rate of bacterial activity with resulting depletion of dissolved oxygen. For example, concentrations of TOC in NF surface sediments at site VK 916 during the post-exploration cruise averaged about one-third greater than found in FF samples or NF samples from the pre-exploration cruise (Figure 1D.5). The maximum value for TOC in FF or NF samples at site VK 916 from the pre-development cruise was 1.9%. Four NF samples and the three DISC samples collected during the post-development cruise at site VK 916 contained >2% TOC with a maximum level of 3.45%. Each of the seven samples with >2% TOC contained >3% Ba.

The thicknesses of layers containing drilling discharges observed during the post-exploration cruise at site VK 916, based on concentrations of Ba and TOC, were ~4 cm in each of the three DS cores collected. This rapidly deposited, thin layer of material promoted depletion of dissolved oxygen in the sediments and a distinct decrease in redox potential as previously described. The apparent impact on the chemical composition of the interstitial water seemed limited to the top few centimeters of the core and was most obvious for concentrations of dissolved ammonia and Mn^{2+}. Concentrations of dissolved ammonia were below detection limits

(<1 µM) in the top of the core from station FF 3 at site VK 916, increasing to ~50 µM at 25 cm. Dissolved ammonia levels of 16 to 40 µM were found in the top 4 cm of the core from station DS 2 at site VK 916, with maximum levels downcore of 70 µM. A somewhat similar comparison was observed for Mn^{2+} at site VK 916 with low Mn^{2+} levels of 10 µM at the top of the core from station FF 3 relative to 200 to 500 µM at station DS 2. No sulfate reduction was discernible in either core; and, the vertical profiles for Fe^{2+} were similar in both cores. Overall, the shift in redox state was readily discernible, yet limited to the top few cm of the sediment column.

John H. Trefry is a Professor of Chemical Oceanography at Florida Institute of Technology where he has been on the faculty for 26 years. He earned his Ph.D. at Texas A&M University. John's areas of research include trace element geochemistry and pollution, material fluxes to the oceans via rivers, and the geochemistry of hydrothermal solutions and deposits at mid-ocean ridges. He is presently active in studying the environmental aspects of offshore oil activities in the Alaskan Arctic and the Gulf of Mexico.

Robert P. Trocine is a Senior Research Associate at Florida Institute of Technology where he has specialized in trace metal analysis for 25 years. He earned B.S. and M.S. degrees in cell and molecular biology from Florida Institute of Technology. His research interests include development of new techniques for the analysis of trace metals in water and suspended particles at extremely low levels.

Michelle L. McElvaine is a recent graduate of Florida Institute of Technology with an M.S. degree in chemical oceanography. She received a B.S. degree from Bradley University in Peoria, Illinois. Michelle has extensive experience with the collection and analysis of sediment interstitial water and the used of probes for MMS study.

Robert D. Rember is a Research Scientist at Florida Institute of Technology where he received his Ph.D. in chemical oceanography. He received a B.S. in chemistry at Mount Allison University in New Brunswick, Canada. His research interests include chemical weathering and transport of dissolved and particulate metals by rivers.

SEDIMENT AND TISSUE HYDROCARBON CHEMISTRY

Thomas J. McDonald and James M. Brooks, TDI-Brooks International

Introduction

During three cruises, sediments were collected for hydrocarbon analysis from four deepwater sites in the northern Gulf of Mexico (GOM):

- Viosca Knoll Block 916 (VK 916) – exploration site
- Garden Banks Block 516 (GB 516) – exploration/development site
- Garden Banks Block 602 (GB 602) – post-development site
- Mississippi Canyon Block 292 (MC 292) – post-development site

Cruise 1B (October/November 2000) was the pre-drilling survey for GB 516 and VK 916. Cruise 2B (July 2001) was the post-drilling survey for GB 516 and the two post-development sites (GB 602 and MC 292). Cruise 3B (August 2002) was the post-drilling survey at VK 916.

Sediment samples were collected at 12 near-field stations and 12 far-field stations at each site. In addition to these routinely collected sediments, three discretionary box-core samples were located in drilling mud and cuttings depositional areas mapped during geophysical surveys. All of the sediment samples were analyzed for the presence of polycyclic aromatic hydrocarbons (PAH) by gas chromatography-mass spectrometry (GC/MS) and synthetic based mud (SBM) by gas chromatography-flame ionization detection.

Two species of deep-water organisms, the isopod *Bathynomous giganteus* and the crab *Geryon quinquedens*, were collected during the July 2001 (Cruise 2B) using traps located at both the near field and far field locations at two of the well locations (GB 602 and MC 292). Both species were analyzed for the presence of polycyclic aromatic hydrocarbons.

Polycyclic aromatic hydrocarbons are widely used as an indicator of petroleum input in environmental samples. PAHs containing condensed rings and simple alkylations (naphthalenes, fluorenes, phenanthrenes, dibenzothiophenes, fluoranthenes, and chyrsenes, etc.) are generally the analytes of interest. PAHs are ubiquitous in the marine environments and can have multiple sources such as petroleum, early diagenesis, coals, combustion, immature/mature sediments, and anthropogenic inputs.

Synthetic hydrocarbons used in SBMs include linear-α-olefins, poly-α-olefins, and internal olefins. They resemble petroleum alkanes except that they contain one or more carbon-carbon double bonds.

Results – Sediments

Viosca Knoll Block 916 – Exploration Site

Sediments from the near-field and far-field stations at the VK 916 location were sampled during Cruise 1B (October/November 2000) and Cruise 3B (August 2002). In addition to the box cores collected at the near-field and far-field locations, three discretionary box cores were located in suspected SBM depositional areas during Cruise 3B. These box cores were sampled in 2-cm intervals from 0-cm to 10-cm.

The SBM concentration in the Cruise 1B near-field sediments ranged from 2.4 to 6.6 µg/dry g and the far-field sediments ranged from 4.3 to 7.2 µg/dry g. The SBM concentration in the Cruise 3B near-field sediments ranged from 7.5 to 47,920 µg /dry g and the far-field sediments ranged from 2.2 to 111 µg/dry g. The total PAH concentration in the Cruise 1B near-field sediments ranged from 159 to 294 ng/dry g and the far-field sediments ranged from 175 to 388 ng/dry g. The total PAH concentration in the Cruise 3B near-field sediments ranged from 244 to 275 ng/dry g and the far-field sediments ranged from 181 to 399 ng/dry g. Four of the Cruise 3B near-field locations could not be analyzed for PAH due to the high concentrations of SBM in the sediments.

Using the Tukey's HSD test, there was no significant difference among the sediment SBM concentrations at Cruise 1B near-field stations, Cruise 1B far-field stations, and the Cruise 3B far-field stations. However, a significant difference was detected between the sediment SBM concentrations in Cruises 1B and 3B near-field stations (the post-drilling concentrations were higher). There was no significant difference among the sediment PAH concentrations at the near-field stations and far-field stations during both cruises.

Sediment SBM concentrations in the three discretionary box-core samples all displayed high concentrations (>10,000 µg/dry g) in the 0-2 cm section. The SBM concentration decreased with depth in all three box cores. The sediment PAH concentrations in discretionary box-cores generally decreased with depth but all of the 0-2 cm sections could not be analyzed due to the high SBM concentrations.

Garden Banks Block 516 – Exploration/Development Site

Sediments from the near-field and far-field stations at the GB 516 location were sampled during Cruise 1B (October/November 2000) and Cruise 2B (July 2001). In addition to the box cores collected at both the near-field and far-field locations, three discretionary box cores were located in suspected SBM depositional areas during Cruise 2B. These box cores were sampled in 2-cm intervals from 0-cm to 10-cm.

The SBM concentration in the Cruise 1B near-field sediments ranged from 5.4 to 25,131 µg/dry g and the far-field sediments ranged from 2.0 to 9.4 µg/dry g. The SBM concentration in the Cruise 2B near-field sediments ranged from 7.0 to 29,167 µg/dry g and the far-field sediments ranged from 3.0 to 7.0 µg/dry g. The total PAH concentration in the Cruise 1B near-field sediments ranged from 194 to 3470 ng/dry g and the far-field sediments ranged from 115 to 444 ng/dry g. The total PAH concentration in the Cruise 2B near-field sediments ranged from 142 to 431 ng/dry g and the far-field sediments ranged from 152 to 250 ng/dry g.

Using the Tukey's HSD test a significant difference was detected between the sediment SBM concentrations at near-field and far-field stations during both cruises. Near-field concentrations were higher than far-field concentrations on both cruises. There was no significant difference between the sediment PAH concentrations at the near-field and far-field stations during both cruises.

Sediment SBM concentrations in the three discretionary box-core samples all displayed high concentrations (>5,000 µg/dry g) in the 0-2 cm section. The SBM concentration generally decreased with depth in all three box cores although two of the discretionary box cores had significant (>1,000 µg/g dry) SBM concentration even 10-cm. The sediment PAH concentrations in discretionary box-cores generally decreased with increasing depth. The sediment PAH concentrations in DC-B2 had elevated levels ranging from 23,840 ng/dry g at 0-2 cm to 1,667 ng/dry g at 8-10 cm. The naphthalenes, biphenyl, and acenaphthene dominated the total PAH in these samples. The source of these PAHs is suggested to be from some other contaminant from the drilling activity as SBM does not contain PAHs.

Garden Banks Block 602

Sediments from the near-field and far-field sampling stations at the GB 602 location were sampled during Cruise 2B (July 2001). In addition to the box cores collected at both the near-field and far-field locations, three discretionary box cores were located in suspected SBM depositional areas. These box cores were sampled in 2-cm intervals from 0-cm to 10-cm

The SBM concentration in the Cruise 2B near-field sediments ranged from 462 to 13,792 µg/dry g and the far-field sediments ranged from 3.0 to 10.0 µg/dry g. The total PAH concentration in the Cruise 2B near-field sediments ranged from 132 to 552 ng/dry g and the far-field sediments ranged from 93.8 to 143 ng/dry g.

Using the Tukey's HSD test, a significant difference was detected between the sediment SBM concentrations in the Cruise 2B near-field and far-field stations (near-field concentrations were higher). There was no significant difference between the sediment PAH concentrations in the Cruise 2B near-field and far-field stations.

Sediment SBM concentrations in the three discretionary box-core samples all displayed high concentrations (>900 µg/dry g) in the 0-2 cm section. The SBM concentration generally decreased with depth in all three box cores. The sediment PAH concentrations in discretionary box cores generally decreased with increasing depth.

Mississippi Canyon Block 292

Sediments from the near-field and far-field sampling stations at the MC 292 location were sampled during Cruise 2B (July 2001). In addition to the box cores collected at both the near-field and far-field locations, three discretionary box cores were located in suspected SBM depositional areas during Cruise 2B. These box cores were sampled in 2-cm intervals from 0-cm to 10-cm.

The SBM concentration in the Cruise 2B near-field sediments ranged from <1.4 to 2,408 µg/dry g and the far-field sediments ranged from <1.4 to 19.0 µg/dry g. The total PAH concentration in the Cruise 2B near-field sediments ranged from 174 to 743 ng/dry g and the far-field sediments ranged from 210 to 745 ng/dry g.

Using the Tukey's HSD test a significant difference was detected between the sediment SBM concentrations in Cruise 2B near-field and far-field stations. No significant difference was detected between the sediment PAH concentrations in Cruise 2B near-field and far-field locations.

Sediment SBM concentrations in the two of three discretionary box-core samples displayed elevated concentrations (>600 µg/dry g) in the 0-2 cm section. The first discretionary box-core samples displayed concentrations slightly above background (>50 µg/dry g) in the 0-2 cm section The SBM concentration generally decreased with depth in all three box cores. The sediment PAH concentrations in discretionary box-cores generally decreased with increasing depth.

Results – Tissue Samples

Two species of deep-water organisms, the isopod *Bathynomous giganteus* and the crab *Geryon quinquedens*, were collected during the July 2001 (Cruise 2B) using traps located at both the near field and far field locations at two of the well locations (GB 602 and MC 292). Three organisms from each of the sampling locations were selected at random. The internal organs were removed, combined, and homogenized into one sample. Both species were analyzed for the presence of polycyclic aromatic hydrocarbons.

PAH body burden concentrations ranged from 38.6 to 416 ng/g dry. Using the student *t-test* no significant difference was found between the total PAH body burden concentrations in the two deepwater organisms (α= 0 .05). No significant difference was also found between the total PAH body burden concentrations at near-field and far-field stations (α= 0 .05).

Discussion

The lateral distribution and concentrations of SBMs in the deep-sea sediments during this study were the direct result of drilling activities. The lateral distribution and concentration of the SBMs in the sediments was extremely heterogeneous. This patchy distribution of SBMs in marine sediments has been reported in other studies (McIlroy 1998; Terrens et al. 1998; Gallaway et al. 1997; Fechhelm et al. 1999). It has been suggested that the cuttings discharge depth, rate and total mass of discharge, currents, and storm currents are the main determinants of the dimension of the cuttings piles near offshore platforms (Neff et al. 2000).

One way to assess the significance of the PAH contaminant load in sediments is to compare the concentrations measured in the near-field and far-field locations with previous MMS studies and the National Oceanic and Atmospheric Administration (NOAA) Status and Trends Mussel Watch Program (Brooks et al. 1989). The sediment PAH values detected at the four deepwater sites are similar to the concentrations that were detected in the sediments collected during the GOOMEX Study (Kennicutt et al. 1996) and an American Petroleum Institute study (Brooks et. al. 1989). The concentration ranges of the detected PAHs in the near-field and far-field locations were similar, suggesting that the concentrations of PAHs in the sediments was not significantly increased due to drilling. However, there was a significant increase in the concentration of PAHs in the second discretionary box core from GB 516 during Cruise 2B. Also, some samples from VK 916 near-field locations on Cruise 3B could not be analyzed for PAH due to the high concentrations of SBM in the sediments.

The total PAH body burden concentrations in the two test species of deep-water organisms, the isopod *Bathynomous giganteus* (152 ng/dry g ± 109 ng/dry g) and the crab *Geryon quinquedens* (110 ng/dry g ± 45.5 ng/dry g) collected during Cruise 2B from the near-field and far-field sites in GB 602 and MC 292 were similar in concentration to other benthic samples collected during the GOOMEX Study (Kennicutt et al. 1996). Even though the concentrations of the majority of the individual PAH analytes were at or below the MDL, the presence of contaminants in the internal organs does represent exposure to mature hydrocarbons. The PAH contaminants detected in the internal organs of these two species is probably due to their intimate relationship with the sediments.

References

Brooks, J.M., M.C. Kennicutt II, T.L. Wade, A.D. Hart, G.J. Denoux, and T.J. McDonald. 1989. Hydrocarbon distributions around a shallow water multiwell platform. Environmental Science and Technology 24(7):1079–1085.

Fechhelm, R.G., B.J. Galaxy, and J.M. Farmer. 1999. Deepwater sampling at a synthetic drilling mud discharge site on the outer continental shelf, northern Gulf of Mexico. In: 1999 SPE/EPA Exploration and Production Environmental Conference. SPE 52744. Austin, TX 28 February–3 March. Society of Petroleum Engineers. Richardson, TX. Pp. 509–513.

Gallaway, B.J., R.G. Fechhelm, G.F. Hubbard, and S.A. MacLean. 1997. Opportunistic sampling at a synthetic drilling fluid discharge site on the continental slope of the northern Gulf of Mexico: The Pompano development. Report by LGL Ecological Research Associates, Inc. for BP Exploration, Inc., Houston, TX.

Kennicutt II, M.C., R.H. Green, P. Montagna, and P.F. Roscigno. 1996. Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX), Phase I: Sublethal responses to contaminant exposure—Introduction and overview. Canadian Journal of Fisheries and Aquatic Science 53:2540–2553.

McIlroy, W. 1998. Review of BHP's experience into the persistence of drilling fluid pollutants. In: International Workshop on Drilling Fluids Exotoxicology and Biodegradation. Curtin University, Perth, Western Australia, 8–9 October. Pp. 121–134.

Neff, J.M., S. McKelvie, and R.C. Ayers, Jr. 2000. Environmental impacts of synthetic based drilling fluids. Report prepared for MMS by Robert Ayers & Associates, Inc., August 2000. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-064. 118 pp.

Terrens, G.W., D. Gwyther, M.J. Keough and R.D. Tait. 1998. Environmental assessment of synthetic based drilling mud discharges to Bass Strait, Australia. In: 1998 SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Development. Caracas, Venezuela, 7–10 June. SPE 46622. Society of Petroleum Engineers, Inc. Richardson, TX. Pp. 1–14.

Dr. Thomas J. McDonald received his Ph.D. in oceanography from Texas A&M University in 1988. His main are of interest is in hydrocarbon chemistry and is currently a Senior Project Manager at TDI-BI.

Dr. James M. Brooks is President of TDI-Brooks and a Director of B&B Labs. Dr. Brooks has been a Project Director on numerous federal projects for NOAA, EPA, ONR, MMS, NSF, USFWS, and other agencies, he has extensive experience in the management of large environmental and oceanographic projects as well as the technical competency in these areas. He has academic credentials consisting of 200 peer-review publications and chairman of 19 M.S. and Ph.D. committees. He is a member of the Graduate Faculty at Texas A&M University in the Faculty of Toxicology. This academic position is strictly to support graduate student research and pursue research-oriented projects.

SEDIMENT PROFILING IMAGERY

Robert Diaz, Virginia Institute of Marine Science

Sediment profile cameras were used to characterize bottom sediments for physical and biogenic features. At Garden Banks 516, areas of poor habitat quality were observed in vicinity of platforms on both cruises. Extensive areas of thin RPD layer associated with azoic conditions, microbial mats and sulphidic deposits, indicative of hypoxia, were present at Nearfield stations. Mats not observed in post-drilling survey; however, transects were not the same. Overall, there was little or no bioturbating macrofauna present. By contrast, Farfield stations had better habitat quality than Nearfield stations. At Viosca Knoll 916, RPD depths were about 1.0 cm with no azoic conditions observed.

Stage I-III Successional stage fauna dominated Nearfield and Farfield stations. Both Nearfield and Farfield stations had high benthic habitat quality. At the post-development Garden Banks 602 site nearly all Nearfield stations appeared to be impacted by oil and gas development activities. Multiple layers of darker gray sediments were present and likely associated with drilling muds and cuttings. Farfield stations were reddish-brown over light grayish clayey sediment and appeared to represent ambient sediment conditions.

Based on RPD layer depth, bottom-water dissolved oxygen may have been low at some Nearfield and Farfield stations. Neither Nearfield or Farfield stations appeared to have well developed bioturbating macrofauna communities. At the post-development Mississippi Canyon 292 site, 82% of Nearfield stations had reddish-brown surficial sediments overlaying light grayish clayey sediments with 18% of Nearfield stations having darker gray layers that might contain drilling muds and cuttings. All Farfield stations were reddish-brown over light grayish clayey sediment and appeared to be ambient sediments. Based on RPD layer depth, bottom-water dissolved oxygen may have been low at some silty-clay Nearfield stations, Neither Nearfield or Farfield stations appeared to have well developed bioturbating macrofauna communities.

Possible causes for the degraded benthic habitats at these four sites were sediment disturbance from oil/gas activities, sedimentation from oil/gas activities, “Ponded” hypersaline water, ebullition of natural gas or oil seeps, historical discharge from past drilling events, and low dissolved oxygen events.

Dr. Robert Diaz is a Professor at the Virginia Institute of Marine Science. Dr. Diaz’s research interests focus on understanding organism-habitat interactions and trophic dynamics within ecosystems from estuaries to the deep-sea. Recently he has focused on organism-habitat interaction on the inner continental shelf to predict how sand dredging will affect fish and invertebrate communities. He also developed methods for mapping benthic habitat that would be useful for quantifying essential fish habitat and assessing potential impacts from disturbance.

MACROFAUNAL IMAGE ANALYSIS

Robert S. Carney, Louisiana State University

Bottom images were taken during 37 deployments of a towed camera sled at a series of nearfield and farfield sites on the upper slope of the Gulf of Mexico (GOM) at Vioska Knoll 916, Garden Banks 516, Garden Banks 602, and Mississippi Canyon 292. A total of 16,770 images were subjected to a three-aspect content analysis: fauna, color, and texture in an effort to increase the information yield from the images. Only 1,147 images contained fauna; sessile cnidarians were most abundant, followed by shrimp, ophiuroids, fish, crabs, and gastropods. The low counts were due to the small area of the seafloor imaged, 0.22 m^2. These close-up images did not reveal smaller fauna. Only two statistically significant faunal results emerged. Fish were more abundant in the nearfield images and ophiuroids in the farfield. These results may reflect actual abundance or behavior differences. Color analysis found a very consistent relationship between surficial sediment hue and proximity to activity. Sediments in drilled areas were gray to black and often supported bacterial mats. Subjectively, there were textural differences between sites and within tows, but simple statistical evaluation of texture did not capture that variation. In the future, similar content analysis of high-resolution digital images should replace more cumbersome film-based surveys.

Dr. Robert Carney is a biological oceanographer in the Coastal Ecology Institute and Department of Oceanography and Coastal Sciences at Louisiana State University. He works broadly in benthic ecology with special emphasis on deep margin systems, cold seeps, and oil & gas related environmental issues. He has participated in numerous research cruises in the Atlantic, Pacific, and Gulf of Mexico, beginning in 1967. He began deep submersible research in 1975. He received a B.S. in zoology from Duke (1967), an M.S. in oceanography from Texas A&M (1971) following military service, and a Ph.D. in oceanography from Oregon State (76). Professionally, he has been a Smithsonian Fellow, director of Biological Oceanography at NSF, director of Coastal Ecology at LSU, and director of the joint MMS/LSU program, Coastal Marine Institute. He has participated in several MMS projects in the Gulf, off California, and in Panama. Most recently, he has been appointed U.S. coordinator for CoMargE, an international effort in Continental Margin Ecology.

SESSION 1E

DEEPWATER TECHNOLOGY

Chair: **Mike Conner, Minerals Management Service**

Co-Chair: **Elizabeth Komiskey, Minerals Management Service**

OVERVIEW OF DEEPWATER TRENDS IN THE GULF OF MEXICO

Richie D. Baud and Ronald C. Bowser, Minerals Management Service

Deepwater hydrocarbon exploration and development in the Gulf of Mexico (GOM) have grown immensely over the past decade and continue to show great promise. Most of the active GOM leases are in water depths greater than or equal to 1,000 ft, and over half of these deepwater leases are in water depths greater than 5,000 ft.

Since the first deepwater well was drilled in 1975, there has been a steady progression of drilling into deeper and deeper waters. As wells are drilled in deeper waters, discoveries and development projects progress outward into the GOM, expanding the infrastructure with each new deepwater facility. This expanding infrastructure creates opportunities to develop marginal deepwater fields that would not have been economically feasible just a few years ago.

The average deepwater oil well completion produces at about 20 times the rate of a shallow-water well, and the average deepwater gas well completion produces at about eight times the rate of its shallow-water counterpart. The GOM now accounts for about 30% of the nation's domestic oil production and 25% of the nation's gas production. Deepwater oil and gas production continue to increase, making the deepwater GOM the crown jewel in the nation's domestic energy portfolio.

Numerous deepwater projects come online each year, and several massive projects, such as Mad Dog, Atlantis, and Thunder Horse, are coming online soon. As a result of these and other new projects, deepwater GOM oil production is expected to rise to record levels within the next few years. Although production from individual fields typically declines after a brief ramp-up period, the Minerals Management Service forecasts that GOM production can be sustained at these record-high rates with continued exploration and development from deepwater operators.

References

Melancon, J.M., R.D. Baud, A.G. Boice, R. Bongiovanni, T. DeCort, R. Desselles, E.G. Kazanis. 2004. Gulf of Mexico Oil and Gas Production Forecast: 2004–2013. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Report MMS 2004-065. 27 pp.

Richardson, G.E., L.S. French, R.D. Baud, R.H. Peterson, C.D. Roark, T.M. Montgomery, E.G. Kazanis, G.M. Conner, and M.P. Gravois. 2004. Deepwater Gulf of Mexico 2004: America's Expanding Frontier., Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Report MMS 2004-021. 150 pp.

Richie Baud is a supervisor in the Minerals Management Service's Office of Production and Development, Gulf of Mexico OCS Region. He holds a B.S. degree in geophysics from Bowling Green State University and an M.S. in geophysics from Purdue University. Richie has authored numerous publications and has 16 years of Gulf of Mexico experience between the MMS and industry.

Ronald Bowser is a section chief in the Minerals Management Service's (MMS) Office of Production and Development, Gulf of Mexico Outer Continental Shelf (OCS) Region. He holds a B.S. degree in geology with a minor in environmental science from Elizabeth City State University in North Carolina. Ronald has 28 years of experience with MMS and United States Geological Survey working in the Atlantic and Gulf of Mexico OCS.

ADVANCES IN SUBSEA PROCESSING

Larry D. Forster, Shell Exploration & Production Co., New Orleans

Subsea Processing is a newly developing technology—it has not been deployed in the Gulf of Mexico (GOM) as yet—which involves active conditioning of the wellstream or injected fluids, on the seabed, or in a well. Subsea processing adds value to oil and gas projects in several areas: by pressure boosting to enable or accelerate certain projects or to increase ultimate recovery; by de-bottlenecking topsides facilities by moving separation and related equipment off the topsides and onto the seabed. By pressure boosting and/or dealing with flow assurance issues at the seabed, subsea processing can enable long offset projects, subsea wells which are located multiple miles from the respective hosts. Finally, subsea processing can assist in gas dehydration/dewpointing, and EOR support, such as providing heating for heavy oil recovery.

The key technologies involved in subsea processing include first of all, pumping, single-phase or multiphase (twin screw or centrifugal,) two-phase or three-phase separation, gas compression, and gas processing (e.g., dehydration.) Certain supporting technologies are key to the success of subsea processing systems: power distribution (cable, connectors, and variable speed drives) to provide high power over potentially long distances; heavy lift systems (some of the equipment components/packages may weigh in the 70- to 100-ton range), and the subsea architecture, to package the equipment so that deploying the equipment to the seabed is done efficiently; so that operating and maintaining the equipment and diagnosing problems can be performed on a system basis; and so that retrieving equipment for repair can be performed quickly and efficiently when necessary.

System concepts for pressure boosting systems for oil applications are beginning to take several forms. Some system concepts are akin to "artificial lift" systems such as riser base gas lift (continuous gas lift), and blowcase systems (intermittent gas lifting in a cyclic mechanism.) Electrical (or hydraulic) submersible pumps (ESP/HSP) are under consideration as boosting system alternatives, either in-well or in a caisson-based dummy well. Lastly, single-phase or multiphase pumping systems utilize either the centrifugal or positive displacement (twin screw) pump systems installed on mudline based deployment systems. The use of dummy well or caisson systems offers a simple yet innovative form of separator. Petrobras has developed and piloted a Vertical Annular Separation and Pumping System (VASPS) which includes helical guides in the upper portion of the caisson to improve separation performance.

As previously stated at the beginning, the actual applications to date have been outside the GOM, and many of the further design efforts are aimed beyond the U.S. region. The Ormen Lange gas project in 1,100 meters of water in the Norwegian North Sea is developing concepts and qualifying key components of a gas compression facility (which would be operational by 2015). Developments here are being eyed by others for potential applications elsewhere, but several years will be required to perfect the technology. Qualification depends on two factors: proof of sufficient reliability and of suitability for the marine environment.

Key elements of subsea gas compression systems include

- The compressors themselves, wet-gas and dry-gas versions
- Separator/scrubbers
- Variable speed drives
- Controls systems
- Electrical cables, connectors and penetrations
- Coolers/valving

Separation has seen a pilot application at the Norsk Hydro Troll gas field, in which separated water was reinjected into an injection well near the equipment site, while oil and gas were produced back to the Troll host. This pilot application was primarily for host de-bottlenecking, to add more water handling equipment off the topsides facility. A gravity separation concept with cyclonic internal features to enhance the gas/liquid separation was utilized here. Design concepts for subsea separation are including novel internal schemes to reduce size and weight of the separation equipment. In particular, a Gas to Liquid Cylindrical Cyclone (GLCC) and a Liquid to Liquid Cylindrical Cyclone have been under evaluation at the University of Tulsa.

Risks have been recently evaluated for subsea processing schemes as opposed to topsides. The former pose lower risk to personnel than the latter, due to equipment installed remotely on the seabed, but somewhat higher environmental risk due to the increased number of leak paths in subsea equipment. No show stoppers have been envisaged since the underlying philosophy behind subsea processing is that the flow stream is a closed system, with no planned discharge into the environment.

So where might subsea processing be applied? Where has it been applied already? First to see application are likely to be riser-base separation and pumping systems as well as multiphase pumping systems. Applications have become apparent for boosting and/or separation to increase production for oil fields whose water content has risen to significant levels. Non-geopressured fields, particularly with long offsets, and also heavy and/or viscous oils will require boosting to either enable the projects or enhance recovery. Fields such as the Amerada Hess Ceiba field in Equatorial Guinea, will likely see additional use of centrifugal pumping systems. Agip, in the Balmoral field, has recently applied twin-screw multiphase pumping in shallow water of the North Sea, and Santos Mutineer also applied helicoaxial multiphase pumping in shallow water offshore Australia, in the latter part of 2004.

So what are the focus areas to get this technology where it needs to be? Specific programs are underway for 1) riser base separation and pumping, particularly for ultradeep water; 2) low cost, moderate depth light oil pumping; 3) gas compression (with Ormen Lange as a key driver); and lastly, 4) flow assurance issues associated with long offset production.

Other issues remain, particularly with supporting technologies, such as control and measurement systems and the deployment and retrievability related to the subsea architecture issues mentioned previously. For an emerging technology, however, the focus needs to be on the basics of pumping and separation, ensuring the concepts are viable, and finally with attention to enhancements. Piloting will no doubt point to further issues which can be uncovered in no other way. We thus hope to see successful installations, in the GOM and elsewhere, in the not-too-distant-future, as new fields approach and as existing fields age, both presenting new challenges for the technology.

Larry Forster is a Staff Facilities Engineer with Shell Exploration & Production Co., working in Technology Planning and Implementation in New Orleans, Louisiana. He has been involved in subsea systems for most of his twenty-one years with Shell, working on the early design concepts for deepwater, and operationalizing the systems in the Gulf of Mexico. Prior to his recent involvement with Subsea Processing Systems, he worked on a special assignment to achieve faster project execution times for subsea projects.

SUBSEA HIGH INTEGRITY PRESSURE PROTECTION SYSTEMS (HIPPS)

Christopher Lindsey-Curran, British Petroleum

Some of BP's prospects in the GOM are expected to have shut-in pressures and reservoir temperature near or in excess of 12.5 ksi and 250 °F (i.e. as in BP's Thunder Horse field) combined with water depths of up to 10,000 ft. BP's experience in HPHT (High Pressure, High Temperature) design has demonstrated that the industry may be at the limits of thick flowlines and risers (design, procurement, and welding) for such developments.

One new technology, which is seen as a key enabler, is subsea HIPPS (High Integrity Pressure Protections Systems). Subsea HIPPS safely isolate downstream flowlines and risers from the high tubing shut-in pressure (SIP) and therefore allow the facilities to be designed to more conventional pressures. A small number of subsea HIPPS have been used in or are under consideration for North Sea and GOM projects at lesser pressures, temperatures and water depths. To date no subsea HIPPS have been employed in the GOM. Furthermore, no subsea HIPPS have yet been used in deepwater or for developments tied-back to floating production vessels (FPV).

HIPPS Overview

What is HIPPS?

HIPPS (High Integrity Pressure Protection Systems) are Safety Instrumented Systems (SIS) which isolate downstream facilities from an overpressure, upset condition developing upstream. The initiation of the overpressure can be from upstream (loss of control of a well or pump) and/or downstream (process trip, inadvertent valves closure, hydrate or other blockage). In the event of a high-pressure event, the HIPPS should isolate the flowline and/or riser from the high pressure source. Therefore downstream flowlines, risers etc. can be rated for a lower pressure than the full Shut-In Pressure (SIP) of the upstream well or pump. Subsea HIPPS systems can either be located at individual wellheads or at a commingled location such as a subsea manifold. In the latter case the upstream facilities must be fully rated to the SIP.

HIPPS is an additional isolation layer within the existing pressure protection layers which may include downhole valves, wellhead valves, manifold valves, SSIV (Subsea Isolation Valves). As such HIPPS should not be regarded as a single safety system but part of a series of isolation systems that protect lower-rated downstream facilities from the source of high pressure.

HIPPS generally comprise initiators (pressure transducers), controllers (logic solvers) and final elements (valves). HIPPS must achieve very high levels of reliability; the required reliability is expressed as a Safety Integrity Level (SIL) or probability of failure on demand (PFD). SIL levels typically range from SIL1 to SIL4; with the SIL4 giving the lowest PFD. Subsea HIPPS are likely to be required to achieve SIL2 or more probably SIL3. Such high SIL levels will typically require high integrity and high availability coupled with redundancy (fault tolerance), remote communications, autonomous shutdown functions, and regular testing and monitoring.

To date a small number of subsea HIPPS have been installed or are under consideration in the North Sea. These are

- Shell Kingfisher
- Statoil Gullfaks
- Shell Penguins
- BG Juno (operated by BP)
- BP Rhum (under construction)
- Statoil Kristin (under construction)

HIPPS Components

The basic components of a subsea HIPPS are illustrated by a typical manifold system shown in Figure 1E.1.

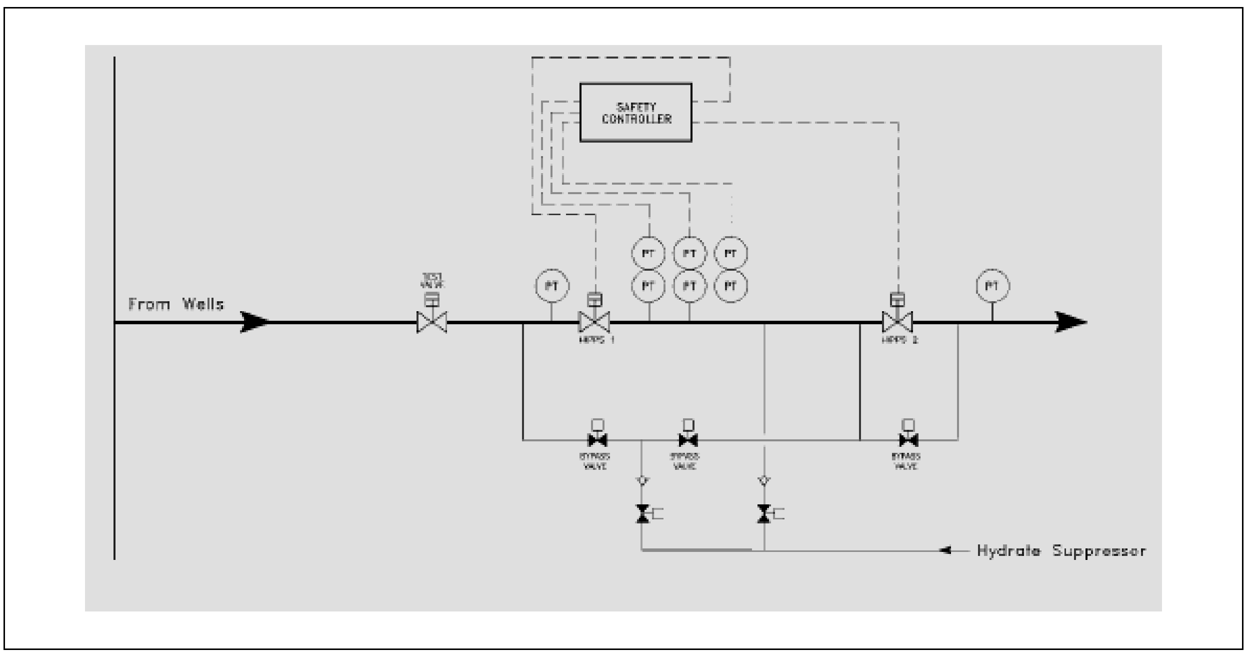


Figure 1E.1. Subsea HIPPS manifold system.

The system comprises HIPPS valves located on the manifold header, pressure transducers and a HIPPS safety controller.

<u>Pressure Transducers</u>. The figure indicates dual banks of three pressure transducers located between the valves. The number of transducers and their voting systems are a function of required reliability and fault tolerances.

<u>HIPPS Controller</u>. All HIPPS requires an autonomous controller which monitors the pressure transducers. The controller closes the HIPPS valves if a high-pressure event is detected. The controller should allow operational testing to be performed.

HIPPS Valves. The HIPPS valves comprise the final elements which isolate the high pressure hazard. The figure indicates two HIPPS valves which would be typical of a SIL3 rating. An upstream test valve is also shown to allow operational testing by pressuring the section between the test valve and the HIPPS valve(s).

A test valve may be required to allow operation testing. The test valve is generally immediately upstream of the HIPPS valve but could be located immediately downstream. The test valve is often of identical specification to the HIPPS valves.

Testing and Bypass Facilities. Any SIS must include facilities for allowing frequent, effective testing. Subsea HIPPS generally utilize a hydrate suppressor (e.g. methanol) injection system to induce pressure between the HIPPS and the upstream test valve, thereby tripping the HIPPS system. If required, the system may be configured to allow valve leakage rates to be measured.

HIPPS in GOM

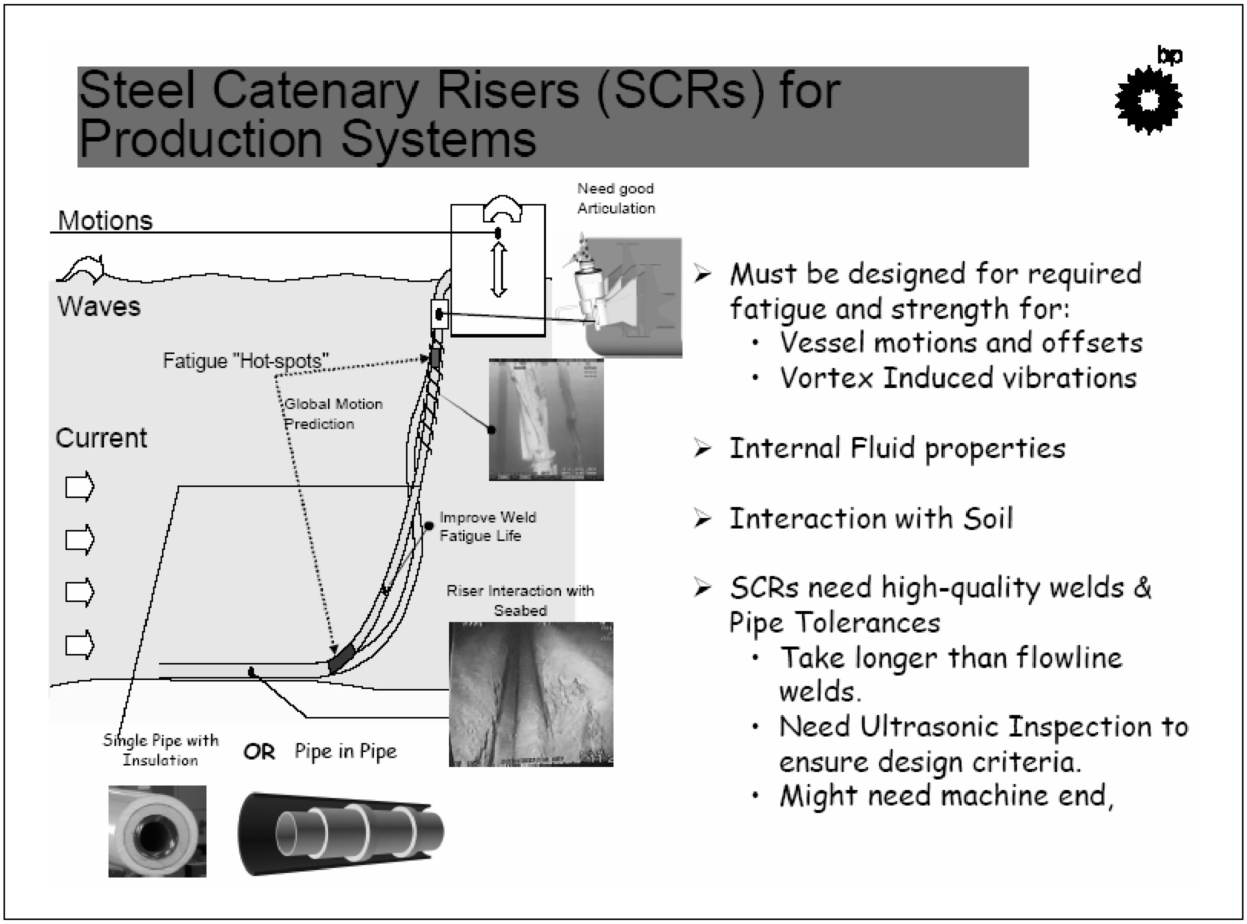
HIPPS is essential to the development of deepwater HPHT fields (> 12.5 ksi) and should be regarded as a priority item for development. HIPPS will also be required to enable existing pipeline infrastructure to be utilized.

For HPHT prospects at 12.5 ksi to 20 ksi, a no HIPPS pipe-in-pipe solution capable of resisting full shut-in pressure is impractical. The required wall thicknesses are well beyond current manufacturing practices, and welding may not be feasible at these thicknesses; this is combined with installation loads becoming prohibitively high. Even for fields with shut-in pressure of less than 15 ksi, HIPPS may well offer a better engineering solution than the conventional heavy-wall flowline designs.

Christopher Lindsey-Curran has over 26 years' experience of subsea systems, concentrating primarily on subsea production systems. Experience includes shallow water and deepwater systems from around the world, including North Sea, Asia, Australia and Gulf of Mexico. Christopher has a degree in physics from Bristol University and is the founding Chairman of the Society for Underwater Technology's Houston Branch.

SCRs IN HPHT APPLICATIONS

Thanos Moros, British Petroleum



Important Parameters in HPHT SCR Design

Pressure → Wall thickness + Water Depth → Hang Off Loads + Installation

Wall thickness ↓
- Manufacturing, Clad Pipe (if needed)
- Welding & Inspection

Temperature →
- Material Yield Strength
  - Can have 10 ksi + reduction for >250 °F
- Articulations, i.e Flex Joints
- Corrosion rates
- Wet Insulation

Flow Assurance → Cooldown → Insulation → Hydrodynamic OD,
- Affects stability
- Weight to diameter ratio.

Note: For deep water > 4,500 ft, the water depth is not the most critical parameter in the design of an HPHT SCR. The vessel motions and internal fluid properties are.

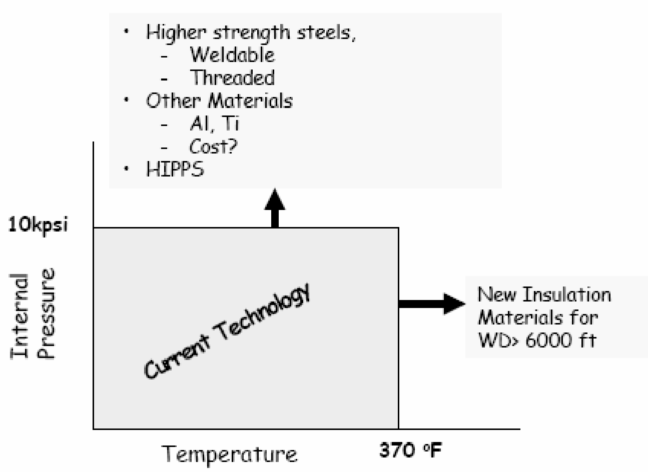
Limits Today

- 40 mm WT for 12" and 35 mm for 8" is the limit for required CTOD and NACE Hardness steels.
- Because of WT pipes are not easy to produce. - Have thickness variability along the length. Impact on fabrication and inspection, AUT.
- Big Effort required on metallic component fabrication, i.e
  - Wye forgings
  - Welding of forgings
- Because of wall thickness, BP had to re-calibrate/tune AUT methods for inspection.
  - Accuracy of the AUT affected by the WT. Still to within 0.5 mm for surface indications.

Limits Today

- For CRA/CLAD and WT > 35 mm over standard Pipe lengths
  - Weld overlay is the only method proved today
  - Careful inspection is required.
- AUT methods for clad pipe require significant changes in the fabrication process to achieve the same accuracy as in CS.
  - OD needs to be **machined**.
  - AUT methods party proven, but accuracy not defined yet for thick wall clad pipes.

What is needed for >10,000 psi and 370 °F



- Understand feasibility of producing Carbon Steel pipes of 70 ksi with WT > 40 mm and NACE requirements.
- Develop Components/Articulations, elastomers for fluid temp > 240 °F.
- Wet insulation for > 380 °F and 2,500 psi (~6,000 ft WD). PIP will eliminate the wet need, but will increase significantly the installation loads.
- Fully develop AUT methods for clad pipe.
- Work with installation contractors to understand capability for deep water (>7,000 ft) and risers of weight > 400 mT. - Current laying capability is at BP's TH loads.

Thanos Moros is a Chartered Mechanical Engineer with extensive expertise in the areas of subsea floating and riser systems, fluid transport, and safety engineering. He is the Riser Systems Team Leader for BP's Thunder Horse Development in the Gulf of Mexico. Thanos has been involved in the coordination of various Industry forums and JIPs both in Europe and the U.S. and he has published over 35 technical papers in journals and conferences. He holds a Ph.D. in mechanical engineering from the University of Cambridge, UK.

TECHNICAL ASSESSMENT OF OPTIONS FOR HANDLING ASSOCIATED GAS FROM DEEPWATER FPSO DEVELOPMENTS IN THE GULF OF MEXICO

E.G. Ward, OTRC/TAMU
A.J. Wolford, A.J .Wolford & Associates
M.B. Mick and L. Tapia, Paragon Engineering
W. Hauser, Minerals Management Service
A.J. Verret, Offshore Operators Committee

Goal

The goal of the project is to conduct a technical assessment of options for handling associated gas for deepwater oil developments in the Gulf of Mexico (GOM). The MMS plans to use the results to review the readiness and safety of gas handling options proposed for deepwater development projects. Results could also be useful for studies pertaining to deepwater oil and gas development in the GOM.

Scope

The project assumes a deepwater oil development from an FPSO and considers various options for handling the associated gas (see Figure 1E.2). Gas-handling technology options that are being studied include export via pipeline (the base case); processes such as LNG, CNG, and GTL that convert the gas to another state or product for export via shuttle tanker; generation of electricity for transmission to shore; and injection and deferred production. FPSO production developments in depths of 6,000 ft and 10,000 ft are being studied with various export destinations for the gas or gas-product (see Figure 1E.3). A range of gas rates are considered for each gas handling technology.

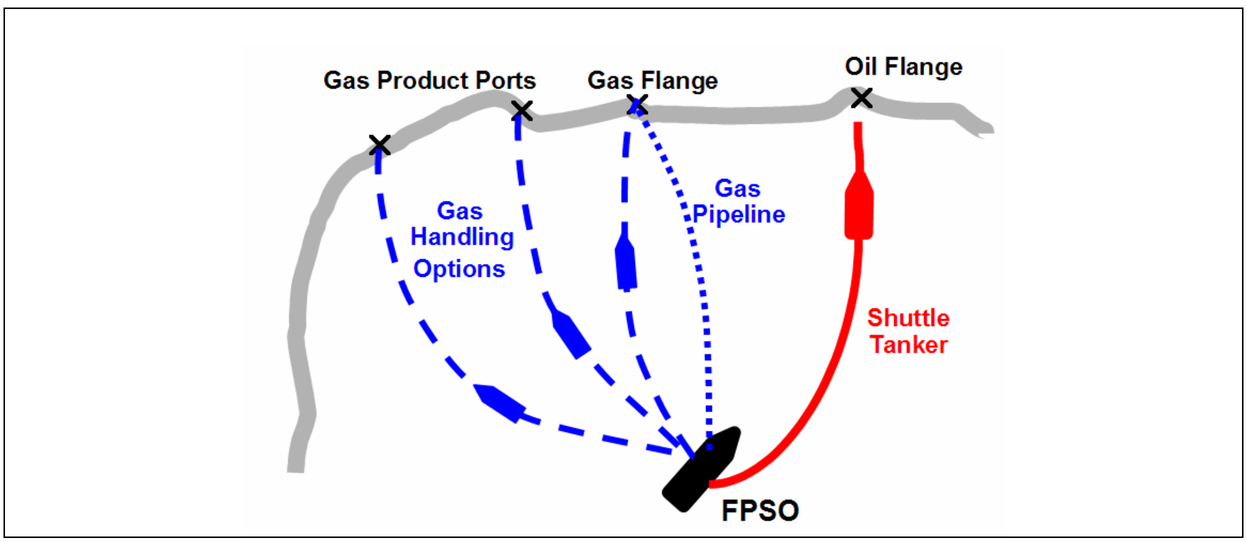


Figure 1E.2. Study scope.

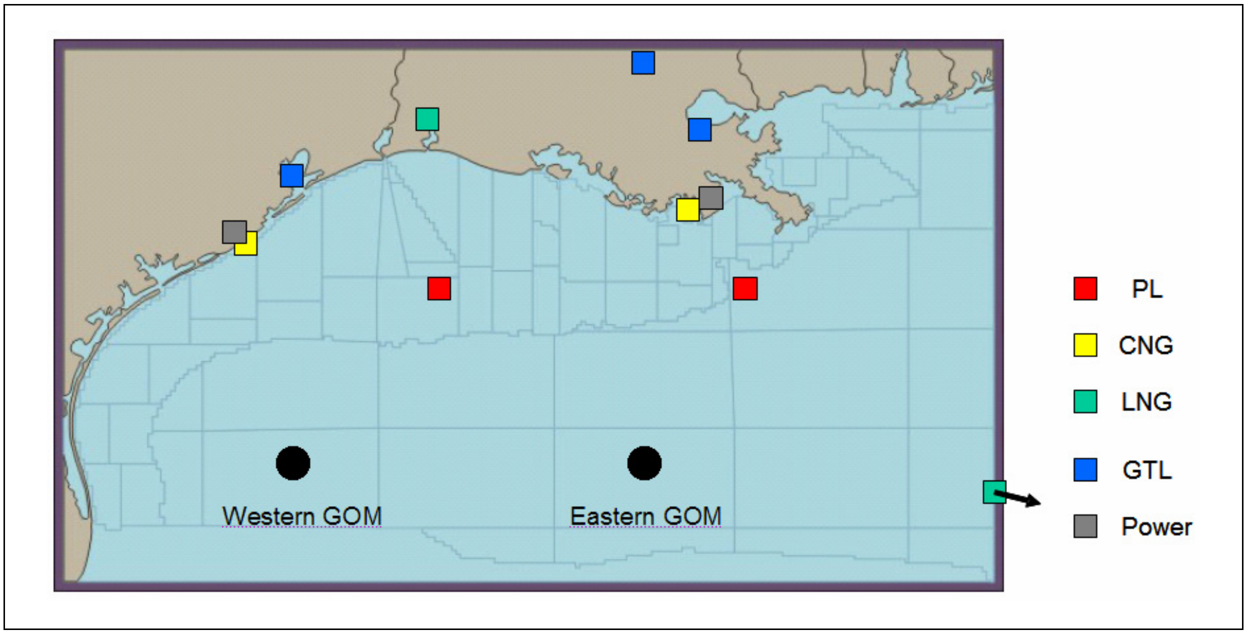


Figure 1E.3. Gas export scenarios.

Figure 1E.4 schematically illustrates the FPSO with oil processing and gas processing systems. A previous study determined that risks for an FPSO development utilizing shuttle tankers to export oil and a pipeline to export gas were similar to the risks of existing deepwater systems in the GOM (TLP's, spars, platforms serving as a hub/host for deepwater production) that use pipelines to export both the oil and gas. Thus, the gas pipeline case is considered to represent a *baseline* for this study. The technical assessment reported on here is focused on the incremental or additional risks and readiness issues posed from the different gas-handling systems being operated on the FPSO (see Figure 1E.5). Figure 1E.6 illustrates the gas handling process steps.

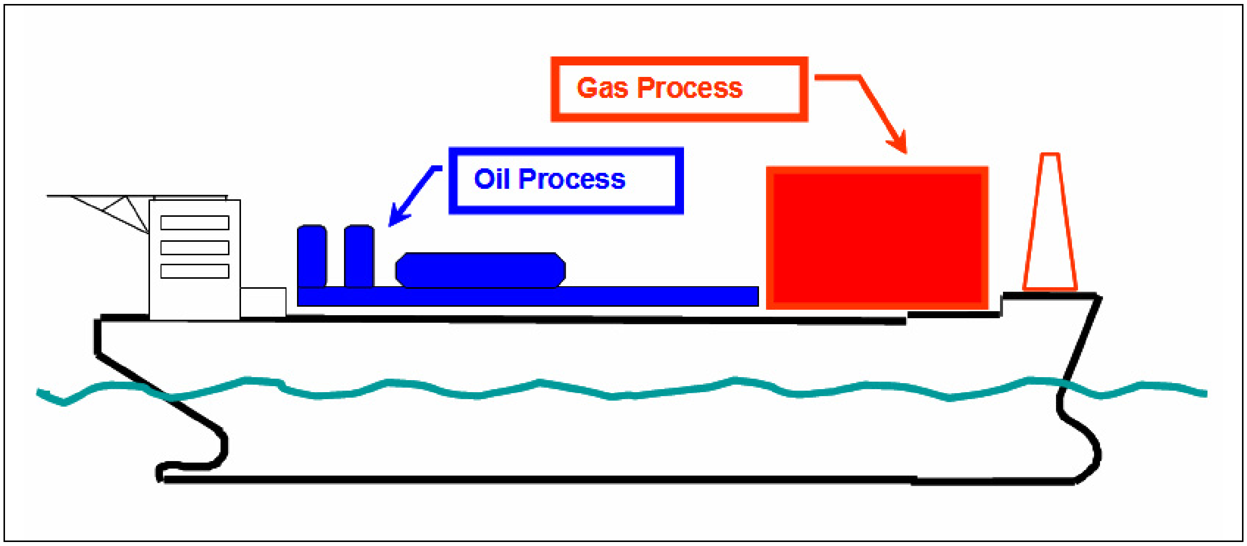


Figure 1E.4. FPSO with gas handling process.

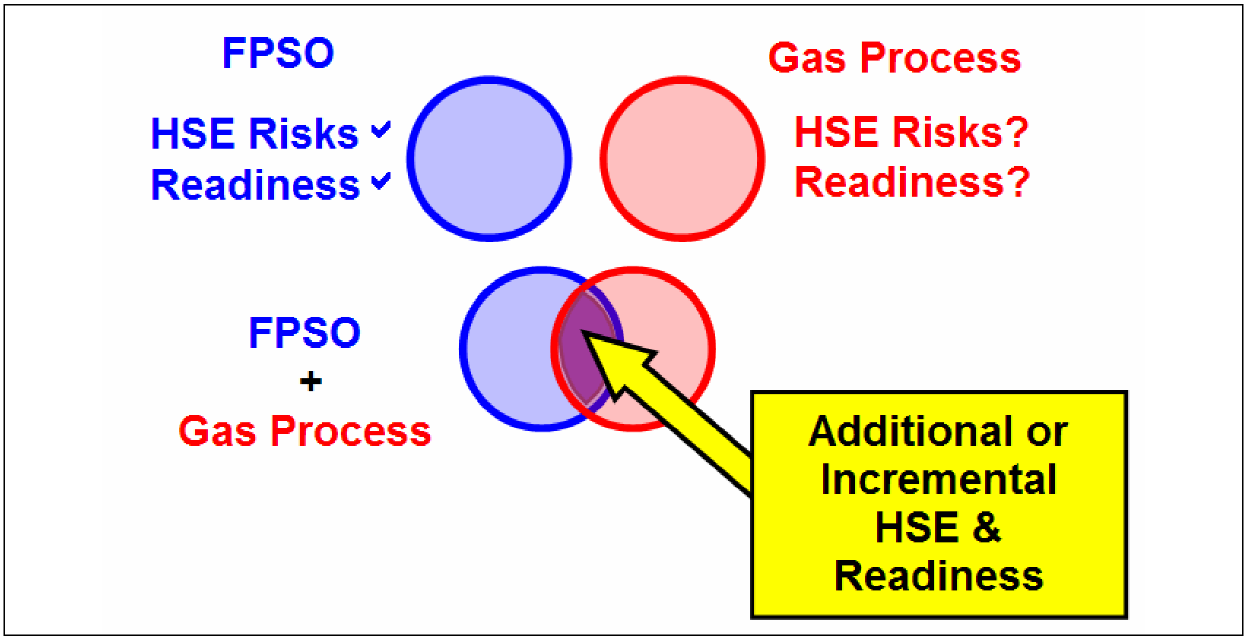


Figure 1E.5. Assessment focus.

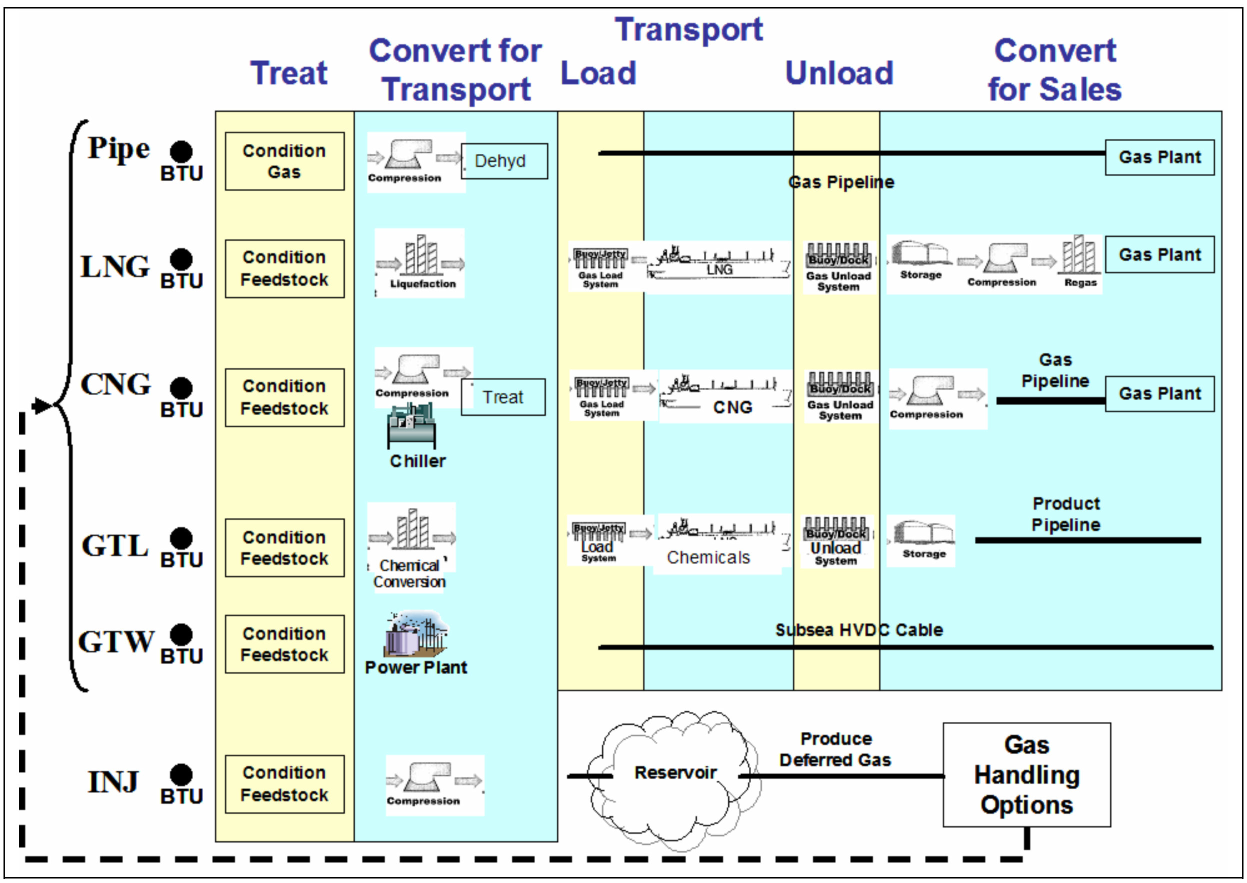


Figure 1E.6. Gas-handling process steps.

Technical Assessment

The technical assessment is addressing

- Technical and regulatory readiness. Key *readiness challenges* and estimates of the years to "project ready" status for each challenge are identified.
- HSE risks. Key *hazards* and potential *consequences* are identified. These *hazards* and *consequences* reflect the HSE risks being considered in this assessment, i.e., risks of fatalities and damage to the environment. A risk matrix is used to rank the *severity* and *likelihood* of consequence and determine a risk level.
- Costs. The incremental CAPEX and OPEX are being estimated to illustrate the feasibility of a particular technology for a given production scenario. These costs are over and above the costs associated with installing and operating the FPSO and the shuttle tankers exporting the oil.
- Efficiency. The overall Process Efficiency is being estimated. This efficiency is defined as BTUs delivered to sales or transfer point divided by the BTU content of the associated gas produced.

Workshops

The assessment of each gas-handling technology is being addressed in a separate workshop. Invited workshop attendees include gas technology and marine experts, representatives for the MMS and industry, members from the steering committee, and representatives from class societies. The goal of the workshop is to develop a consensus assessment for that gas-handling technology. A preliminary assessment for the technology is prepared prior to each workshop. At the workshop, presentations by invited experts provide additional detailed information on the overall process or specific components. The preliminary assessment and presented material are discussed and are used as the basis for completing a consensus assessment for that technology.

Status

Workshops to gather information to assess the Pipeline, LNG, CNG, and GTL gas-handling options have been completed. The Gas-to-Electricity and Reinjection options will be completed this spring, and the overall assessment will then be documented and published.

Acknowledgments

We acknowledge and appreciate the Minerals Management Service sponsorship and participation, the support and participation by the Offshore Operators Committee, and participation by the industry experts and class societies in the workshops.

Dr. E.G. (Skip) Ward joined the Offshore Technology Research Center at Texas A&M University as the Associate Director following his retirement from Shell Oil Company in 1998. He is responsible for planning and coordinating the OTRC research program to meet the needs of the industry and Minerals Management Service. Skip had thirty years of experience with Shell, including research, managing technology development and applications for deepwater structures, and managing deepwater structure design.

Dr. A.J. Wolford is founder and President of Risknology Inc. in Houston, a firm specializing in risk-informed approaches to technology issues in the production, energy and power industries. He has directed risk applications on a diverse range of engineered systems, including offshore and onshore oil and gas installations, mobile offshore drilling units, marine and land-based transportation systems, chemical and nuclear fuel processing plants, nuclear power and test reactors, and the Space Shuttle. He is an accomplished and highly-experienced risk analyst, having worked in the field of industrial risk assessment for the past 19 years.

M.B. (Skip) Mick is Vice President, Deepwater / Special Projects for Paragon Engineering Services. Skip has more than 30 years' varied experience in the oil and gas industry. Prior to his career at Paragon, he worked at Marathon Oil Co. for nearly 25 years, most recently as the Deepwater Development manager. He began his industry career and spent six years at Exxon. He earned B.S. in chemical engineering from the University of Dayton, his M.S. in chemical engineering from the University of Florida, and his M.B.A. from Texas A&M in Kingsville, Texas. He is a registered professional engineer in the state of Ohio, and is a member of the SPE and AIChe.

Luis Tapia has an M.S. in petroleum engineer from Texas A&M and an M.S. in petroleum economics and management from IFP. He has extensive expertise in technical and business matters of the oil and gas industry. He worked for Occidental Oil & Gas as operations engineer and is now working for Paragon Engineering Services as flow assurance specialist.

William Hauser is a petroleum engineer with the Minerals Management Service. He is currently the Chief of the Regulations and Standards Branch, which is responsible for managing the assessment, development, and promulgation of OCS regulations related to the exploration and development of oil, gas, and other minerals. For several years, he was responsible for managing MMS' drilling research activities and revising MMS' drilling regulations. Mr. Hauser has worked with MMS and the Department of the Interior since 1978.

UPDATE ON U.S. COAST GUARD ACTIVITIES

LCDR Jeff Ramos, USCG, Eighth Coast Guard District, New Orleans, LA

Inspections Overview—Regulated OCS Activities

The Coast Guard conducts safety inspections of several activities occurring on the Outer Continental Shelf (OCS). Our inspections range from certificating Floating Offshore Installations (FOIs) to certificating Offshore Supply Vessels that support the offshore industry. We ensure that these vessels are built, manned and operated to applicable standards. We also ensure that they are equipped with adequate firefighting and lifesaving equipment.

Over the past several years, the Coast Guard has seen a dramatic increase in the construction of FOIs for deepwater operations and in the applications for developing LNG Deepwater Ports. Currently, there are approximately 28 FOIs operating in the GOM, and in the past year, we have received approximately six new applications for LNG Deepwater Ports for the GOM. We have met this increase in workload by increasing the number of OCS inspectors at certain units, especially overseas where a number of these FOIs are being built. Our Coast Guard Headquarters has also established a new branch, G-MSO-5, which is dedicated to handling deepwater port applications.

New Construction Projects under NVIC 10-82

The Coast Guard continues to work with the American Bureau of Shipping (ABS) in the new construction of FOIs by using Navigation and Vessel Inspection Circular (NVIC) 10-82 as a guideline. This NVIC allows ABS to perform plan review & inspection items on behalf of the Coast Guard. ABS approves hull structure, marine engineering, electrical engineering, and piping systems. The Coast Guard approves stability, fire control, and lifesaving systems. Coast Guard & ABS continue to work in close cooperation by scheduling formal and informal meetings to discuss issues of concern.

In-Service Inspection Program (ISIP) for FOIs

The Eighth Coast District (D8) has promulgated several policy letters during this past year, which are applicable to deepwater operations. One of these policy letters addresses the In-Service Inspection Program (ISIP) for FOIs. An ISIP Plan describes the hull exam procedures to be conducted while the FOI remains on-station. Our Headquarters previously approved these plans; however, they have now delegated this approval to the local Officer in Charge, Marine Inspection (OCMI). The plan requires 40% of the hull to be inspected annually (equivalent to twice-in-five years), and allows a reduction of the hull exam to 20% annually (once-in-five) under certain circumstances. This reduction is called a “Modified Inspection Program.”

In May 2004, D8 developed a policy to clarify “circumstances” for placing FOIs in the Modified Inspection Program. The criteria for allowance into the Modified Inspection Program are as follows:

a) Not “novel” or “unconventional” design class,
b) No history of design problems within last five years,
c) No problems with quality of company inspection procedures, and
d) No unique operating conditions.

Use of Hose Reels on FOIs

Another policy letter D8 recently promulgated addresses the use of hose reels on FOIs. 46 CFR 108.425 requires hoses to be: 1 ½ or 2 ½ inches in diameter, and 50 ft in length. They must also meet UL-19 Standard (collapsible). However, our headquarters (G-MSE-2) has approved certain hard-rubber non-collapsible hoses (hose reels) for limited use as long as they meet UL-92 Standard or Mil Spec H24580.

D8 policy letter dated September 2004 allows the use of these hose reels subject to the following:

a) Hose reels can only be installed on open decks; or inside columns, pontoons, & machinery spaces if not congested;
b) They can not be installed inside accommodation spaces; and
c) If there are no fire stations inside the accommodation spaces, the accommodation module size is limited to 70 ft x 40 ft.

This policy letter replaces the policy letter issued in May 2004, which had required hose ports to be installed in exterior doors of accommodation spaces if there were no internal fire stations installed. These hose ports are now not required.

Guardrails & Storm Rails on FOIs

In December 2004, D8 promulgated a policy letter on the installation of guardrails and storm rails on FOIs. 33 CFR 143.110 (OCS Facilities) requires a 42” rail height, and 46 CFR 108.217 (MODUs) requires a 39” rail height. D8 will allow either of the above designs as long as it is consistent throughout the facility. The maximum horizontal distance between vertical guardrail sections must also be minimized. And finally, due to the absence of adverse movements in FOIs, internal storm rails are not required.

Revision of Crane Regulations

46 CFR 107.309 and 107.259 currently require the Coast Guard to certify and conduct tests of offshore cranes in accordance to API 2C and 2D. However, Coast Guard inspectors do not have the expertise to physically examine these cranes. D8 is currently revising regulations to allow qualified third parties, i.e., other class societies and companies certified by crane manufacturers, to conduct crane certifications & tests on behalf of the Coast Guard. The Coast Guard will still maintain oversight authority.

MOU between MMS/USCG

The Coast Guard has enjoyed a great working relationship with the Minerals Management Service (MMS). A new Memorandum of Understanding (MOU), signed on 30 September 2004, is an overlapping bridging document, which will be supported by technical annexes known as

Memorandum of Agreements (MOAs). These MOAs will be formulated and sequentially numbered as needed by working groups incorporating regulatory and industry representation. MOA #OCS-01, which is already part of the MOU, restates the 1998 MOU as a starting point for guidance on which agency has overall responsibility on certain systems on board a MODU or fixed/floating facility. Basically, the CG is responsible for the marine systems, and MMS is responsible for the production & drilling systems. We also share responsibility where the systems overlap (i.e. mooring systems, evacuation plans).

Future MOAs will be developed to address other emerging issues, such as security, fixed facilities, floating facilities, MODUs, FPSOs, and casualty investigations. Once these MOAs are completed, they will become part of the main MOU.

Floating Storage & Offloading (FSO) Systems

After Hurricane Ivan, a number of pipelines were damaged, preventing oil from being transferred to shore. FSOs were proposed as an alternative in bringing oil ashore. Since there were no regulations in place for this type of operation, the Coast Guard worked closely with MMS in developing a Regulatory Model. The offshore industry has since determined that it may be more cost-effective to repair its pipelines. Therefore, no written proposals have been received to date.

U.S. & Mexico Joint Response Agreement (MEXUS)

The Eighth District is one of two Districts in the U.S. that borders Mexico. The Mexico-U.S. (MEXUS) Initiative provides for bilateral cooperation in response to pollution incidents that could seriously affect the coastal waters and coastal region of one or both countries, or in cases where the impact of the incident in one country's maritime zone would be of such magnitude that would justify the request to the other country for coordinated assistance. The signing of the MEXUS Plan in February of 2000 and its supporting geographical annexes - MEXUS Gulf and MEXUS Pacific (MEXUS PAC)—in February 2003 marked a significant advancement in Mexico-U.S. joint collaboration for protection of the coastal marine environments of both nations. In April 2004, a MEXUS activation took place as part of an oil spill exercise in the Pacific Ocean. In May of 2004, the first MEXUS Gulf notification was initiated by the Mexican Navy to notify all involved parties of the finding of significant amounts of tar balls on Mexican beaches near the U.S. border. The Coast Guard, the State of Texas and NOAA responded accordingly to the notification.

The recently jointly signed MEXUS *"Strategic Work Program Through Goals to Be Achieved in Five Years"* delineates a road map to maintain a common focus for a progressive approach and advancement of the joint cooperation.

Domestic Security Requirements
33 CFR Subchapter H – "Maritime Security"

The Maritime Transportation Security Act (MTSA) regulations were published as final rules on 22 October 2003. They are the U.S. equivalent to the ISPS Code, which was adopted by IMO as an amendment to SOLAS in December 2002.

33 CFR Part 101 establishes the criteria for alternative security programs, establishes and defines Maritime Security or MARSEC levels, prescribes communications between the Coast Guard Captain of the Ports (COTPs) and industry to communicate threat information (MARSEC level attainment, notifications of suspicious activity, breaches of security, and notifications of transportation security incidents), and establishes control measures that the COTPs can use on vessels and facilities that are not in compliance with the regulations.

33 CFR Part 103 focuses on area maritime security and is intended to identify and protect critical port infrastructure; identify risk in terms of threats, vulnerabilities and consequences; determine mitigation strategies; and determine security measures for the MARSEC levels. Part 103 designates COTPs as Federal Maritime Security Coordinators. Under this authority they establish, convene and direct Area Maritime Security Committees; appoint members; develop, maintain, and exercise Area Maritime Security Plans. The Area Maritime Security Plan specifies operational and physical security measures in place at all MARSEC levels and addresses evacuation, communication, and jurisdiction.

33 CFR Parts 104, 105 and 106 pertain to vessels, facilities and OCS facilities, respectively. They contain similar security requirements for each entity, including specifying the responsibilities of owners and operators for compliance with the MTSA regulations and detailed security requirements including Declarations of Security, drills and exercises, communications, measures for access control, restricted areas, security assessments and security plans.

Offshore Facilities

Offshore facilities pose unique security challenges. They are both manned and unmanned, surrounded by water, and are located up to 100 + miles from shore. Most also have limited security forces onboard.

33 CFR Part 106 applies to all fixed and floating facilities, including Mobile Offshore Drilling Units and transmission hubs, if they meet any of the following criteria:

1. Hosts greater than 150 personnel onboard for 12 hours or more in a 24-hour period, continuously, or for 30 days or more.
2. Produces oil in an amount greater than 100,000 barrels per day.
3. Produces gas in an amount greater than 200 million cubic feet per day.

Of the 4,000 oil and gas facilities in the GOM, there are presently 49 that meet these regulatory thresholds.

The regulations for deepwater ports (Oil or LNG) were recently amended (Interim Federal Rule effective 6 January 2004). Although MTSA does not directly apply to the deepwater ports (DWPs), the DWP regulations (33 CFR 148-150) require their security plan to contain the same elements as the regulations for OCS facilities in 33 CFR Part 106. DWP Operations Manuals are reviewed and approved by Commandant (G-M).

It is important to note that the offshore oil and gas industry was the only regulated community that met all security plan submission deadlines and required no enforcement action. All regulated OCS facilities were issued final approval letters by 31 December 2004.

Area Maritime Security Committees

One of the key components of the MTSA regulations is that it required the formation of Area Maritime Security Committees (AMSCs). Late in the regulatory project, it was decided that the GOM would be handled as a single "port" with the District Commander as the Federal Maritime Security Coordinator (FMSC). As such, he was charged (on short order) with establishing an AMSC for the "port" of the GOM.

The current AMSC membership includes USCG, FBI, MMS, FAA, API, and industry representatives from the OSV, drilling, production, helicopter, commercial and recreational fishery, offshore lightering, offshore towing, pipeline, and LNG industries.

Some of the issues that the AMSC are working on include:

a. AMS Assessment: For the purpose of the GOM Area Maritime Security Plan (AMSP), the protected resources include 49 regulated OCS facilities, all DWPs (currently one with approximately six LNG applications filed), offshore lightering zones (four OPA-90 and six traditional), cruise ships, and other deep draft shipping.

b. Communication: A process to quickly communicate with AMSC members, Security Officers and other persons with a security interest has been developed. This system has been used regularly (six times to date) and continues to be improved. The AMSC is looking into new communications technologies that will automate and improve the communication process.

c. OCS Boundary: For the purpose of the GOM AMSP, the area of responsibility will include all D8 GOM waters outside of the state boundaries out to the extent of the EEZ (200 miles).

d. Future Dissemination of Sensitive Security Information (SSI): In the past, companies were required to go to a local Marine Safety Office to pick up MARSEC Directives and other sensitive security information. In September, we advised our offshore security community that our headquarters is close to rolling out a new web portal known as "Homeport." This system will provide each user with a unique password and will allow individuals to access classified information over the web. Persons with a need-to-know will be identified by the FMSCs (including D8 for the OCS).

Lieutenant Commander Jeff Ramos graduated from the U.S. Merchant Marine Academy in 1989 with a B.S. degree in marine transportation. After graduating, he served in various positions at

Marine Safety Offices in Honolulu, Hawaii; Singapore; and Mobile, Alabama. Afterwards, he spent three years as the Coast Guard Liaison Officer at the Merchant Marine Academy in Kings Point, New York. In 1999, he was assigned to the Marine Safety Unit in Galveston, Texas and served as Chief, Merchant Vessel Safety Department, and later as Chief, Port Operations Department. In August of 2003, Lieutenant Commander Ramos assumed his current position as Chief, Compliance Branch, at the Eighth Coast Guard District in New Orleans, Louisiana.

SESSION 1F

SPERM WHALE SEISMIC STUDY

Chair: Bill Lang, Minerals Management Service

Co-Chair: Colleen Benner, Minerals Management Service

(continued on next page)

OVERVIEW OF THE SPERM WHALE SEISMIC STUDY IN THE GULF OF MEXICO

Ann E. Jochens, Texas A&M University

The Sperm Whale Seismic Study (SWSS) is a cooperative study of sperm whales in the Gulf of Mexico (GOM), their habitat, and their response to man-made noise. SWSS is sponsored by the Minerals Management Service in cooperation with the Industry Research Funders Coalition (IRFC), National Science Foundation (NSF), and Office of Naval Research (ONR). The study is being conducted by scientists from Oregon State University (OSU), Scripps Institution of Oceanography (SIO), Texas A&M University (TAMU), Texas A&M University-Galveston (TAMUG), University of Colorado (CU), University of Durham (UD), University of St. Andrews (UStA), Woods Hole Oceanographic Institution (WHOI), and Ecologic Ltd. A Science Review Board is established to provide review and comment on the Synthesis Report. This board consists of five members: one from the federal government (NOAA), one from industry, one retired from the Marine Mammal Commission, and two from the academic community. All activities involving sperm whales are performed under the terms of valid permits from NOAA Fisheries.

In 1991, MMS began a series of environmental studies to investigate cetaceans in the GOM. In the 1990s, the MMS-sponsored GulfCet Study used ships and aircraft to survey the western and eastern parts of the northern Gulf to determine seasonal variability in the occurrence and distribution of marine mammals (Davis and Fargion 1996; Davis et al. 2000). In 1999, MMS hosted a Gulf of Mexico Protected Species Workshop (McKay et al. 2001) to review past research, evaluate new issues, and recommend research priorities. MMS, ONR, and the National Marine Fisheries Service (NMFS) then sponsored the Sperm Whale Acoustic Monitoring Program (SWAMP) in fiscal years 2000 and 2001. SWAMP was a pilot study that developed methods and began documenting a baseline on "usual" behavior of sperm whales in the GOM. This study, as well as earlier survey results, indicated that sperm whales tend to be most likely observed near the 1,000-m isobath.

As oil and gas activities in the deepwater GOM increase and move into deep water, the potential increases for them to occur in regions frequented by the endangered sperm whale. At the 1999 MMS Workshop, a panel of experts identified the potential effects of noise from seismic operations on sperm whales as a key research priority. During the January 2002 MMS Information Transfer Meeting, the International Association of Geophysical Contractors (IAGC; now part of the IRFC) hosted a meeting to discuss future acoustic research relevant to seismic operations, and in particular, as related to understanding the effects of seismic exploration on sperm whales in the GOM. IAGC offered its support for sperm whale research through contribution of a seismic source vessel for controlled exposure experiments. In response, SWSS was proposed and approved by MMS in April 2002 under a Cooperative Agreement between MMS and the scientists.

The study consisted initially of three years of field research with analysis and synthesis. Plans now extend this study to provide for an additional year of field work and to conduct several interactive meetings in 2006 with SISS researchers to complete the final synthesis report. The study area is primarily the northern GOM, with focus on the region immediately off the Mississippi River Delta. The objectives of SWSS are three-fold:

1. establish the "normal" behavior of sperm whales in the northern GOM,
2. characterize habitat use, and
3. determine possible changes in behavior of sperm whales when subjected to man-made noise, particularly from seismic airgun arrays.

In addition to program management (TAMU), SWSS consists of six components: S-tag (OSU), D-tag (WHOI, UStA), mesoscale population behavior (TAMUG, Ecologic, UStA), genetic analyses (UD), habitat characterization (TAMU, CU), and passive acoustics research (SIO). MMS provides fiscal support, project oversight, and cruise participants under the Cooperative Agreement. ONR provides funding for development of both the S-tags and D-tags used in this study. IRFC provides the seismic source vessel and its crew for the controlled exposure experiments in field years one and two, as well as funding to support the Mesoscale Population Study and purchase of the 3-D passive acoustic tracking array in field year three. NSF provides the R/V *Maurice Ewing* as the science vessel for the controlled exposure experiment in field year two, as well as support for other, non-SWSS acoustics studies.

The S-tag component monitors seasonal changes in distribution of sperm whales in the GOM and identifies behaviors, summer and other seasonal habitats, and, in coordination with the habitat characterization task, associations with oceanographic features. The D-tag component quantifies diving behavior and vocalizations in Gulf sperm whales on short time scales (hours) and conducts controlled exposure experiments to measure reactions of these whales to controlled airgun sounds. The Mesoscale Population Study uses photo identification, photogrammetry, and passive acoustics to study sperm whale group behavior and coda analyses; in year three this work was conducted aboard a quiet sailboat so that specific whale groups could be studied over several days. The genetic analyses component allows study of groups of sperm whales in terms of relatedness through DNA analyses of skin/tissue samples. The habitat characterization component merges biological oceanography, physical oceanography, and remote sensing data to provide an interdisciplinary description of the oceanographic habitat in which sperm whales are encountered. Passive acoustic experiments are conducted to estimate 3-D whale locations underwater from their sounds.

During SWSS 2002-2004, there were three S-tag cruises, two D-tag cruises with controlled exposure experiments using airguns on seismic vessels provided through IRFC, one cruise for a sperm whale survey and habitat characterization study conducted concurrently with the D-tag cruise for that year, and one mesoscale population study cruise aboard a 46' Hunter sailboat. In Table 1F.1 gives the cruise type, ship name, and cruises dates for all three years.

Table 1F.1. 2002-2004 Cruises conducted for and related to the Sperm Whale Seismic Study.

Ship	Cruise	Dates
2002		
R/V *Gyre*	S-tag	06/20/2002 - 07/08/2002
R/V *Gyre*	D-tag	08/19/2002 - 09/15/2002
M/V *Rylan T/Speculator*	CEE[1] with *Gyre*	08/29/2002 - 09/12/2002
2003		
R/V *Gyre*	Whale & Habitat Survey	05/31/2003 - 06/21/2003
R/V *Maurice Ewing*	D-tag	06/03/2003 - 06/24/2003
M/V *Kondor Explorer*	CEE with *Ewing*	06/07/2003 - 06/22/2003
R/V *Gyre*	S-tag	06/26/2003 - 07/14/2003
2004		
R/V *Gyre*	S-tag	05/24/2004 - 06/19/2004
Summer Breeze	MPS[2]	06/20/2004 - 08/15/2004

[1]CEE is the controlled exposure experiment using airguns of the seismic source vessel
[2]MPS denotes the Mesoscale Population Study cruise from the 46' Hunter sailboat

The Summary Report for SWSS 2002–2004 will become available in late 2005. Planning is proceeding among the scientists and sponsors to extend the SWSS Cooperative Agreement to allow field work in summer 2005 and 2006 and additional analysis and synthesis in 2006. The Synthesis Report from such work is targeted for spring/summer 2007. The extent and nature of any follow-on work would be determined after the recommendations of the Marine Mammal Commission Advisory Committee on Acoustic Impacts on Marine Mammals become available (see *http://mmc.gov/sound/*.

References

Davis, R.W. and G.S. Fargion, eds. 1996. Distribution and abundance of cetaceans in the northcentral and western Gulf of Mexico: Final Report. Volume I: Executive. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 96-0026.

Davis, R.W., W.E. Evans, and B. Würsig, eds. 2000. Cetaceans, sea turtles and seabirds in the northern Gulf of Mexico: distribution, abundance and habitat associations. Volume I: Executive Summary. U.S. Dept. of the Interior, Geological Survey, Biological Resources division, USGS/BRD/CR-1999-0006 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA, OCS Study MMS 2000-002. 27 pp.

McKay, M., J. Nides, W. Lang, and D. Vigil, eds. 2001. Gulf of Mexico Marine Protected Species Workshop, June 1999. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2001-039. 171 pp.

Ann Jochens is an Associate Research Scientist in the Department of Oceanography at Texas A&M University and Program Manager for SWSS. She has a B.S. in Mathematics and Statistics

with Honor from Southern Methodist University (1974), a Doctor of Jurisprudence with background specialty in ocean law from the University of Oregon (1977), and an M.S. and a Ph.D. in oceanography from Texas A&M University (1989; 1997). Her research focus is in physical oceanography with specific interests in processes at the boundary of the coastal and open oceans; integration of physical and biogeochemical observations to analyze circulation and property transports through the ecosystem with emphasis on coastal environments; meso- and large-scale ocean circulation and property distributions with emphasis on shelf and slope regions; Gulf of Mexico physical oceanography; and development of ocean observing systems.

SEASONAL MOVEMENTS, RANGE, AND ASPECTS OF SPERM WHALE DIVING BEHAVIOR

Bruce Mate, Oregon State University

The broad-scale objective of the SWSS satellite-monitored radio tagging program describes the seasonal distribution of sperm whales in the northern Gulf. The specific objectives of the S-tag program include: 1) identification of habitats, especially high-use areas, and possible migration routes in conjunction with the genetics sampling program led by Dan Englehaupt; 2) characterization of habitat environmental variables; 3) correlation of information directly related to sex-specific movements; and 4) analysis of tagged whale movements with seismic vessel activity that is funded separately by the Industry Research Funding Coalition (IRFC).

Papers on the habitat characteristics, sex-specific social structures and seismic work are presented independently in these proceedings.

Materials and Methods

This tagging program grew from the earlier efforts of SWAMP, which included the tagging of four sperm whales in 2001. One of these whales was tracked for 137 days. Subsequently, 39 sperm whales have been tagged during field efforts in 2002, 2003, and 2004. The latter three field seasons have been conducted from the Texas A&M *R/V Gyre* as a principal platform. Visual observers maintained watch during suitable weather and daylight hours using big-eye binoculars located on the *Gyre's* flying bridge. An acoustics team maintained 24-hour/day monitoring of two towed arrays, which provided an important means of identifying whales in their long dive cycles during the night and periods of inclement weather. When whales were found, one or two rigid-hulled inflatable boats (RHIBs) were launched from the *Gyre* with teams for tagging, photo identification, genetic sampling, behavioral observation, and tagging follow-up.

The tagging boat generally consisted of five people—a driver, tagger, biopsy person, videographer, and photo ID person. Whales were typically approached at low speed; tagging and biopsying were done from a bowsprit pulpit mounted on the front of a 6.4-meter RHIB.

The implantable tags were developed at Oregon State University with the Office of Naval Research Support and have been used successfully on a variety of baleen whale species. The tag includes a coating of long-term dispersant antibiotic to help prevent infection as the whale's tissue encapsulates the tag over time. During the course of this project, two significant developments have made the application of these tags on sperm whales much more successful—the modification of the way attachments are fastened to the tag itself, and the use of an air-powered applicator. The latter consistently provided for nearly flush deployment of the tag, which has external stops to prevent inward migration. While the duty cycle of tags has varied from year to year, in general it provided for transmissions every third or fourth day to extend the operational life of the tags themselves and to provide multi-season coverage. Because tags only reach the satellite during these periods of active transmission, when whales are at the surface and coinciding with satellite passage, the number of satellite-determined locations per day can vary considerably. Sperm whales take long dives. If satellite passage occurs during such a long dive, no messages are recorded by the satellite. However, when satellite coverage coincides with the whale's 7- to 10-minute surfacing to recover oxygen between dives, a large number of messages can be obtained. This results in a higher proportion of high-quality locations than for other whale species tracked to date. In fact, 46% of all the locations acquired to date have been location class 1, 2, and 3, which have estimated accuracies of one kilometer, 350 meters, and less than 150 meters respectively. This outstanding performance has provided high levels of confidence in the resulting location and characterization studies.

In an effort to insure the highest quality information and the least interpretive error, we use only location class 1, 2, and 3 locations for the most sensitive analyses. However, for seasonal movement information, we also find it useful to include 0 Class locations but apply screening criteria to avoid including inappropriate locations. These screening criteria involve around acceptable travel speeds between previous and next consecutive location. Because over 95% of the whale movements we have monitored fall within a speed category of under 6 km/hr, we have tended to favor this category as our screening criteria. It must be kept in mind that because of the longer period of time often elapses between locations because of duty-cycle issues, the distances measured between locations are conservative estimates of the whale's movements. The lines seen on maps should not be interpreted as the whale's track during these movements; they merely link chronological locations together.

The skin biopsies taken by Dan Englehaupt during the course of tagging or in follow-up observations have allowed an analysis of genetic relatedness among individuals when tags have been applied to animals in social groups. The sample also provides analysis of differences in movements and seasonal preferences by sex.

Results

To date, the longest tracking period has been 610 days. This male whale provides an example of how this type of tracking can reveal heretofore unknown activities that include: 1) the use of different summer areas, 2) the return to a common wintering area in both years, 3) the extensive use of offshore deep waters, and 4) the movement out of the Gulf of Mexico (GOM) and into the North Atlantic for two months and an apparent avoidance of heavy weather generated by Hurricane Isabelle.

It would be fair to characterize the movements of animals tagged off the Mississippi River Delta as concentrating along the northern slope edge and portions of the slope itself. Locations in deep water represented less than 10 percent of all locations. Although two females ventured out into deep water for short periods of time, the offshore movements tended to be primarily the movements of males or those of unknown sex (where a biopsy sample was not obtained or recovered, sloughed skin proved inadequate for DNA characterization). This characterization of the activity along the upper Gulf Slope was true for all four years of tagged whale activity. A considerable concentration of locations along the western edge of the northwest Gulf in 2002 was largely the result of a single male's activity over 6 months off the Brownsville, Texas region. The average duration and distances traveled by transmitting whales by year was 345 days and 1,906 km in 2001, 225 days and 3,547 km in 2002, 224 days and 3,719 km in 2003, and through October, 98 days and 722 km for the 2004 field program that is still in progress at this writing. In general, the tags on males and unknown-sex animals lasted longer than those of females. Through October 2004, whales have been tracked for a total distance of 143,728 km, with over 1.5 million dives being enumerated during the course of this effort.

An analysis of home range shows the monthly movements of the population's "core" proceeding from winter off the Mississippi River Delta to more of the central upper slope during spring months, summering again off the Delta, and moving in the fall off to the western portions of the upper Gulf.

In an effort to analyze the effects of tags on whales, we re-photographed tagged whales when we encountered them during the course of subsequent year tagging efforts. Six whale tags have transmitted beyond a single year and led us to areas of whale abundance for subsequent tagging efforts the following year. These efforts to relocate and photograph tagged whales have been gratifying. We saw no examples of whales that appeared emaciated or behaved abnormally. In general, animals that had lost tags showed little evidence of having been tagged, with no tissue sloughage or skin necrosis. One tag was encountered that had migrated about 3/4 of its length out of the animal and still maintained a good attachment while continuing to transmit locations.

The Future

We have begun designing a tag suitable for measuring the dive-depth of sperm whales. These tags can provide a description of the three-dimensional habits of the species record for an extended period of time, including seasonal, diurnal, and geographic differences. We propose using these tags in future SWSS efforts to 1) improve our knowledge of the whales' dive habits, 2) model the whales' potential exposure to sound, and 3) reveal how the whales' foraging habits may vary due to the possible diurnal behavior of their primary prey, squid. Further, this information may ultimately help develop seasonal time of day and/or behavior-specific probabilities of sightings, which may be used as correction factors to improve population estimates from ship and aerial surveys. These satellite-linked depth tags were tested in 2004 on blue whales; the data showed a conspicuous diurnal dive pattern.

We hope future research efforts will also include some emphasis on assessing the biomass of prey species to better understand the distribution of whales. This may also be important in evaluating whether animals potentially displaced from an area find similar or inferior prey concentrations in the area to which they move. Relative to assessing squid biomass during cruises, we hope to correlate the abundance of squids with specific oceanographic features or acoustically detected day-and-night sperm whale activity. We would like to reveal more about the diurnal migratory behavior of squids, and thus sperm whales.

The development of a GPS-linked satellite tag is also underway, using IRFC funding, to provide extremely accurate whale locations (ultimately, with dive and acoustic data). Such a tag would allow us to conduct long-term observations to evaluate possible sound exposure responses based on precise distances from anthropogenic sources.

Overall, our goal to date has been to understand how environmental variables contribute to changes in habitat choice and behavior (natural variability), and use this information in the future to develop a predictive model to help plan surveys, research, or mitigation (if needed). Our current technology provides months' or seasons' worth of broad-scale, low-resolution location data to identify movements and seasonal habitats. Our intent for the future is to provide intermediate scale data on a geographic basis and very fine detail on movements in proximity to sound through controlled and experimental periods. The GPS development activity should result in testable prototypes by the 2006 field season.

Dr. Bruce Mate holds an endowed chair at Oregon State University, where he directs the OSU Marine Mammal Program at the Hatfield Marine Science Center. He has served as a Scientific Advisor to the U.S. Marine Mammal Commission and the U.S. Department of the Interior's Outer Continental Shelf Development Program, a scientific expert to the International Whaling Commission and the United Nation Environmental Program, and a member of the International Union for the Conservation of Nature's Species Survival Commission. He has studied the migrations of marine mammals since 1968 and pioneered the tracking of manatees, dolphins and large whales with satellite-monitored radio tags. With collaborators, his research group has tracked ten stocks of seven large endangered whale species in six different oceans/seas, including temperate, equatorial, Arctic, and Antarctic regions. His specialty is the identification and characterization of seasonal critical habitats for endangered whales and how they migrate between them. An applied aspect of his research focuses on trying to reduce potential impacts of human activities on recovering endangered species.

SOCIAL STRUCTURE OF SATELLITE-TRACKED SPERM WHALES IN THE GULF OF MEXICO

Joel Ortega-Ortiz and Bruce Mate, Oregon State University
Dan Engelhaupt, University of Durham, England

Sperm whales are known to have a complex social structure. Females, calves and immature males inhabit tropical waters while mature males relocate to high latitudes and only visit the lower latitudes to breed. Female and immature whales form cohesive social units that have been reported to last for years. We used satellite telemetry to determine associations between sperm whales in the Gulf of Mexico (GOM) and compared social structure to genetic relatedness of the monitored individuals. Geographic location of tagged sperm whales was used to estimate distance between individuals during simultaneous satellite transmissions. Association between individuals was determined from the distance between individuals. Two whales were considered associated in a particular day if the distance between their simultaneous locations was $\leq$ 20 km. Simple ratio coefficients of association were calculated between individuals. Additionally, genetic analyses of skin samples were conducted to determine gender of the individuals and relatedness among them. A social unit was identified among the whales tagged in 2002. No significant correlation was observed between genetic relatedness and association between individuals. Sperm whale social structure observed in the Gulf is similar to that described for other tropical regions (i.e. Galapagos Islands). Our results indicate that sperm whale social units in the GOM are not strictly matrilineal.

Acknowledgments

We are grateful to the cruise participants and the crew of the *R/V Gyre*. This ongoing research is supported by the Minerals Management Service under MMS Contract 1435-01-02-CA-85186.

Dr. Joel Ortega is a post-doctoral research associate at the Oregon State University Marine Mammal Program. He received his Ph.D. from Texas A&M University in 2002.

Dr. Bruce Mate holds an endowed chair at Oregon State University, where he directs the OSU Marine Mammal Program at the Hatfield Marine Science Center. He has served as: a Scientific Advisor to the U.S. Marine Mammal Commission and the U.S. Department of the Interior's Outer Continental Shelf Development Program, a scientific expert to the International Whaling Commission and the United Nation Environmental Program, and a member of the International Union for the Conservation of Nature's Species Survival Commission. He has studied the migrations of marine mammals since 1968 and pioneered the tracking of manatees, dolphins and large whales with satellite-monitored radio tags. With collaborators, his research group has tracked ten stocks of seven large endangered whale species in six different oceans/seas, including temperate, equatorial, Arctic, and Antarctic regions. His specialty is the identification and characterization of seasonal critical habitats for endangered whales and how they migrate

between them. An applied aspect of his research focuses on trying to reduce potential impacts of human activities on recovering endangered species.

Dan Engelhaupt completed his Ph.D. at the University of Durham, England. His field of study includes the assessment of population structure and social structure for endangered species, with a particular emphasis on sperm whales. Over the past five years, as part of the Minerals Management Service sponsored SWAMP and SWSS projects, he has examined the genetic variation and social structure of endangered sperm whales with a particular focus on putative 'populations' in the northern GOM, Mediterranean Sea and the North Atlantic Ocean using a suite of molecular techniques. Dr. Engelhaupt is collaborating with a number of other researchers to provide an accurate sperm whale dataset so that management can effectively oversee sperm whale populations that exist in areas of anthropogenic noise.

HABITAT CHARACTERIZATION OF SATELLITE-TRACKED SPERM WHALES IN THE GULF OF MEXICO

Joel Ortega-Ortiz and Bruce Mate, Oregon State University
Robert R. Leben, University of Colorado
Douglas C. Biggs and Matthew K. Howard, Texas A&M University

Physical habitat of sperm whales in the northern Gulf of Mexico (GOM) was studied by analyzing environmental variables for locations of individuals tracked with the aid of satellite transmitters. The present analysis includes data from 39 whales: 18 tagged in 2002, 15 in 2003, and six in 2004. Time between deployment and last satellite location ranged from 17 to 607 days and number of locations per tag ranged from three to 183.

Movement paths of satellite-tracked whales were characterized, and each location was assigned to either one of two categories: meandering or transit. Ocean bottom depth and slope were determined for each satellite-determined whale location and comparisons were made between sex classes and movement types. Statistically significant differences were observed in the median values of bottom depth at locations for females and males (W = 5,0930, p-value < 0.01, n = 798 and 214, Median = 884 and 1,171 meters, respectively). Median values of bottom slope were also different between females and males (W = 6,8546, p-value = 0.013, Median = 3.06 and 2.39 degrees, respectively). Significant differences were observed in the median depth for locations assigned to meandering and transit move types (W = 11,9942, p-value < 0.01, n = 853 and 338, Median = 895 and 698 meters, respectively). Median bottom slope was not different between meandering and transit. No significant differences were found in sea surface height (SSH) values between females and males. However, the median value of SSH was different between meandering and transit locations (W = 98,475, p-value < 0.01, Median = -3.86 and -7.12 dynamic centimeters, n = 818 and 326, respectively). The mean value of SSH for all satellite locations (–4.64 dynamic cm) coincides with previous studies that found a higher occurrence of sperm whales in areas of cyclonic circulation and areas of confluence between cyclone-anticyclone. Satellite-tracked female sperm whales were located more frequently on the upper continental slope of the northern GOM. Males were also located in this last region, but some tracked males moved into the central Gulf or over deeper waters with less steep bottom slope (i.e. lower continental slope and abyssal plain). The statistical differences observed in SSH at locations of meandering and transit move types could indicate that sperm whales have differential use for areas of the Gulf. Moreover, home range analysis showed that, although most of the tracked whales were tagged near and frequented the Mississippi Canyon (MC) and the Mississippi River Delta (MRD), there are differences between males and females, as well as among individuals, in the specific areas frequented during the year. A trend was observed for satellite-tracked whales to aggregate near the MC and MRD in the summer. While some individuals may spend several months in those areas, others disperse in different directions the rest of the year.

Acknowledgments

We are grateful to the cruise participants and the crew of the *R/V Gyre*. This ongoing research is supported by the Minerals Management Service under MMS Contract 1435-01-02-CA-85186.

Dr. Joel Ortega is a post-doctoral research associate at the Oregon State University Marine Mammal Program. He received his Ph.D. from Texas A&M University in 2002.

Dr. Bruce Mate holds an endowed chair at Oregon State University, where he directs the OSU Marine Mammal Program at the Hatfield Marine Science Center. He has served as: a Scientific Advisor to the U.S. Marine Mammal Commission and the U.S. Department of the Interior's Outer Continental Shelf Development Program, a scientific expert to the International Whaling Commission and the United Nation Environmental Program, and a member of the International Union for the Conservation of Nature's Species Survival Commission. He has studied the migrations of marine mammals since 1968 and pioneered the tracking of manatees, dolphins and large whales with satellite-monitored radio tags. With collaborators, his research group has tracked ten stocks of seven large endangered whale species in six different oceans/seas, including temperate, equatorial, Arctic, and Antarctic regions. His specialty is the identification and characterization of seasonal critical habitats for endangered whales and how they migrate between them. An applied aspect of his research focuses on trying to reduce potential impacts of human activities on recovering endangered species.

Robert Leben is an Associate Research Professor in the Department of Aerospace Engineering Sciences at the University of Colorado, Boulder. His research interests are satellite oceanography and computational fluid dynamics.

Douglas Biggs is a Professor of Oceanography at Texas A&M University. In addition to his service as a co-PI on DGoMB, Biggs was a co-PI on MMS-sponsored NEGOM-COH and GulfCet-II projects and he is presently working to define the oceanographic habitat use by cetaceans in the NE Gulf of Mexico as part of an interagency MMS-ONR-NSF study known as the Sperm Whales Seismic Studies program (SWSS).

Matthew Howard is an Assistant Research Scientist in the Department of Oceanography at Texas A&M University.

SEISMIC SURVEY ACTIVITY AND THE PROXIMITY OF S-TAGGED WHALES

Martha H. Winsor and Bruce Mate,
Marine Mammal Program, Oregon State University

Introduction

Researchers from Oregon State University's Marine Mammal Program tagged sperm whales in the Gulf of Mexico (GOM) with satellite-monitored radio tags (S-tags) during June/July 2002 and July 2003. The Argos Data Location and Collection System was used to obtain position data from the S-tags (Mate et al. 1997). These whale locations from the S-tags were compared to positions of active seismic vessels in the GOM in an attempt to determine whether satellite-tracked sperm whales occurred less frequently than expected in the vicinity of active seismic vessels (a possible indication of vessel avoidance). High-quality locations (N=1,167) from S-tags on 33 sperm whales were correlated with 6,821 seismic lines from 6 June 2002 through 16 August 16 2004. Seismic vessel information was provided by International Association of Geophysical Contractor members and included the start and end times and locations of central shot points for each seismic line.

Methods

Argos classifies high-quality locations as LC1, LC2, and LC3 with resolutions such that 68% of calculated locations are predicted to be within 350–1,000 m, 150–350 m, and <150 m, respectively, of the true position (Harris *et al.* 1990). All high-quality locations from the 33 S-tagged whales were edited to eliminate erroneous data. Positions resulting in speeds between locations more than 15 k/h were eliminated as being above the maximum capability of the animal, and therefore suspect in validity. When a whale location occurred between the start and end time of a seismic line, the position of the central shot point at the time of the whale location was interpolated from the start and end locations; then the distance between the whale and central shot point was calculated. Only locations within 25 km of an active vessel were considered in this analysis under the assumption that behavioral changes would be more apparent closer to the vessels.

We hypothesize that if there is no behavioral response to an active vessel, the distances between whales and seismic vessels should be randomly distributed. Conversely, if the distribution is non-random, it may be an indication of a response of the whales to the presence of an active seismic vessel. The distribution of distances was tested for randomness in two ways. The first method compared observed distances with expected distances, normalized to area, using a chi-square test for a significant deviation from randomness. The second method employed a Monte Carlo simulation of equivalent random data sets to compare with the observed data. Assumptions inherent in this analysis are that whale location accuracies are within Argos criteria and that temporal variation and vessel differences do not affect responses in significant ways. Also vessel speeds and headings were assumed to be constant so that interpolated positions between start and end locations were accurate.

Results

A total of 30 high-quality locations from 12 animals were determined to be within 25 km of an active vessel (consisting of 53% LC1, 30% LC2 and 17% LC3 locations). The time differences between start of the seismic line and whale location varied from 0.65 h to 4.8 h (mean = 2.2 h; sd = 1.24 h). Distances were tabulated into 5 km classes (Table 1F.2). No distances were less than 5 km and five of the 30 locations were 5 - 10 km from a vessel. When more than one observation was obtained from an individual, its contribution to the distance class was inversely weighted by the total number of observations for that animal. This weighting addressed possible effects of pseudoreplication (Machlis et al. 1985) maintaining a total sample size of 12 animals yet utilizing all the observations.

Table 1F.2. Tabulation of the number of occurrences in each distance class for the observed data set and the expected number for an area-normalized randomly distributed data set (n=12). The mean and standard deviation of each distance class from a Monte Carlo simulation of randomly distributed locations (1,000 sets of 12 distances) and the number of sets with the same number of class values as the observed.

Distance class	0-5 km	5-10 km	10-15 km	15-20 km	20-25 km
Observed data set count (n=12)	0	1.33	0.83	4.25	5.58
Area-normalized randomly distributed count (n=12)	0.48	1.44	2.4	3.36	4.32
Mean (std dev) of Monte Carlo sets (n=1000)	0.5 (0.71)	1.4 (1.16)	2.4 (1.41)	3.3 (1.5)	4.4(1.66)
Monte Carlo sets[1] with value x	597 x=0	330 x=1	196 x=1	206 x=4	128 x=6

[1]Number of simulated data sets out of 1,000 with same number of class values as the observed data set rounded to an integer

Applying the first method, the expected number of observations out of 12, in each 5 km class, was calculated by normalizing to the proportion of area the class represented in a 25 km radius circle (Figure 1F.1). A chi-square test was performed comparing the observed frequencies with the normalized expected frequencies. There was no evidence (p-value = 0.71) that the data were non-randomly distributed.

For the Monte Carlo simulation, 1,000 sets of 12 randomly created locations within a 25 km radius of a central point were tabulated into 5 km classes. Using 1,000 simulations is considered a realistic number of randomizations for determining significance at the 5% level (Manly 1997). A sample size of 12 was used instead of modeling the weighting of the observed data set so that comparisons could be made with discrete values. The number of sets, containing the same number of values as observed (rounded to the nearest integer value), was calculated. The average for each class was also compared (t-test) with the observed value (Table 1). There was no evidence that the observed set came from a non-random distribution of distances since all simulated set proportions were greater than 5% and all t-tests were non-significant (p-values > 0.05).

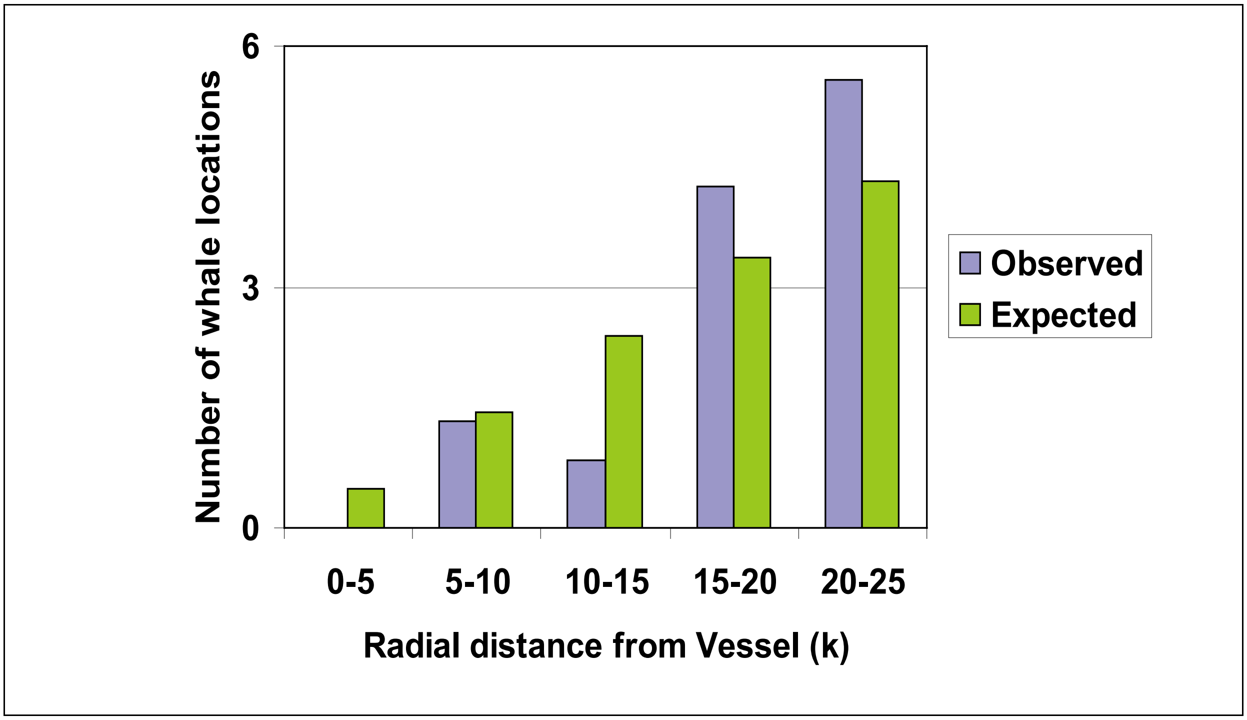


Figure 1F.1. Comparison of the frequencies in 5 km classes of the observed distribution of distances (<25 km) between whales and active seismic vessels with expected values assuming a random distribution (n=12).

Because of the relatively small sample size (12) used in the analysis, it is important to consider the potential power of the statistical tests. To determine if 12 values are sufficient to detect a non-random distribution, additional Monte Carlo simulations of varying sample sizes were performed. By increasing sample size, the percent of simulated data sets with the same value as the observed set decreases. Results indicate that a sample size of at least 75 is required to produce less than 5% of the sets with no distances less than 5 km; therefore, if an observed set of data consisting of 75 distances had no values less than 5 km, the data set would be considered non-randomly distributed at the 5% significance level. For the other distance categories, a sample size of at least 25 was required to produce less than 5% with values the same as the observed results.

Discussion and Conclusions

Although distances between whales and active vessels appear to be randomly distributed, these results cannot refute a possible behavioral response because of a lack of sufficient sample size. The number of individuals would need to be doubled to have the power to detect a non-random distribution from 5km and further. A much larger sample size (75) is needed for analysis closer than 5 km. An additional source of uncertainty is the lack of controlled positional errors from the Argos-derived locations. Future studies would greatly benefit from the use of GPS derived locations and expanded sampling efforts.

References

Harris, R.B., S.G. Fancy, D.C. Douglas, G.W. Garner. S.C. Amstrup, T.R. Mccabe and L.F. Pank. 1990. Tracking wildlife by satellite: Current systems and performance. U.S. Fish and Wildlife Services, Fish and Wildlife Technical Report #30. 52pp.

Machlis, Z., P.W.D. Dodd and J.C. Fentress 1985. The pooling fallacy: Problems arising when individuals contribute more than one observation to the data set. Zeitschrift für Tierpsychology 68:201–214.

Manly, B.F.J. 1997. Randomization, Bootstrap and Monte Carlo Methods in Biology. Washington, DC: Chapman and Hall/CRC. 399 pp.

Mate, B.R., S.L. Nieukirk and S.D. Kraus. 1997. Satellite-monitored movements of the northern right whale. Journal of Wildlife Management 61:1393–1405.

Martha H. Winsor has been a research assistant for the Marine Mammal Program of Oregon State University for 18 years specializing in statistical analysis and GIS. She also worked as an oceanographer with the U.S. Naval Oceanographic Office for eight years and contracted as a statistician with the U.S. Environmental Protection Agency. Her education includes a Sc.B. in aquatic biology from Brown University and a M.S. in applied statistics from Oregon State University.

Dr. Bruce Mate holds an endowed chair at Oregon State University, where he directs the OSU Marine Mammal Program at the Hatfield Marine Science Center. He has served as: a Scientific Advisor to the U.S. Marine Mammal Commission and the U.S. Department of the Interior's Outer Continental Shelf Development Program, a scientific expert to the International Whaling Commission and the United Nation Environmental Program, and a member of the International Union for the Conservation of Nature's Species Survival Commission. He has studied the migrations of marine mammals since 1968 and pioneered the tracking of manatees, dolphins and large whales with satellite-monitored radio tags. With collaborators, his research group has tracked ten stocks of seven large endangered whale species in six different oceans/seas, including temperate, equatorial, Arctic, and Antarctic regions. His specialty is the identification and characterization of seasonal critical habitats for endangered whales and how they migrate between them. An applied aspect of his research focuses on trying to reduce potential impacts of human activities on recovering endangered species.

BRIEF OUTLINE OF SPERM WHALE AIRGUN CONTROLLED EXPOSURE EXPERIMENTS (CEES)

Peter L. Tyack, Biology Department, Woods Hole Oceanographic Institute

There are two classes of adverse impacts that sound may have on marine mammals. If an individual is close to an intense source, it may be injured with hearing loss or other trauma. Behavioral or more subtle physiological responses to sound may occur at lower exposure levels and greater ranges. Injury can best be studied with captive animals under controlled settings using harmless experimental methods such as Temporary Threshold Shift. Once safety zones have been established, the primary method for protecting animals from injury involves monitoring and preventing harmful exposures. Behavioral disturbance is more difficult to monitor and mitigate. If exposure to noise reduces the effectiveness of foraging or communication by a few tens of percent for much of the population for much of the time, it could hinder the recovery of endangered populations or reduce the growth of other populations without injuring any individuals.

Before the SWSS research was initiated, there were several reports indicating that sperm whales avoided airguns at ranges of 50 km (Mate et al. 1994) and might reduce their vocalization rates at ranges of 600-1,000 km (Bowles et al. 1994). These anecdotal accounts raise concern, but are problematic for the following reasons:

- Bias in animals available for study:
  - Would anyone publish cases of no reaction?
  - Lower probability of detecting animals by passive acoustic monitoring if animals have reacted by silencing
- Exposure at the animal can seldom be accurately measured or estimated
- Difficulty in structuring observations to assess how response may vary with exposure
- Scarcity of information to assess biological significance of any reactions observed
- Difficulty in assessing statistical power of study when no reactions observed

Tyack et al. (2004) describe an experimental method using controlled exposures to resolve some of the problems from uncontrolled observations. Many of these controlled exposure experiments have the following features:

- Selection of subject randomly prior to exposure
- Use of specific protocol to test for specific kinds of reaction related to adverse impact
- Measurements of behavior pre-, during, and post- exposure. Individual is its own control
- Use of low exposure levels at beginning, with increase after evaluation of reaction indicates low risk
- Avoid exposures high enough for risk of injury

Johnson and Tyack (2003) describe a new tag, called the D-tag, that was designed to sample sound and behavior of the tagged whale. The tag was also designed to enable CEEs to deep diving toothed whales by allowing experimenters to

1. Track behavioral responses of marine mammals, especially deep divers, throughout their dives
2. Measure acoustic exposure directly at the whale
3. Improve understanding of functions and costs of behaviors to infer biological significance of behavioral disruption
4. Develop dose:response function by measuring received level of stimulus at whale while also measuring behavioral and physiological responses

The initial WHOI D-tag/CEE proposal to SWSS involved the following elements:

Initial Proposed Plan

- Three-year: one 6-week or two 3-week cruises per year
- Stimuli: Two control: nothing or codas; Primary airgun: soft start or ramp up
- In ten days of seismic vessel, hope for four to six experiments with one to two subjects
- Start RLs in 120–140 dB range. Move up if only minor responses observed
- Locations: Include diversity of sites. Need to move to ensure new subjects

The actual research completed involved the following for comparison:

Actual Research

- Two 3-week cruises total
- One coda playback prime focus on airguns
- Four airgun CEE subjects per year for each of two years
- RLs primarily in <120-147 dBrms range
- Problems finding new whales away from ongoing commercial seismic

It is impossible for any experiment or monitoring method to prove that there was no adverse impact to marine mammals, because many potential impacts are very difficult to detect. What CEEs can do is test specific hypotheses about potential impacts. We selected measures based upon likely biological significance to the population. The critical parameters of individuals that affect populations are habitat usage, growth, survival, and reproduction. Some of the behavioral parameters intimately linked to these parameters include avoidance, foraging, and mating. The WHOI D-tag CEEs under SWSS were designed to evaluate effects of airguns on avoidance, foraging, and communication of sperm whales in the northern Gulf of Mexico (GOM). Other members of the WHOI team will discuss baseline behavior of sperm whales, how we measured acoustic exposure, modeling of acoustic propagation to explain unexpected properties of airgun sounds, and reactions to airguns in CEEs.

Table 1F.3summarizes the results of the cruises providing data for these presentations:

Table 1F.3. Summary of cruise results.

Cruise	Swss 02	Swss 03	Swss RV Delaware	Total
Whales tagged	19	11	12	42
Hours	76	69	28	173
# Dives	65	50	18	133
CEEs	2; 4 subjects	3; 4 subjects	NA	5; 8 subjects
Max RLs	134–144 dBrms	146–147 dBrms	NA	

Acknowledgments

We thank the field teams and ship crews of SWAMP, SWSS, Sirena and RV Delaware cruises, the staff of IAGC, LDEO, MMS, NATO Undersea Research Centre, NOAA, TAMU and WHOI. We regret that too many people were involved to allow them to be named individually. Work supported by contract #1435-01-02-CA-85186 from the U.S. Minerals Management Service, ONR and WHOI internal funds for tag development, NSF for RV Ewing support, NOAA for RV support, IAGC and industry for providing source vessels. PJOM Fellowship support from the Royal Society. Work conducted under NMFS research permits 981-1578 and 981-1707-00 issued by the U.S. National Marine Fisheries Service to Peter L. Tyack. The Woods Hole Oceanographic Institution Animal Care Use Committee approved this research.

References

Bowles, A.E., M. Smultea, B. Würsig, D. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. Journal of the Acoustical Society of America 96:2469–2484.

Johnson M. and P. L. Tyack. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. IEEE Journal of Oceanic Engineering 28:3–12.

Mate, B.R., K.M. Stafford, and D.K. Ljungblad. 1994. A change in sperm whale (*Physeter macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. Journal of the Acoustical Society of America 96(5, part 2):3268–3269.

Tyack, P, J. Gordon, and D. Thompson. Controlled exposure experiments to determine the effects of noise on large marine mammals. 2004. Marine Technology Society Journal 37(4): 41-53.

Peter Tyack is Senior Scientist and Walter A. and Hope Noyes Smith Chair in the Biology Department of the Woods Hole Oceanographic Institution. He has an A.B summa cum laude from Harvard College and a Ph.D. from Rockefeller University. His research focuses on acoustic communication and social behavior of cetaceans.

DIVING, FORAGING, AND VOCAL BEHAVIOR OF SPERM WHALES

Stephanie L. Watwood, Mark P. Johnson, Peter T. Madsen, and Peter L. Tyack, Woods Hole Oceanographic Institution
Patrick J.O. Miller, St. Andrews University, Scotland

Digital recording tags ('D-tags') were used to describe the diving and vocal behavior of sperm whales during 198 complete and partial foraging dives made by 37 individual whales in the North Atlantic Ocean, Gulf of Mexico (GOM), and Ligurian sea. Figure 1F.2 shows a typical sperm whale dive profile recorded from the D-tag. Overall, there was little difference in general diving and foraging behavior among regions, but high individual variability within regions. Whales dove to average maximum depths of 985 (124.3) m in the North Atlantic, 644 (123.4) m in the GOM, and 827 (60.3) m in the Ligurian sea. The deepest dive was to 1,202 m by a whale in the North Atlantic. An average dive cycle consisted of a 45- (6.3) minute dive with a 9- (3.0) minute surface interval, with no significant differences among regions. Whales spent 72% of their time in foraging dive cycles in the North Atlantic and GOM, as compared to 98% of their time in the Ligurian sea. This was due to limited observed social behavior in the Ligurian sea.

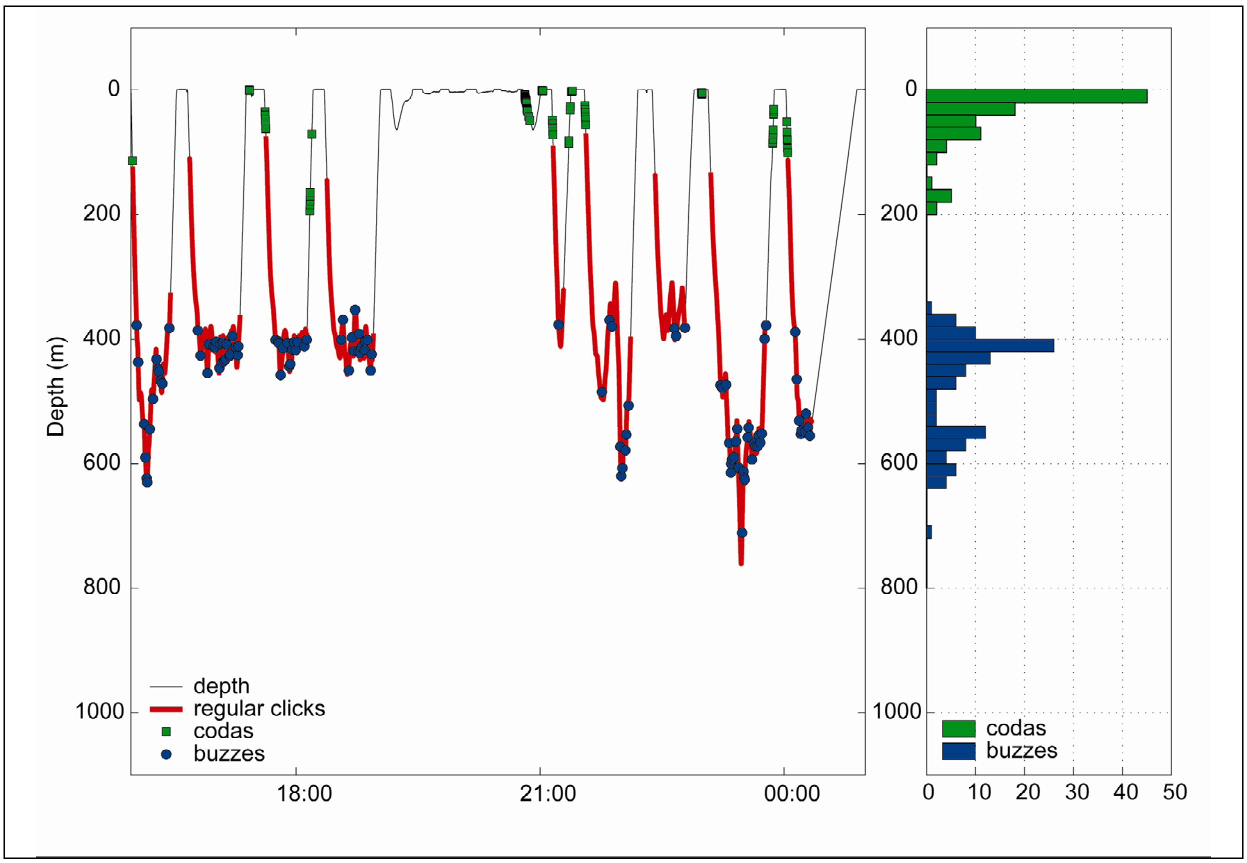


Figure 1F.2. Dive profile of a sperm whale from the Gulf of Mexico.

The vocal behavior of sperm whales was used as an indication of foraging activity. The production of regular clicks was used to determine when sperm whales could be searching for prey patches. Regular clicks have properties suited for long range sonar suited for detection of cephalopod prey (Madsen et al. 2002), and modeling with the sonar equation suggests that sperm whales may be able to detect prey patches at a range of more than 500 m (Møhl et al. 2003). Whales produced regular clicks for 81 (4.1) % of a dive and 64 (14.6) % of the descent phase. The occurrence of buzzes (originally coined "creaks") was used as an indicator of the foraging phase of a dive (Miller et al. 2004). Sperm whales descended a mean of 392 (144) m in depth from the start of regular clicking to the first buzz, which supports the hypothesis that regular clicks function as a long-range biosonar. There were no significant differences in foraging phase duration (28 (6.0) minutes) or percentage of the dive duration in the foraging phase (62 (7.3) %) between the three regions, with an overall average diving efficiency of 0.53 (0.05). Whales maximized their time in the foraging phase by minimizing transit time to and from the foraging depth. The similarity in foraging and diving behavior reported here suggests that general patterns of sperm whale behavior are similar in different regions. However, the data analyzed here only provide a brief image of the behavior of individual sperm whales during a limited time frame. These data do not provide information on differences in long-term foraging success, overall fitness of individuals, or the health of populations in different regions.

Acknowledgments

The authors wish to thank the science parties on the research cruises during which these data were collected (unfortunately too numerous to list), and to Dan Englehaupt and Amy Beier for tissue handling and genetic analysis. The data were collected during collaborative work with NOAA Fisheries Southwest Science Center and NATO Undersea Research Centre. Tom Hurst, Alex Shorter, and Jim Partan were instrumental in developing D-tag hardware and software. Funding was provided under the Office of Naval Research grant numbers N00014-99-1-0819 and N00014-02-10187, Minerals Management Service Cooperative Agreements numbers 1435-01-02-CA-85186 and NA87RJ0445, and the Strategic Environmental Research and Development Program (SERDP) grant number D8CA7201C0011. PJOM was supported by a Royal Society Fellowship. All approaches to the animals for tagging were made following the conditions of NMFS research permits 981-1578 and 981-1707. This research was approved by the Woods Hole Oceanographic Institution Animal Care and Use Committee.

References

Madsen, P.T., M. Wahlberg, and B. Møhl. 2002. Male sperm whale (*Physeter macrocephalus*) acoustics in a high-latitude habitat: Implications for echolocation and communication. Behavioral Ecology and Sociobiology 53:31–41.

Miller, P.J.O., M.P. Johnson, and P.L. Tyack. 2004. Sperm whale behaviour indicates the use of rapid echolocation click buzzes "creaks" in prey capture. Proceedings of the Royal Society of London, B. 271:2239–2247.

Møhl, B., M. Wahlberg, P.T. Madsen, A. Heerfordt, and A. Lund. 2003. The monopulsed nature of sperm whale clicks. Journal of the Acoustical Society of America 114:1143–1154.

Stephanie Watwood completed her Ph.D. in the MIT/Woods Hole Oceanographic Institution Joint Program with Peter Tyack in 2003. Her thesis work focused on the social behavior and vocal communication of male bottlenose dolphins in long-term stable alliances. She is currently a post doc at Woods Hole studying the diving and social behavior of sperm whales.

Dr. Patrick Miller received a Ph.D. in Biological Oceanography jointly from the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution in 2000 with a thesis on the acoustic communication of fish-eating killer whales. After the Ph.D., Patrick had joint postdoctoral positions at MIT and WHOI during which he worked closely on the D-tag project. In 2002, Patrick was awarded a Royal Society International Research Fellowship to study the effects of sound on the ecology of deep-diving mammals at the University of St. Andrews in Scotland. Patrick has worked on several studies of the effects of noise on marine mammals, including the Haro Strait project, the LFA Scientific Research Program, and SWSS; and he is author of several papers on sperm whale behavior and physiology.

Mark Johnson is a Research Engineer at Woods Hole Oceanographic Institution. Dr. Johnson has a Ph.D. in electrical engineering from the University of Auckland, New Zealand. His research interests include real-time digital signal processing for acoustics applications in communications, environmental monitoring, and marine mammology.

Peter T. Madsen graduated from University of Aarhus in 2002 after studying physiological acoustics under Dr. Bertel Møhl. He was post doc in Dr. Roger Payne's lab in 2002–2003, and went on as a post doc to Dr. Peter Tyack's lab at the Woods Hole Oceanographic Institution in 2003. His areas of research includes biosonar, physiological acoustics and effects of man-made noise on marine mammals.

Peter Tyack is Senior Scientist and Walter A. and Hope Noyes Smith Chair in the Biology Department of the Woods Hole Oceanographic Institution. He has an A.B. summa cum laude from Harvard College and a Ph.D. from Rockefeller University. His research focuses on acoustic communication and social behavior of cetaceans.

THE SOUNDS OF AIRGUNS AS RECORDED ON SPERM WHALES AND METHODS TO QUANTIFY ACOUSTIC EXPOSURE

Peter T. Madsen, Mark P. Johnson, and Peter L. Tyack,
Woods Hole Oceanographic Institution
Patrick J.O. Miller, St. Andrews University, Scotland

Sound energy radiated off the axis of an airgun array may be insignificant when compared to the peak pressures generated on the acoustic axis, and may accordingly be dismissed as having little effect on marine mammals. However, the absolute values of these by-products may be of considerable magnitude and at frequencies that are significantly higher than those of the idealized on-axis pulse. So what is considered a relatively low level horizontal by-product from an operational perspective may have absolute levels at frequencies for which the auditory system of the exposed animal is most sensitive and thereby may lead to fitness reduction through threshold shifts, behavioral disruption or masking. Here we report from an ongoing analysis of acoustic data recorded by onboard D-tags on sperm whale (*Physeter macrocephalus*) during feasibility tests of using controlled exposures in concert with sound recording tags. This study provides the first data on the actual sound field received by free-ranging toothed whales during exposure to an anthropogenic noise source. We demonstrate that sperm whales receive several pulses with very different temporal and spectral properties for each firing cycle of the airgun array.

All tags were calibrated before and after deployment. The pre-whitening filter was compensated for during analysis yielding a flat (within ±1dB) frequency response from 0.045 kHz to 16 kHz, respectively. Received levels (RL) for mitigation of cetacean sound exposure are often given by root-mean-square sound pressure levels (RL_{rms}). This measure, however, does not represent the energy of the noise pulse, and it does not prevent exposure to high-peak pressures, so we have also quantified the seismic pulses by peak-peak (RL_{pp}), and sound exposure level (RL_E). For calculation of rms levels of a transient signal, we have adopted the 90% energy approach. The relative energy is computed in a window around the seismic pulse, and the duration (τ) is defined by the sample interval (0:T) containing 90% of the energy content in the window.

$$10\log\left(\frac{1}{T}\int_0^T p^2(t)dt\right)$$ *[p(t)=instantaneous pressure]*

The sound exposure level (also called energy flux density) (RL_E) is given by the rms intensity integrated over the duration τ:

$$10\log\left(\int_0^T p^2(t)dt\right)$$ *[p(t)=instantaneous pressure]*

Not all CEEs rendered a sufficient SNR to allow for analysis of all pulses, and some pulses were discarded due to overlap with sperm whale clicks. In an attempt to accommodate how a mamalian ear process transients, all pulses have been filtered according to the NMFS G-weighting criterion for mid-frequency odontocetes. Figure 1F.3 provides the distribution of received levels in c-weighted rms levels for all pulses analyzed.

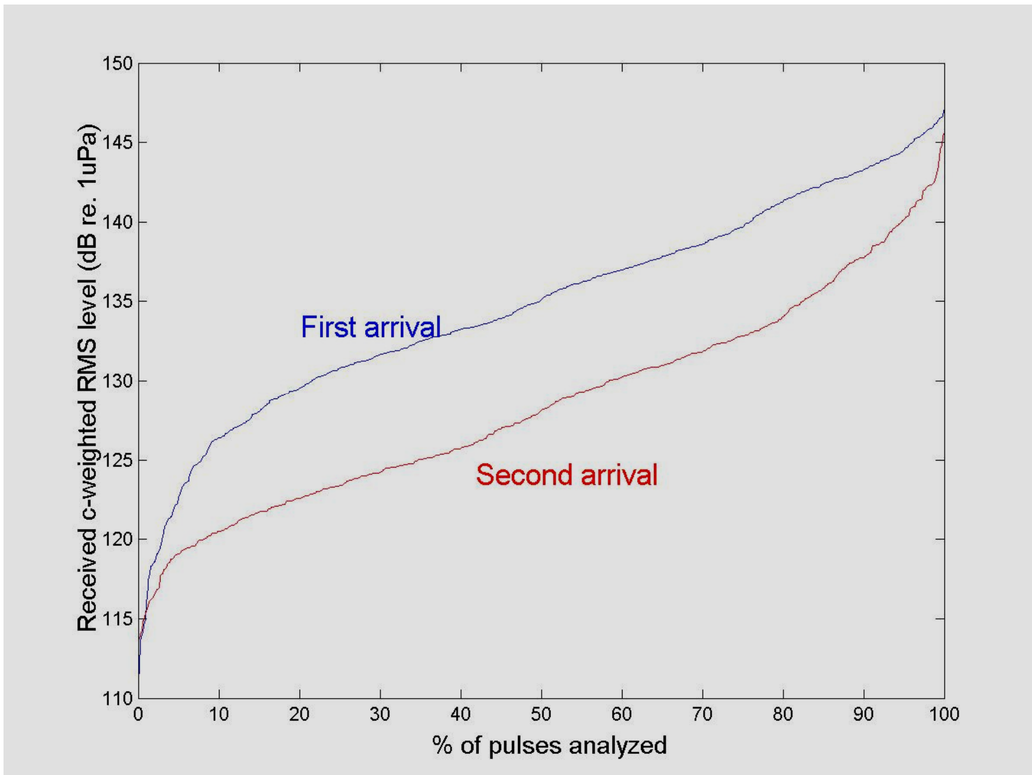


Figure 1F.3. Acoustic exposure cycles.

The acoustic exposure of the animal consists of two or more temporally separated pulses with different properties for every duty cycle of the air gun array. These are the result of a direct arrival followed by a series of pulses generated by multipath propagation in water and sediment. Figure 1F.4a provides an example of such a multipulsed event recorded on a sperm whale at 15 meters depth. The first arrival is a well-defined transient with a short duration of around 50 μsec and with most energy between 0.5 and 2.5 kHz (Figure 1F.4b). Note how there is energy all the way up to the Nyquist frequency at 16 kHz. The second arrival is a much more reverberant pulse that arrives some 500 msec after the first arrival. The waveform is smeared out in time and is likely the combined effect of a bottom reflection and energy traveling in the sediment. While this pulse also contains energy at high frequencies, it is dominated by energy below 200 Hz.

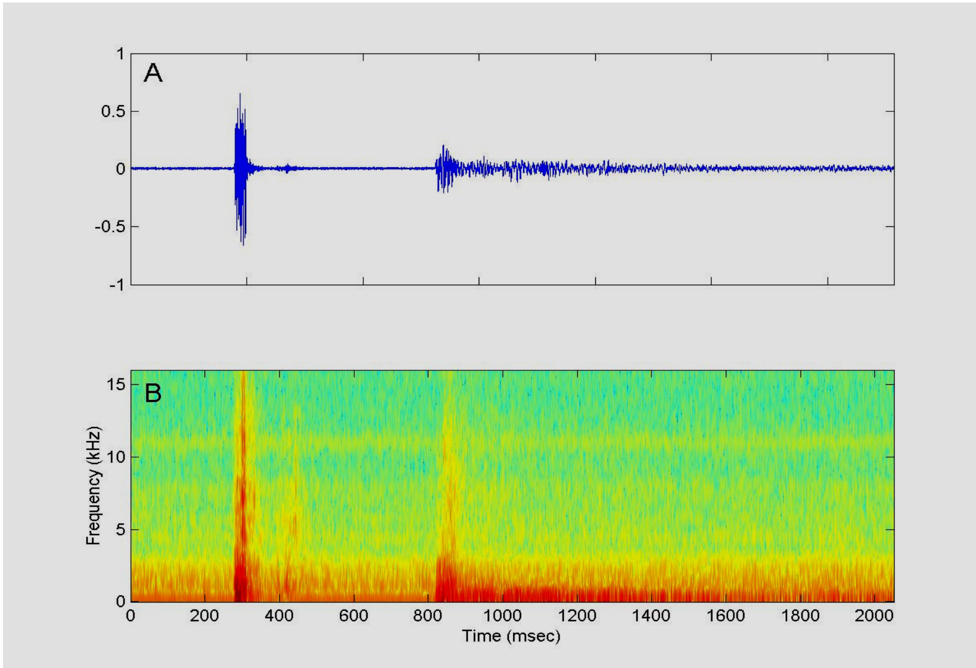


Figure 1F.4. (A) Waveform of the first arrival (direct) and a bottom bounce/bottom ducted second arrival as received by a sperm whale at 30 meters depth. (B) Spectrogram of the waveform of A. FFT size 1024, Hann windowed data, 90% overlap.

Thus, it is demonstrated that sperm whales are exposed to a series of pulses with different spectral, energetic and temporal properties for each duty cycle of the air gun array. The analysis shows that some of the direct arrivals when the whale is close to the surface have dominant energy at much higher frequencies than currently reported or modeled for air gun arrays. While this energy is radiated off the axis of the array, the absolute levels of these high frequency pulses may reach levels of more than 140 dB re 1µPa (rms). This points to a hereto overlooked potential problem of airguns producing significant energy at frequencies that may evoke significant sensation levels in toothed whales that all have their most sensitive range of hearing outside the 0-1,000 Hz band modeled by the industry, and therefore not normally considered sensitive to airgun pulses.

Peter T. Madsen graduated from University of Aarhus in 2002 after studying physiological acoustics under Dr. Bertel Møhl. He was post doc. in Dr. Roger Payne's lab in 2002–2003, and went on as a post doc to Dr. Peter Tyack's lab at the Woods Hole Oceanographic Institution in 2003. His areas of research includes biosonar, physiological acoustics and effects of man-made noise on marine mammals.

Mark Johnson is a Research Engineer at Woods Hole Oceanographic Institution. Dr. Johnson has a Ph.D. in electrical engineering from the University of Auckland, New Zealand. His research interests include real-time digital signal processing for acoustics applications in communications, environmental monitoring, and marine mammology.

Peter Tyack is Senior Scientist and Walter A. and Hope Noyes Smith Chair in the Biology Department of the Woods Hole Oceanographic Institution. He has an A.B. summa cum laude from Harvard College and a Ph.D. from Rockefeller University. His research focuses on acoustic communication and social behavior of cetaceans.

Dr. Patrick Miller received a Ph.D. in Biological Oceanography jointly from the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution in 2000 with a thesis on the acoustic communication of fish-eating killer whales. After the Ph.D., Patrick had joint postdoctoral positions at MIT and WHOI during which he worked closely on the D-tag project. In 2002, Patrick was awarded a Royal Society International Research Fellowship to study the effects of sound on the ecology of deep-diving mammals at the University of St. Andrews in Scotland. Patrick has worked on several studies of the effects of noise on marine mammals, including the Haro Strait project, the LFA Scientific Research Program, and SWSS; and he is author of several papers on sperm whale behavior and physiology.

PRELIMINARY MODELING OF D-TAGS ACOUSTIC ARRIVALS FROM THE GULF OF MEXICO IN 2002 AND 2003

James F. Lynch, Stacy DeRuiter, Peter L. Tyack, Arthur Newhall, and Ying-Tsong Lin, Woods Hole Oceanographic Institution

The modeling effort we discuss centers on observations from summer 2002 and summer 2003 controlled exposure experiments in the Gulf of Mexico (GOM). The goal of the experiments was to investigate the effects of seismic airgun noises on sperm whale foraging behavior. Data were collected by placing D-tag recording devices on the backs of free-ranging sperm whales before, during, and after controlled exposure to airgun array sounds. Acoustic data from the GOM study include recordings of airgun noises at various ranges and water depths. Initial analyses of the data indicate variable frequency content and variable relative amplitude of the airgun arrivals recorded on the D-tags. We have attempted to explain these observations using acoustic models which include ray theory, narrowband normal mode theory, and broadband and narrowband parabolic equation codes.

We first discuss the 2002 data. During summer 2002, the sound speed profile, as measured both by CTDs and XBTs, showed the presence of a strong and persistent surface acoustic duct extending down to ~30m. Such ducts are capable of efficiently transmitting high frequency sounds between sources and receivers within the duct, and indeed that seemed to be the case in 2002. The source was at about 7m depth, well within the duct. Spectrograms of airgun sounds recorded when whales were near the surface (see Figure 1F.5) showed high frequency (~500–5,000 Hz) first arrivals, while recordings from deeper depths did not. Moreover, the first arrival did not show significant energy below 300 Hz, which we calculated from normal mode theory was the cutoff frequency for the lowest frequency mode trappable by the duct. Theory and experiment thus agree well for the ducted arrival in this case. Using simple ray theory, we also predict a single bottom reflected arrival 0.3 seconds after the ducted arrival, which is seen clearly in the data. This arrival should not show much high frequency content, and indeed (looking at Figure 1F.5) it does not. There is also a second (in time) arrival seen in the data, which has both high and low frequency content, and this might be a head wave, which our simple modeling does not include to date. This will be an interesting arrival to model.

We next discuss the 2003 data. In this case, there is no significant surface duct, and indeed spectrograms of the D-tags arrivals do not show the high frequency content in the arrivals that one sees in the 2002 data. Simple ray theory and also broadband parabolic equation calculations seem to be adequate to describe the arrival structures that are seen in the D-tags data. As these data were from greater range, we do not see a head wave arrival, either, as this type of wave decays more rapidly with range.

Looking toward the future, we will be examining not just the arrival time structure with our models, but the amplitude structure as well. Interesting phenomena such as head waves will be examined, and we will certainly be investing more serious efforts into looking at the effects of near-surface oceanographic sound ducts.

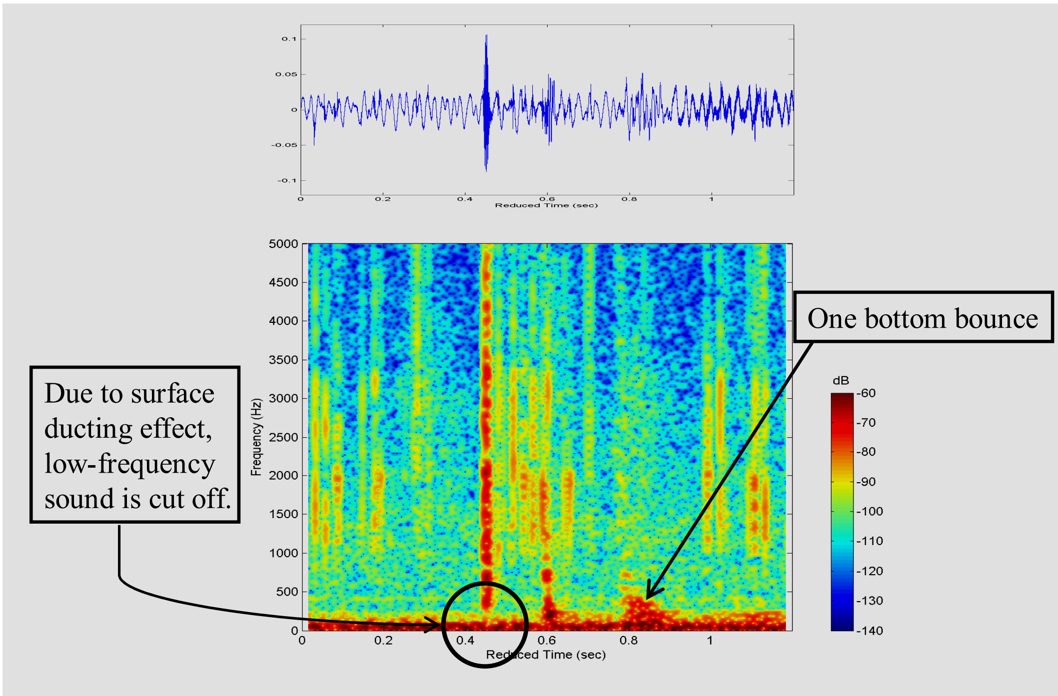


Figure 1F.5. Airgun signal in the 2002 D-tags data.

James F. Lynch is Senior Scientist in the Acoustical Oceanography Group of the Department of Applied Ocean Physics and Engineering at Woods Hole Oceanographic Institution and holds the Robert Morse Senior Scientist Chair at WHOI. He has a B.S. from Stevens Institute of Technology and a Ph.D. from the University of Texas. His research interests are in underwater acoustics, shallow water acoustics, arctic acoustics, acoustic tomography, and high frequency backscatter from particles.

Stacy DeRuiter is a graduate student in the MIT/WHOI Joint Program in oceanography and oceanographic engineering.

Peter Tyack is Senior Scientist and Walter A. and Hope Noyes Smith Chair in the Biology Department of the Woods Hole Oceanographic Institution. He has an A.B. summa cum laude from Harvard College and a Ph.D. from Rockefeller University. His research focuses on acoustic communication and social behavior of cetaceans.

Arthur Newhall is a Research Specialist in the Acoustical Oceanography Group at Woods Hole Oceanographic Institution. He has a B.S. in mathematics from the University of Maine. His research interests include underwater acoustics, acoustic propagation modeling, acoustical oceanography, acoustic backscattering, data analysis, and computer programming and administration.

Ying-Tsong Lin is a Postdoctoral Scholar in applied ocean physics and engineering at Woods Hole Oceanographic Institution. He has a Ph.D. in engineering science and ocean engineering from National Taiwan University. His research interests include acoustical oceanography; geoacoustic inversion; underwater acoustic modeling and signal processing; and uncertainty analysis.

CONTROLLED SEISMIC AIRGUN EXPOSURES: EFFECTS ON THE MOVEMENT AND FORAGING BEHAVIOR OF SPERM WHALES

Patrick J. O. Miller, St. Andrews University, Scotland
Mark P. Johnson, Peter L. Tyack, Peter T. Madsen, and Stephanie L. Watwood, Woods Hole Oceanographic Institution

We conducted a set of five controlled exposure experiments (CEEs) on eight sperm whales tagged with D-tags (four in 2002; four in 2003). After the tags were attached, a pre-exposure data collection period ensued, followed by a half-hour ramp-up period, then a full-array period when all the airguns were firing, and finally a post-exposure period when all guns were turned off. We included pre- and post-exposure data within 90 minutes of an airgun firing. For 2002 data, one to two dives were recorded after tag attachment, while in 2003 ramp-up started after three to eight dives were made after the tag was attached. Here we report on the whales' movement relative to the source vessel and the foraging behavior of the tagged sperm whales by exposure condition.

Data recorded by the tag were converted to animal orientation, whale-frame pitching (which reflect fluking movements by the whale; Miller et al., 2004b), calibrated depth, and the associated audio record (Johnson and Tyack, 2003). Combining the continuous orientation record with an estimate of whale speed and current speed and direction, we constructed a 3-D pseudotrack of the whales' movement during the experiments. The accuracy of the track was checked against whale fixes made from the observation vessel and was good in all cases except one, where insufficient sightings of the shale were obtained and for which some data blocks at the start of the tag record were not decodable due to a software error. The vocal behavior of sperm whales was used as an indication of foraging activity, with the production of buzzes ("creaks") indicative of a prey-capture attempt (Miller et al. 2004a). As reported by Madsen, maximum received sound levels at the whales ranged from 142-147 dB re 1µPa RMS, corrected for the predicted hearing sensitivity of the sperm whale with NMFS c-weighting.

To test whether whales avoided the airgun source, the direction-of-movement of each whale was scored over a 30-minute period in pre-exposure, ramp-up and full-array conditions. Circular statistics were used to compare the movements of each relative to the airgun source vessel and to each whale's previous direction of movement (Zar 1984). Movement before exposure relative to that during ramp-up was non-randomly distributed (Rayleigh $r = 0.92$, $z = 5.9$, $P<0.001$), but was statistically identical to movement in the pre-exposure intervals (mean difference 95% CI -12.2º to 36.0º). Likewise, movement during full-array conditions was statistically equivalent to that in combined pre-exposure and ramp-up intervals (Rayleigh $r = 0.94$, $z = 6.1$, $P<0.001$) mean difference 95% CI (-18.3º to 31.9º). In contrast, whale movement was distributed randomly relative to the source bearing in both ramp-up (Rayleigh $r = 0.58$, $P>0.10$) and full-array conditions ($r = 0.46$, $P>0.20$).

Seven of the eight whales made at least one deep dive in all three conditions, while the remaining whale (sw173b) rested at the surface for an unusually long interval, diving immediately following the final airgun transmission in that experiment. Resting bouts as made by sw173b have been observed on ten other occasions, with durations never exceeding two hours while the bout made by sw173b was over four hours duration. This whale also received the most intense received levels of the source. One other whale (sw253a) switched to a non-foraging shallow dive that lasted until the transmissions stopped, after which it resumed deep diving. These observations suggest that some whales might respond to sound exposure by disrupting their foraging dives and resting at the surface.

Foraging behavior of the seven whales that made at least one deep dive in all conditions was assessed as a function of exposure condition. We used an energy-budget model to define response parameters likely to be of biological significance (Figure 1F.6). Whale-specific pitching energy reflects fluking movements of the whale and was therefore used as a measure of locomotion cost (Miller et al. 2004b), while buzz-rates ("creaks") as a metric of prey-encounter and thereby feeding rate (Miller et al. 2004a).

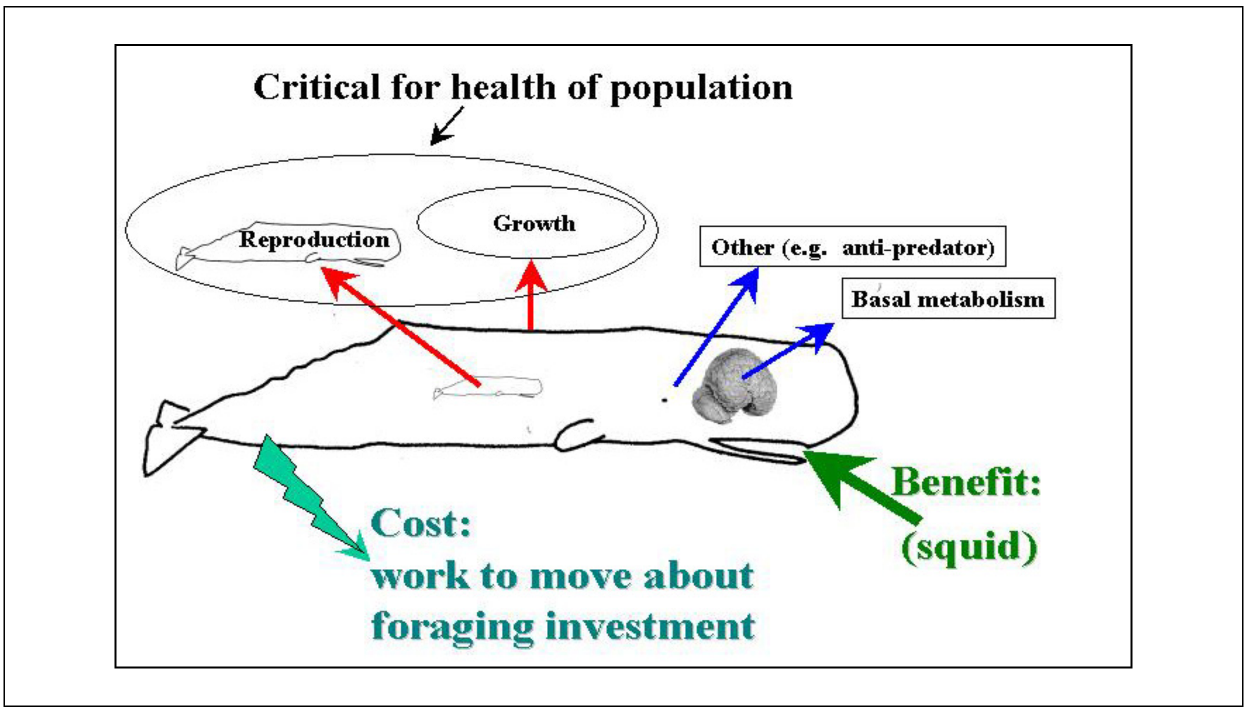


Figure 1F.6. A simple energy model of the sperm whale showing energy input from food, and various energy outputs for locomotion (green), basal metabolism (blue), and energy for growth and reproduction which are critical for maintenance of the health of an animal population (red).

Analysis of buzz-rates and whale-specific pitching energy from all D-tag deployments on sperm whales revealed that both were significantly reduced during the first dive after tag attachment relative to subsequent dives. Data were only recorded for one to two dives following tagging before playback starting during the CEEs conducted in 2002, so the pre-exposure period for those subjects was not long enough to represent post-tagging baseline. Because of this problem, and to assure that equal sample sizes were represented in all conditions, we had to remove the pre-exposure condition entirely from the analysis. Ramp-up as an exposure condition was also not considered as it consists of a mix of very low-level transmissions at the start increasing to full array over a 25-30 minute period. Therefore, all of our analyses only compared full-array versus post-exposure conditions. The bottom-phase of foraging dives was divided into blocks of roughly ten-minute duration, as autocorrelation analyses determined that ten-minute blocks were sequentially independent. The effect of exposure condition was statistically tested using a mixed-model two-way ANOVA in which whale id was treated as a random factor (reflecting the fact that whales were chosen at random from the population) while exposure condition was treated as a fixed factor (Zar 1984).

Whale-specific pitching energy was 11% lower in the full-array condition relative to the subsequent post-exposure condition ($F_{1,6} = 6.80$, $P < 0.05$). Similarly, buzz rates were 24% lower in the full-array condition relative to post-exposure, but this effect was not statistically significant at the 0.05 level ($F_{1,6} = 2.62$, $P = 0.16$).

The results of these analyses of the CEE data suggest that reduced foraging effort invested by sperm whales coincided with the presence of seismic airgun transmissions. Two of the eight whales appeared to avoid making deep foraging dives for some interval during the exposure period, and across all subjects, whale-specific pitching energy during the bottom phase of dives was lower during the full-array condition than in the post-exposure condition. Prey-encounters during the bottom phase of deep dives, as measured by buzzes, also had lower rates during the full-array condition, but more variability was observed for this effect and we cannot reject a null hypothesis of no effect at the 0.05 level. The tested whales did not show horizontal avoidance of the airgun sources during transmissions, though, but continued along their previous direction of movement.

In subsequent work, we will analyze whale-specific pitching energy and buzz rates to describe more fully these metrics of foraging activity, and attempt to relate these metrics more precisely to predicted energy flows into and out of a whale. We will also combine the foraging effort and prey-encounter rates of both deep-diving and non deep-diving subjects to obtain a more complete understanding of how the energy flows changed in relation to the presence or absence of airgun transmissions. Finally, we plan to explore how short-term changes in foraging energetics (which can be measured in controlled experiments such as the CEEs reported here) might have broader population-level consequences (NRC 2005).

Acknowledgments

The authors wish to thank the science parties on the research cruises during which these data were collected (unfortunately too numerous to list), and to Dan Englehaupt and Amy Beier for coordination of ship movement during the CEEs, tissue handling, and genetic analysis. Tom Hurst, Alex Shorter, and Jim Partan were instrumental in developing D-tag hardware and software. PJOM was supported by a Royal Society Fellowship. All approaches to the animals for tagging were made following the conditions of NMFS research permits 981-1578 and 981-1707. This research was approved by the Woods Hole Oceanographic Institution Animal Care and Use Committee.

References

Johnson, M. and P.L. Tyack. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. IEEE Journal of Oceanic Engineering 28:3–12.

Miller, P.J.O., M.P. Johnson, and P.L. Tyack. 2004a. Sperm whale behaviour indicates the use of rapid echolocation click buzzes "creaks" in prey capture. Proceedings of the Royal Society of London, B. 271:2239–2247.

Miller, P. J. O., M.P. Johnson, P.L. Tyack, and E.A. Terray. 2004a. Swimming gaits, passive drag, and buoyancy of diving sperm whales (Physeter macrocephalus). Journal of Experimental Biology 207:1953–1967.

NRC (National Research Council). 2005. Marine Mammal Populations and Ocean Noise: Determining when Noise Causes Biologically Significant Effects. Washington, DC: National Academies Press.

Zar, J. H. 1984. Biostatistical Analysis. Englewood Cliffs, NJ: Prentice-Hall.

Dr. Patrick Miller received a Ph.D. in Biological Oceanography jointly from the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution in 2000 with a thesis on the acoustic communication of fish-eating killer whales. After the Ph.D., Patrick had joint postdoctoral positions at MIT and WHOI during which he worked closely on the D-tag project. In 2002, Patrick was awarded a Royal Society International Research Fellowship to study the effects of sound on the ecology of deep-diving mammals at the University of St. Andrews in Scotland. Patrick has worked on several studies of the effects of noise on marine mammals, including the Haro Strait project, the LFA Scientific Research Program, and SWSS; and he is author of several papers on sperm whale behavior and physiology.

Mark Johnson is a Research Engineer at Woods Hole Oceanographic Institution. Dr. Johnson has a Ph.D. in electrical engineering from the University of Auckland, New Zealand. His research interests include real-time digital signal processing for acoustics applications in communications, environmental monitoring, and marine mammology.

Peter Tyack is Senior Scientist and Walter A. and Hope Noyes Smith Chair in the Biology Department of the Woods Hole Oceanographic Institution. He has an A.B. summa cum laude from Harvard College and a Ph.D. from Rockefeller University. His research focuses on acoustic communication and social behavior of cetaceans.

Peter T. Madsen graduated from University of Aarhus in 2002 after studying physiological acoustics under Dr. Bertel Møhl. He was post doc in Dr. Roger Payne's lab in 2002–2003, and went on as a post doc to Dr. Peter Tyack's lab at the Woods Hole Oceanographic Institution in

2003. His areas of research includes biosonar, physiological acoustics and effects of man-made noise on marine mammals.

Stephanie Watwood completed her Ph.D. in the MIT/Woods Hole Oceanographic Institution Joint Program with Peter Tyack in 2003. Her thesis work focused on the social behavior and vocal communication of male bottlenose dolphins in long-term stable alliances. She is currently a post doc at Woods Hole studying the diving and social behavior of sperm whales.

D-TAG/CEE CONCLUDING REMARKS

Peter L. Tyack, Biology Department, Woods Hole Oceanographic Institute

Summary of CEE Results

The two CEE responses presented at this ITM were avoidance and foraging (effect of exposure on communication is being analyzed and is not ready for presentation). We are working on methods to analyze responses as a function of Received Level for each individual, but this work is in progress.

Avoidance

Miller (this volume) presented a case of possible vertical avoidance of an oncoming seismic survey vessel, but we have found no evidence for horizontal avoidance. No horizontal avoidance was detected either during ramp-up or full array seismic CEEs at ranges of 1-11 km. The complex way in which sounds propagate from airgun arrays, as presented by Lynch (this volume), may complicate analysis of avoidance. If a whale is moving down a local sound gradient, its motion may not be directly away from the vessel. There is no justification from the D-tag/CEE work that sperm whales show horizontal avoidance of oncoming seismic vessels. The D-tag/CEE data provide no support for the assumption that behavioral avoidance will reduce the risk of injury at close range. This was not studied at ranges of <1km, but 1 km is only twice the current mitigation range, and whales would have little time to move far from a vessel as it closed from 1,000 to 500 m.

Foraging

The study design for the first-year CEE cruise was set for tag durations available three years ago. The pre-exposure data from year one was affected by the response to tagging, so we concluded that longer pre-exposure periods are required. A major redesign of the tag and attachment was made between years one and two of SWSS, and these improvements enabled sufficient pre-exposure periods in year two by improvements in attachment, but if we are to include year one data it is only possible to compare exposure to post-exposure data. These modifications also improve the noise floor of acoustic sampling from the tag.

Data from the seven whales that did deep foraging dives during CEE exposure show a significant ($p<0.05$) change in fluking effort comparing exposures at <120-147 dBrms re 1 μPa (see Madsen this volume for details on calculating exposure) to the post-exposure interval. Judging by changes in buzz rates, there was also a 25% reduction of foraging comparing exposures at <120-147 dBrms re 1 μPa to the post-exposure interval. If the whales did not immediately return to baseline once the exposure stopped, this comparison would underestimate the effect. We can cast the results from the first two years of CEEs under SWSS as leading to the hypothesis that sperm whales exposed to 120-147 dBrms re 1 μPa have a 25% reduction of foraging. From a frequentist statistical point of view, we cannot reject the null hypothesis of no difference between exposure and post-exposure buzz rates at the $\alpha <= 0.05$ level. However, modern statisticians point out the critical need for statistical power analysis if H_o is rejected, especially in this kind of study used for management (Peterman 1990). Figure 1F.7 from Miller's ITM presentation introduces the two types of error one may make in deciding whether or not a data set indicates an effect.

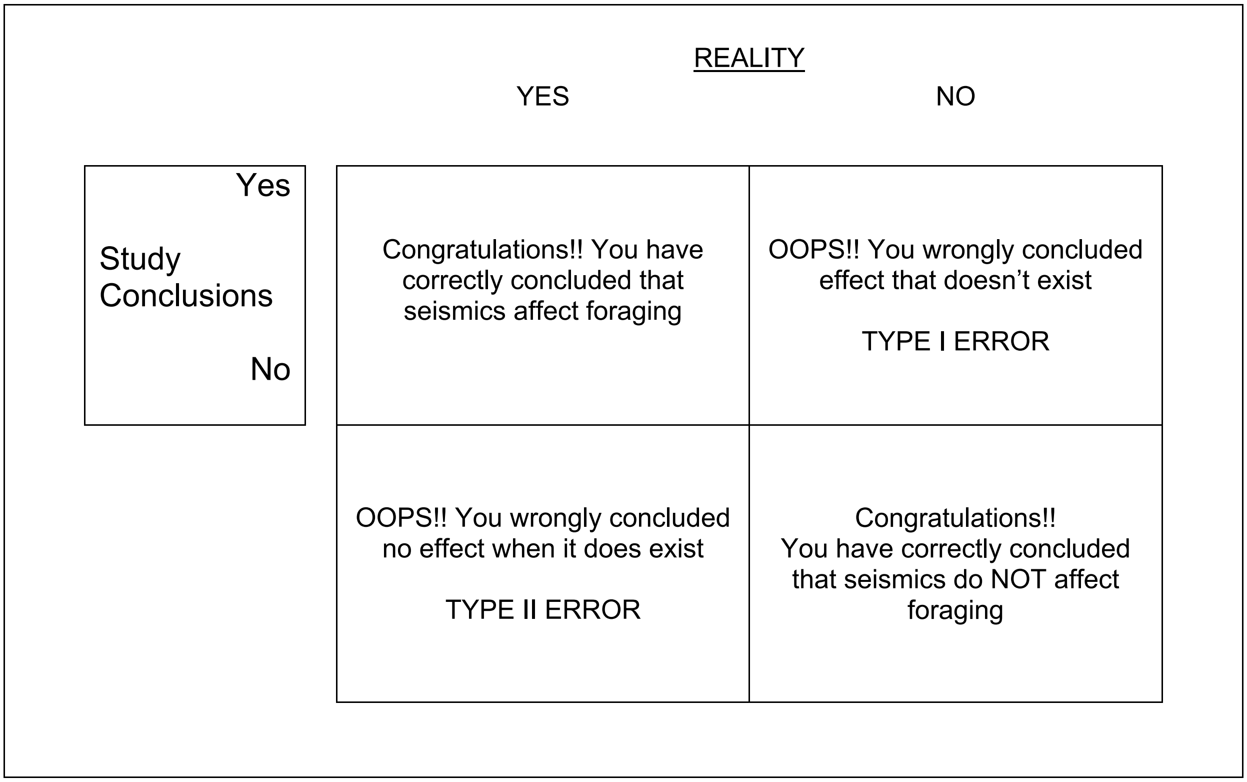


Figure 1F.7. Two error types.

The critical issue for the buzz rate effect is type II error. Statistical analyses of the buzz rate data indicate that if you conclude no effect, there are roughly 85% odds of a Type II error. If on the other hand, you conclude the effect is true, data suggest 16% odds of a Type I error. The odds of a type II error are 5.6 times higher than those of the type I error. Ellison (1996) interprets this odds ratio as substantial positive evidence for the effect. From the perspective of environmental decision-making, there is a need now for an interim decision about whether the CEE data indicating a reduction in foraging correctly defines the effect. There has been discussion among ecologists about different situations suggesting different acceptability of Type I vs. Type II errors. Peterman and McGonigle (1992) make a specific suggestion for "cases in which the H_o was *not* rejected but the study had *low* statistical power for the effect size deemed important. In these latter cases, especially where the confidence interval on the effect size is large, regulatory action to reduce emissions should be recommended as a precautionary measure in case an important effect exists." (p. 232) From the industry perspective, a type I error might lead to the expense of unnecessary monitoring and mitigation measures. From the conservation perspective, the endangered status of sperm whales in the U.S. would suggest a low tolerance for type II errors, especially for such a large reduction in foraging. Peterman (1990) points out that decision makers often must weigh the costs of type I vs type II errors. Purely on the basis of the odds ratio, regulators would have to weigh the costs to industry of the type I error 5.6 times higher than those to endangered sperm whales to justify not adopting interim acceptance of the effect.

There has been considerable discussion in ecology that a Bayesian approach is more appropriate to estimate responses of wildlife to anthropogenic stressors (Ellison 1996, Harwood 2000). From this perspective, the SWSS D-tag/CEE work can establish *a priori* probabilities for specific hypotheses about the effect of airguns on foraging. This analysis suggests that a sample size of about 50-60 CEEs would be required to reach near 80% level of statistical power to test for the same 25% reduction in feeding. The low statistical power and sample size of the D-tag/CEE work under SWSS must be evaluated taking into account decisions on the part of MMS and industry to reduce the initial request for six weeks/year to three weeks/year and the decision after the second cruise to cancel the planned third D-TAG/CEE cruise and to redirect cruise funds to other components of SWSS. Miller's power analysis of the CEE results on foraging shows that while the sample size resulting from two three-week cruises is low, the original WHOI proposal for three six-week or six three-week field efforts would likely have yielded a power of close to 0.5, while a 0.8 level is often used as a benchmark in study design for statistical power.

One of the surprises of recording airgun signals from whales at a distance from the source ship was how different the signals were from the initial predictions. While the bottom bounce contained the low frequency energy predicted, the direct path arrival was much broader band. There is enough overlap of the spectrum from airgun arrays with the dolphin audiogram that airgun sounds are detectable to dolphins at many km, as has been pointed out previously by Goold and Fish (1998). Surface ducts sometimes supported efficient propagation of mid-frequency energy, while not supporting low frequencies. This concentration of mid-frequency sound in surface ducts raises concern for other toothed whales. The presence of mid-frequency sound energy in surface ducts has been raised as a risk factor for strandings of beaked whales (Evans and England 2000). Airguns put considerably less sound energy into these ducts than mid-frequency military sonars, but until safe exposures are determined, there is cause for concern.

Considerations for Future Work

The difference between measurements and predictions of the spectrum, directionality, and propagation of sounds from airgun arrays was a surprise, and interfered with execution of CEEs. A better understanding is required of how sound propagates from airgun arrays. Propagation should be calculated out to large enough ranges to predict exposures to whales at levels of 120 dBrms or below. Data on sound propagation should be linked to models of sound exposure for different species (e.g. AIM) in order to predict the amount of time sperm whales and other species are exposed to different levels of airgun sounds as they move in three dimensions.

Sperm whales in the northern Gulf of Mexico (GOM) hear airguns much of the time. It is unlikely that whales behaving as described by Mate et al. (1994) and Bowles et al. (1994) would have been found for the GOM CEEs, given the intensity of ongoing commercial surveying. This raises concerns about whether the sample of sperm whales in the northern Gulf may already be biased—are they the least responsive members of a larger population? The GOM CEE data cannot be extrapolated to other areas with fewer seismic surveys; but it is reasonable to predict that less habituated animals may be more responsive than those in the studies. Future airgun CEE work should include other areas with fewer seismic surveys. A problem for the GOM CEEs was finding new groups of sperm whales far enough from ongoing commercial surveys that their selection would not bias the sampling. Better field sites with less commercial survey activity and more evenly distributed whales may increase the number of experiments achievable per cruise

It was difficult to achieve received levels much > 150 dBrms on tagged whales using the airgun arrays provided for these experiments. We doubt that there is much need for higher exposure levels until further CEEs resolve the effect of exposure at 120-150 dBrms re 1 μPa. If work is to involve much higher levels, the following are required:

- Better specification of the sound field around airgun arrays and better propagation modeling
- Better real-time monitoring of location and range of subject whale
- Smaller, more cohesive groups for easier monitoring and mitigation (large dispersed groups typical of Gulf complicate approach of tagged subjects)

These improvements will be crucial for studies to evaluate horizontal avoidance of sperm whales at close range (<1 km) to either ramp up or full arrays.

Acknowledgments

We thank the field teams and ship crews of SWAMP, SWSS, Sirena and RV Delaware cruises, the staff of IAGC, LDEO, MMS, NATO Undersea Research Centre, NOAA, TAMU and WHOI. We regret that too many people were involved to allow them to be named individually. Work supported by contract #1435-01-02-CA-85186 from the U.S. Minerals Management Service, ONR and WHOI internal funds for tag development, NSF for RV Ewing support, NOAA for RV support, IAGC and industry for providing source vessels. PJOM Fellowship support from the Royal Society. Work conducted under NMFS research permits 981-1578 and 981-1707-00 issued by the U.S. National Marine Fisheries Service to Peter L. Tyack. The Woods Hole Oceanographic Institution Animal Care Use Committee approved this research.

References

Bowles, A.E., M. Smultea, B. Würsig, D. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. Journal of the Acoustical Society of America 96:2469–2484.

Ellison, A.M. 1996. An introduction to Bayesian inference for ecological research and environmental decision-making. Ecological Applications 6:1036-1046.

Evans W. and G England. 2001. Joint interim report: Bahamas marine mammal stranding event of 15–16 March 2000. U.S. Dept. of Commerce, National Oceanic Atmospheric Administration. National Marine Fisheries Service, Secretary of the Navy, Assistant Secretary of the Navy, Installations and Environment. 61 p.

Goold, J.C. and P.J. Fish. 1998. Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds. Journal of the Acoustical Society of America 103:2177–2184.

Harwood, J. 2000. Risk assessment and decision analysis in conservation. Biological Conservation 95:219–226.

Mate, B.R., K.M. Stafford, and D.K. Ljungblad. 1994. A change in sperm whale (*Physeter macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. Journal of the Acoustical Society of America 96(5, part 2):3268–3269.

Peterman R.M. 1990. Statistical power analysis can improve fisheries research and management. Canadian Journal for Fisheries and Aquatic Sciences 47:2–15

Peterman R.M. and M. McGonigle. 1992. Statistical power analysis and the precautionary principle. Marine Pollution Bulletin 24:231–234.

Peter Tyack is Senior Scientist and Walter A. and Hope Noyes Smith Chair in the Biology Department of the Woods Hole Oceanographic Institution. He has an A.B. summa cum laude from Harvard College and a Ph.D. from Rockefeller University. His research focuses on acoustic communication and social behavior of cetaceans.

SESSION 2D

EFFECTS OF OIL AND GAS EXPLORATION & DEVELOPMENT AT SELECTED CONTINENTAL SLOPE SITES IN THE GULF OF MEXICO, PART II

Chair: Greg Boland, Minerals Management Service

Co-Chair: Margaret C. Metcalf, Minerals Management Service

MEIOFAUNA AND MACROINFAUNA

Barry A. Vittor, Barry A. Vittor & Associates

Responses of benthic organisms to offshore Gulf of Mexico (GOM) petroleum exploration and production have been studied extensively on the continental shelf. Some studies have addressed meiofaunal and macroinfaunal community structure and detected acute and chronic effects on these organisms by surveying around drilling/production sites of varied duration. However, few studies have been designed to focus on sublethal effects on benthos. The Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX) investigated potential chronic, sublethal, and long-term oil and gas production effects on meiofauna and macroinfauna as well as other ecosystem components on the continental shelf (Montagna and Harper 1996). That program detected changes in benthic assemblages due to both organic enrichment and toxicity of drilling muds and cuttings discharged to the bottom. The present investigation employed many of the methods used in GOOMEX but was designed to assess meiofaunal and macroinfaunal community responses to discharges of synthetic drilling muds in deep-sea environments in the GOM.

Benthos were sampled at selected wellsites before to and after drilling to detect short-term (acute) effects of exploratory and development activities. Benthic community responses were intended to be detected through enumeration of individual abundance among major groups (Order or higher taxonomic level in most cases) of meiofauna and macroinfauna. Twenty-four stations were selected for more in-depth taxonomic macroinfauna identification (i.e., to Lowest Practical Identification Level or LPIL). Family-level censusing of meiofaunal nematodes was performed for selected sites sampled during the July 2001 survey to determine changes in trophics among these taxa. Harpacticoid copepod reproductive condition was also noted at selected locations to detect potential sublethal effects of synthetic drilling muds.

Meiofauna

Meiofaunal assemblages at GB 516 stations differed significantly with respect to both cruise (pre-drilling vs. post-drilling) and area (nearfield vs. farfield). Nematodes, ostracods, and polychaetes were more abundant during November 2000 (pre-drilling) compared to July 2001 (post-drilling), but harpacticoid copepod abundance did not differ between pre- and post-drilling surveys. Ostracod abundance was significantly greater at farfield stations, whereas polychaetes were significantly more abundant at nearfield stations. At VK 916 stations numbers of harpacticoid copepods, polychaetes, and nematodes were significantly more abundant pre-drilling; however, there were no differences between areas (nearfield vs. farfield) for these taxa. There were no nearfield vs. farfield differences in meiofaunal assemblages at GB 602 or MC 292 stations.

We observed a very wide range in meiofaunal abundance among the four study sites and between surveys. Average meiofauna densities (19 to 608 per 10 cm^2) were much lower than found by Montagna and Harper in shelf waters (734 to 2571 per 10 cm^2). This difference was consistent with the widely reported inverse relationship between water depth and meiofauna abundance. Sediments at VK 916 were reported to be carbon-rich, with extensive foraminiferan composition. After drilling, deposition, and disturbance were detected close to the wellsite (within about 30 m). At the other wellsites drilling muds extended outward about 150 m. Nearfield stations had higher abundances than farfield stations at all four sites. While these increases appeared to be due in part to higher numbers of nematodes, harpacticoids also occurred at higher abundances at most nearfield stations. Elevated organic content at GB 516 did not elicit nematode abundance increases; rather, post-drilling nematode abundance was slightly lower at nearfield stations than at farfield stations. The similarity of nearfield meiofaunal abundance at GB 602 to other post-drilling sites was surprising because of what sediment profile imagery indicated to be a bacterial mat on the surface, with no apparent infauna.

Synthetic based muds (SBM) did not appear to affect meiofauna abundance or numbers of nematodes or harpacticoids. In an attempt to detect longer-term effects of SBM on harpacticoid reproduction, female copepod reproductive condition was recorded for samples obtained at MC 292 and GB 602 (where SBM discharges had occurred at least two years earlier). However, the numbers of harpacticoids observed were very small and the data are not considered to be conclusive. Potential shifts in nematode feeding types were also considered, but nearfield and farfield stations were similar with respect to numbers of deposit feeders and numbers of predators.

Macroinfauna

Macroinfaunal abundance was significantly greater pre-drilling at GB 516 for amphipods, harpacticoid copepods, and nematodes. Bivalves, gastropods, and polychaetes were more abundant at nearfield stations. At VK 916 stations, most taxa were more abundant prior to drilling than after. Annelids were more abundant during post-drilling and decapods showed no between-cruise difference. Except for ostracods and rhynchocoels, there were no abundance differences between areas (nearfield vs. farfield) at VK 916. At GB 602, aplacophorans, bivalves, gastropods, harpacticoid copepods, polychaetes, and rhynchocoels were more abundant at nearfield stations, while nematodes and tanaids were more abundant at farfield stations. At MC 292, bivalves, harpacticoid copepods, and polychaetes were more abundant at nearfield stations.

Macroinfauna results corresponded well with prior observations of deep-water macoinfaunal community structure. Some probable drilling effects were reflected in the data, though drilling-related disturbance was not evident in most assemblage patterns at the wellsites. Highest average macroinfaunal densities occurred at nearfield stations at GB 516, MC 292, and GB 602, all in post-drilling surveys. Abundance of ostracods and tanaids was greater at GB 516 farfield stations, whereas bivalves, gastropods, and polychaetes were more abundant at nearfield stations, potentially a reflection of drilling-related effects according to the paradigm suggested by Montagna and Harper (1996). They found that polychaete density increased near wellsite platforms, and there was a corresponding decline in abundance and diversity of certain crustaceans (amphipods and harpacticoid copepods) near platforms. At VK 916 stations, amphipods and harpacticoid copepods were more abundant before drilling than after drilling, while polychaetes were more abundant after drilling. These differences between cruises may indicate drilling-related effects; however, except for ostracods and rhynchocoels, there were no differences between nearfield and farfield stations at VK 916. Furthermore, at GB 602, which was surveyed only after drilling, harpacticoid copepods were more abundant at nearfield stations. At MC 292, harpacticoid copepods also were more abundant at nearfield stations, but amphipods, ostracods and tanaids did not exhibit differences in abundance between nearfield and farfield stations.

References

Montagna, P.A. and D.E. Harper, Jr. 1996. Benthic infaunal long-term response to offshore production platforms in the Gulf of Mexico. Canadian Journal of Fisheries and Aquatic Science 53:2567–2588.

Dr. Barry Vittor is President of Barry A. Vittor & Associates, Inc. a consulting firm that has specialized in coastal and marine benthic ecosystem studies since 1977. Dr. Vittor has over 30 years' experience in assessing the effects of offshore oil and gas exploration/production activities on benthic communities.

EFFECTS OF OFFSHORE OIL AND GAS DEVELOPMENT ON THE GENETIC DIVERSITY OF HARPACTICOID COPEPODS

Christopher S. Gregg, David W. Foltz, and John W. Fleeger,
Louisiana State University

The deep sea in the northern Gulf of Mexico (GOM) is an increasingly active area for exploration of oil resources, but there are currently no data on the effects of oil exploration and production on genetic diversity of deep-sea infauna. Sites adjacent to (near field) and distant from (far field) oil-drilling platforms were sampled at two locations in the northern GOM off the coast of Louisiana both at depths of ≈ 1,100 m. The sites were located at Garden Banks Area Block 602 (GB602) and Mississippi Canyon Area Block 292 (MC292). Near-field sites were characterized by low species diversity and high dominance. Many specimens of a single species in the family Cletopsyllidae, Cletopsyllidae gen. nov. sp. nov. (R. Huys pers comm.; referred to as Cletopsyllidae sp.), were recovered from box cores at near-field sites. Far-field sites were characterized by high species diversity and low dominance, more typical of deep-sea communities. Because no single harpacticoid species was found in high abundance at both near- and far-field sites, the objectives of the present study were modified to examine the relationship between sediment disturbance and abundance as well as genetic diversity of Cletopsyllidae sp. at the two exploration sites. Additionally, DNA sequence data was used to determine if the harpacticoids examined were a single species or a complex of cryptic species. We examined DNA sequence variation of the mitochondrial cytochrome c oxidase subunit I (COX I) gene. The patterns of genetic diversity and structure or the presence of cryptic species were used to determine how Cletopsyllidae sp. may have responded to the environmental disturbance.

Cletopsyllidae sp. was the most abundant harpacticoid at both the GB602 and MC292 near-field sites. Only one Cletopsyllidae sp. was observed at the far-field sites. Observations of the distribution of cuttings from the drilling process indicated that level of disturbance was not uniformly distributed throughout the near-field sites. We, therefore, examined the relationship between a measure of disturbance, total petroleum hydrocarbons in the synthetic-based mud range (TPH; data from Tom McDonald), and copepod abundance. When TPH levels were below 2,500 µg dry g^{-1}, there was a significant positive linear relationship between TPH concentration and Cletopsyllidae sp. abundance at both sites (GB602 - $R^2 = 0.45$; MC292 – $R^2 = 0.92$). At GB602 four out of 12 boxcores had TPH concentrations greater than 2,500 µg dry g^{-1}. Copepod abundance at GB602 showed a decline when TPH concentrations were above this concentration suggesting there was a threshold level of disturbance, above which copepods cannot survive. Cletopsyllidae sp. may have responded directly to petroleum hydrocarbons or to an indirect effect associated with disturbance caused by oil production activities. Therefore, the identification of the cause of this pattern requires further study

Genetic analysis of the two populations revealed two important observations. First, divergence at the COX I gene was within the range expected (maximum 1.6%) for intraspecific variability. Thus, the Cletopsyllidae sp. populations sampled at the two production sites were a single species and not a complex of cryptic species. Second, low genetic diversity indicated the Cletopsyllidae sp. populations were not in genetic equilibrium, indicating that they have undergone population fluctuations, such as a founder event and population expansion. Haplotype diversity was 0.61 (SD ± 0.089) and 0.89 (SD ± 0.033) and nucleotide diversity was 0.0020 (SD ± 0.0014) and 0.0066 (SD ± 0.0038) at GB602 and MC292, respectively. The low haplotype and nucleotide diversities observed in the present study were comparable to those seen in populations of other harpacticoid copepods in the genus *Cletocamptus*, which are known to undergo population fluctuations, and populations of the species *Microarthridion littorale*, which are found in disturbed habitats.

The present study suggests that the harpacticoid copepod Cletopsyllidae sp. responds to disturbance by rapidly increasing in abundance in response to disturbance in the deep sea. First, a positive correlation between abundance of this copepod species and total petroleum hydrocarbons (TPH) was observed up to a TPH concentration of 2,500 µg dry g^{-1}. Second, low genetic diversity suggests that the harpacticoid population has undergone population fluctuations, such as a founder event and rapid population expansion. Further study of this species is required to confirm these results and to determine the mechanisms by which it colonizes and tolerates hydrocarbon-rich sediments. If further sampling at other deep-sea oil platforms and organically enriched habitats shows similar results, then Cletopsyllidae sp. may prove to be a useful indicator of disturbance or hydrocarbon enrichment in deep-sea sediments.

Christopher Gregg is a post-doctoral student working with David Foltz and John Fleeger at Louisiana State University.

David Foltz is a Professor in the Department of Biological Sciences, Louisiana State University. He obtained his Ph.D. from the University of Michigan in 1979. His research is concerned with the molecular evolutionary genetics of marine invertebrate species. The questions addressed concern rates of evolution, patterns of lineage splitting and extinction, and the roles of geological events and various life history factors in shaping the population genetic structures of these species. Organisms studied include marine bivalves, other marine and freshwater molluscs, echinoderms, and crustaceans. Other ongoing related projects include a study of pollution tolerance in a cryptic species complex of harpacticoid copepods.

John Fleeger is a Professor in the Department of Biological Sciences, Louisiana State University. He obtained his Ph.D. at the University of South Carolina in 1977. His research focuses on the ecology, evolution and ecotoxicology of benthic invertebrates. His interests include factors that control the abundance patterns of meiofauna (benthic metazoans <1 mm in body length) and small macrofauna. His recent projects focus on the joint effects of nutrient addition and fish exclusion on the benthos of tidal creeks, the effects of CO2 disposal (to mitigate the greenhouse effect) on deep-sea benthos and contaminant ecotoxicology including issues related to the effects of contaminant mixtures, assimilation efficiency and bioavailability.

SEDIMENT MICROBIAL BIOMASS

Paul A. LaRock, School of the Coast and Environment,
Department of Oceanography and Coastal Sciences, Louisiana State University

Introduction

The thrust of the current effort was to determine the effects of oil drilling activities on sedimentary microbes using adenosine triphosphate (ATP) determinations as the primary analytical tool. ATP serves as a useful measure of bacterial colonization and survival in extreme or altered environments as it is directly tied to the physiological functioning of the community.

The nature and magnitude of the sedimentary bacterial community have been the subject of a number of studies. The initial approach to quantify sedimentary bacteria was to separate them from the sediment matrix and count the resultant cells using epifluorescent microscopy. A consensus developed that the size of the bacterial community was inversely proportional to sediment grain size (Dale 1974; DeFlaun and Mayer 1983; Yamamoto and Lopez 1985), and that it also varied directly with organic carbon. The reasoning for the increase in bacterial numbers with decreasing grain size was the greater availability of sediment surface area for colonization. Early experiments at sediment oxygen uptake indicated that more oxygen was consumed by small grain-size sediments than by coarser materials. However, the experiment was carried out by suspending less than a gram of material into 28 ml BOD bottles and following oxygen loss (Hargrave 1972). This approach ignores *in situ* conditions and the fact that very fine materials may have more pore space, but the pores are so small that flow into the sediments is greatly inhibited thus limiting the introduction of nutrients and oxygen into the sediment matrix (Maier et al. 2000). The work of Yamamoto and Lopez (1985) revealed that increased surface was only one aspect of microbial colonization and recognized that the size and shape of sediment particles affect sediment packing. Larger, more sorted particles, as found in sands, would actually make nutrients more available to the sedimentary bacterial community. Both DeFlaun and Mayer (1983) and Yamamoto and Lopez (1985) noted that clays were a poor substrate for bacterial attachment.

The ATP assay offers considerable advantage over conventional microbiological methods when assessing the effect of the environment on microbial communities because it is non-cultural, avoids the issue of nutrient limitations and reflects the *in situ* properties of the community. ATP is present in physiologically active cells and thus offers a means of assessing the relationship between the microbial community and the suitability of the prevailing habitat. Environmental ATP determinations can, therefore, provide quantification of the effects of toxicants, nutrient enrichment or other alteration of the environment. A few of the more recent applications of ATP technology have been to examine issues in marine ecology (Karl 1986; Karl 1993; Bjorkman and Karl 2001), to study the effects of nutrient loading in coastal waters (Malin et al. 2001), to quantify hydrothermal communities (Atkinson et al. 2000), to assess river water and sediment quality (Dutka et al. 1991), to follow the toxic effects of zinc released from trout farms

(Martinez-Tabche et al. 2000), to determine the toxicity of pollutants on waste water treatment (Dalzell and Christofi 2002; Dalzell et al. 2002), and to assess the effects of wastewater-borne heavy metals in mangroves (Yim and Tam 1999).

As the ATP assay became more widespread it became evident that there were substances that resulted in a loss of ATP during extraction and had to be compensated for. It was shown that suspended material in water samples, for example, was capable of reducing ATP quantification by either affecting the extraction efficiency or by inhibiting the luciferin-luciferase reaction. To overcome these deficiencies we employed radiolabeled ATP as an internal standard to assess losses encountered during extraction and a stable ATP internal standard to correct for interference during the counting phase.

Sediments from the study sites were predominantly clay with a mean sedimentary particle diameter ranging from about 1 to 3 µm. Over 80% of the sediment consisted of components smaller than 10 µm. Thus we were dealing with materials that are very fine-grained, highly porous but very impermeable (Maier et al. 2000).

Additionally, a bioluminescent assay using the dinoflagellate *Pyrocystis lunula* was used to test the relative inhibitory effects of sediment extracts in the pre- and post-drill materials. A detailed methodology for the luminescent assay may be found in ASTM protocol E 1924, and the procedure as reported here was performed by the Lumitox Co., Slidell, LA who developed the technique

The ATP results for all stations and cruises are summarized in Table 2D.1 and although there is spatial variation, they show that for all the post-drilling conditions the ATP is significantly reduced relative to the pre-drill materials. A comparison of the pre- and post-drilling ATP values at GB 516 and VK 916, on the average, show a marked decrease of from five- to fifteen-fold after drilling. At GB 516, the average ATP concentration on Cruise 1B was 44.2 ng g^{-1} for the NF site and 43 ng g^{-1} for the FF sites. The Cruise 2B averages were 4.3 ng g^{-1} for the NF site and 2.5 ng g^{-1} for the FF sites. At VK 916, the average pre-drilling ATP concentration was 32 ng g^{-1} for the NF site and 36 ng g^{-1} for the FF sites. The post-drilling averages for VK-916 NF (7.7 ng g-1) and FF (7.1 ng g-1) indicate a five-fold reduction in the microbial ATP biomass although it should be noted that again there is spatial heterogeneity in the data. The difference between the pre-drilling and post-drilling ATP concentrations is statistically significant ($p< 0.0001$ for GB 516 and $p< 0.0002$ for VK 916). Statistically there was no significant difference between the near field and far field ATP levels for either GB 516 or VK 916 ($p<0.137$ for GB 516 and $p<0.157$ for VK 916).

Our findings show that drilling does affect the sedimentary microflora, but what happens when drilling ceases? Unknown at the time the project was designed was the fact that GB 516 had exploratory wells drilled the year prior to our sampling, thus GB 516 was not a pristine site but rather a recovered site. What this indicates is that while there may be an initial impact as a result of development the sedimentary microflora does recover and at a relatively rapid rate.

Table 2D.1. Sediment ATP concentrations (ng g^{-1} dry wt) for all near-field and far-field sites.

Site	Sample[a]	GB 516		VK 916		GB 602	MC 292
		Cruise 1B	Cruise 2B	Cruise 1B	Cruise 3B	Cruise 2B	Cruise 2B
NF	B01	288.3	2.1	47.5	<1.7[b]	--	4.5
	B02	418.2	0.6	42.1	<1.3[b]	3.4	1.2
	B03	13.1	7.9	30.2	<1.8[b]	3.3	1.4
	B04	27.9	0.5	34.5	<1.8[b]	2.3	0.9
	B05	26.4	1.1	29.3	15.3	14.1	4.4
	B06	--	11.9	48.3	25.6	4.7	4.4
	B07	33.5	4.4	30.1	41.5	2.3	1.1
	B08	104.1	1.5	21.9	<0.3[b]	17.6	5.4
	B09	39.2	9.6	25.1	1.1	2.7	1
	B10	29.2	0.7	23.3	1.3	15.2	1.6
	B11	56.3	5.1	23.4	<1.5[b]	16.2	5.5
	B12	68.7	6.8	29.1	1.1	ND	1.7
FF1	B01	28.7	5.5	--	61.1	2.1	2.9
	B02	43.4	5.8	--	1.1	1.1	--
FF2	B01	102.4	2.3	57.9	1.3	1.7	2.5
	B02	25.3	2.8	61.4	1.1	1.9	66.6
FF3	B01	92.3	0.5	34.2	2.7	3.6	1.7
	B02	35.3	3.1	29.6	<1.5[b]	2.4	2.8
FF4	B01	29.1	5.4	19.7	2.7	1.1	2.1
	B02	38.1	1.1	28.4	2.3	2.2	0.7
FF5	B01	64.4	0.5	24.5	2.3	3.2	1.1
	B02	14.2	0.6	--	2.7	216.3	2.2
FF6	B01	29.3	1.4	36.4	0.9	2.6	1.5
	B02	16.7	0.8	32.1	5.6	2.7	1

[a] Sample locations were randomly selected on each cruise; therefore, the pre- and post-drilling samples at GB 516 and VK 916 are not paired samples from the same location.
[b] A < symbol indicates that interference reduced the sensitivity of the assay to the value indicated; thus, ATP may be present at a lower concentration but be undetectable.

Toxicity Bioassay

In order assess possible causes for the post-drill decrease in ATP levels, a toxicity bioassay was performed that measured the relative changes in light output of the dinoflagellate *P. lunula* as it was exposed to extracts made from the various pre and post-drilling sediments. The addition of

SDS, either 10 or 20 µl was used as a positive control to elicit a measurable response that can be compared to the negative control (*P. lunula* with no additives). The results obtained for VK 916 indicated that all of the pre-drilling materials yielded the same response as the unamended *P. lunula* control, but the post-drilling samples exhibited some inhibition with the NF sediments being more inhibitory than the FF sediments. Bear in mind that the design of these tests was only to indicate the relative effects of the various sediments and that only a small aliquot of the extract was used which does not indicate the full inhibitory potential of the materials.

The results for GB 516 essentially paralleled those obtained for VK 916: the post-drilling samples were inhibitory with the NF materials exerting a stronger effect than the FF samples did. Tests on GB 602 post-drilling sediments showed some inhibition in the bioassay, but the results for MC 292 indicated no inhibition whatsoever. This rather curious finding may reflect circulation within the Mississippi Canyon itself. Submarine canyons are known to support upwelling and therefore flush the region, thus removing foreign material.

References

Atkinson, T., S. Gairns, D.A. Cowan, M.J. Danson, D.W. Hough, D.B. Johnson, P.R. Norris, N. Raven, C. Robinson, R. Robson, and R.J. Sharp. 2000. A microbiological survey of Montserrat Island hydrothermal biotopes. Extremophiles. 4:305–313.

Bjorkman, K.M. and D.M. Karl. 2001. A novel method for the measurement of dissolved adenosine and guanine triphosphate in aquatic habitats: applications to marine microbial ecology. Journal of Microbiological Methods. 47:159–167.

Dale, N.G. 1974. Bacteria in intertidal sediments: Factors related to their distribution. Limnology and Oceanography 19:509–518.

Dalzell, D.J.B. and N. Christofi. 2002. An ATP luminescence method for direct toxicity assessment of pollutants impacting on the activated sewage sludge process. Water Research 36:1493–1502.

Dalzell, D.J.B., S. Alte, E. Aspichueta, A. de La Sota, J. Etxebarria, M. Gutierrez, C.C. Hoffmann, D. Sales, U. Obst, and N. Christofi. 2002. A comparison of five rapid direct toxicity assessment methods to determine toxicity of pollutants to activated sludge. Chemosphere. 47:534–545.

DeFlaun, M.F. and L.M. Mayer. 1983. Relationships between Bacteria and Grain Surfaces in Intertidal Sediments. Limnology and Oceanography 28:873–881.

Dutka, B.J., K.K Kwan, S.S. Rao, A. Jurkovic, R. Mcinnis, G.A. Palmateer, and B. Hawkins. 1991. The use of bioassay to evaluate river water and sediment quality. Environmental Toxicology and Water Quality 6:309–327.

Hargrave, B.T. 1972. Aerobic decomposition of sediment and detritus as a function of particle surface area and organic content. Limnology and Oceanography 17:583–596.

Karl, D.M. 1986. Determination of the *in situ* microbial biomass, viability, metabolism, and growth. Bacteria in Nature. 2:85–176.

Karl, D.M. 1993. Total microbial biomass estimation derived from the measurement of particulate adenosine-5'-triphosphate. In: Kemp, P.F., B.F. Sherr, E.B. Sherr, and J.J. Cole, eds. Handbook of Methods in Aquatic Microbial Ecology. Pp. 359–368.

Maier, M.A., I.L. Pepper, and C.P. Gerba. 2000. Environmental Microbiology. Academic Press. 585 pp.

Malin, M.A., L.B. Cahoon, D.C. Parsons, and S.H. Ensign. 2001. Effects of nitrogen and phosphorus loading on plankton in coastal plain blackwater rivers. Journal of Freshwater Ecology 16:455–466.

Martinez-Tabche, L., I.G. Cabrera, L.G. Olivan, M.G. Martinez, and C.G. Faz. 2000. Toxic effects of zinc from stout farm sediments on ATP, protein, and hemoglobin concentrations of *Limnodrilus hoffmeisteri*. Journal of Toxicological Environmental Health-Part A.59:575–583.

Yamamoto, N. and G. Lopez. 1985. Bacterial abundance in relation to surface area and organic content of marine sediments. Journal of Experimental Marine Biology and Ecology 90:209–220.

Yim, M.W. and N.F.Y. Tam. 1999. Effects of wastewater-borne heavy metals on mangrove plants and soil microbial activities. Marine Pollution Bulletin 39:179–186.

Paul LaRock is a professor of biology in the School of the Coast and Environment of Louisiana State University. His primary research interests are estuarine pollution, microbiology, geomicrobiology, and oceanography.

CHARACTERIZATION OF NORTHERN GULF OF MEXICO DEEPWATER HARD BOTTOM COMMUNITIES WITH EMPHASIS ON *LOPHELIA* CORAL

Stephen T. Viada, Continental Shelf Associates, Inc.

Continental Shelf Associates, Inc. and its subcontractors/consultants are conducting a multi-year study to characterize the types of non-chemosynthetic megafaunal and macroinfaunal communities that live on deepwater hard-bottom substrate areas of selected study sites and to investigate and describe environmental conditions that are correlated with the observed distribution and development of these high-density biological communities, particularly extensive areas of the scleractinian coral *Lophelia pertusa*. Six study sites were selected for investigation during the first field sampling effort (Cruise 1). The selection of these sites was based upon an analysis of existing data, using the following criteria: where the presence of the coral *Lophelia pertusa* and other significant hard-bottom megafaunal assemblages have been confirmed; where unidentified corals and other non-chemosynthetic megafauna have been reported; where corals or other megafauna have been collected; and from supportive geophysical data. From this selection process, six sites were chosen within the following lease area blocks: Viosca Knoll 826 (VK 826), Viosca Knoll 862 (VK 862), Mississippi Canyon 885 (MC 885), Mississippi Canyon 709 (MC 709), Green Canyon 234 (GC 234), and Green Canyon 354 (GC 354) (Figure 2D.1).

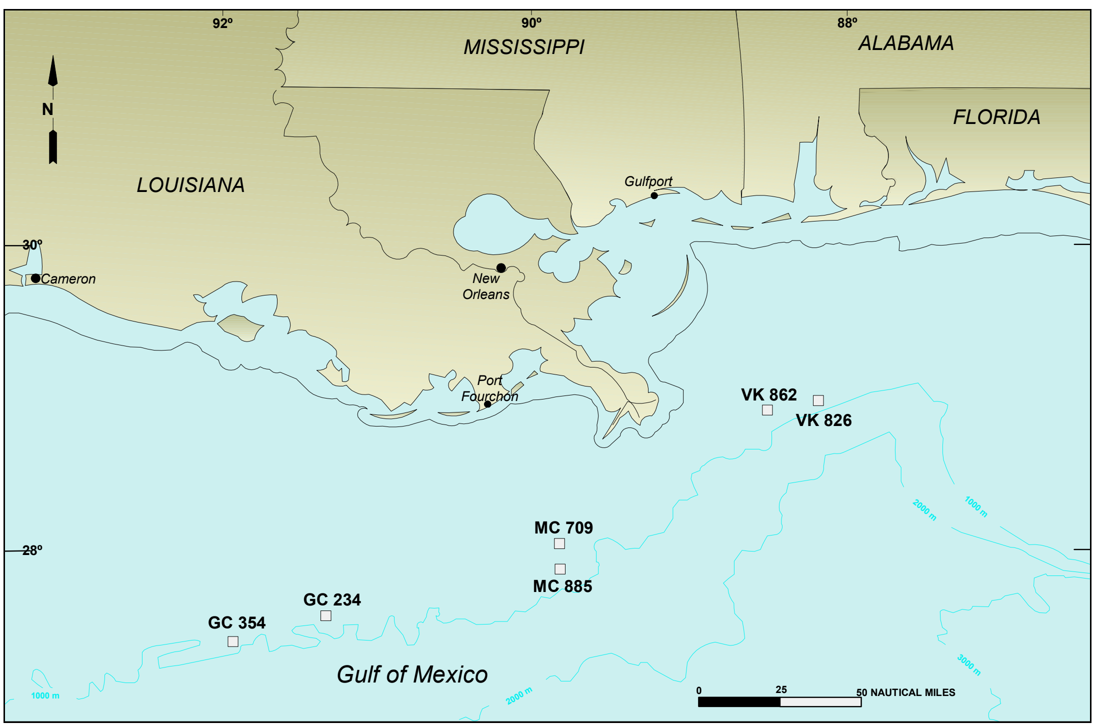


Figure 2D.1. Cruise 1 sampling sites.

The program has three components: physical oceanography studies; geological characterization; and biological characterization and studies. The objectives of the physical oceanography studies are to obtain information on the horizontal and vertical transport of suspended organic material and to investigate potential dispersal patterns for *Lophelia* larvae released at the study sites. The objectives of the geological characterization component are to provide detailed information pertaining to the landscape geology, geomorphology, and subsurface geology of each study site and to collect and interpret existing regional scale geologic data. The objectives of the biological characterization and studies component are 1) to provide qualitative and quantitative descriptions of the hard-bottom megafaunal assemblages found on each of the study sites; 2) to determine whether these assemblages are established on authigenic hard-bottom; 3) to determine if chemosynthetic/methanotrophic production is important for *Lophelia* nutrition; 4) to determine if these coral communities are similar to tubeworm-associated communities; 5) to determine tolerance limits of adult *Lophelia* to a range of temperatures, sediment loads, and food supply; 6) to help define the environmental constraints of suitable *Lophelia* habitat; and 7) to determine the flux of sediment and zooplankton within habitat type which, in the case of sediment, may inhibit larval settlement or smother corals and, in the case of zooplankton, may indicate a lack of suitable food.

Cruise 1 was conducted between 20 and 28 July 2004. Acceptable areas for study were located and surveyed at all of the proposed sites except MC 709, where no exposed hard bottom habitat or associated megafaunal assemblages were located. Current meter arrays were deployed at two sites (VK 826 and GC 234). Other tasks completed during Cruise 1 included video transects, photomosaics, quantitative collections using the Bushmaster sampling device, collections of organisms and carbonates for stable isotope analyses and taxonomic vouchers, collections of water samples for total petroleum hydrocarbon analyses, collections of living *Lophelia* colony fragments for laboratory experiments, collections of sediment core samples for sediment grain-size analyses, sediment trap deployments, *Lophelia in situ* staining, and *Lophelia* transplant deployments.

Stephen Viada is a Senior Staff Scientist with Continental Shelf Associates, Inc., located in Jupiter, Florida. He has 24 years of experience in marine environmental science, including major research programs for federal, state, and industrial clients. He has been involved in characterization and monitoring studies covering a wide range of human activities in the marine environment, including oil and gas operations, naval ship shock trials, and coastal development activities. Mr. Viada received his B.S. degree in zoology from Texas A&M University in 1978 and his M.S. in biological oceanography from Texas A&M University in 1980.

SESSION 2E

AIR QUALITY

Chair: **Robert Cameron, Minerals Management Service**

Co-Chair: **Richard McNider, University of Alabama Huntsville**

AIR QUALITY ISSUES FOR THE GULF OF MEXICO

Robert Cameron, Minerals Management Service

Introduction

The Minerals Management Service (MMS) has jurisdiction over Outer Continental Shelf (OCS) sources in the Gulf of Mexico (GOM), west of 87.5 degrees longitude. The OCS Lands Act established MMS' authority and responsibility for OCS sources and established the requirement to comply with onshore national ambient air quality standards (NAAQS), as specified in the 1990 Clean Air Act amendments. MMS promulgated air quality regulations (30 CFR, Part 250) governing oil and gas related operations on the OCS.

Goals and Strategies

The overarching goal of the air quality program is to comply with the governing regulations as outlined above. To accomplish the objective it is necessary to assess onshore air quality impacts to insure that operations under the regulatory authority of the MMS do not harm the environment. To this end, MMS evaluates OCS operator plans, collects air quality data, conducts air quality studies, and partners with other federal and state agencies to minimize duplication of effort and effectively leverage available resources.

Bob Cameron is a senior air quality meteorologist for the Minerals Management Service (MMS) in New Orleans. He is currently working on MMS air pollution issues that may affect the air quality for states surrounding the GOM. He has previously been employed as a meteorologist in several other economic sectors—private, state government, and the military. In the private sector he worked as a television weathercaster in Omaha, Nebraska, with state government, he performed meteorological data analysis and modeling that was used in air quality models to assess Texas air pollution problem areas. His military weather jobs were varied, and ranged from aviation weather forecasting to instructing weather courses to managing a forecast team at a centralized weather forecasting facility.

BRETON EMISSIONS INVENTORY (BOADS)
GULFWIDE EMISSIONS INVENTORY, 2000 (GOADS 2000)

Darcy Wilson and Richard Billings, Eastern Research Group, Inc.

Introduction

The MMS' Gulf of Mexico Outer Continental Shelf Regional office sponsored two recently completed air quality emissions inventory projects, the *Gulfwide Emission Inventory for the Regional Haze and Ozone Modeling Effort* (Wilson et al. 2004), and the *Data Quality Control and Emissions Inventories of OCS Oil and Gas Production Activities in the Breton Area of the Gulf of Mexico* (Billings and Wilson 2004). These studies build upon the *Gulf of Mexico Air Quality Study* (GMAQS) (U.S. DOI, MMS 1995) to assess the potential impacts of air pollutant emissions from offshore oil and gas exploration, development, and production sources in the Outer Continental Shelf (OCS).

The Gulfwide Inventory is a base year 2000 air pollution emissions inventory for all OCS oil and gas production-related sources in the Gulf of Mexico (GOM), including non-platform sources. Pollutants covered in this inventory are the criteria pollutants—carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter-10 (PM_{10}), $PM_{2.5}$, and volatile organic compounds (VOC); as well as greenhouse gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The Breton Inventory covers SO_2 and NO_x emission sources, from September 2000 through August 2001, within 100 kilometers of the Breton National Wildlife Refuge/Wilderness Area (BNWA), which is a Prevention of Significant Deterioration Class I Area.

Methodology

To develop the inventories, the Breton Offshore Activities Data System (BOADS) and the Gulfwide Offshore Activities Data System (GOADS) were used to collect monthly activity data from platform sources. The activity data were combined with the most recent emission factors published by the U.S. Environmental Protection Agency (U.S. EPA) and Emission Inventory Improvement Program (EIIP) emission estimation methods to develop comprehensive criteria pollutant emissions inventories. Non-platform emission estimates were developed for sources such as the Louisiana Offshore Oil Platform (LOOP), commercial marine vessels, and helicopters. For the most part, the emission factors used to calculate the emissions from all of the engines for these sources were obtained from the U.S. EPA's Office of Transportation and Air Quality (OTAQ) in Ann Arbor, Michigan. The resulting non-platform emission estimates are disaggregated to MMS lease blocks.

In the Gulfwide Inventory, nearly 2,900 oil and gas production platforms submitted monthly equipment activity data files. The platform equipment surveyed includes

• Amine units	• Loading operations
• Boilers/heaters/burners	• Mud degassing
• Diesel engines	• Natural gas engines
• Drilling equipment	• Natural gas turbines
• Flares	• Pneumatic pumps
• Flashing losses	• Pressure/level controllers
• Fugitive sources	• Storage tanks
• Glycol dehydrators	• Vents

Non-platform sources covered in the inventory are:

• Biogenic/geogenic sources	• Pipe laying operations
• Commercial fishing	• Platform construction and removal vessels
• Commercial marine vessel	• Support helicopters
• Drilling rigs	• Support vessels
• The LOOP	• Survey vessels
• Military vessel operations	• Vessel lightering

In the Breton Inventory, data for nearly 600 platforms were submitted. Platform equipment surveyed excluded equipment that does not emit SO_2 or NO_x. Non-platform sources were excluded if they were outside of the 100 km radius (i.e., the LOOP and vessel lightering).

Results

Technical reports and inventory data files for both inventories can be found at:

http://www.gomr.mms.gov/homepg/regulate/environ/requirements.html#Air%20Quality

Tables 2E.1 and 2E.2 summarize the emission estimates developed in each study. The technical reports provide details on the quality assurance/quality control (QA/QC) and emission estimation methods, compare the inventories to previous studies, and discuss their limitations. The inventory files are provided in U.S. EPA's National Emissions Inventory (NEI) Input Format (NIF). A follow-on study, the *Year 2005 Gulfwide Emission Inventory Study*, is now underway.

Table 2E.1. Gulfwide inventory platform and non-platform emission estimates.

Equipment/ Source Category	CO Emissions (tpy)	NO_x Emissions (tpy)	PM_{10} Emissions (tpy)	SO_2 Emissions (tpy)	VOC Emissions (tpy)
Total Platform Emissions	92,144	78,049	789	3,472	59,536
Drilling Rigs	2,862	27,270	677	4,587	263
Helicopters	6,060	1,438	107	177	2,285
Pipelaying Vessels	1,877	17,887	444	3,009	173
Platform Construction and Removal Vessels	474	3,637	91	620	49
Support Vessels	5,104	37,118	929	6,352	542
Survey Vessels	19	188	5	32	2
Total OCS Oil/Gas Production Source Emissions	108,540	165,587	3,042	18,249	62,850
Total Non-OCS Oil/Gas Production Source Emissions	13,536	49,923	1,371	9,280	24,444
Total Emissions (tpy)	122,076	215,510	4,413	27,529	87,294

Table 2E.2. Breton inventory platform and non-platform emission estimates.

Equipment/Source Category	NO_x Emissions (tpy)	SO_2 Emissions (tpy)
Total Platform Emissions	21,617	503.33
Drilling Rigs	3,908	659
Helicopters	51	6
Pipelaying Vessels	3,228	542
Platform Construction and Removal Vessels	135	22
Support Vessels	3,275	560
Survey Vessels	4	1
Total OCS Oil/Gas Production Source Emissions	32,218	2,293.33
Total Non-OCS Oil/Gas Production Source Emissions	8,368	1,519
Total Emissions (tpy)	40,586	3,812.33

References

Billings, R.S. and D.L. Wilson. 2004. Data Quality Control and Emissions Inventories of OCS Oil and Gas Production Activities in the Breton Area of the Gulf of Mexico: Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-071. 94 pp.

U.S. DOI, Minerals Management Service (MMS). 1995. Gulf of Mexico Air Quality Study: Final Report, Volumes I-III. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 95-0038, 95-0039, and 95-0040.

Wilson, D.L., J.N. Fanjoy, and R.S. Billings. 2004. Gulfwide Emission Inventory Study for the Regional Haze and Ozone Modeling Effort: Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-072. 273 pp.

Darcy Wilson is a Senior Program Manager with Eastern Research Group (ERG) with over 17 years of experience. Her expertise includes air pollutant emission factor and emission inventory development, technical writing, database development, and quality assurance/quality control. She has been serving as the Program Manager on several MMS Air Quality Emissions Inventory Studies since 1999.

Richard Billings has an M.S. in environmental science and engineering from Virginia Tech, and has worked with Eastern Research Group (ERG) for 12 years. His work has focused on the quantification of air emissions in support of regulatory decision making and development of control strategies; it includes development of criteria pollutant and hazardous air pollutant emission factors and emission inventories for a variety of emission sources, with particular attention to mobile sources such as marine vessels and support helicopters. He has also developed emission estimates for platform emission sources and marine biogenic and geogenic sources.

YEAR 2005 GULFWIDE INVENTORY STUDY

Darcy Wilson and Richard Billings, Eastern Research Group, Inc.

Introduction

The MMS' Gulf of Mexico Outer Continental Shelf Regional Office is sponsoring this project to develop a gulfwide, base-year 2005, emissions inventory for criteria pollutants and greenhouse gases. This study builds upon several previous emissions inventory efforts in the Gulf of Mexico (GOM) designed to assess the potential impacts of air pollutant emissions from offshore oil and gas exploration, development, and production sources in the Outer Continental Shelf (OCS). In particular, this study will serve as an update to the base year 2000 *Gulfwide Emission Inventory Study for the Regional Haze and Ozone Modeling Effort* (Wilson et al. 2004).

MMS published Notice to Lessees and Operators (NTL) 2004-G17 to introduce the "Production Activities Information Collection and Reporting for Calculations of Air Emissions in the Western Gulf" requirements for lessees and operators of federal oil, gas, and sulfur leases in the Gulf of Mexico OCS Region. A workshop was held in New Orleans, Louisiana, 13 October 2004 to discuss and explain the 2005 Gulfwide Offshore Activities Data System (GOADS-2005) information collection and reporting procedures, the pollutants to be covered in the study, and why the 2005 GOADS study was being undertaken. Much of the information provided is available on the GOADS website:

http://www.gomr.mms.gov/homepg/regulate/environ/airquality/goad.html

Information posted on this website by MMS includes:

- The NTL issued informing operators about the 2005 Gulfwide Inventory Study and telling them about the 13 October 2004 workshop.
- Technical support with information on how they can obtain their 2000 data sets to use as a starting point for the 2005 inventory.
- The GOADS-2005 data collection software and User's Guide.
- Frequently Asked Questions (FAQs) and a link to an ERG listserv website developed so platform operators can submit questions and get technical responses directly from the ERG and MMS inventory development team.
- The 13 October 2004 workshop presentation.

Similarities to the 2000 Gulfwide Inventory Study

The development of the 2005 Gulfwide Inventory will be similar to that of the 2000 Gulfwide Inventory in a number of ways:

- Emission estimates will be developed for criteria pollutants—carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter-10 (PM_{10}), $PM_{2.5}$, and volatile organic compounds (VOC); and greenhouse gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

- The inventory will cover the western Gulf of Mexico (OCS west of 87° 30' west longitude and north of 25° 15' North latitude).

- Both platform and non-platform sources will be included in the inventory.

- Monthly activity data and stack parameters for platform equipment will be collected electronically with the Visual Basic GOADS-2005 software.

- The activity data will be combined with emission factors published by the U.S. Environmental Protection Agency (U.S. EPA), and Emission Inventory Improvement Program (EIIP) emission estimation methods.

- Emission estimates for amine units will be developed with AMINECalc.

- Emission estimates for glycol dehydrators will be developed using regression equations for typical operating conditions.

- Activity data for 2005 will be collected for all non-platform emission sources such as support vessels, the Louisiana Offshore Oil Platform, and pipelaying operations.

- The emission factors used to calculate the emissions from all of the engines for the non-platform sources will be those developed by the U.S. EPA's Office of Transportation and Air Quality (OTAQ) in Ann Arbor, Michigan.

- The resulting non-platform emission estimates will be disaggregated to MMS lease blocks.

- Diurnal emission curves will be revised or developed for all source categories.

- Files for use in air quality modeling and other studies will be provided in U.S. EPA's National Emissions Inventory (NEI) Input Format (NIF) and supporting GIS data sets.

Details on the quality assurance/quality control (QC/QC) and emission estimation methods, and the inventory data files for the 2000 Gulfwide Inventory can be found at:

http://www.gomr.mms.gov/homepg/regulate/environ/requirements.html#Air%20Quality

Improvements Over the 2000 Gulfwide Inventory Study

As the 2000 Gulfwide Inventory was being developed, several areas for improvement were noted. For the 2005 Gulfwide Inventory, the following improvements will occur:

- The GOADS-2005 data collection software has been improved to make the program operate faster and more efficiently. We worked closely with members of the Offshore Operators Committee (OOC) to identify and implement these improvements.
- An on-line GOADS-2005 FAQ forum (the GOADS-2005 listserv) has been established for platform operators to directly submit questions and receive responses related to technical and software issues encountered.
- The emission estimates will be developed using up-to-date emission factors as needed, and any additional recommended emission estimation improvements will be implemented.
- In-depth surveys will be conducted to improve the activity data collected for support helicopters, support vessels, and survey vessels.
- Commercial marine vessel shipping lanes will be mapped using the latest GIS tools in conjunction with detailed vessel data from the U.S. Army Corps of Engineers.
- The diurnal emission curves will be reviewed and revised as needed, especially those developed for support helicopters and vessels.

Results

The *Year 2005 Gulfwide Emission Inventory Study* will be completed by June 2007. Deliverables associated with the project will include a technical report detailing the QA/QC and emission estimation approaches used for platform and non-platform sources located in the Western GOM. Files for use in air quality modeling studies will be provided in U.S. EPA's National Emissions Inventory (NEI) Input Format (NIF). The users of the data files include U.S. EPA, state and local agencies, and Regional Planning Offices (RPOs) studying regional haze and ozone nonattainment issues, as well as scientists studying the impact of greenhouse gas emissions and the contribution of sources in the GOM. Oil and gas industry personnel may also benefit by reviewing the data to identify and quantify sources of profitable natural gas losses and prioritizing research into loss product prevention methods.

References

Wilson, D.L., J.N. Fanjoy, and R.S. Billings. 2004. Gulfwide Emission Inventory Study for the Regional Haze and Ozone Modeling Effort: Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-072. 273 pp.

Darcy Wilson is a Senior Program Manager with Eastern Research Group (ERG) with over 17 years of experience. Her expertise includes air pollutant emission factor and emission inventory development, technical writing, database development, and quality assurance/quality control. She has been serving as the Program Manager on several MMS Air Quality Emissions Inventory Studies since 1999.

Richard Billings has an M.S. in environmental science and engineering from Virginia Tech, and has worked with Eastern Research Group (ERG) for 12 years. His work has focused on the quantification of air emissions in support of regulatory decision making and development of control strategies; it includes development of criteria pollutant and hazardous air pollutant emission factors and emission inventories for a variety of emission sources, with particular attention to mobile sources such as marine vessels and support helicopters. He has also developed emission estimates for platform emission sources and marine biogenic and geogenic sources.

A PRELIMINARY ASSESSMENT OF ON-SHORE AIR QUALITY IMPACTS FOR THE EASTERN GULF COAST (LOUISIANA TO FLORIDA) USING THE 2000 GULFWIDE EMISSIONS INVENTORY

Jay L. Haney and Sharon G. Douglas, Systems Applications International, LLC

Introduction and Background

This paper summarizes the results of a photochemical modeling analysis conducted to provide a preliminary assessment of impacts from offshore emission sources on the coastal areas of Louisiana, Mississippi, Alabama, and Florida using a newly developed offshore emission inventory for 2000 for the Central and Western Planning Areas of the Gulf of Mexico (GOM) region.

The Minerals Management Service of the U.S. Department of Interior has jurisdiction over the activities involved in the exploration and development of mineral resources in the Outer Continental Shelf (OCS) of the GOM. The agency's responsibility includes, among other things, the assessment of the environmental effects of such activities in both offshore and onshore areas. During 1992–1995, the MMS conducted the Gulf of Mexico Air Quality Study (GMAQS), which was specifically mandated by Congress in the Clean Air Act Amendments of 1990 to assess air quality impacts in onshore ozone nonattainment areas from emission sources located in the Western and Central Planning Areas of the OCS (Systems Applications International et al. 1995). The study included the development of a comprehensive inventory of emission sources in OCS waters for 1993, which was recently updated for 2000 through the development of the Gulfwide Offshore Activities Data System (GOADS).

Since the conclusion of GMAQS, three regional ozone modeling studies, involving the application of the variable-grid Urban Airshed Model (UAM-V) modeling system, have been conducted to address one-hour and potential eight-hour ozone issues in coastal areas of the eastern GOM. These include the Gulf Coast Ozone Study (GCOS), the Baton Rouge ozone SIP modeling analysis, and the follow-on study to GCOS, known as the West Florida Ozone Study (WFOS). From these studies, six episodes (September 1997, August 1997, May 1996, July 1998, 1–8 August 1999, and 13–26 July 2000) were available, and the 1–8 August 1999 period was selected as the period exhibiting the largest potential for emissions from offshore sources to affect ozone concentrations in the coastal areas of Louisiana, Mississippi, Alabama, and Florida.

Offshore Emissions Inventory

The first major task involved the acquisition and processing of the new Gulfwide 2000 emission inventory, as developed by ERG (2003) into a format that could be merged with the existing modeling inventories for the 1–8 August 1999 period using EPA's UAM Emission Preprocessor System, Version 2.5 (EPS 2.5). (It should be noted that a preliminary inventory was obtained and used in this modeling analysis, and that, subsequent to the completion of this study, large errors in platform VOC emissions were discovered and corrected by MMS in the final release of the inventory which is presented in the report "Gulfwide Emissions Inventory Study for the Regional

Haze and Ozone Modeling Effort," October 2004, OCS Study MMS 2004-072. The preliminary inventory platform VOC emissions totals are 409 tpd, while the final emissions are 163 tpd). The 2000 inventory included emissions from OCS oil-production related platform and non-platform sources as well as from non-oil-related sources, such as commercial marine vessels, a comparison of which is presented in Figure 2E.1.

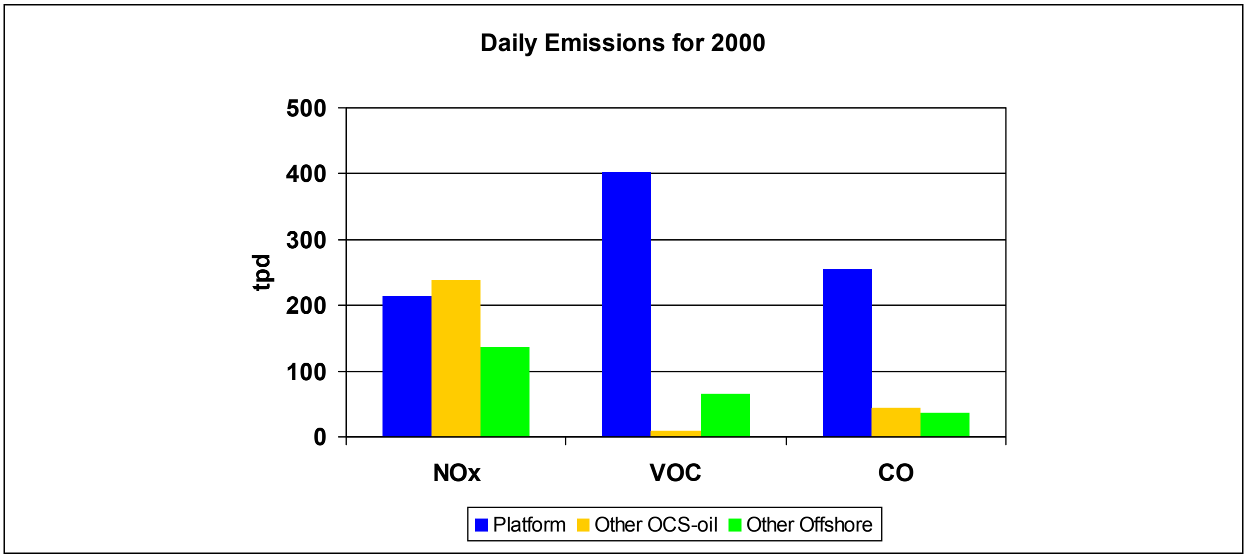


Figure 2E.1. Comparison of emissions from platform, oil-related non-platform, and other offshore sources operating in the Gulf of Mexico for 2000. (Preliminary draft platform VOC inventory (409 tpd) in lieu of final platform inventory (163 tpd).).

Emissions from oil-related sources are substantially larger than those associated with non-oil related activities in this area. One objective of this modeling analysis is to assess impacts of offshore emissions on onshore areas of interest in Louisiana, Mississippi, Alabama, and Florida. Figure 2E.2 depicts the parishes and counties that make up the Baton Rouge, New Orleans, Mississippi coastal counties, Mobile, and Pensacola areas.

Air Quality Modeling Approach

Once the new offshore inventory was processed and merged with the existing onshore inventory, the second major task of this analysis involved the application of the UAM-V photochemical model with the Carbon Bond 5 chemical mechanism (UAM-V5) using the grid configuration of the Gulf Coast Ozone Study (Figure 2E.3) and includes 36-, 12-, and 4-km resolution grids encompassing the offshore and onshore areas of interest. After the new 2000 offshore emissions inventory was prepared, processed, and incorporated into the modeling inventory for the August 1999 episode, the base case simulation, one emission reduction simulation, and two simulations in which the precursor emissions were tagged or tracked using the Oxidant and Precursor Tagging Methodology (OPTM) feature of UAM-V5 were completed for the 2000 OCS inventory impact assessment:

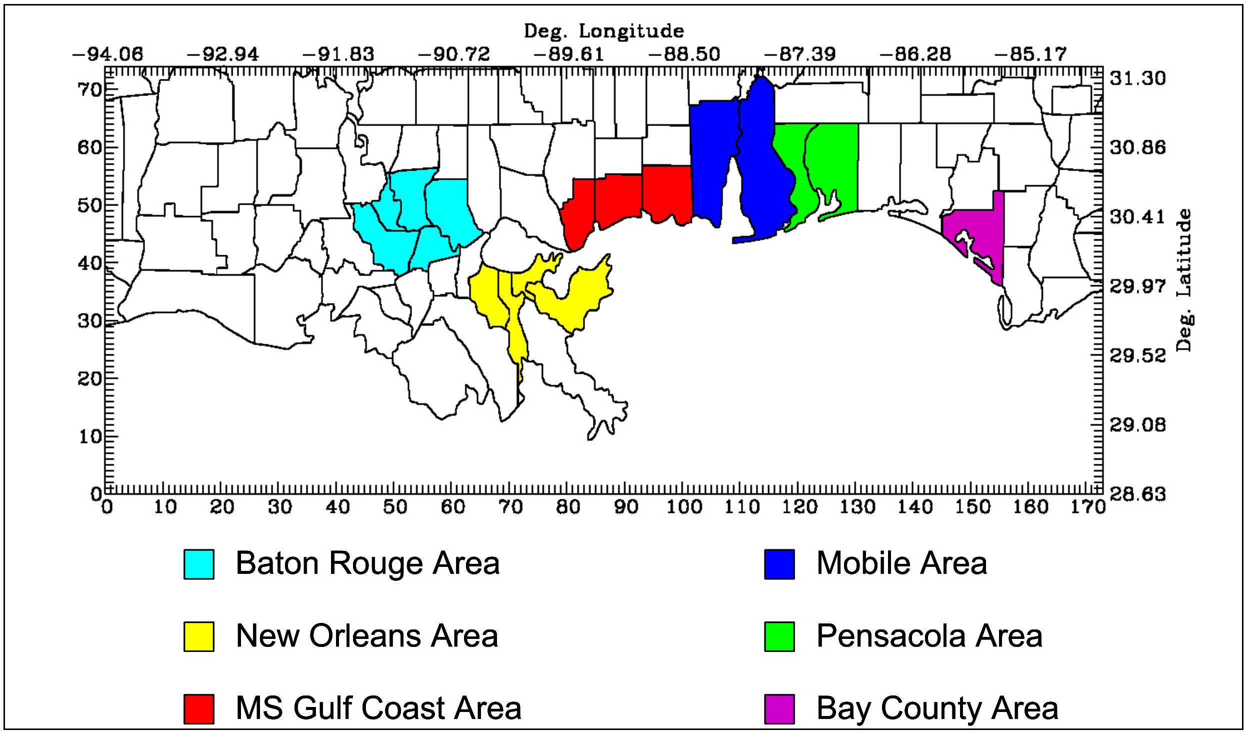


Figure 2E.2. Coastal areas of interest for assessment of on-shore impacts

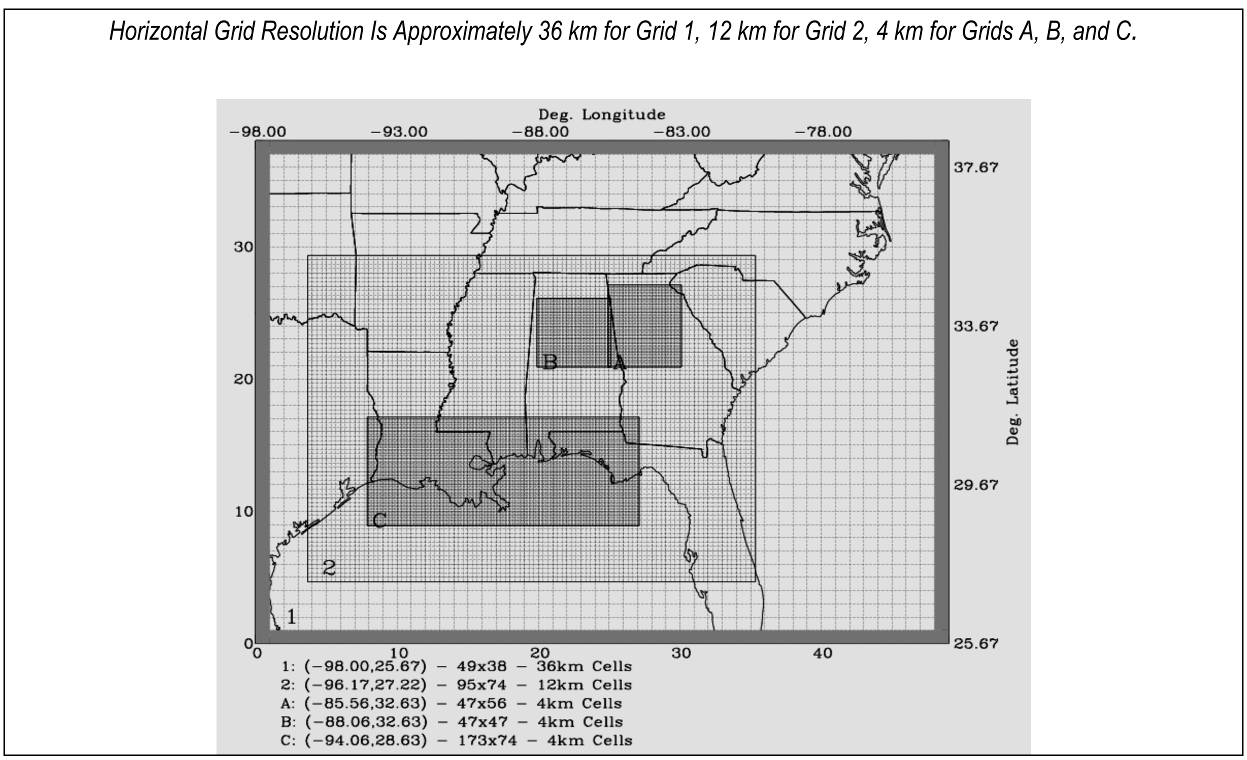


Figure 2E.3. GCOS/WFOS UAM-V5 modeling domain used for the MMS OCS 2000 modeling analysis.

- M-1 2000 Base case simulation with no oil-related offshore emissions
- MT-1 2000 Base case with geographic emissions tags (OPTM simulation)
- MT-2 2000 Base case with source category emission tags (OPTM simulation)

In the sensitivity simulation (M-1), emissions from all OCS oil-related sources were zeroed out. Figure 2E.4 presents differences of simulated daily maximum one-hour concentrations for Grid C for 8 August 1999 showing the "impacts" from all oil-related offshore sources. Because of the prevailing wind conditions, there are very few impacts in the onshore coastal areas of interest during the first few days of the episode. With the change in the winds to a more southerly direction, the magnitude and inland extent of the impacts are larger on 7–8 August, with impacts generally less than 10 ppb reaching the Alabama and Florida panhandle areas on 8 August.

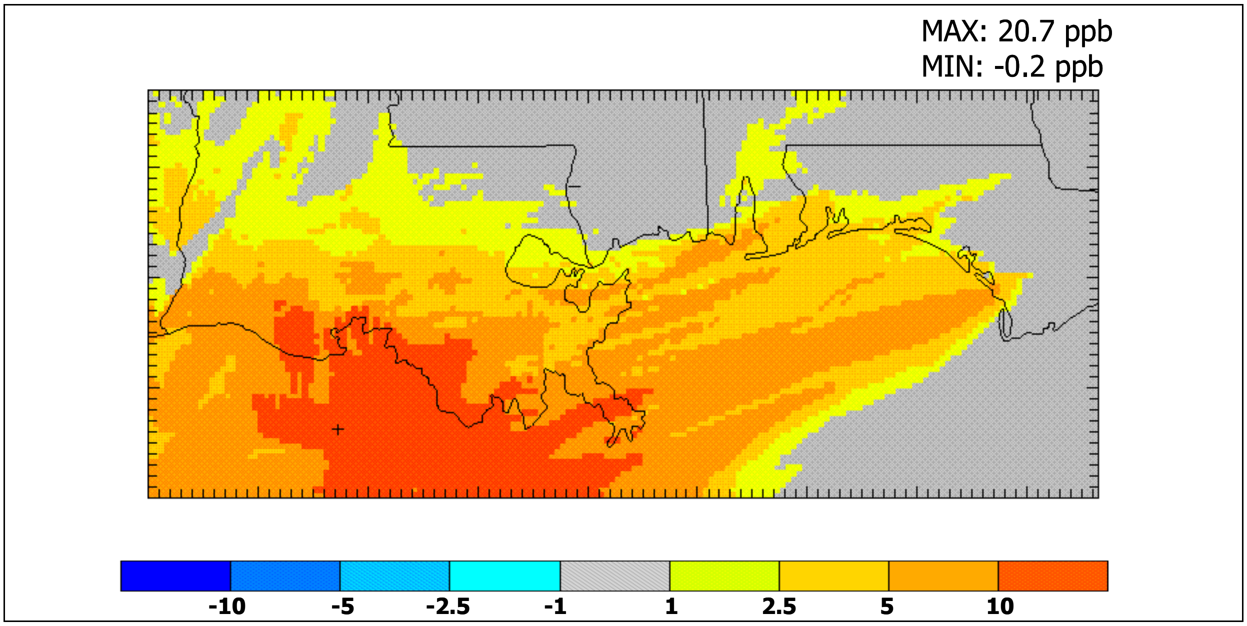


Figure 2E.4. Simulated maximum hourly ozone impacts (ppb) from OCS oil-related emission sources for 8 August 1999. (Preliminary draft platform VOC inventory (409 tpd) in lieu of final platform inventory (163 tpd)).

Impacts were assessed at a number of in-land monitoring sites in the areas of interest. The results indicate that there are no impacts at these monitors on 3–5 August, that there are some impacts at a few monitors on 6 August, and that OCS impacts occur at most sites on 7–8 August, with the largest impacts occurring on 8 August, when the prevailing flow along the coast is southerly. Although the largest impacts occur on 8 August (as much as 7 ppb), this is a clean-out day and observed and simulated one-hour concentrations are lower throughout the Grid C area compared to 7 August.

In addition to the impacts on simulated one-hour average concentrations, differences of simulated daily eight-hour maximum concentrations for Grid C show that the maximum simulated concentrations are located offshore (within Grid C) for each of the simulation days and that the simulated eight-hour impacts are quite similar in spatial characteristics to the one-hour concentration impacts, with the maximum impacts occurring on 7–8 August. The results indicate that, as with the one-hour concentrations, there are no impacts at these monitors on 3–5 August, that there are some impacts at a few monitors on 6 August, and that OCS impacts occur at most sites on 7–8 August, with the largest impacts occurring on 8 August. Although the largest impacts to eight-hour averages occur on 8 August (as much as 6.6 ppb), this is a clean-out day and observed and simulated eight-hour concentrations are lower throughout the Grid C area than for 7 August. An examination of impacts at monitoring sites located in Grid C indicates that the OCS emissions contribute to a simulated exceedance at eight sites in the Baton Rouge area on 7 August, with contributions less than 1 ppb. There are a few sites on 8 August (Capitol, French Settlement, and Grosse Tete, Louisiana) for which the simulated maximum eight-hour concentrations are greater than 85 ppb, and the simulated contributions of the OCS emissions to ozone concentrations are on the order of 2–3 ppb. However, there were no observed eight-hour exceedances at these sites on 8 August, and therefore, this metric should not be considered for this day.

Another way of assessing impacts from the zero-out sensitivity simulations is to evaluate the effects in terms of 1- and eight-hour ozone exceedance exposure. As noted above, these metrics provide a summary of the amount of one-hour average ozone in each grid cell greater than 124 ppb, and the amount of eight-hour average ozone in each grid cell greater than 85 ppb. For this analysis, the 1- and eight-hour exposure metrics were computed for all hours of all non-startup days of the episode (3–8 August 1999). For this particular metric, the oil-related sources contribute about 7.4% to the total one-hour exceedance value in Grid C, about 9% to this metric in the offshore portion of Grid C, and less than 1% to this metric in the onshore areas of Grid C. Figure 2E.5 presents differences in simulated eight-hour average concentrations for 8 August for grid cells where simulated concentrations are greater than 85 ppb. The results indicates that offshore oil-related emissions contribute to simulated eight-hour exceedances in the onshore areas of interest on 4–6 August with contributions of 1 ppb or less. However, on 7 and 8 August, the impacts to simulated eight-hour exceedances in the Baton Rouge area are on the order of 1–6 ppb. For eight-hour exceedance exposure, the oil-related sources contribute about 8% to the total eight-hour exceedance value in Grid C; about 11% to this metric in the offshore portion of Grid C, and about 2% to this metric in the onshore areas of Grid C. Figure 2E.6 presents eight-hour exceedance exposure values for these areas.

Oxidant Tagging Simulations

Another way of assessing impacts is to use the UAM-V5's Ozone and Precursor Tagging Methodology (OPTM) approach and tag the offshore precursor emissions. OPTM provides estimates of the contribution of emissions from specified source categories or source regions to the simulated ozone concentrations. The estimates are made for the existing conditions within the simulation and do not require that the system be perturbed (e.g., zeroed out) in order to make the estimate. In addition, estimates for several categories can be made in a single simulation. The OPTM system tracks the amount of oxidant (the sum of NO_2 and ozone) formed from various tagged source categories as a method of estimating the contributions to ozone.

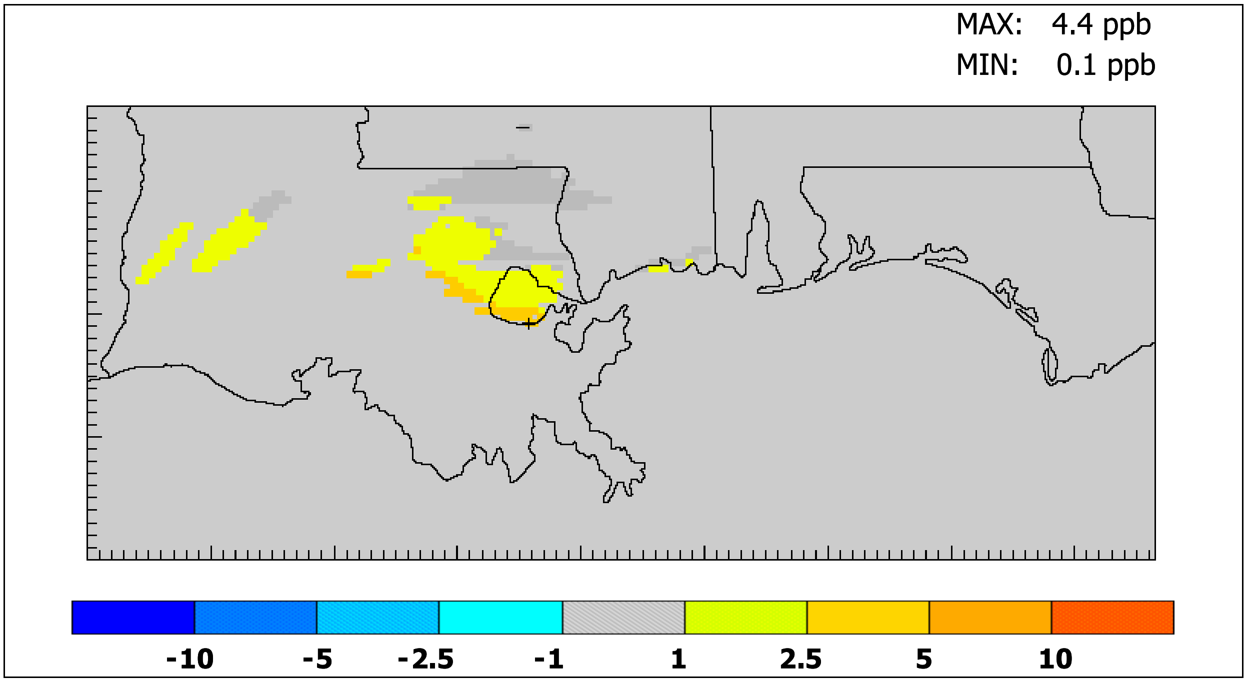


Figure 2E.5. Simulated maximum eight-hour average ozone impacts (ppb) from OCS oil-related emission sources for 8 August 1999 for grid cells with simulated eight-hour concentrations in the base case greater than 85 ppb (preliminary draft platform VOC inventory (409 tpd) in lieu of final platform inventory (163 tpd).).

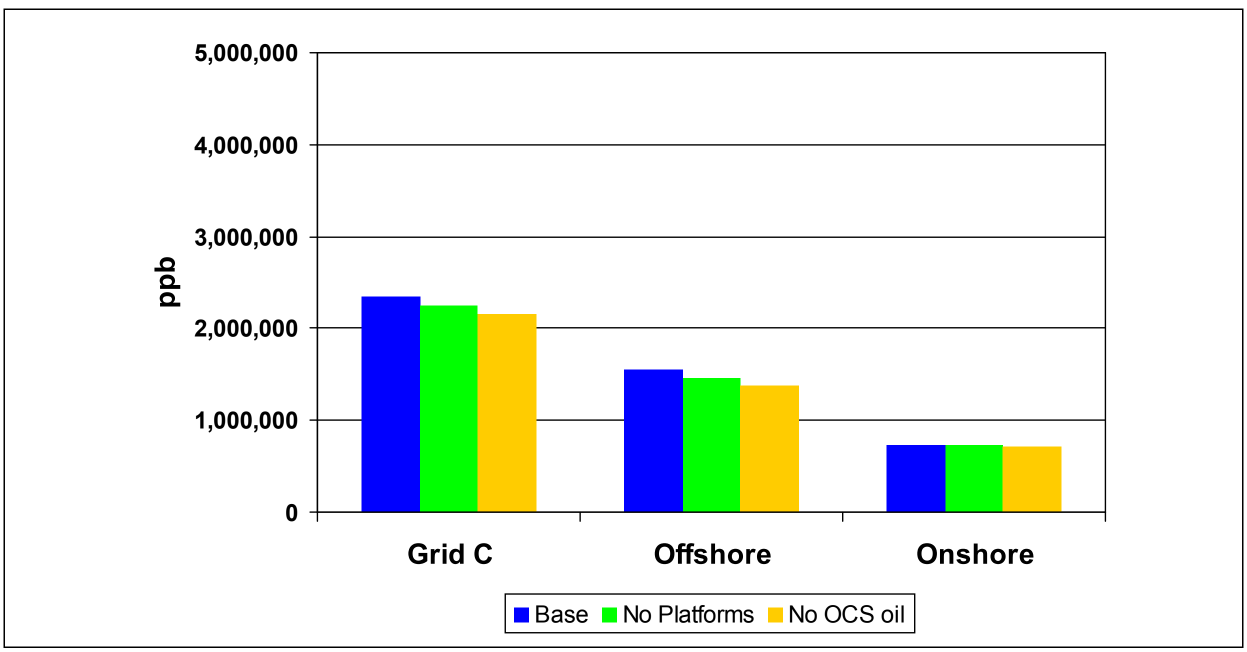


Figure 2E.6. Comparison of simulated eight-hour ozone exceedance exposure (ppb) for grid c, the offshore portion of grid c, and the onshore portion of grid c, comparing the base case with the OCS zero-out sensitivity simulations (3–8 August 1999). Preliminary draft platform VOC inventory (409 tpd) in lieu of final platform inventory (163 tpd).).

OPTM Scenario MT-1

For this first scenario, the assignment of the tags focused on the offshore areas and the emissions contained in the four key Gulf Coast states. The first tag tracked emissions from anthropogenic emissions in Louisiana; the second tracked emissions from Mississippi; the third tagged emissions from Alabama; and the fourth tag tracked emissions from Florida. A fifth tag tracked emissions from all offshore sources beyond state waters. A sixth tag tracked emissions from all other areas, including biogenic emissions.

The OPTM results are displayed in Figure 2E.7 and depict the contribution to simulated eight-hour average ozone from NO_x and VOC, respectively, corresponding to emissions tagged for each geographic area for 1700 EST for 7 August 1999. This is one of the key high ozone days for monitoring sites located along the eastern Gulf Coast. The "footprint" of the contribution to simulated ozone for NO_X indicates that for this day and time, offshore sources of NO_x contribute to the ozone concentrations in onshore areas of southern Louisiana and coastal Mississippi. The contributions from VOC emissions are smaller and are confined to southern Louisiana.

An analysis of the contributions to eight-hour ozone concentrations in the offshore portion of Grid 2, the largest contributor to eight-hour concentrations, is from biogenic emissions and sources located onshore in states other than the four Gulf Coast states. Moderate contributions are shown for Louisiana and Mississippi emissions, with offshore sources showing a non-negligible contribution.

OPTM Scenario MT-2

For the second tagging scenario, individual tags were placed on NO_x and VOC emissions of all offshore/OCS oil-related platform sources, all offshore/OCS oil-related non-platform sources, all offshore non-oil related sources, all sources operating in state waters, and all other sources in the modeling domain. Figure 2E.8 depicts the contribution to simulated maximum eight-hour average ozone from NO_x and VOC, respectively, corresponding to emissions tagged for each tag for 7 August 1999. For these figures, the contributions from the two offshore source tags were combined. The figures show the relative contributions from both oil-related and non-oil related offshore sources, including those in state waters. For this particular day, contributions from the offshore oil-related NO_x sources are found in the southern Louisiana and along the coastal areas of Mississippi and are larger than contributions from non-oil related and state waters sources. For VOC emissions, small contributions are seen in southern Louisiana from oil-related sources.

Figure 2E.9 shows the individual contributions to the average maximum eight-hour concentrations in the offshore area of Grid 2 for the period 3–8 August 1999. The figure depicts the contribution from NO_x and VOC emissions from each offshore source categories to the total offshore contribution to the maximum eight-hour concentrations. The figure indicates that when the average maximum eight-hour ozone is considered over the key episode days, for VOC emissions, the major contributors to the offshore portion of the maximum eight-hour average ozone concentrations in the offshore area of Grid 2 are platform sources, and for NO_x emissions, the largest contributors are non-oil related sources followed by sources in state waters and platform sources.

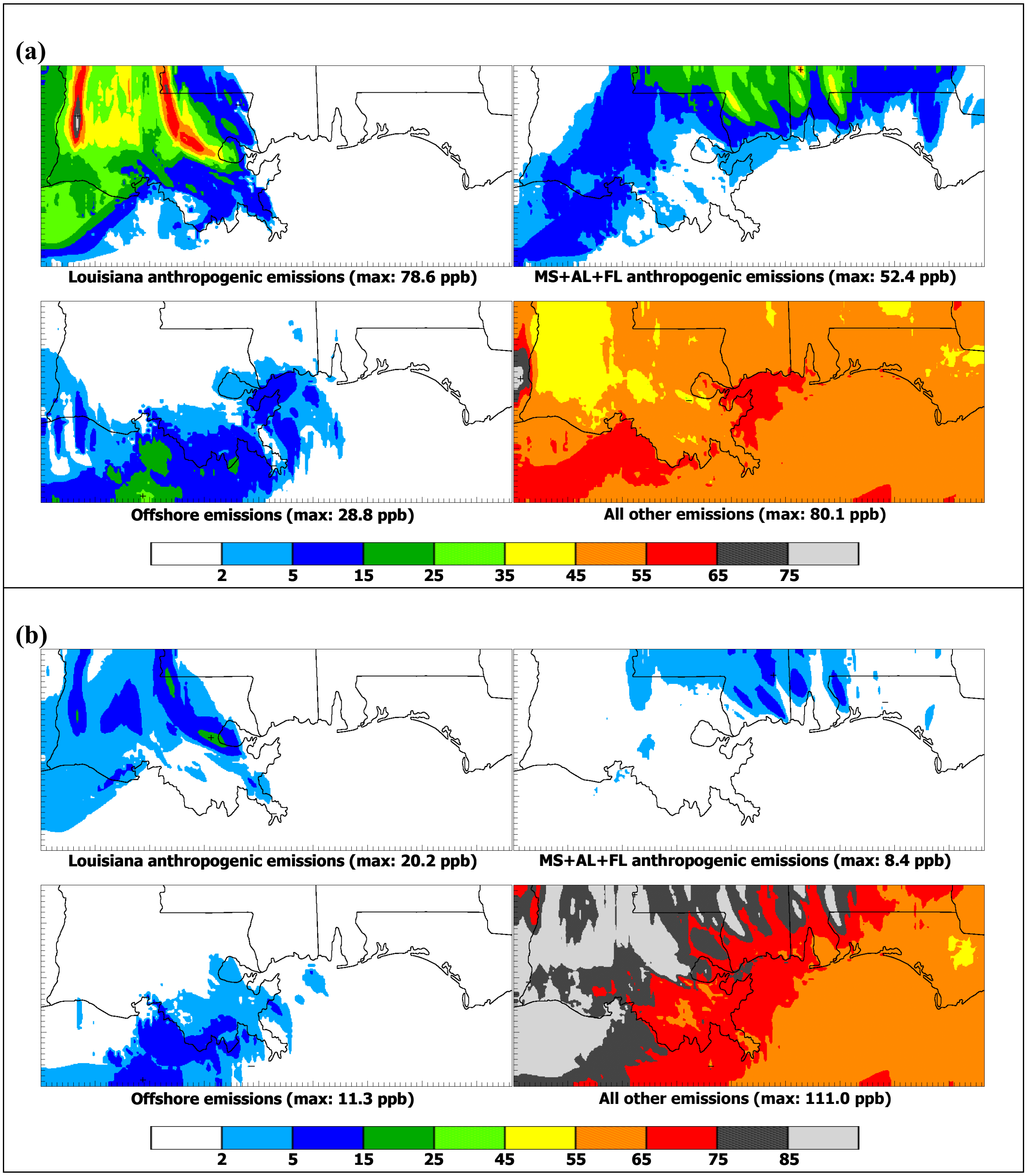


Figure 2E.7. (a) Max eight-hour ozone apportioned by NO_X emissions (ppb) for 7 August 1999. Showing contributions from onshore and offshore emissions. (b) Max eight-hour ozone apportioned by VOC emissions (ppb) for 7 August 1999. Showing contributions from onshore and offshore emissions. (Preliminary draft platform VOC inventory (409 tpd) in lieu of final platform inventory (163 tpd).)

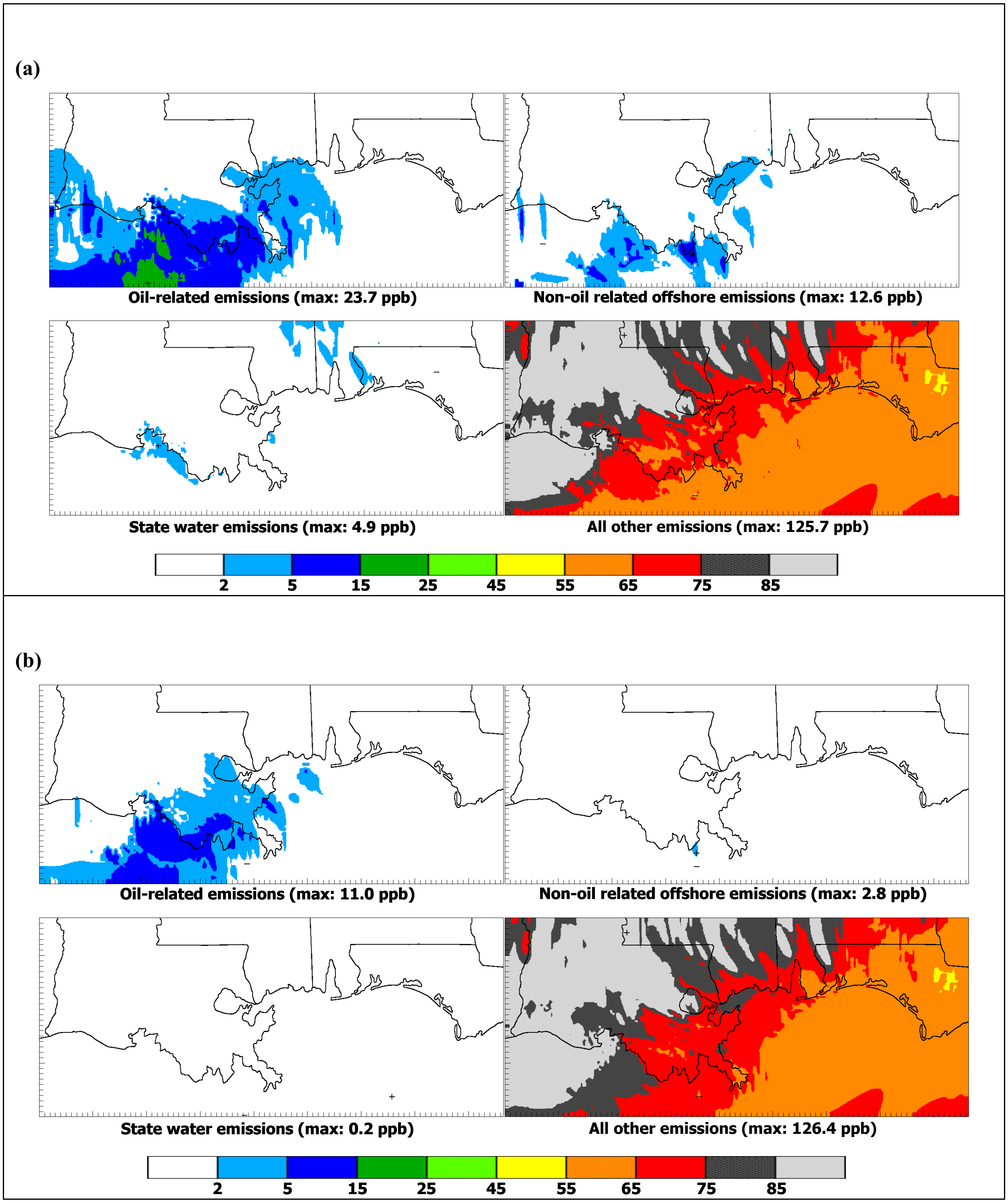


Figure 2E.8. (a) Max eight-hour ozone apportioned by NO_X emissions (ppb) for 7 August showing contributions from onshore and offshore emissions (Scenario MT-2). (b) Max eight-hour ozone apportioned by VOC emissions (ppb) showing contributions from onshore and offshore emission (Scenario MT-2). (Preliminary draft platform VOC inventory (409 tpd) in lieu of final platform inventory (163 tpd).)

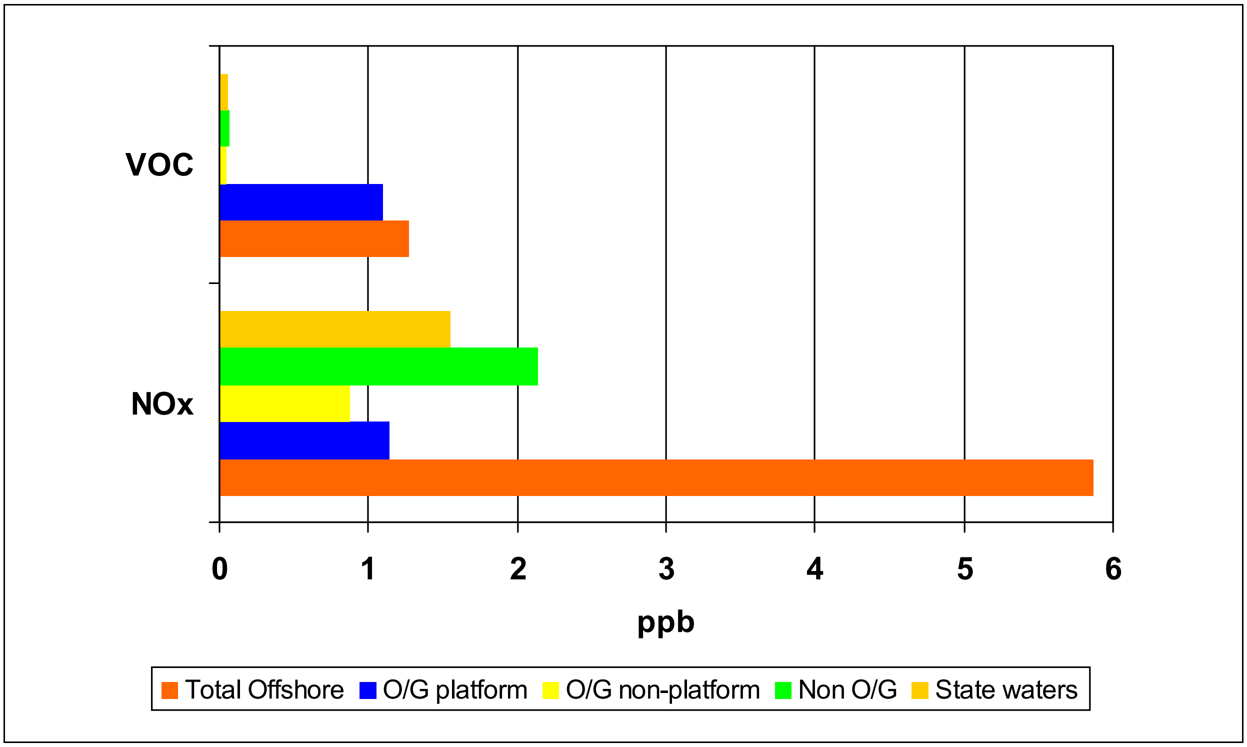


Figure 2E.9. Simulated contributions (ppb) from each offshore source category to the total offshore contribution to the daily average maximum eight-hour ozone concentrations in the offshore area of grid 2 from sources located in offshore areas of the Gulf Coast (OPTM Scenario MT-2 for 3–8 August 1999). (Preliminary draft platform VOC inventory (409 tpd) in lieu of final platform inventory (163 tpd).)

Summary

In this study, a photochemical modeling analysis was conducted to assess the impacts of offshore sources located in the Central and Western Gulf of Mexico OCS areas on onshore areas of interest in the states of Louisiana, Mississippi, Alabama, and Florida, using the newly developed (although draft) 2000 Gulfwide offshore emission inventory.

After the base case was re-run with the new offshore inventory, a simulation involving the omission of platform sources and all oil-related sources was conducted. The results indicate that for this particular modeling episode, the onshore impacts from all offshore oil-related sources are less than 10 ppb. The contribution to grid cells in which the one-hour average simulated concentration is greater than 124 ppb was assessed to determine whether the offshore emissions possibly contributed to exceedances of the one-hour standard. For this episode, simulated one-hour exceedances occurred on 6–7 August in the Baton Rouge area, and the contribution of offshore emissions was 2 ppb or less. An examination of impacts at monitoring sites located in Grid C indicates that the OCS emissions contribute to a simulated exceedance of the one-hour standard at only one site on one day: the LSU, Louisiana site on 7 August, with a very small contribution of 0.3 ppb. Similarly, the contribution to grid cells in which the eight-hour average simulated concentration is greater than 85 ppb was examined to determine whether the offshore emissions possibly contribute to an exceedance of the eight-hour standard. The results indicate that offshore oil-related emissions contribute to simulated eight-hour exceedances in the onshore areas of interest on 4–6 August with contributions of 1 ppb or less. However, on 7 and 8 August, the impacts to simulated eight-hour exceedances in the Baton Rouge area are on the order of 1–6 ppb. An examination of impacts at monitoring sites located in Grid C indicates that the OCS emissions contribute to a simulated exceedance at eight sites in the Baton Rouge area on 7 August, with contributions less than 1 ppb, and at three sites (Capitol, French Settlement, and Grosse Tete) on 8 August, with impacts of 2–3 ppb. Although there are simulated exceedances of the eight-hour standard at these sites, there were no observed exceedances at these sites on 8 August, so the OCS impacts are being affected by an overestimation of ozone by the model in the Baton Rouge area on this particular day.

Ozone exceedance exposure metrics were also computed for one- and eight-hour ozone. The results indicate that oil-related offshore emissions contribute about 7.4% to the total one-hour exceedance exposure in Grid C, about 9% to this metric in the offshore portion of Grid C, and less than 1% to this metric in the onshore areas of Grid C. For eight-hour exceedance exposure, the offshore oil-related sources contribute about 8% to the total eight-hour exceedance value in Grid C, about 11% to this metric in the offshore portion of Grid C, and about 2% to this metric in the onshore areas of Grid C.

In addition to the emission reduction simulations, two simulations were conducted using the OPTM feature of UAM-V5, which allows one to tag and track the contributions from specific source categories or regions to simulated ozone concentrations in the modeling domain. The results of these simulations indicate that, for this particular modeling episode, the contribution to simulated ozone in the onshore areas of interest from offshore oil-related sources is small. It should be noted that, in light of the use of an incorrect preliminary VOC platform inventory containing 50% more emissions than the final inventory, the simulated impacts on one- and eight-hour concentrations may be less than reported here.

References

ERG. 2003. Gulfwide Emission Inventory for the Regional Haze and Ozone Modeling Effort. Final Report. ERG Inc.

Systems Applications International, Sonoma Technology, Inc., Earth Tech, Alpine Geophysics, and A.T. Kearney. 1995. Gulf of Mexico Air Quality Study, Final Report. Volume I: Summary of Data Analysis and Modeling. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS95-0038. 654 pp.

Sharon G. Douglas is a Project Manager in Atmospheric Sciences for Systems Applications International Inc. (SAI), a She has an M.S. in meteorology from Penn State University.

Ms. Douglas has more than 17 years of experience at SAI/ICF and has been principally involved in the development and application of innovative data analysis techniques and meteorological and air quality modeling tools.

Jay L. Haney is Group Vice President and Director of the Air Quality Modeling Group at Systems Applications International (SAI), a wholly-owned subsidiary of ICF Consulting. He is a Certified Consulting Meteorologist and has an M.S. in meteorology from Saint Louis University. He as 25 years of experience in the refinement of data analysis and modeling techniques applied to the study of tropospheric ozone, carbon monoxide, and particulate matter.

2000 GULF-WIDE EMISSIONS INVENTORY – OCS ON-SHORE IMPACTS MODELING (TEXAS), A PRELIMINARY LOOK

Greg Yarwood, Gerard Mansell, Michele Jimenez and Steven Lau,
ENVIRON International Corporation

The MMS oversees exploration and production of mineral resources in the Gulf of Mexico (GOM) including oil and gas activities on the outer continental shelf (OCS). Air emissions from OCS oil and gas related activities include ozone precursors, namely nitrogen oxides (NOx), volatile organic compounds (VOCs) and carbon monoxide (CO). There are several urban areas near the Gulf Coast that exceed the National Ambient Air Quality Standard (NAAQS) for ozone. Ozone levels in these ozone non-attainment areas depend both upon local emissions and transport of ozone and precursors from upwind areas. The MMS and Gulf Coast States share an interest in evaluating the influence of OCS emissions on ozone levels in NAAs near the Gulf Coast.

The MMS completed an emission inventory for year 2000 called the Gulf-Wide Emissions Inventory (2000 GWEI). This study provides a preliminary assessment of impacts of the 2000 GWEI on ozone levels in the Houston area of Texas. Houston was chosen because the Houston/Galveston/Brazoria (HGB) non-attainment area has the most severe ozone problem in Texas and is adjacent to the GOM. The Texas Commission on Environmental Quality (TCEQ) is responsible for air quality planning in Texas and uses photochemical modeling to develop State Implementation Plans (SIPs) for the HGB ozone non-attainment area. This study used ozone models and modeling tools used by the TCEQ for SIP planning in the Houston area (TCEQ 2004). Ozone modeling used the CAMx air quality model (ENVIRON 2004) with an 22 August–6 September 2000 episode period. The CAMx modeling domain had two-way nested grids with 36-km, 12-km, 4-km and 1-km resolution and 15 to 24 vertical layers as shown in Figure 2E.10.

FINDINGS

This assessment used a preliminary version of the 2000 GWEI in which the VOC emissions from platform sources were more than 50% higher than they should have been: This fact should be taken into account in considering the reported ozone impacts. The main findings on modeled impacts of OCS emissions in the 2000 GWEI on ozone levels in the Houston area are

- The 2000 GWEI emissions produce similar episode average impacts for 1-hr and 8-hr ozone in the 11 county Houston/Beaumont area of 2.3 ppb and 2.2 ppb, respectively.
- The average impacts of OCS emissions on ozone levels in the Houston area are smaller (and negative in the case of 1-hr ozone) when the analysis is restricted to ozone levels above the NAAQS.
- The average impact of the 2000 GWEI emissions on eight-hour ozone levels above 85 ppb in the 11 county Houston/Beaumont area is 0.2 ppb.

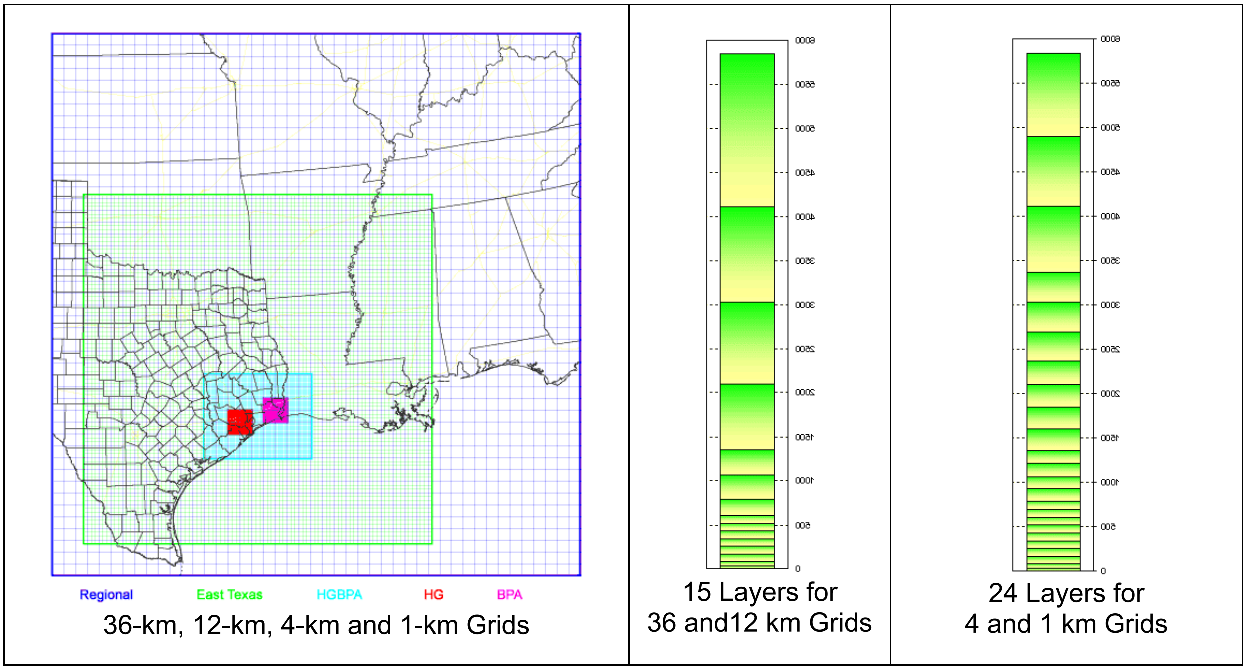


Figure 2E.10. CAMx nested grid modeling domain and layer structures for the TexAQS 22 August to 6 September 2000 ozone episode in the Houston area.

Larger ozone impacts occur over the GOM. The episode maximum impacts of the 2000 GWEI emissions on eight-hour ozone are shown in Figure 2E.11 for the CAMx 12-km grid. The ozone impacts were estimated using the "zero-out" method that measures the change in ozone when the 2000 GWEI emissions are removed.

The ozone impacts from the 2000 GWEI were compared to impacts from the GMAQS emission inventory being used by the TCEQ in current modeling studies. The average impact of the GMAQS emissions on eight-hour ozone above the level of the eight-hour standard in the Houston area is 0.6 ppb, which is three times larger than the impact of the 2000 GWEI.

A sensitivity test was conducted to investigate the relative roles of NOx vs. VOC emissions in the 2000 GWEI ozone impacts. This analysis indicates that the ozone impacts of OCS emissions are limited by the VOC emissions over the GOM. The finding that the ozone impacts of OCS emissions are limited by VOC emissions is potentially important since it suggests that the most effective way of managing OCS impacts on ozone in the GOM will be to control VOC emissions. Other analyses should be undertaken to independently confirm this finding.

ACKNOWLEDGMENT

The emissions modeling staff of the TCEQ assisted this study by preparing certain emissions data for use in the ozone modeling. The graphics for Figure 2E.10 were provided by the TCEQ.

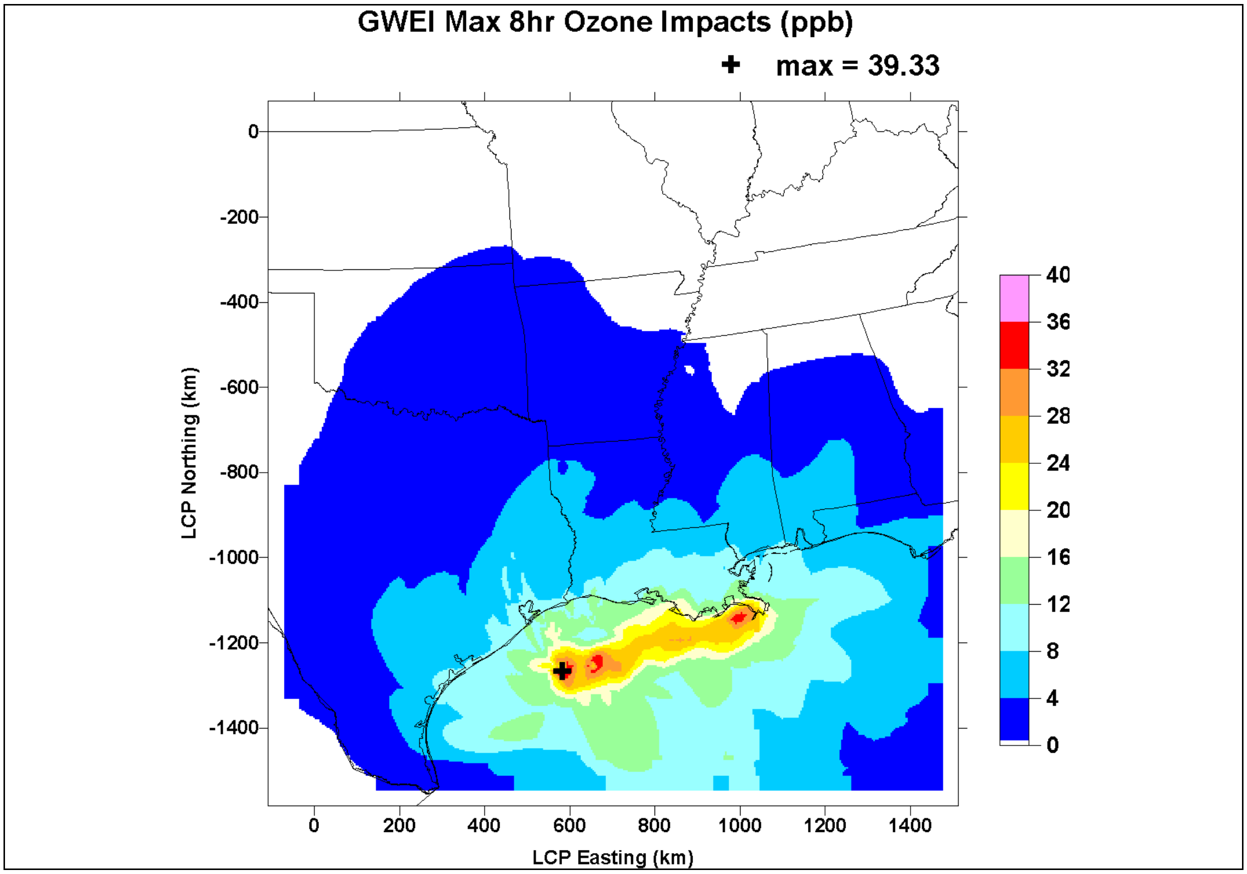


Figure 2E.11. Episode maximum eight-hour ozone impacts of the 2000 GWEI for the 12-km grid. Preliminary modeling/assessment using draft platform VOC emissions that were more than 50% higher than they should have been.

REFERENCES

ENVIRON. 2004. User's Guide, Comprehensive Air Quality Model With Extensions (CAMx), Version 4.00. ENVIRON International Corporation. Novato, CA. January. *http://www.camx.com*.

TCEQ. 2004. HGB Mid-Course Review SIP Narrative. Texas Commission on Environmental Quality. June 23. *http://www.tnrcc.state.tx.us/oprd/sips/june2004hgb_EDrec.html#docs*.

Dr. Greg Yarwood is a Principal with the ENVIRON Air Sciences group in Novato, California. He is an international expert in photochemical modeling and atmospheric chemistry. He designs the Comprehensive Air Quality model with extensions (CAMx) which is a public domain photochemical grid model for ozone, fine particulate and visibility modeling developed by ENVIRON.

Dr. Gerrard Mansell is a Senior Consultant with the ENVIRON Air Sciences group in Novato, California. He is an expert in GIS, emissions modeling and air quality modeling. He developed GIS-based ammonia and dust models currently being used for regional haze modeling.

Ms. Michele Jimenez is an expert in emissions modeling for photochemical air-quality modeling with the ENVIRON Air Sciences group in Novato, California. She was an original developer of the EPS2 emissions processing system and now is developing the CONCEPT emissions modeling system based on open-source SQL tools suitable for cluster computing.

Mr. Steve Lau is an air quality modeler with the ENVIRON Air Sciences group in Novato, California. He is proficient with many air-quality modeling systems including CAMx, CMAQ, CalPuff/CalMet and UAM.

SIMULTANEOUS VISIBILITY, MIXING HEIGHT AND PARTICULATE MATTER MEASUREMENTS FOR THE BRETON NATIONAL WILDLIFE AREA

S. A. Hsu and Brian W. Blanchard, Coastal Studies Institute, Louisiana State University

Introduction

In response to regulations imposed by the 1999 Regional Haze Rule, a visibility and meteorological monitoring station has been established within the Delta National Wildlife Refuge at Pass-A-Loutre (PAL, 29°7.133'N 89°12.296'W). The station has been operational since April 2004, and the data return rate has been excellent. Two other visibility stations are also being maintained, offshore at LSU WAVCIS CSI-3 and CSI-6 (see *www.wavcis.lsu.edu* for more information). Data sets from all stations are being compiled, and research continues on occurrences of reduced visibility (fog and haze), and associated characteristics of the atmospheric boundary layer. This presentation summarizes some preliminary findings, including a restricted visibility case study and observations of winds above the 100 m level over the Louisiana coast.

Regional Conditions

In mid-September 2004, Hurricane Ivan moved through the eastern Gulf of Mexico (GOM) and made landfall along the Alabama coast. Our PAL station recorded very high winds (approximately 28 m/s) and a minimal pressure of about 980 mb. It was later determined that the relative humidity sensor was damaged during this event. Therefore, the summer period of May through August 2004 is discussed here.

The atmospheric boundary layer is generally classified as either unstable, near-neutral, or stable. The buoyancy length scale L is a parameter used to determine the stability by describing the relative importance between the buoyancy effect (or thermal turbulence) and the wind shear (or mechanical turbulence) (see Panofsky and Dutton, 1984). Hsu and Blanchard (2004) have shown that for unstable conditions (when $T_{sea} > T_{air}$),

$$L = -\frac{\left(T_{air} + 273.2\right)U_z^2}{100\left(T_{sea} - T_{air}\right)\left(1 + {}^{0.07}\!/_{B}\right)} \tag{1}$$

and for stable conditions ($T_{sea} < T_{air}$),

$$L = \frac{\left(T_{air} + 273.2\right)U_z^2}{62\left(T_{air} - T_{sea}\right)} \tag{2}$$

where B is the Bowen ratio provided by (see Hsu, 1999)

$$B = 0.146\left(T_{sea} - T_{air}\right)^{0.49} \tag{3}$$

This criterion was applied to the hourly records from the National Data Buoy Center buoys 42007 to the north of the PAL location, and buoy 42040 to the east. It is found that during May and June, neutral conditions prevail over unstable at both stations; about 65% of the time at 42007 and 74% at 42040. However, in July and August, unstable conditions occurred almost as frequently as neutral, about 52% at 42007 and 53% at 42040. Less than ten hours per month were identified as stable at both stations.

In air pollution studies, estimation of the mixing height (Z_i) is essential to determine the vertical limit for pollution dispersion. For unstable conditions, according to Hsu (2004)

$$Z_i = 828 + 4|L| \tag{4}$$

where L is obtained from Eqs. (1) and (3). In neutral conditions (see Hsu 1998)

$$Z_i = 125(T_{air} - T_{dew}) \tag{5}$$

The average monthly mixed heights computed for buoy 42007 increase from 664 m in May to 823 m in August. Similarly, heights at 42040 increase from 533 m in May to 767 m in August; slightly higher values occur at 42007 each month.

Haze Episode

A modified version of the ASOS Obstructions to Vision Algorithm is applied to our PAL data record such that when the visibility drops below 7 miles, the dew-point depression (DPD) is checked to distinguish between fog (DPD ≤ 2.2 °C) and haze (DPD > 2.2 °C). An eight-hour period of haze is identified at PAL from 18 Z 23 May to 01 Z 24 May 2004. The southeastern U.S. is under the influence of a high pressure ridge, and winds over south Louisiana are light to moderate from the south-southeast. NOAA satellite imagery depicts scattered fair clouds, and restricted visibility is indicated over the Delta area. CSI-6 also reports reduced visibility, but the DPD is lower there. Stability at buoys 42007 and 42040 is neutral, and computed mixed heights rise from about 600 m to peak around 800 m. This is in reasonable agreement with the estimated afternoon mixed height of 866 m derived from the 12 Z 23 May Slidell rawinsonde. The Louisiana Department of Environmental Quality has several PM stations operating in the New Orleans area, but data is not yet available for this period.

Wind Observations

According to Huang (2004), the Louisiana coastal and OCS region may provide a suitable environment for the harvest of wind energy. Large wind turbines (about 80 m hub height) could be deployed on existing platforms to take advantage of the support and maintenance facilities already in place. Measurements of winds at this altitude over the Gulf are necessary to estimate the performance and design of the wind energy system. As a first look, we employ data recorded by the Vaisala Profiler installed at LUMCON, Cocodrie, Louisiana in early October 2004. The distribution of the 158 m level winds during the period of 15 October through 16 November 2004 is shown in Figure 2E.12. Winds are most often from the southeast, with a secondary maximum from the southwest. The average speed is 6.3 m/s, with many hours exceeding 10 m/s.

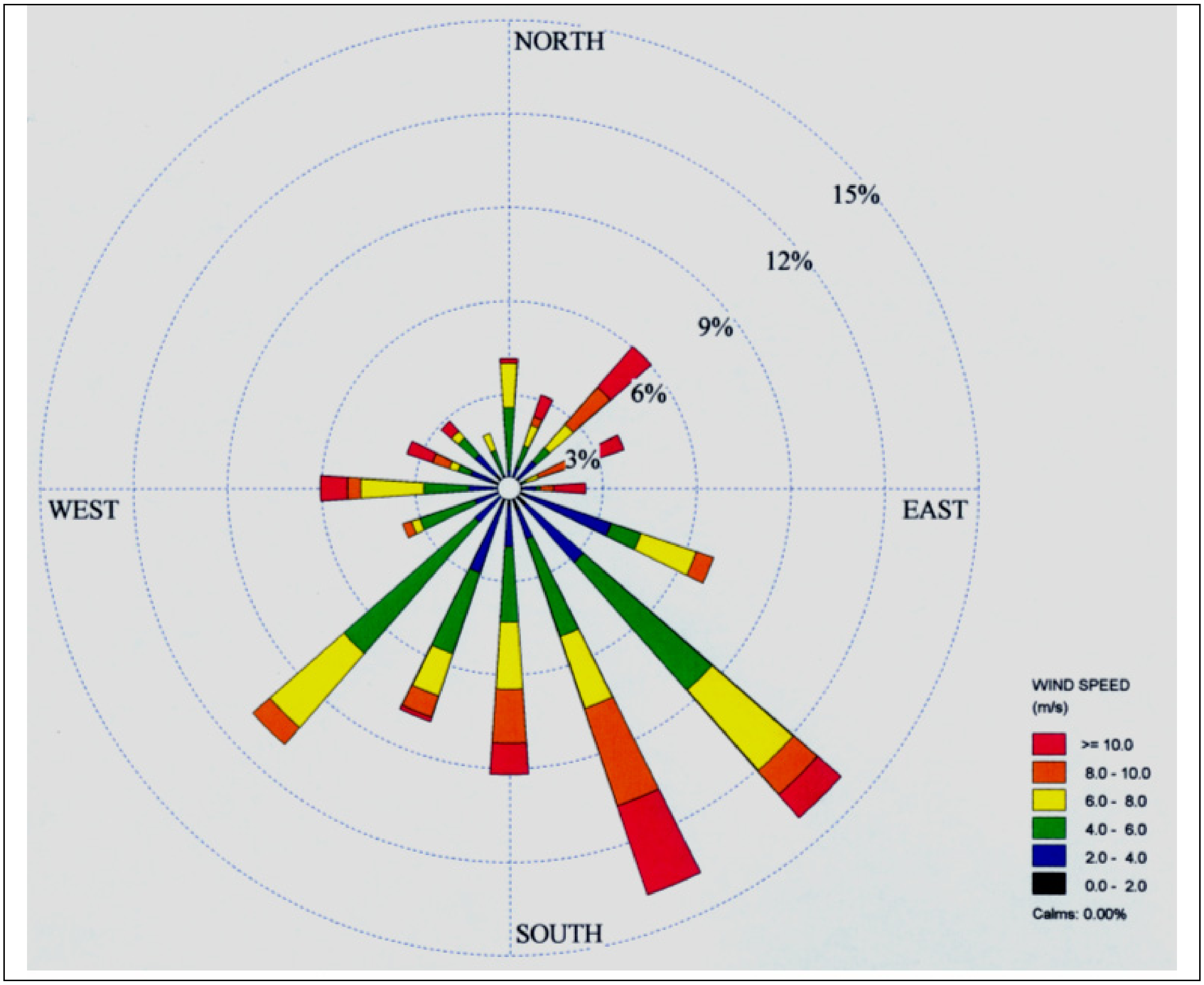


Figure 2E.12. 158 m level wind rose for the period of 15 October through 16 November 2004 as recorded by the LUMCON profiler.

References

Hsu, S.A. 1998. A relationship between the Bowen ratio and sea-air temperature difference under unstable conditions at sea. Journal of Physical Oceanography 28:2222–2226.

Hsu, S.A. 1999. On the estimation of overwater Bowen ratio and sea-air temperature difference under unstable conditions at sea. Journal of Physical Oceanography 29:1372–1373.

Hsu, S.A. 2004. A parameterization of overwater mixing height in unstable conditions. Submitted to Environmental Fluid Mechanics.

Hsu, S.A. and B.W. Blanchard. 2004. On the estimation of overwater buoyancy length from routine measurements. Environmental Fluid Mechanics.

Huang, C.H. 2004. Some air quality and meteorological issues confronting the Minerals Management Service. In: Proceedings of the Seventh International Marine Environmental Modeling Seminar, Washington D.C., pp. 36–45.

Panofsky, H.A. and J.A. Dutton. 1984. Atmospheric Turbulence. New York: Wiley.

S. A. Hsu received his Ph.D. in meteorology from the University of Texas at Austin. He has been a Professor at Louisiana State University since 1969. His research interests are coastal and marine meteorology, air-sea interaction, and pollution transport physics. Dr. Hsu has published extensively, including a textbook entitled Coastal Meteorology.

Brian Blanchard was awarded his B.S. degree in atmospheric sciences from Northeast Louisiana University in 1983. He has been a Research Associate at Louisiana State University for over 20 years, and has contributed to many meteorological studies. He is the co-author of several journal articles and technical reports.

THE CURRENT STATUS OF THE SO_2 AND NO_2 INCREMENT ANALYSIS FOR THE BRETON NATIONAL WILDERNESS AREA

Neil Wheeler, Sonoma Technology, Inc.
David Stauffer, Pennsylvania State University

Project Background

The Breton National Wilderness Area (BNWA) is surrounded by onshore sources of oxides of sulfur (SO_x) and oxides of nitrogen (NO_x) to the north and west and offshore sources to the south and east. The Clean Air Act Amendments limit how sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) concentrations may increase over areas such as the BNWA. These limits are referred to as increments. The Minerals Management Service (MMS) has funded several studies to provide the emissions and meteorological databases needed to support a modeling-based cumulative increment analysis for the BNWA. The most recent study involves collecting meteorological and air quality data from October 2000 through September 2001 (year 2000–2001), and provides the final data needed to perform the increment analysis. The databases from these prior studies will be used to perform air quality modeling for past and present years. The model results will be used to evaluate the contribution of Outer Continental Shelf (OCS) emission sources to SO_2 and NO_2 levels over the BNWA and determine the amount of increment consumed.

Technical Approach and Current Status

Episode Selection

Episode selection was based on an analysis of air quality (Miller et al. 2003) and the synoptic weather types used by the Louisiana Office of State Climatology (2003). Five of the episodes selected had high SO_2 or NO_2 concentrations and a distribution of weather types similar to the annual distribution. One episode had low concentrations and was selected to test the models' ability to predict non-episodic conditions. The following periods were selected for episodic modeling: 8–13 November 2000; 1–6 December 2000; 30 December 2000 through 4 January 2001; 2–8 March 2001; 9–14 July 2001; and 8–13 August 2001 (low concentration period).

Meteorological Modeling

Meteorological modeling is being performed with the Penn State/NCAR Mesoscale Model, MM5 (Dudhia 1993; Grell et al. 1994). The modeling strategy includes the use of Kain-Fritsch 2 convective parameterization; the Gayno-Seaman planetary boundary layer scheme; an explicit moisture scheme; the column cloud radiation scheme; satellite-derived sea surface temperatures for lower boundary conditions; and a multi-scale four-dimensional data assimilation technique developed by Stauffer and Seaman (1994) involving analysis nudging, surface analysis nudging, and observational nudging with routine and special observational data. Modeling of the 36-km and 12-km domains has been completed for the episodes and the annual simulation is in progress. Two of the episodic periods will be modeled with a 4-km nest to investigate the importance of horizontal grid spacing on model performance. Annual modeling will be performed only on the 36- and 12-km domains for 1 October 2000 through 30 September 2001.

Emission Inventory Preparation

Three emission inventories are being prepared: The current year (2000–2001) inventory, the SO_2 baseline year (1977) inventory, and the NO_2 baseline year (1988) inventory. The Breton Offshore Activity Data System (BOADS [Billings and Wilson 2004]), the Gulfwide Offshore Activity Data System (GOADS [Wilson et al. 2004]), and the National Emission Inventory (NEI) are being used. STI has consolidated the databases and performed checks for completeness, duplication, and reasonableness. Emissions have been speciated, non-point sources have been spatially allocated, and model-ready emissions files have prepared for the 2000–2001 year.

Episodic Air Quality Simulations

The purpose of the episodic simulations is to assess air quality model performance and select the final model to be used in the cumulative increment analysis. Episodes are currently being modeled using both an Eulerian photochemical model, CMAQ (U.S. Environmental Protection Agency, 1999) and a Lagrangian puff model, CALPUFF (Scire et al. 1998), with the meteorological fields prepared using MM5. A model performance evaluation is being undertaken for each episode and model combination. Sensitivity simulations will be an integral part of the model performance evaluation. The model inputs will be modified based on estimates of uncertainty and air quality model simulations will be performed.

Annual Air Quality Simulations

These simulations will be used to establish baseline and current year concentrations of SO_2 and NO_2 for use in the increment analysis. Annual simulations of NO_2 and SO_2 with year 2000–2001 emissions will be performed. The results of these simulations will be evaluated for model performance both statistically and graphically using the same methods as used for evaluating the episode-type simulations. Annual simulations of SO_2 with year 1977 OCS-related emissions and of NO_2 with year 1988 emissions will be performed to establish the baseline concentrations. Onshore and non-OCS related offshore emissions will be estimated for 1977 and 1988 using emission inventory trends data.

Air Quality Assessment

An air quality assessment will be performed to determine the amount of increment that has been consumed in the BNWA. Receptors in the BNWA will be identified and the annual average NO_2 concentrations at each receptor in the BNWA will be calculated from the 2000–2001 year and the 1988 baseline year simulations. Annual, daily, and three-hour average SO_2 concentrations at each receptor in the BNWA will be calculated from the current (2000–2001) year and the 1977 baseline year simulations.

References

Billings, R.S. and D.L. Wilson. 2004. Data Quality Control and Emissions Inventories of OCS Oil and Gas Production Activities in the Breton Area of the Gulf of Mexico: Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-071. 94 pp.

Dudhia J. 1993. A nonhydrostatic version of the Penn State-NCAR mesoscale model: Validation tests and simulation of an Atlantic cyclone and cold front. Monthly Weather Review 121:1493–1513.

Grell G.A., J. Dudhia, and D.R. Stauffer. 1994. A description of the fifth-generation Penn State/NCAR Mesoscale Model (MM5). NCAR Technical Note-398. National Center for Atmospheric Research, Boulder, CO.

Louisiana Office of State Climatology. 2003. Monthly Newsletter. *http://www.losc.lsu.edu/newsmonthly.html*.

Miller D.S., P.T. Roberts, and C.P. MacDonald. 2003. Breton Aerometric Monitoring Program Data Analysis. Executive summary prepared for Offshore Operators Committee and Minerals Management Service, Dept. of the Interior, New Orleans, LA, by Sonoma Technology, Inc., Petaluma, CA, STI-999479-2267-ES2, August.

Scire, J.S., D.G. Strimaitis, and R.J. Yamartino. 1998. A User's Guide for the CALPUFF Dispersion Model (Version 5.0). Concord, MA: Earth Tech, Inc.

Stauffer D.R. and N.L. Seaman. 1994. On multi-scale four-dimensional data assimilation. Journal of Applied Meteorology 33:416–434.

U.S. Environmental Protection Agency. 1999. Science Algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. Byun, D.W. and J.K.S. Ching, eds. EPA/600/R-99/030, USEPA, ORD, Washington, DC 20460.

Wilson, D.L., J.N. Fanjoy, and R.S. Billings. 2004. Gulfwide Emission Inventory Study for the Regional Haze and Ozone Modeling Effort: Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-072. 273 pp.

Mr. Neil J. M. Wheeler is Vice President for Atmospheric Modeling and Information Systems at Sonoma Technology, Inc. (STI). He has more than 30 years of practical experience in the atmospheric sciences and 22 years experience with the development, application, and evaluation of meteorological and air quality models for regulatory purposes. Before joining STI, Mr. Wheeler was Chief of Environmental Applications at the North Carolina Supercomputing Center and Manager of Control Strategy Modeling at the California Air Resources Board. He is a Certified Consulting Meteorologist.

Dr. David R. Stauffer is a Senior Research Associate and Associate Professor of Meteorology in the Department of Meteorology at the Pennsylvania State University where he directs graduate-level research and teaches undergraduate and graduate-level courses. Professor Stauffer has over 23 years of related experience in meteorology, software development and management,

mesoscale numerical modeling and data assimilation in support of hydrodynamics, transport and dispersion. Dr. Stauffer is a principal developer of the Penn State University/National Center for Atmospheric Research MM5 Modeling System, which has become the most widely used mesoscale modeling system in the world. Dr. Stauffer is widely recognized for his expertise in mesoscale numerical weather prediction and data assimilation and is the author of more than 100 scientific papers.

SATELLITE DATA ASSIMILATION INTO METEOROLOGICAL/AIR QUALITY MODELS

Richard T. McNider, University of Alabama in Huntsville
Arastoo P. Biazar, University of Alabama in Huntsville

Introduction

Surface moisture availability and surface heat capacity are critical to accurate temperature and boundary layer prediction overland. Regional-scale air quality models require specification of these variables on grids down to scales near four kilometers. Unfortunately, there are not routine observations of these variables available on these scales. Even current state-of-the-art meteorological models have difficulty in predicting correctly the space, time and optical depth clouds. Yet, clouds in places such as the Gulf Coast have a critical role in the development of surface temperatures and photolysis rates due to cloud shading. In the coastal environment under weak synoptic forcing, proper simulation of temperature is especially critical since the thermal contrast between land and ocean controls the strength and timing of sea and land breezes. At higher latitudes and near cold ocean currents such as New England or California, the cold sea surface temperatures dominate the thermal contrast. In places like the Gulf Coast, relatively warm water, high sun angles, and large variation in surface thermal characteristics make the simulation of the land temperature important in the thermal contrast. Use of GOES satellite imagery and sounding information have the potential to specify more accurately these critical parameters—moisture, heat capacity and cloud radiative characteristics in regional models than other present techniques. These are discussed below.

Moisture Availability

Moisture availability in current models is generally specified using land use characteristics and land surface parameterization schemes. In the southeast, however, moisture due to plant transpiration can dominate moisture availability, and specifying root zone moisture and transpiration characteristics *a priori* is difficult. In the satellite assimilation technique, the morning rate of change of satellite-observed surface skin temperature is used as a constraint to adjust moisture availability (McNider et al. 1994). Basically, if the satellite shows a rate of change that is larger (smaller) than the model grid rate of change then surface moisture is adjusted downwards (upwards) through an analytical inversion of surface similarity relations.

Surface Heat Capacity

Specifying heat capacity for single soil types and soil moisture is relatively easy. However, model grid boxes are made up of a variety of materials from vegetation to bare soil to manmade structures. Heat capacity is a critical parameter in temperature prediction, especially at night. Using evening skin tendencies observed by GOES as a constraint, improved specification of model grid surface heat capacity can be made.

Solar Insolation and Photolysis Rates

As mentioned above, models have great difficulty predicting clouds. Since models in air quality studies such as those being addressed are used in a retrospective mode, observed cloud cover by satellites can be used. The recovery of solar insolation can be accomplished very directly from measures of GOES broadband reflectivity (Gautier et al. 1980). Additionally, the retrieval of cloud transmittance from this process can be used along with satellite observed cloud top pressures to provide the necessary cloud characteristics needed in photolysis calculations (McNider et al. 1998).

Specification of Land/Water Boundaries

An issue that creates difficulty when modeling coastal areas like Louisiana, previously identified in MMS modeling studies, is the correct determination of the land/sea boundary. MM5 Model water specification (all or none) can cause difficulty along complex coastlines. Additionally, geometric definition for complex coastlines in marshy or tidal areas can be problematic for land use models. The satellite assimilation methodology for recovering moisture availability and heat capacity makes the coast line determination in a natural way.

Application to East Texas Sea Breezes

The East Texas Gulf Coast has been the focus of air quality studies over the past two decades because of the ozone attainment problem in the Houston/Galveston area. These are relevant because of the large petrochemical and refining facilities in part supported by the large offshore production along the Texas and Louisiana coasts. As part of a current MMS study currently underway, the role of satellite data in improving the strength, time, and characteristics of the East Texas sea breezes is under way. The following reports on a preliminary evaluation of the impact of satellite assimilation on sea breezes in the Houston/Galveston area.

Model Configuration

The MM5 model was run for the Texas Gulf Coast. Four grid nests were used, ranging from a 96km continental scale to a 4 km nest over the Houston/Galveston area. The 4 km grid results, which more effectively capture the coastal configuration, are emphasized here. The model options were chosen based on the guidance of the Texas modeling group. The cases to be presented employed an analysis nudging procedure. Three model cases will be presented. The first is the “Control Case” and does not employ satellite assimilation. Land-use characteristics from the default MM5 data sets for moisture availability, and heat capacity were employed for this case. Second, a “Moisture Availability Case” is presented that included satellite insolation assimilation and moisture availability assimilation. A third case that employed satellite insolation assimilation, moisture availability and heat capacity assimilation was also carried out.

Model Performance

As part of previous analyses of model performance of the satellite assimilation, model 2-m temperatures were compared against National Weather Service observations. The satellite retrieval of moisture availability improved day-time temperatures by increasing them over those of the control case. This occurred as the model dried the surface. The heat capacity simulation improved the day and night-time performance of the model.

Sea Breeze Impacts

The drying out of the surface produces a much higher temperature over land and corresponding larger gradient between the land and sea. As might be expected, the strength of the sea breeze is much stronger. Interestingly, in the moisture assimilation case, the area ahead of the developing sea breeze has lighter winds than the control case. In cooperation with MMS additional detailed analyses of these cases will be carried out.

Acknowledgments

This work was sponsored in part by a Cooperative Agreement between the Minerals Management Service and the University of Alabama in Huntsville.

References

Gautier, C., G.R. Diak, and S. Mass, 1980: A simple physical model for estimating incident solar radiation at the surface from GOES satellite data. Journal of Applied Meteorology 19:1005–1012.

McNider, R.T., A.J. Song, D.M. Casey, P.J. Wetzel, W.L. Crosson, and R.M. Rabin. 1994. Toward a dynamic-thermodynamic assimilation of satellite surface temperature in numerical atmospheric models. Monthly Weather Review 122:2784–2803.

McNider, R.T., W.B. Norris, D. Casey, J.E. Pleim, S. Rosell, and W. Lapenta, 1998. Assimilation of satellite data in regional scale models. Air Pollution Modeling and Its Application. New York: Plenum Press. Pp. 25–35.

Richard T. McNider began his professional career with the Alabama Air Pollution Control Commission in 1973. He obtained his Ph.D. from the University of Virginia in 1981. He has been a Professor of Atmospheric Science and Mathematics at the University of Alabama in Huntsville for 25 years, where he helped found the Atmospheric Science Department. His interest is in developing mathematical models of geophysical phenomena. He is currently Distinguished Professor Emeritus at UAH. He is also a Fellow of the American Meteorological Society.

Arastoo Biazar is a Senior Research Associate in the Earth System Science Center at the University of Alabama in Huntsville. He received his Ph.D. in atmospheric sciences from the University of Alabama in Huntsville. Mr. Biazar's interest is in addressing air pollution and atmospheric chemistry issues. This includes both addressing physical/chemical problems as well as building/improving the numerical models of the atmosphere. He has worked with a wide range of air quality models from simple regulatory models to research grade three-dimensional models on scales from local to global. He has developed a chemical transport model and has been involved in the development of the EPA's Models3/CMAQ and CRCSHM's global chemical transport model.

COASTAL ATMOSPHERIC DATA GATHERING ENHANCEMENTS

Gary S. Zeigler, Vaisala Inc.

This paper provides a status report on initiatives to redeploy two LAP®-3000 radar profilers owned by the Minerals Management Service (MMS) Gulf of Mexico (GOM) Region to sites along the GOM coastline to enhance available meteorological measurements for use in air quality assessments.

Background

Air pollution studies using air quality models have established the crucial need for meteorological data in determining the contribution of pollution impacts from various sources. Meteorological data from the GOM coastal zone are necessary in assessing what contribution, if any, Outer Continental Shelf sources make to existing or projected future visibility impairment to the Breton National Wildlife Area and the other three Class I areas in the GOM Region.

History of Use of Radar Profilers by MMS

Upper-air meteorological measurements using radar profilers have been collected by the MMS GOM Region as part of two previous air quality studies initiated in 1993 and 1997. During the summer ozone season in 1993, data were collected for a six-month period from six leased LAP®-3000 profilers sited at four coastal land sites in Texas and Louisiana, and on two off-shore platforms. For the study that began in 1997, MMS purchased two used LAP®-3000 profilers and deployed them to two off-shore platform sites. Surface and upper-air data were subsequently collected for a 40-month measurement period at the two platform sites, starting in June 1998 and concluding in October 2001. During this collection period, data were retrieved hourly through the GOES satellite communications network. At the end of the measurement period in October 2001, MMS had the two LAP®-3000 profilers placed in storage at the contractor's facility, pending planned redeployment by MMS for further use in enhancing meteorological data availability in the GOM coastal zone.

Upper-Air Meteorological Measurement Capabilities of LAP®-3000 Profilers

The LAP®-3000 radar profiler is a vertically-pointing, pulsed Doppler radar that operates in clear air, reporting meteorological data up to approximately 3 kilometers above ground level. It includes an indoor suite of electronics that controls the radar hardware and processes the data measurements, as well as an outdoor antenna that remotely senses the atmosphere. The technology for the radar profiler was developed by the U.S. National Oceanic and Atmospheric Administration (NOAA). The manufacturer of the profiler is Vaisala Inc. The LAP®-3000 gives information for successive strata of the atmospheric boundary layer, producing measurements of wind and virtual temperature in vertical profile above the system's transmitting and receiving antenna. Pulsed radio frequency (RF) signals are transmitted at an operating frequency of 915 MHz. A portion of the transmitted energy is reflected back to the antenna from small-scale turbulence in the atmosphere which moves with the speed and direction of the wind. These returned signals are time/height gated and are individually analyzed for Doppler frequency shifts that yield horizontal wind direction and speed measurements. Wind data are typically available from about 150 meters above the antenna, in approximately 60-meter to 200-meter intervals, up to a height of about 3 kilometers above the antenna. The LAP®-3000 also provides virtual temperature measurements from about 150 meters above the antenna, in approximately 60-meter height intervals, up to about 500 to 1,000 meters above the antenna. Virtual temperature profile measurements are achieved by directing an audio signal vertically and tracking it with the vertical RF beam of the radar. Using the Doppler shift information for each height increment from this acoustic wave tracking, the profiler is able to calculate the speed of sound in the atmosphere as a function of height, and then to convert that information into atmospheric virtual temperature measurements as a function of height. The maximum sensing height for virtual temperature measurements is much less than for wind measurements because virtual temperature measurements rely on sound propagation, which is much more height limited due to atmospheric attenuation than is RF energy propagation. Virtual temperature measurements are also height-limited by strong wind conditions, which can rapidly transport the acoustic wave out of the vertical view of the RF antenna. Wind measurements by the LAP®-3000 profiler are normally available up to about 3km unless atmospheric conditions below that altitude limit the availability of turbulent eddies to act as RF reflectors.

Initiatives in Progress to Redeploy MMS Radar Profilers to Gulf Coast Sites

In 2002, the MMS, assisted by Vaisala Inc., began efforts to locate suitable sites for redeployment of the two MMS-owned profilers to GOM coastal sites. Following a series of site surveys, MMS decided to re-establish one of the profiler sites used in the 1993 MMS study, near Cocodrie, Louisiana at the Louisiana Universities Maritime Consortium (LUMCON) facility. For the other profiler, MMS worked in coordination with VISTAS (Visibility Improvement – State and Tribal Association of the Southeast) in deciding to establish a new data collection site on Naval Air Station (NAS) Pensacola, Florida.

LUMCON Site Implementation

In early 2004, MMS contracted with LUMCON for necessary site preparation work at their Cocodrie facility, and with Vaisala Inc. for installation, operation and maintenance of the profiler at that site for a planned three-year data measurement period. Vaisala completed the profiler installation and system readiness checks on 8 October 2004, and the LUMCON profiler site became operational as of that date.

Site Configuration

The LUMCON radar profiler site is shown in Figure 2E.13, looking toward the west. The large white fiberglass structure on the cement pad is the vertically-pointing RF antenna, and the white cylinders surrounding it are the audio generators for virtual temperature sensing. The small, elevated building in the background is the shelter for the profiler electronics. An underground cable connects the antenna to the electronics in the equipment shelter. Not shown in Figure 2E.13 is the LUMCON 10-meter meteorological tower about 125 ft to the north and the main LUMCON building about 600 ft to the east. A radio link connects the 10-meter tower to the communications center in the LUMCON building, and a wireless LAN connects the profiler computer to the LUMCON communications center.

Figure 2E.13. LUMCON radar profiler site.

Data Generation and Distribution

Measured wind and virtual temperature profiles are generated hourly at the LUMCON site and are appended to daily files on the profiler's computer within a few minutes past each clock hour. Each daily file is named "DYYJJJ.CNS, where D is the data type (i.e., W for wind and T for virtual temperature), YY is the last two digits of the year (e.g., "04" for 2004), JJJ is the Julian date, and CNS (i.e., short for "Consensus") is the file extension. At midnight, the daily W file and daily T file are closed and a new one of each type is opened for the succeeding day. Throughout each day, the current W file and T file that are being appended to each hour, as well as all W and T files from preceding days, are available through the LUMCON web site, at *http://weather.lumcon.edu*. Surface weather data are accessed on the LUMCON web site by clicking on the word "LUMCON" either on or below the map. Profiler data are available by clicking on "New Doppler Wind Profiler" below the map. On the "Wind Profiler at LUMCON" page, clicking on the applicable bullet items in the "Data" section provides access to the current-day and past-days profiler data, as well an explanation of the data format of both wind and virtual temperature files. Clicking on the "Graphical View" bullet in the "Data" section, brings up a time-height plot of current LUMCON profiler wind data by linking to the NOAA Profiler Network (NPN) web site. While both the alpha-numeric and graphical data files from the LUMCON profiler can be printed or downloaded when accessed through the LUMCON web site as described above, it is important to note that the hourly file time convention is different for these two data formats. The alpha-numeric files use the EPA convention of showing the start time of each hourly data report, and are in Central Standard Time (CST) year around. The graphical displays use the NOAA convention of showing the end time of each hourly data report, and are in Universal Time (UTC) year around. An example of LUMCON wind profile data displayed graphically on the NPN web site is shown in Figure 2E.14. Any missing data hours are because the LUMCON profiler data at those times were not available to the NPN web site either because of equipment or communications problems.

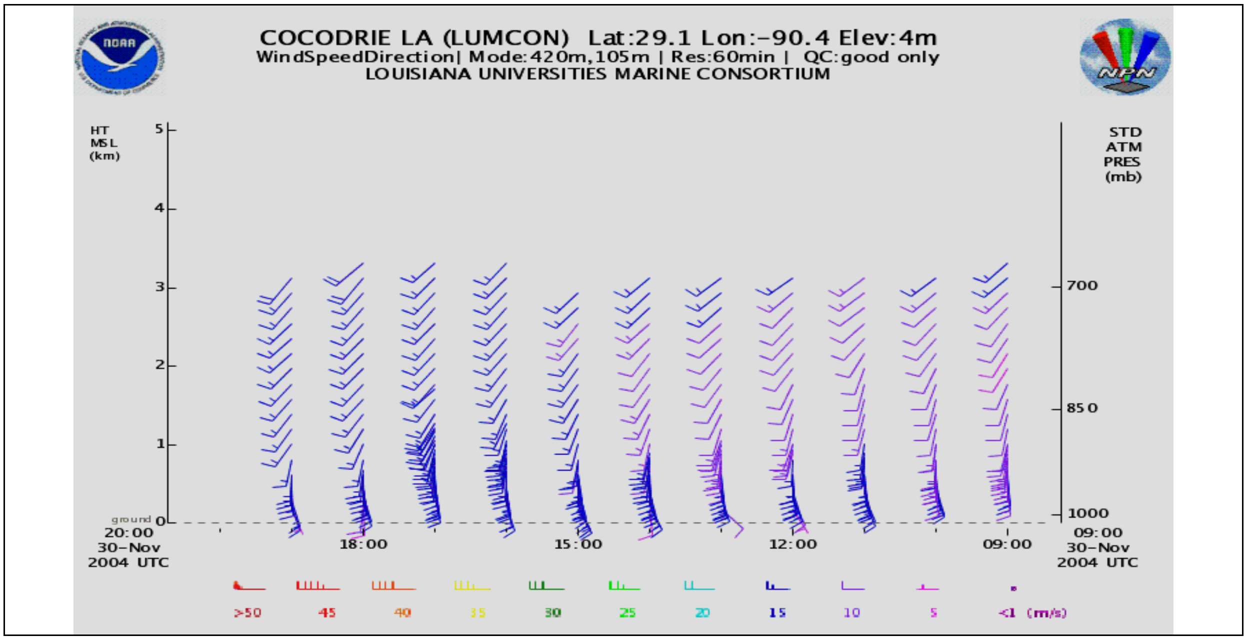


Figure 2E.14. Example graphical NPN wind display from LUMCON profiler.

NAS Pensacola Site Implementation

Under MMS sponsorship and direction, Vaisala performed an initial site survey at NAS Pensacola, Florida in June 2002, and subsequently worked with VISTAS representatives to firm up planning for installing an MMS profiler at that location. Unfortunately, a number of delays were encountered in this process, including a time-consuming frequency compatibility study by the U.S. Navy and a number of schedule disruptions caused by hurricane hits or near misses in the NAS Pensacola area. As a result, the planned installation of the MMS profiler at NAS Pensacola necessarily slipped until early 2005. Site preparation work is being handled by VISTAS through its Florida DEP representative, who is arranging for an equipment shelter and for power and telephone service to be installed at the planned NAS Pensacola site. Under contract to VISTAS and Southern Company Services, Inc., Vaisala will install the MMS profiler system at the site and operate and maintain it for a planned three-year measurement period. A local site operator will be provided by Florida DEP to assist Vaisala in performing maintenance activities.

Planned Site Configuration. Figure 2E.15 shows the planned layout of the profiler site on NAS Pensacola, near the existing 10-meter meteorological tower adjacent to the runways.

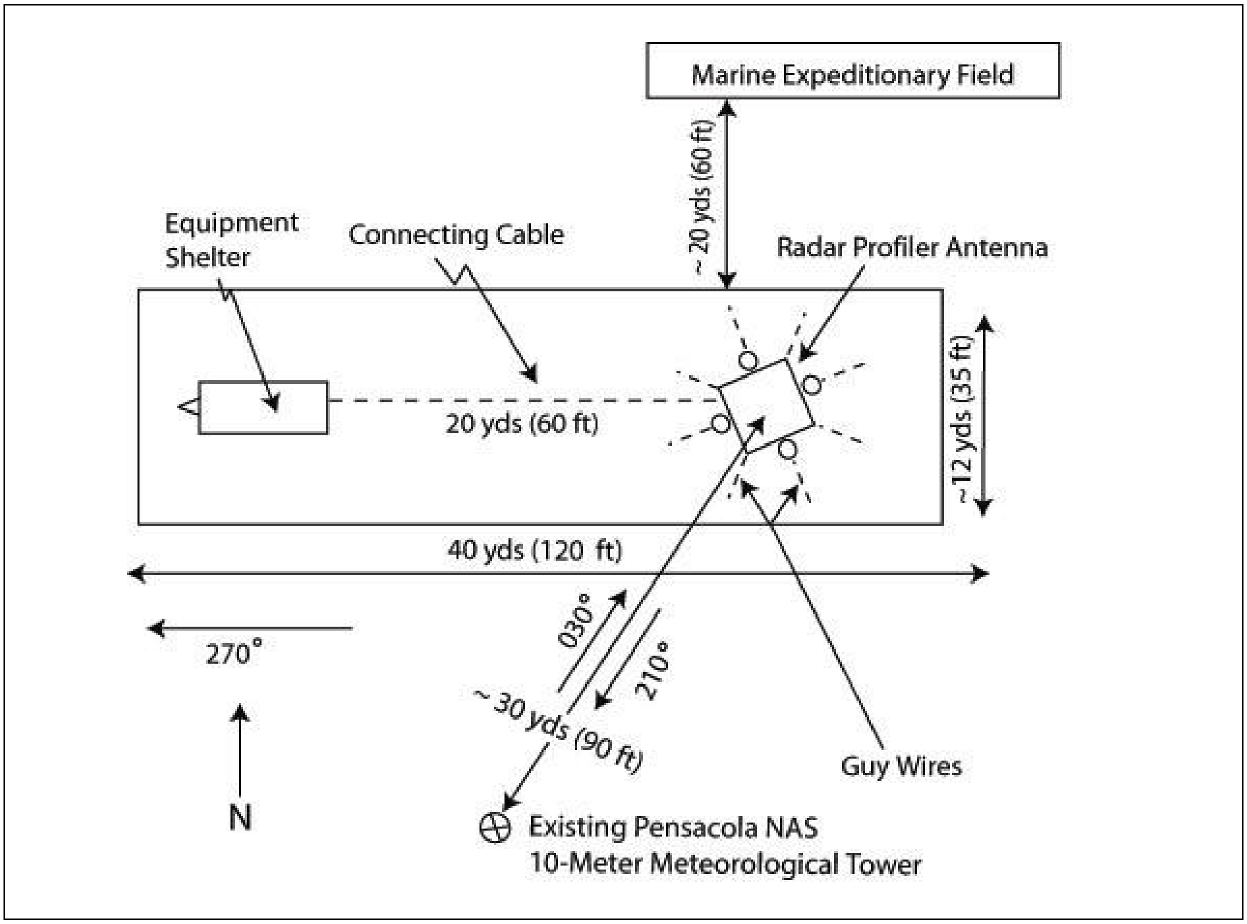


Figure 2E.15. Planned NAS Pensacola profiler site configuration.

Planned Data Generation and Distribution. Hourly wind and virtual temperature measurements will be generated by the NAS Pensacola profiler. These data will be retrieved through the GOES satellite data communications system and will be posted on the NOAA Profiler Network web site.

Summary

MMS is in the process of redeploying its two LAP®-3000 radar profilers to GOM coastal sites. One of the MMS profilers became operational at the LUMCON facility near Cocodrie, Louisiana in early October 2004 and hourly measurements from that site are now routinely available on the LUMCON web site. The second MMS profiler is planned to become operational at NAS Pensacola, Florida in early 2005, under a cooperative effort between MMS and VISTAS. When implemented, the NAS Pensacola site will generate hourly measurements to be made available on the NOAA Profiler Network web site. Upper-air wind and virtual temperature profile data planned for the next three years from these two new radar profiler sites are expected to significantly enhance available meteorological measurements for air quality assessments in the GOM coastal zone.

Mr. Gary Zeigler is the Operations Manager of the Wind Profiler Business Unit at Vaisala, Inc., Boulder, Colorado. He is a career meteorologist with extensive experience in meteorological remote sensing. Mr. Zeigler has provided contractor project management support to MMS field studies employing wind profilers since 1993. He is currently the contractor project manager for two new field measurement programs employing MMS radar wind profilers.

ENHANCEMENTS TO THE CALPUFF MODELING SYSTEM FOR OCS APPLICATIONS

Joseph Scire, David Strimaitis and Francoise Robe, Earth Tech, Inc.

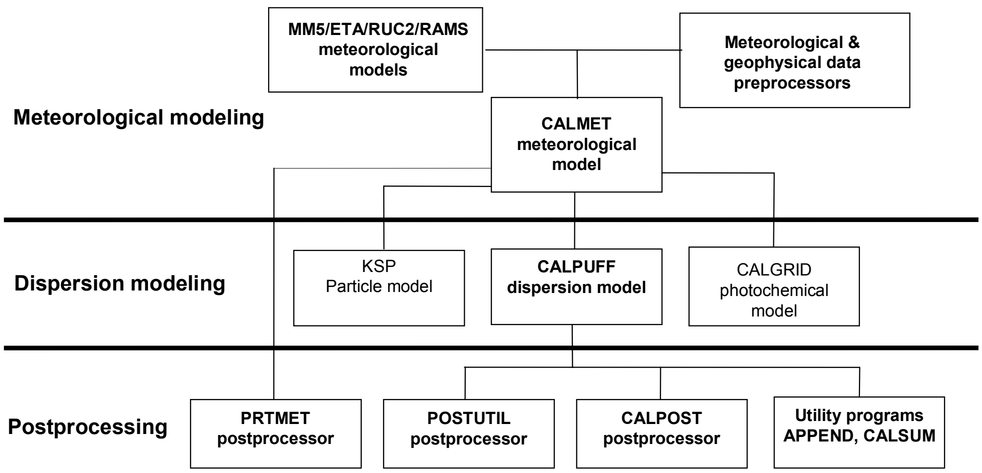
Outline

- Improvements in datasets for OCS applications
  - Enhanced interface (MM5) and new interfaces (RUC, Eta, RAMS)
    - 3d and 2d datasets
  - High resolution SST data
  - Standard one-year MM5 meteorological dataset
- Ease-of-use enhancements
  - Graphical user interfaces
  - Graphics – vectors, isopleths, animations
- Technical enhancements to CALPUFF modeling system
  - COARE algorithms
  - Improve mixing height algorithm over water including buoyancy effects
  - Option for AERMOD-like turbulence profiles
  - Subgrid-scale coastline treatment and TIBL growth
  - Non-Boussinesq numerical plume rise for all sources
  - Platform adjustments to building downwash algorithms

Background

- CALPUFF is a Lagrangian, non-steady-state puff dispersion model
- Achieved status as a U.S. EPA Guideline Model (Federal Register, 15 April 2003)
- Recommended by IWAQM (1998) for long-range transport applications
- Recommended by FLAG (2000) for Class I impact assessments and air quality related value impact evaluation

CALPUFF Modeling System



CALMET Model

- CALMET boundary layer modules
  - Computes mixing heights, surfaces fluxes, stability and turbulence fields
  - Overland PBL model uses an energy balance approach
  - Overwater PBL model uses a profile method
- CALMET 3-D diagnostic wind field module
  - Uses observations and/or gridded prognostic meteorological fields
  - Wind fields adjusted for fine-scale terrain effects and mass-consistency
    - Slope flows, kinematic effects, terrain blocking effects
    - Divergence minimization
    - Objective analysis procedure to assimilate observational data

CALPUFF Model

- CALPUFF non-steady-state Lagrangian puff model
  - Uses 3-D wind and turbulence fields for transport and dispersion
  - Near-source effects such as building downwash, transitional plume rise, partial plume penetration
  - Subgrid-scale terrain and coastal interaction module
  - Longer range effects such as chemical transformation, overwater transport and dispersion, wet and dry deposition
  - Special non-Boussinesq plume rise model designed for very hot plumes such as from flares

Improvements in Datasets

- High resolution satellite data in defining SST
- Prognostic model to define conditions, especially in data sparse offshore areas
- Gridded air-water temperature structure (gridded SEA.DAT file)
- Introduction of "no-observations" mode in CALMET
  - Closer coupling of CALMET with prognostic meteorological models
- New interfaces to additional prognostic models such as RUC, Eta, RAMS in addition to MM5

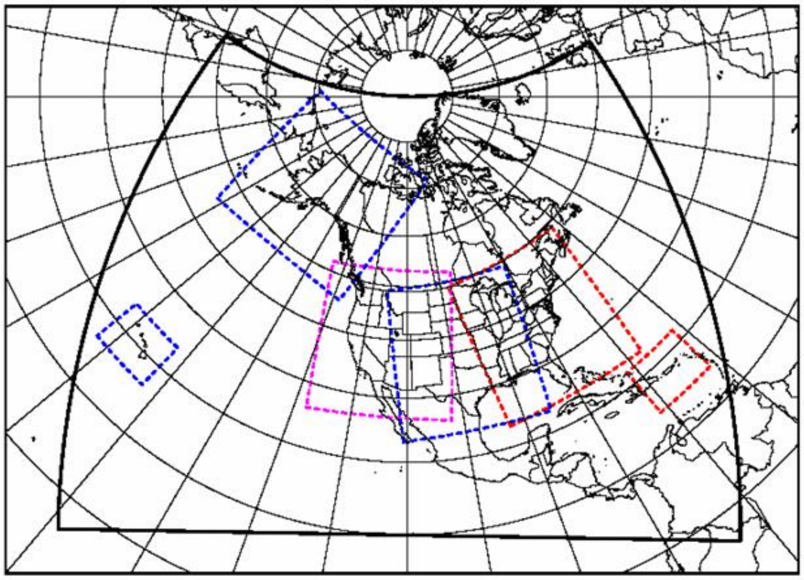
Hybrid Approach to Meteorological Models

- Mesoscale prognostic model output on larger scale
  - Includes synoptic and mesoscale features
  - ~1 km – 20 km grid spacing
  - Provides information on conditions offshore
- Diagnostic model on fine grid (CALMET)
  - Includes mesoscale model output + optional observations
  - Fine grid spacing (0.25 km-3 km)
  - Terrain effects on fine scale
  - Provides high-resolution PBL parameters for dispersion model
  - Reasonable run time

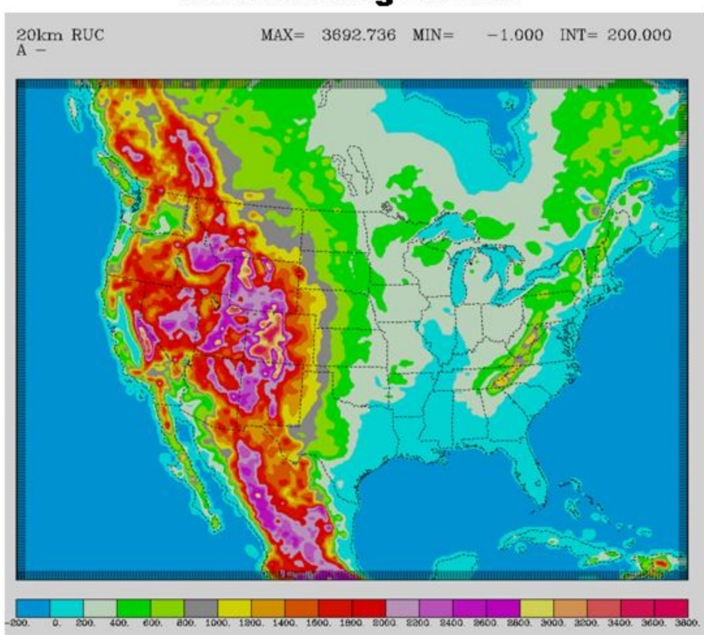
Standard Meteorological Dataset

- Standard dataset for regulatory applications
  - Consistency of meteorological fields across applications
  - Substantial savings of effort
  - Evaluated dataset with known performance
- MM5 dataset being developed under separate MMS contract for the GOM area
  - One year period (1 October 2000–30 September 2001)
  - Three nests: 36km, 12km and 4km grid spacings
  - High-resolution SST data
- Additional years with MM5 or output from other models
  - New programs developed to interface CALMET to RUC, Eta and RAMS

Eta Modeling Domains



RUC Modeling Domain



Summary of Eta/RUC Operational Runs

Model	Horizontal Resolution (km)	Vertical Resolution	Run Frequency	Output Interval		Forecast Length
				Analysis	Forecast	
ETA	12	60 Levels	4 per day	6-hours	3-hours	84 Hours
ETA	8	60 Levels	4 per day	6-hours	3-hours	48 Hours
RUC	20	50 Levels	24 per day	1-hour	1–3 hours	12-Hours

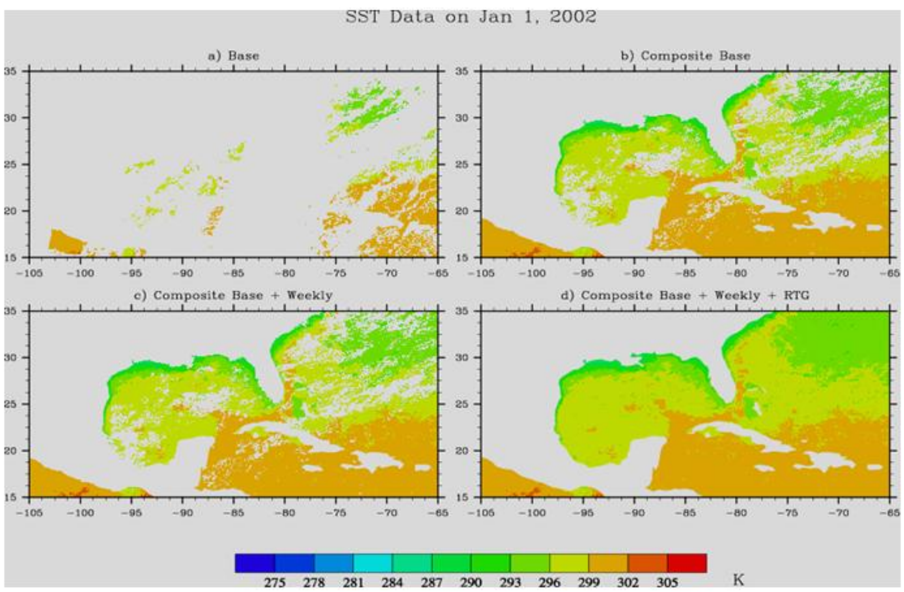
Satellite SST Datasets

- Final Analysis Data (FNL)
  - 1 deg x 1 deg data
  - Available 4 times daily
  - Data assimilation
- Real-time, global SST Analysis (RTG)
  - 0.5 deg x 0.5 deg
  - Available daily
  - Analysis of satellite measurements, surface obs and interpolation
- Moderate Resolution Imaging Spectroradiometer (MODIS)
  - 4km data
  - Daily and weekly
  - Satellite measurements

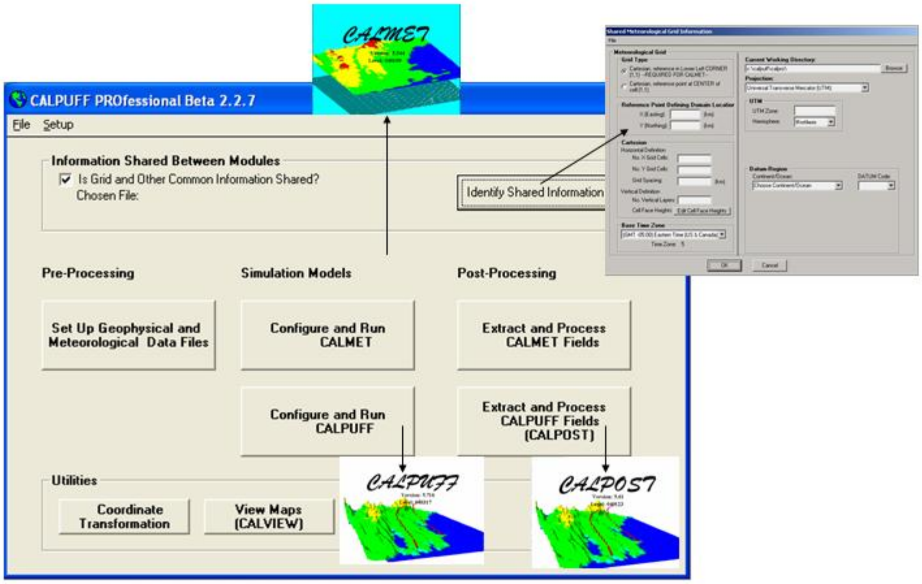
Development of MODIS SST Dataset

- Any given satellite pass has potentially large amounts of missing data due to clouds
- Procedure being tests:
  - Base: Satellite data for Day: n
  - Composite: Fill missing cells iteratively with data for day n+1, n-1, n+2, n-2, n+3, n-3
  - Composite + weekly: Fill missing cells with data from weekly MODIS dataset
  - Composite + weekly + RTG: Fill any remaining missing data with daily RTG data

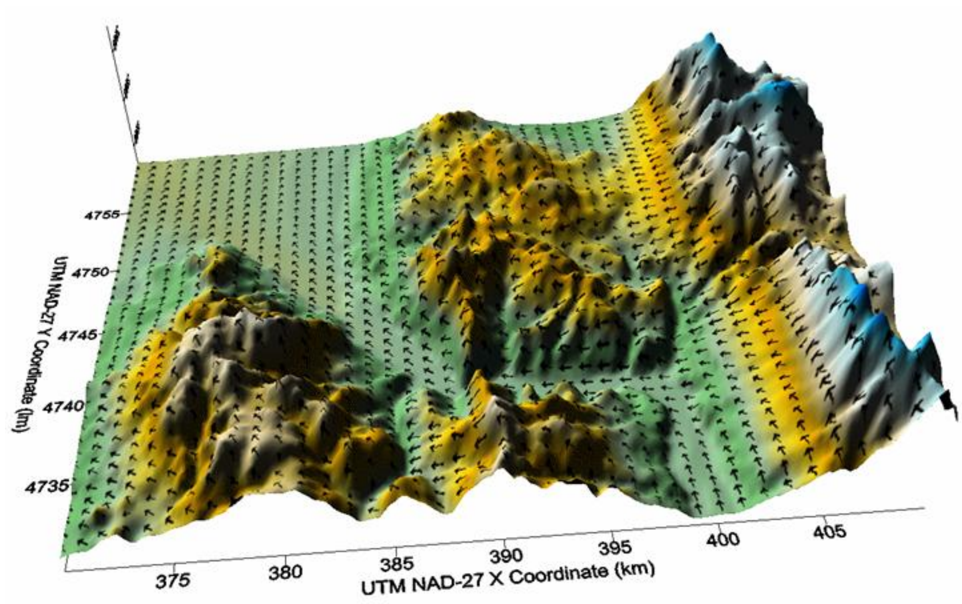
Illustration of Steps in Developing SST Dataset



CALPRO GUI – Integrated Interface



Wind Vectors on 3-D Perspective Plot



Surface Layer Parameters

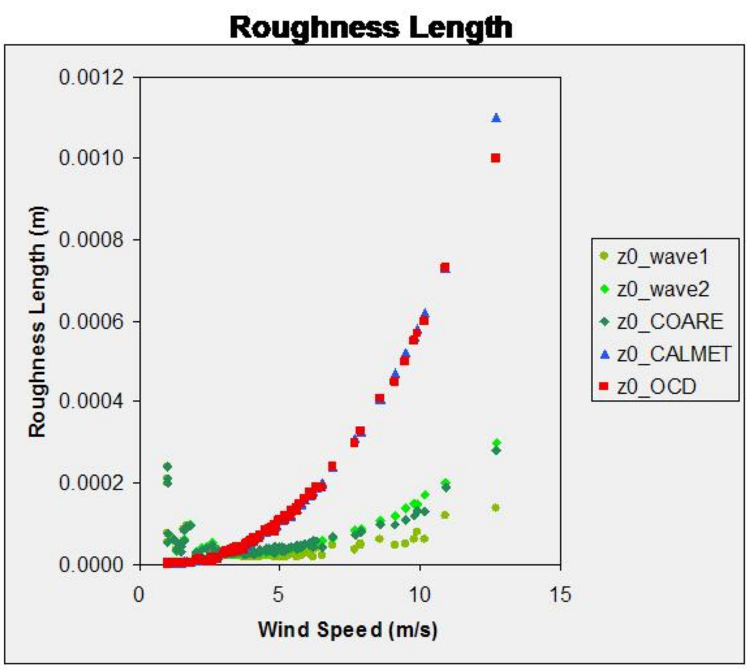
- OCD
  - Bulk aerodynamic principles and surface layer formulas using measured T(10m), Ts, RH, u(10m)
    - $z_0 = 2.0e\text{-}06\ (u_{10})^{2.5}$
    - $C_{uN} = (0.75+0.067\ u_{10})\ 10^{-3} = (u_*/u_{10})^2$
    - $L = 196.2\ \theta_v\ (C_{uN})^{1.5}\ u_{10}^2 / (\theta_v - \theta_{vs})$
  - MOST profiles estimate 10m values
  - Iteration refines u_*, L

Surface Layer Parameters

- CALMET
  - OCD methods are used to obtain local surface parameters for each grid cell
  - Meteorological data for each cell is assumed to be at 10m (first model layer top is 20m)
  - SST and air-sea T obtained from buoys (or from remote sensing and model delta T calculation)

Surface Layer Parameters

- COARE
  - Refined bulk aerodynamic and surface layer formulas, with submodels for:
    - sea surface skin temperature
    - diurnal warm layer temperature structure
    - wind-wave roughness adjustments
  - Iterative solution retained to balance profile extrapolations with surface fluxes
  - $z_0 = \alpha u_*^2 / g + 0.11\nu / u_*$
  - Charnock α ~ 0.011 increases with wind speed greater than 10 m/s
  - Deep sea formulation, adjustments for shallow water



Surface Layer Parameters

- COARE module added to CALMET
  - Calculated roughness length z_0 with COARE is significantly smaller than OCD/CALMET, especially for wind speeds > 3 m/s
    - Behavior at low wind speeds may need adjustment
  - Differences in u_* and L result in differences in overwater turbulence characterization
    - COARE reduces friction velocity by about 10%
    - Monin-Obukhov length from COARE about 25% higher (convective conditions) and about the same for stable conditions
  - Wave information from buoys and remote sensing can be incorporated when data are available

Current Overwater Mixing Height

- Overwater mixing height
  - either specified by the user (SEA.DAT)
  - or computed internally: (Blackadar and Tennekes 1968)

$$h_{water} = \frac{C_W \cdot u_*}{|f|}$$

where

C_W is a constant (~0.16)

f is the Coriolis parameter (~10^{-4} s^{-1})

Problems with Overwater Mixing Heights

- MMS Boundary Layer Study (STI) suggests underprediction of mixing heights by CALMET during light wind speed conditions (100-200m vs 600m observed)
- Lack of consideration of buoyancy effects over water
- Testing new method for computing overwater mixing heights that includes both mechanical and convective mixing processes

Mixing Height

- Maximum of mechanical or convective mixing heights
- Convective mixing height

$$(z_i)_{t+1} = \left[(z_i)_t^2 + \frac{2Q_h(1+E)dt}{\psi_1 \rho c_p} - \frac{2d\Theta(z_i)t}{\psi_1} \right]^{1/2} + (d\Theta)_{t+dt}$$

- Modified Carson method (Maul 1980)

$$(d\Theta)_{t+dt} = \left[(2\psi_1 E Q_h \Delta t) / (\rho c_p) \right]^{1/2}$$

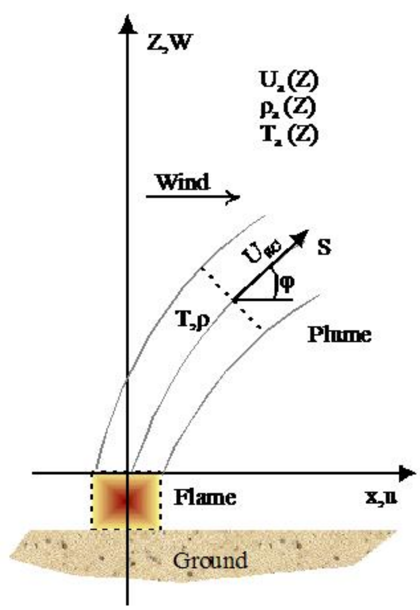
Numerical Plume Rise

- Numerical solution to conservation and state equations in non-Boussinesq form (used for high temperature sources such as flares or fires)

- Initial properties at release
  - temperature
  - effective vertical velocity
  - effective radius

- Explicitly accounts for vertical structure of atmosphere
  - wind speed profile
  - wind direction profile
  - temperature (density) profile

Schematic for a Plume in a Crosswind



Numerical Plume Rise Conservation Equations

- Mass

$$\frac{d}{ds}(\rho u_{sc} r^2) = 2r\alpha\rho_a |u_{sc} - u_a \cos\phi| + 2r\beta\rho_a |u_a \sin\phi|$$

- Momentum - along-wind

$$\frac{d}{ds}(\rho u_{sc} r^2 (u - u_z)) = -r^2 \rho w \frac{du_a}{dz}$$

- Momentum – vertical

$$\frac{d}{ds}(\rho u_{sc} r^2 w) = g r^2 (\rho_a - \rho)$$

- Energy

$$\frac{d}{ds}\left[\rho u_{sc} r^2 (T - T_a)\right] = -\left(\frac{dT_a}{dz} + \frac{g}{c_p}\right)\rho w r^2 - R_p r\left(T^4 - T_a^4\right)$$

Building Downwash

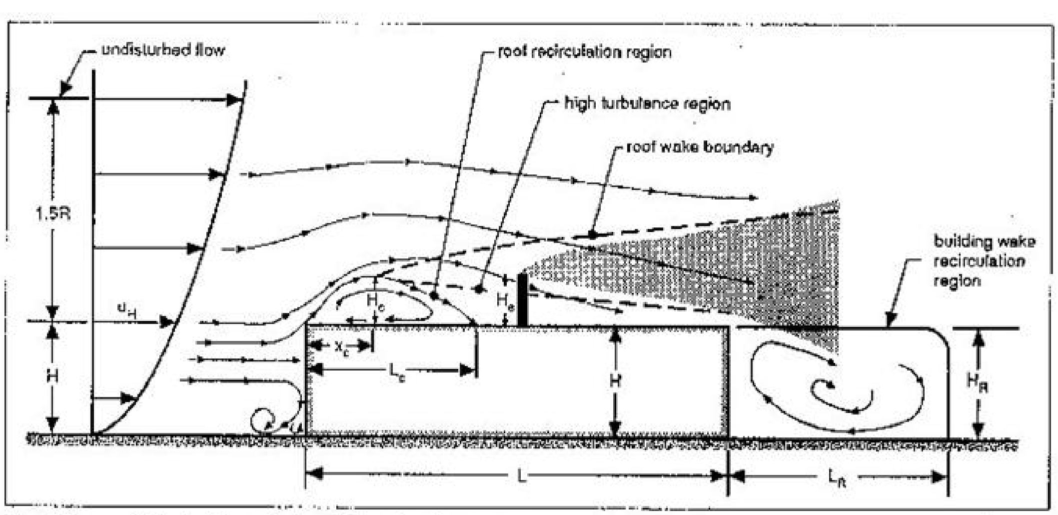


Figure 1. Flow over a building for wind normal to the upwind face (adapted from Wilson).

Downwash

- OCD
  - Based on empirical fit to API wind tunnel data for a 'large' offshore oil platform (Petersen 1986)
    - Platform A
    - W = 55m;   Hb (above water) = 48m
    - X/Hb = 2.2, 12.6, 25.0, 37.5
    - Horizontal release (180° wind direction)
  - Wind tunnel fit modified to remove 'ambient' turbulence, leaving downwash sigma (σ_d) component
  - σ_d is added in quadrature to ambient sigma at all distances (σ_d at 12.6 Hb used for x > 12.6 Hb)
  - Controlling parameters are platform width and total height; adjustment factor is applied for release height
  - Downwash sigmas included in dilution radius for plume rise (as in BLP)

Petersen Sigma-z

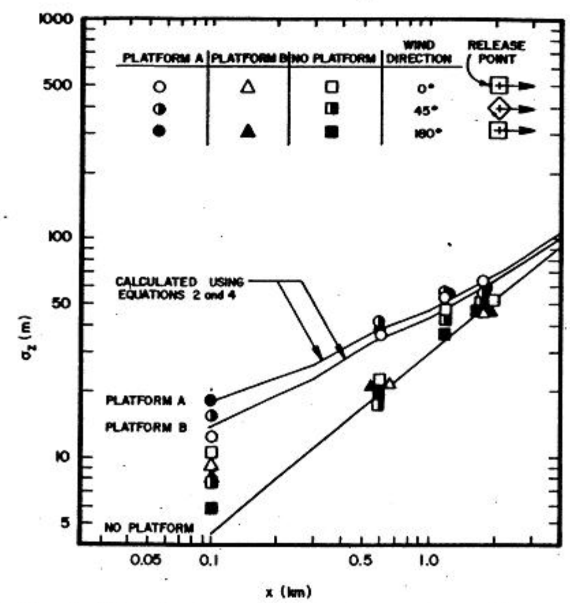


Figure 5. Observed and computed variation of σ_z versus downwind distance, neutral stratification.

Petersen Sigma-y Figure

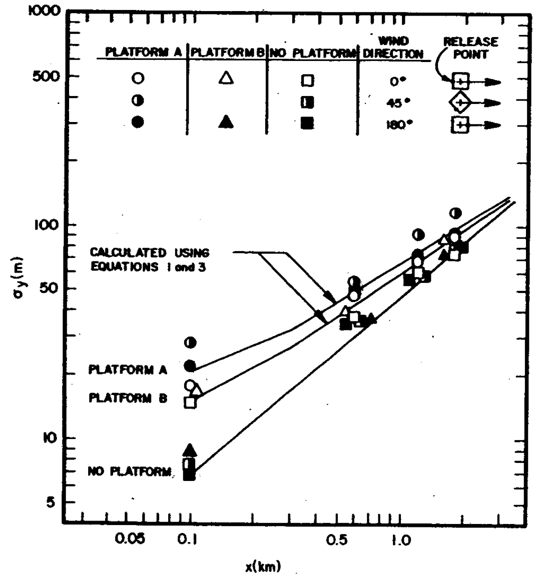


Figure 4. Observed and computed variation of σ_y versus downwind distance, horizontal release, neutral stratification.

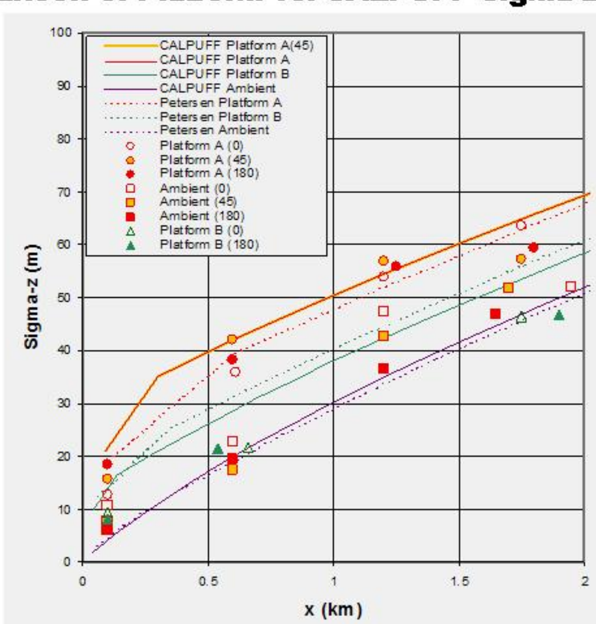
Downwash

- CALPUFF - ISCST3 methods
  - Buildings are treated as solid structures
  - Controlling parameters are building width and height, provided for each 10° of flow direction; adjustment factor is applied for release height
  - Downwash sigmas (σ_d) used up to 10 L, and σ_d(10 L) is converted to a virtual distance for x > 10 L (L is smaller of Hb and W)
  - Downwash sigmas used to define a dilution radius for plume rise (as in BLP)

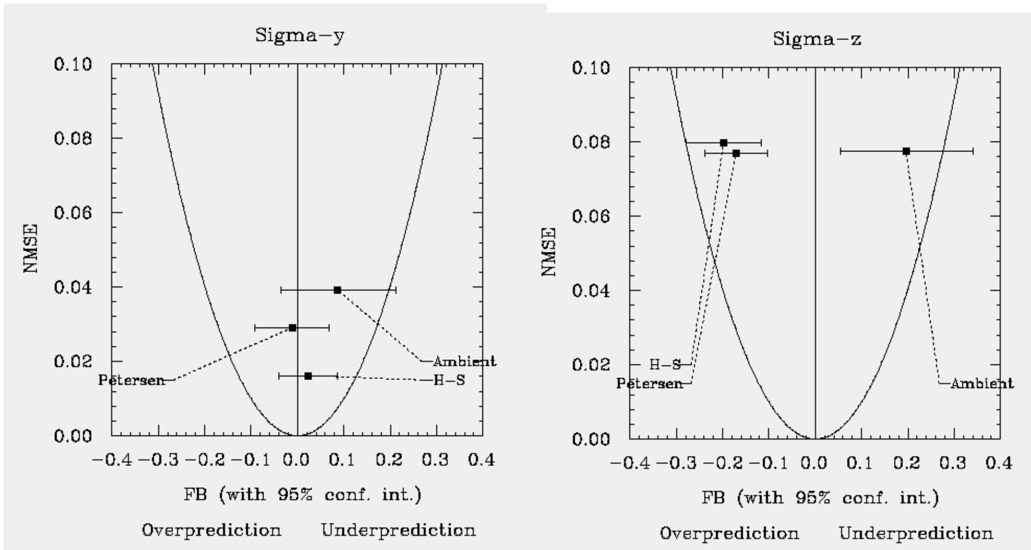
Downwash – PRIME Method

- Includes:
  - Source-building separation effects
  - Explicit streamline ascent/descent
  - Velocity deficit due to presence of building
  - Integrated cavity (near-wake) and far-wake modules
  - Effects of downwash on plume rise and turbulence (spatially-varying)
  - Partial capture of plume into cavity allowed
  - Enhancement of sigma y and sigma z

Comparison of Platform vs. CALPUFF Sigma-z Values



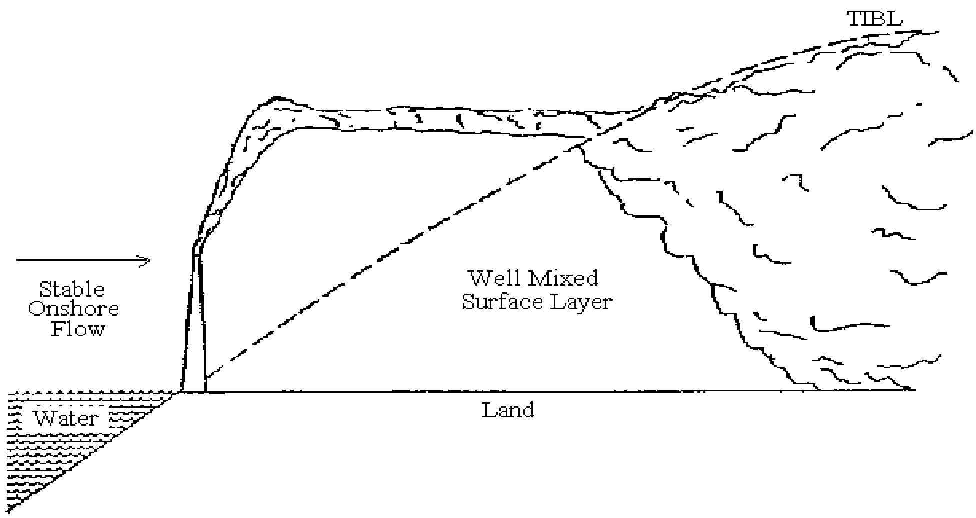
Downwash Model Performance



Platform Downwash

- Testing suggests that the CALPUFF equations are as effective as the algorithm in OCD in simulating the effect of platform downwash
- Existing CALPUFF modules retained for platforms with addition of a modified structure height and height above the water surface

Plume Fumigation



TIBL

- OCD
  - Piece-wise linear mixed layer height is prescribed along the direction from the source to a receptor with distance measured from the coast
  - h = 0.1 x for $x \leq 2000$m
  - h = 200 + 0.03 (x-2000) for $x \geq 2000$m)
  - Designed to approximate a generic TIBL without inputs for wind speed, heat flux, marine layer lapse rate

TIBL

- CALMET
  - Two-step mixing height procedure
  - (1) Gridded mixing height field computed using local grid-cell properties
  - (2) Advective averaging scheme controlled by user inputs smoothes transitions by averaging heights along flow
  - Provides robust treatment of coastal-zone transitions, recognizing difference in along-shore / on-shore / off-shore situations

TIBL

- CALPUFF
  - Sub-grid TIBL option refines the gridded mixing height structure in coastal zones using the TIBL model of Garrett (1992)

$$\frac{dh}{dx} = \frac{(1 + 2\beta)H}{\gamma \rho c_p u h}$$

  - Model is applied along the puff trajectory using local grid cell properties.
  - For steady conditions,

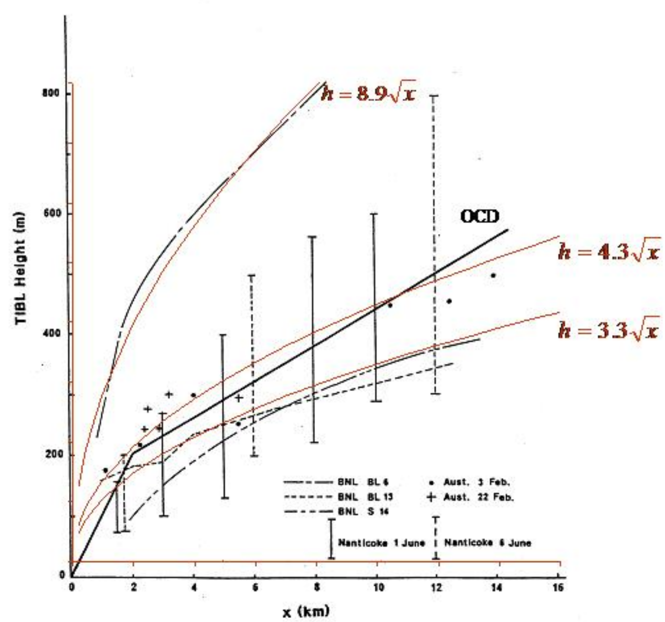
$$h = \sqrt{\frac{2(1 + 2\beta)H}{\gamma \rho c_p u} x}$$

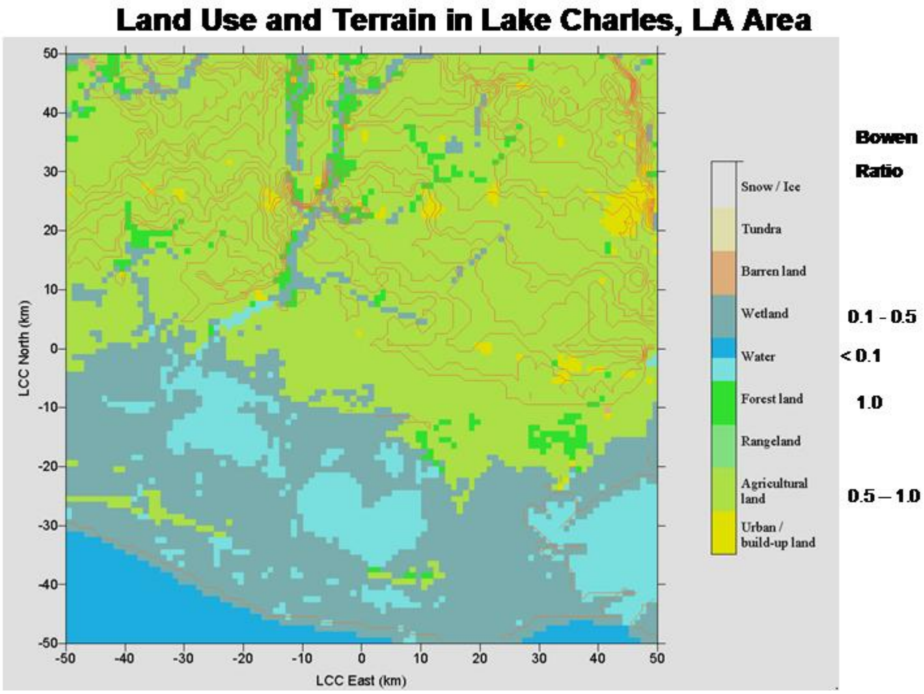
TIBL

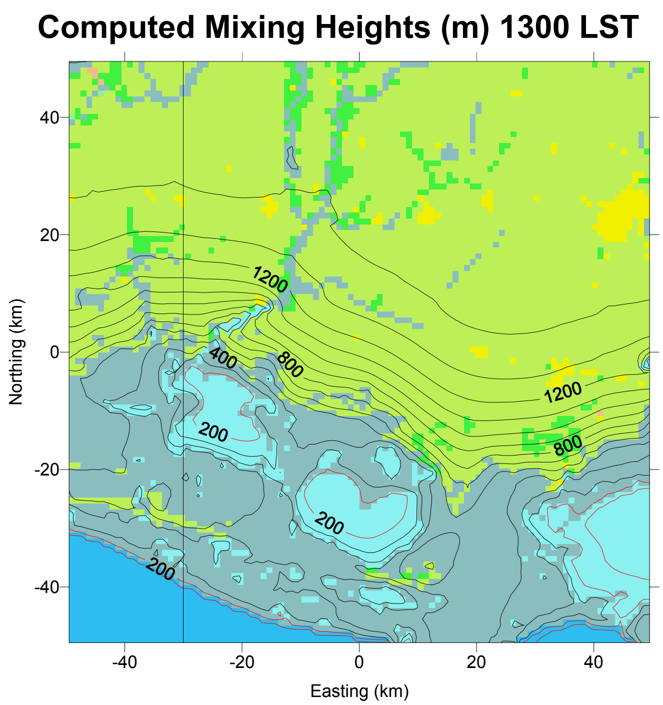
- CALPUFF (Coastal Zone Representation)
  - Gridded land use includes wetlands and inland water bodies
  - Properties tied to land use includes roughness length and Bowen Ratio
  - Sensible heat flux (H) is proportional to Bowen Ratio
  - Computed TIBL growth rate will respond to coastal zone properties:

$$\frac{dh}{dx} = \frac{(1 + 2\beta)H}{\gamma \rho c_p u h}$$

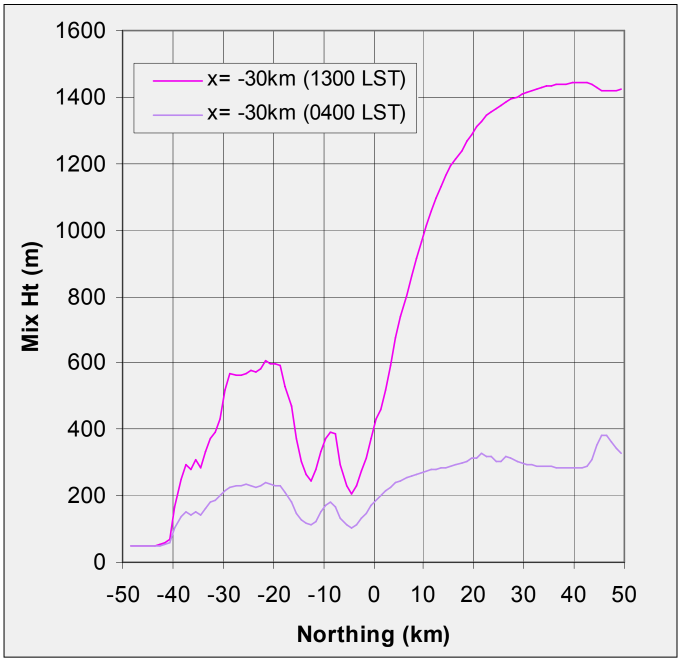
OCD TIBL Comparison with Field Data




Land Use and Terrain in Lake Charles, LA Area
LCC North (km)
LCC East (km)
Bowen
Ratio
Snow / Ice
Tundra
Barren land
Wetland
0.1 - 0.5
Water
< 0.1
Forest land
1.0
Rangeland
Agricultural land
0.5 – 1.0
Urban / build-up land


Computed Mixing Heights (m) 1300 LST
Northing (km)
Easting (km)
1200
400
800
200

Mixing Heights along X=-30km



Conclusions

- Improvements made in datasets for OCS applications
  - Use of prognostic datasets important in data-sparse areas offshore
  - Enhancements to allow better use of prognostic meteorological datasets
  - Addition of new interfaces to allow new options for data sources (MM5 + RUC, Eta, RAMS)
  - High resolution SST data developed based on MODIS 4km data
  - Standard one-year MM5 meteorological dataset to be prepared for regulatory use
- Enhancements made to facilitate use of CALPUFF for regulatory applications
- Technical enhancements to CALPUFF modeling system
  - COARE algorithms
  - Improve mixing height algorithm over water including buoyancy effects
  - Option for AERMOD-like turbulence profiles
  - Subgrid-scale coastline treatment and TIBL growth
  - Non-Boussinesq numerical plume rise for all sources
  - Platform adjustments to building downwash algorithms

Joseph Scire is a Vice President and the manager of Earth Tech's Atmospheric Studies Group. He has over 26 years' experience in the design, development, and application of research and regulatory air quality models. He has played a major role in the development of several widely-used models including the CALPUFF modeling system, the CALGRID photochemical model, the Buoyant Line and Point Source (BLP) model, the MESOPUFF II mesoscale puff dispersion model, the building downwash algorithm in the Industrial Source Complex (ISC) model, a new building downwash model called PRIME, and the FOG cooling tower model. He has taught more than 45 training courses on the CALPUFF model for government agencies, private industry and universities in the United States and abroad. He has taught several modeling courses for the Air &Waste Management Association. Mr. Scire has served as an expert witness in projects involving CALPUFF modeling, building downwash and the deposition of toxic pollutants.

David Strimaitis is a research meteorologist and senior air quality consultant with over 26 years of experience in developing and evaluating air quality models. He is one of the principal developers of the CALPUFF modeling system. Mr. Strimaitis served as manager of the EPRI Atmospheric Sciences Data Center contract for over ten years, during which time the Center moved from a mainframe computing environment to a web-based distribution environment. He developed a modified version of EPA's ISCST model to include wet and dry deposition and the refined building downwash model PRIME. He implemented a dry deposition scheme for mercury compounds into the MESOPUFF II model. As a principal investigator in EPA's 7-year Complex Terrain Model Development program, Mr. Strimaitis developed the modules central to the Complex Terrain Dispersion Model (CTDM). Mr. Strimaitis has applied many of the dense gas and air toxics models currently available for acute exposure analyses, and has evaluated their performance against existing data from field experiments. To facilitate these evaluations, he contributed to the design of a Modelers Data Archive of these datasets. He has also developed a number of model evaluation tools, including a SAS-based program that employs the jackknife resampling technique to assess the statistical significance of evaluation measures.

Francoise Robe is an air quality modeling specialist with over 12 years' experience in advanced meteorological and dispersion modeling. She is one of the authors of CALMET, the meteorological model of the US regulatory CALPUFF modeling suite. She has taught 18 CALMET-CALPUFF training courses for the US-EPA, universities, consultants and industry around the world. She has also managed and conducted numerous air quality studies worldwide with the MM5, CALMET, and CALPUFF models. She is the author of over 30 technical reports and scientific articles, and has presented several papers at international scientific conferences. She has previously worked in the oil and gas industry and is familiar with upstream and downstream air quality issues.

SESSION 2F

SPERM WHALE SEISMIC STUDY, PART II

Chair: **Deborah Epperson, Minerals Management Service**

Co-Chair: **Carol Roden, Minerals Management Service**

MESOSCALE SPERM WHALE STUDIES IN THE GULF OF MEXICO I: RESPONSES TO SEISMIC LINE STARTS, ACOUSTIC LENGTH MEASUREMENTS, CODAS AND CULTURAL ORGANIZATION

Jonathan Gordon and Ricardo Antunes, Ecologic, Newport on Tay, Fife and Sea Mammal Research Unit, University of St. Andrews, Scotland
Nathalie Jaquet and Bernd Würsig, Texas A&M University–Galveston
Luke Rendell, Sea Mammal Research Unit, University of St. Andrews, Scotland

Introduction

This is the first of two presentations about what has come to be called the "mesoscale" project. It gained this epithet because within it, information is often collected and analyzed at scale intermediate between the large scale satellite tagging and fine scale from the D-tag observations. However, it has often also involved the application of what must now be considered the "traditional" approach to sperm whale behavioral research involving methods such as observation, photo-identification, photogrammetry and passive acoustic monitoring from small research vessels.

Fine Scale Movements in Response to Seismic Line Starts

This work involved an analysis of data on whale headings and surface behavior collected by the visual team on the Gyre during 2002 S-tag and 2003 habitats cruises and a database of seismic survey activity collected and kindly made available for restricted use by IAGC. During SWSS cruises on the Gyre, a visual team maintained watch from the flying bridge on a rolling rotation with a minimum of three observers on effort at any one time. Two were usually searching using big-eye binoculars and the third supplemented search effort with hand-held binoculars and entered data on search effort and sightings into the "Logger" data collection program (IFAW). Once a group of whales had been acquired, the visual team's main role was to track whale groups and guide researchers in rigid hull inflatable boats close to whales on the surface for tagging, photo-id or biopsy research. Data on the range, bearing, heading, group size and behavior of all groups were entered into Logger and used to create real time maps to assist with tracking. The seismic survey dataset consisted of the start and end time and location of most seismic lines shot in the northern Gulf of Mexico (NGOM) during 2002 and 2003.

By integrating these two datasets we were able to observe whale tracks and headings on logger maps for periods before and after line starts and line ends. We also calculated the mean whale heading relative to the bearing to the seismic line (0^{o}, 180^{o} away), surface time and surfacing rates for all whale sightings for the two hours before and the two hours after line starts and ends. These were compared statistically as a series of matched pairs using Wilcoxson's signed rank non-parametric matched pairs technique for all encounters within 25, 50, and 100 miles of a seismic survey; results from these tests are summarized in Table 2F.1. Neither the inspection of the logger maps nor the statistical tests provided any suggestion of responses by whales to line starts or ends.

Table 2F.1. Results of seismic line starts and ends tests.

Seismic Line Starts	Before Mean (n)	After Mean (n)	Significance (2 tailed)	Range to Seismic Vessel (N. Miles)
Relative Heading	108 (28)	102 (28)	.524	<100
Surface Time (secs)	905 (23)	460 (23)	.125	<100
Sighting Rate (Sighting hr^{-1})	11.1 (27)	11.29 (27)	.962	<100
Relative Heading	106 (16)	108 (16)	.717	<50
Surface Time (secs)	457 (14)	403 (14)	.470	<50
Sighting Rate (Sighting hr^{-1})	11.1 (16)	12.1 (16)	.756	<50
Relative Heading	121 (6)	124 (6)	.463	<25
Surface Time (secs)	450 (5)	386 (5)	.138	<25
Sighting Rate (Sighting hr^{-1})	10.1 (6)	11.7 (6)	.917	<25
Seismic Line Ends	**Before Mean (n)**	**After Mean (n)**	**Significance (2 tailed)**	**Range to Seismic Vessel (N.Miles)**
Relative Heading	105 (30)	111 (30)	.309	<100
Surface Time (secs)	571 (23)	720 (23)	.753	<100
Sighting Rate (Sighting hr^{-1})	11.8 (29)	15.7 (29)	.214	<100
Relative Heading	101 (17)	110 (17)	.332	<50
Surface Time (secs)	420 (15)	403 (15)	.910	<50
Sighting Rate (Sighting hr^{-1})	12.8 (16)	17.8 (16)	.469	<50
Relative Heading	82 (5)	77 (5)	.893	<25
Surface Time (secs)	418 (4)	298 (4)	.273	<25
Sighting Rate (Sighting hr^{-1})	13.6 (5)	22.6 (5)	.225	<25

Several caveats should be kept in mind, however. Most exposures were at substantial ranges: the shortest distance was 6.7 miles, and there were only three ranges less than 20 miles. The observational techniques used were not very precise and there was substantial scope for the animals in this area to have become habituated. This analysis would have been impossible without the IAGC database of seismic activity, and it indicates the value of that initiative. It would be worth repeating the analysis including the tracking data collected on all the Gyre cruises completed during SWSS.

Small Boat Studies in 2004

In 2004 a 46' motor sailor was chartered and used to complete four cruises totaling 37 days at sea. Vessels of this type have been used extensively to conduct the majority of sperm whale behavioral research offshore in other areas; they have a number of generic advantages. Being small, quiet, independent and highly maneuverable, they are ideal platforms for tracking groups of sperm whales for several days at a time using passive acoustic techniques and for approaching individual animals for photo-id, observation, and biopsy. They can be run and maintained by a small team of sailor scientists, are reasonably comfortable and stable, and have proven a highly cost-effective method of working safely and independently offshore. We found that we generally matched or exceeded the rate of collection of key data we had achieved on the Gyre but with a much smaller team and at a much lower cost.

Acoustic Monitoring and Habitat Use

Passive acoustic monitoring of streamlined stereo hydrophones towed on cable lengths of 100-400m has been the principle method of finding sperm whales on both the Gyre and the motor sailor. Search/survey tracks were chosen according to predetermined rules to provide a reasonable coverage of the study area, and detailed records of search effort, maintained on Logger, allow periods when searching meets the criteria for being considered legitimate survey (full effort and survey tracks random with respect to any knowledge of whale distributions) to be identified. Though these data cannot be analyzed to determine absolute density estimates, we have been with spatial modeling techniques with general additive models (GAMS) to calculate surfaces of relative densities in the study area. This work is ongoing but results so far are encouraging, with highest detection rates in water depths between 500 and 1,500m and at intermediate angles of slope. We hope to incorporate other potential predictors, such as oceanographic factors and bottom type into future models.

Acoustic Length Measurement

The body length of sperm whales can be determined by measuring the time interval between sound pulses in each click and scaling this information to body size using empirically-derived equations. While the principles behind the techniques are now well established and accepted, making inter-pulse interval (ipi) measurements from field recordings can be problematic; existing methods may require a lot of operator interaction and/or be prone to negative bias. To overcome this problem, we have been developing a new analysis method based on temporal integration of click waveforms for series of clicks from individual whales. The results are encouraging, but more work is needed to better quantify the technique’s performance. Acoustic measures of length made in 2003 and 2004 agree well with photogrammetric measures of the same animals (see below). Acoustic length measurement is both complimentary to photogrammetric techniques and particularly useful in situations where photogrammetric methods cannot be used, but is also potentially capable of measuring length with sufficient precision to allow the growth rate of individuals to be measured between years. When both photographic and acoustic measures are available, the relative proportions of head length and body length, which are known to vary with sex and age, can be determined for individuals.

Coda Analysis

Codas are stereotyped patterns of clicks typically heard from groups of sperm whales resting or socializing at the surface. They are thought to be important for communication. Recent analysis of coda repertories from different sperm whale groups has revealed a level of social organization called "clans." Sperm whale social units that have similar coda repertoires are considered members of the same clan. Although clans may be sympatric, social units only associate with other units that are members of the same clan. Further, clans have been shown to behave differently in other ways related to movement and foraging behavior. Codas are presumed to be learned socially and have been taken as indicative of culture in sperm whales. The culturally mediated social organization indicated by coda analysis could have a number of important implications for management.

We have analyzed codas recorded from mixed groups encountered in the NGOM during SWAMP and SWSS cruises (a total of 3,129 codas) and compared these to codas recorded during other studies in the Azores (5,092), the Mediterranean (543) and the Caribbean (121) using a multivariate measure of similarity. Coda repertories from the Gulf of Mexico (GOM) cluster out as a discrete unit suggesting that NGOM mixed groups belong to a single discrete clan whose members are rarely encountered in other areas. This analysis is ongoing; future work will incorporate the substantial new recordings made in 2004 and, where possible, allocate recordings to identified social groups based on photo-identification data. These findings support those from other parts of the SWSS project which suggest that the female and immature male components of the GOM is a small discrete sub-population that should be considered a management unit.

Jonathan Gordon has studied sperm whales for the last 25 years. He did his Ph.D. work with sperm whales in the Indian Ocean with Hal Whitehead developing methods of working offshore from small boats that have now become the "traditional techniques" for observational studies of sperm whales. He ran a research boat for IFAW for many years, and this provided further opportunities for developing passive acoustic monitoring methods, many of which are being adapted and adopted as part of mitigation monitoring during seismic surveys. He has been involved as a consultant and a PI on both the SWAMP and SWSS research projects in the Gulf of Mexico and is currently based as the Sea Mammal Research Unit at the University of Saint Andrews.

Nathalie Jaquet is currently a Research Scientist at Texas A&M University at Galveston, TX. She completed her honor's degree in natural sciences at Lausanne University, Switzerland in 1986 and an M.S. in marine ecology at Aberdeen University, Scotland in 1988. She completed her Ph.D. with Dr Hal Whitehead at Dalhousie University, Halifax, Canada in 1996. From 1997 to 2001, she conducted post-doctoral studies at Otago University, Dunedin, New Zealand. She investigated the impact of whale-watching activities on the sperm whale population off Kaikoura, New Zealand. During this time she also initiated a research project on sperm whale distribution, abundance, and behavior in relation to jumbo squid density in the Gulf of California, Mexico. In 2001 she joined Texas A&M University at Galveston as a TIO post-doctoral fellow where she worked with the SWSS project.

Ricardo Antunes received a degree in marine biology and fisheries from the University of the Algarve, Portugal. During the past five years he has worked as a cetacean researcher in the Whale Museum in Madeira, and on other cetacean research projects in the Azores, the Mediterranean Sea, Norway and the Gulf of Mexico. He is currently a Ph.D. student at the University of St. Andrews, studying sperm whale coda communication in the Atlantic.

Luke Rendell is an NERC Research Fellow at the Gatty Marine Research Institute at the University of St. Andrews in the UK. He has studied aspects of vocal behavior in various cetacean species since 1995 but his Ph.D. and postdoc research have focused on the sperm whale, Physeter macrocephalus, a fantastic yet still surprisingly mysterious animal. He is interested in the behavioral ecology and evolution of communication systems and how these relate to social learning and culture in humans and other animals. He also maintains broader based interests in ecology, behavior and conservation.

Bernd Würsig is Professor of Marine Biology at Texas A&M University at Galveston. He received his Ph.D. from the State University of New York at Stony Brook. His research interests focus on the behavioral ecology of marine mammals.

SPERM WHALES IN THE NORTHERN GULF OF MEXICO: ABUNDANCE, HABITAT USE, AND ASPECTS OF SOCIAL ORGANIZATION

Nathalie Jaquet and Bernd Würsig, Texas A&M University–Galveston
Jonathan Gordon, Sea Mammal Research Unit,
University of St. Andrews, Scotland

The mesoscale population cruise finished on the 17 August 2004. Thus, only four months have been available to analyze the large data set collected during summer 2004 and to integrate it to the data collected in 2002 and 2003. Therefore, the following results and discussions are considered preliminary. The next several months will be used to analyze these results in depth and to prepare peer-reviewed publications. It is possible that some of the results and conclusions outlined below will change once the data set is analyzed in greater detail.

Distribution and abundance

In 2004, sperm whales were found in the entire study area, along the west coast of Florida, in the De Soto Canyon, in the Mississippi Canyon and in the area south of the Mississippi River Delta. In 2004, because methodology and search patterns were consistent during the two-month field season, the relative abundance of sperm whales was measured using search time (Kahn et al. 1993). The mean search time for the entire study area was 7.4 hours with a maximum of 22 hours between 2 encounters; never more than 22 hours were spent without encountering one or several sperm whales. Search time was then compared between the "Florida-De Soto Canyon" area and the "Mississippi" area. The mean search time for the Florida-De Soto Canyon was 8.16 hrs (SE = 1.50) and for the Mississippi area 6.99 hrs (SE = 0.87). A t-test between these two mean encounter rates was not statistically significant ($t = 0.690$, $p = 0.4932$, df=50, NS), suggesting that, although the mean time spent between two encounters in the Florida-De Soto area was slightly larger than in the Mississippi area, both areas had roughly similar relative abundance of sperm whale encounters.

Out of the 27 visual encounters, four were with lone sperm whales, six were with small dispersed groups of whales, likely bachelors' groups; 16 were with groups of females and immature, and one was undetermined. There was a strong segregation in distribution between males and females. All groups of female/immature sperm whales were found in the Mississippi River Delta-Mississippi Canyon area, while the lone males and groups of bachelor males were mainly found in the De Soto Canyon-West Florida area. Such segregation had never been described before and could be due, for example, to differences in foraging behavior or in diet.

Sperm whale absolute abundance for the entire SWSS study area was calculated using mark-recapture techniques (Hammond 1986). As most of the identification photographs came from a short period of time, three weeks each in 2002 and 2003, and seven weeks in 2004, the full open model described by Whitehead (1990) could not be applied; a simple open model was fit to the data (SOCPROG, Whitehead 1999). The results indicate that approximately 398 individuals utilized our study area (95% confidence interval = 253 to 607). This result is consistent with previous estimates of population size for this area. All mean estimates are within the 95% confidence intervals of the other estimates.

Large Scale Movements

Geographic population structure is a result of large-scale movements, and thus understanding the large-scale movement of Gulf of Mexico (GOM) sperm whales will give us an understanding of stock identity and indicate whether there are important movements between the GOM and other areas of the Atlantic Ocean. To investigate large-scale movements, we compared our SWSS catalogue (199 individuals) to about 2,500 sperm whales identified in the Atlantic in the last 15 years. No matches were found, suggesting few movements between the GOM and the rest of the Atlantic.

Small Scale Movement Patterns and Feeding Success

Sperm whales are near the top of a long food chain, and in general, the diet of female and immature sperm whales consists almost exclusively of deep-living squid (Kawakami 1980; Clarke 1986). There is little knowledge on sperm whale diet in the GOM or on the distribution of deep-living squid; thus, no information is available on the amount of food resources available to sperm whales. It is important for management to understand why sperm whales occur in areas close to platforms and whether other areas have similar feeding potential. It has been shown that sperm whale small-scale movement patterns change with feeding success, with sperm whales traveling in a relatively straight line when feeding success is poor and zig-zagging over a smaller area when feeding conditions are good (Jaquet and Whitehead 1999; Whitehead 2003). Therefore, small-scale movement patterns provide an indication of feeding success in particular areas. During 2004, we had 16 independent encounters with groups of females/immature sperm whales that were followed closely days and nights from 5.75 hrs to 52.5 hrs with a mean of 23.3 hrs. Twelve of the encounters lasted for over 10 hours, and small-scale movements and displacements were calculated for these 12 different encounters. Figure 2F.1 shows the root mean square (rms) displacement in kilometers against time lag for these 12 encounters. For any time lag of x hours, the rms is the average straight-line distance between the position of the group at time *t* and its position at time *t*+x. Horizontal displacement is the straight line distance and does not take into account zig-zag movements.

Figure 2F.1 shows that on average, sperm whales move at a speed of 3.3 km per hour in the Mississippi area. This speed is consistent with what has been found in other areas of the world and is likely an optimum speed that minimizes the cost of transport and maximizes the rate of finding and acquiring food (Whitehead 2003). Figure 2F.1 also shows that in this area, sperm whales have an average horizontal displacement of about 35 km in 24 hours and 40 km in 48 hours. It has been shown that, in general, the smaller the daily horizontal displacement, the higher the feeding success (Whitehead 2003); however, daily horizontal displacement will also be related to types of prey as well as to the aggregative behavior of the squid prey. Therefore, large differences in daily horizontal displacement were found in different areas of the world (45 km in the Galápagos, 65 km in Peru/Ecuador, 70 km in Chile and 85 km in the Western Pacific: Whitehead 2003). Our results in the GOM suggest that the Mississippi area has good feeding conditions for sperm whales and that the patches of squid may be smaller (less horizontal displacement) but denser or longer-lasting (as they zig-zag over this area for at least more than a day instead of just a few hours, as in Chile) than in areas of the South Pacific where small-scale movements have been investigated. These results give us a first insight into the northern GOM foraging conditions and prey aggregations.

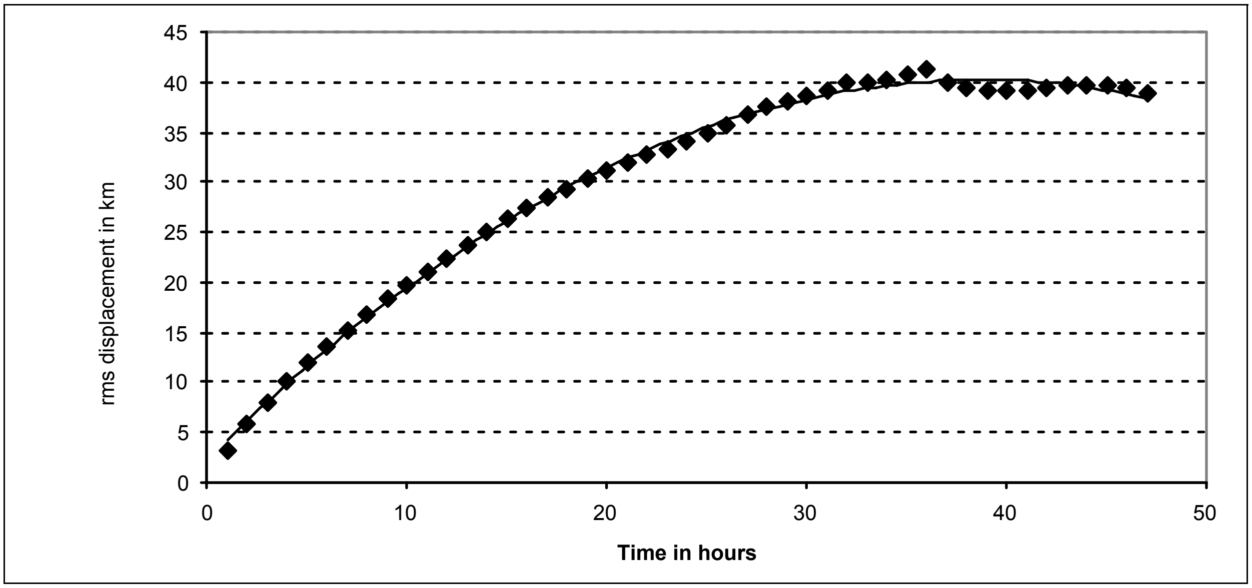


Figure 2F.1. Root Mean Square (rms) displacement for the 12 groups of female immatures that were followed for more than 10 hours (11 to 50 hours).

Index of reproductive success

During 2002 and 2003, few first-year calves were observed, raising concerns for the health of the GOM sperm whale population. However, the platforms used to study sperm whales in 2002 and 2003 (R/V Gyre and Rhibs) were not very appropriate for this task, and calves were likely missed due to the difficulty of observing them from a large vessel and due to the inability to follow a group over more than 10 hours. In 2004, we found that eight groups out of 11 had one or two calves with them. This provides an overall proportion of calves of 11.5%. This proportion of calves is of similar magnitude as what has been found in different areas of the South Pacific (Whitehead 2003) and is only slightly smaller than what has been found in the Gulf of California (Jaquet et al. 2003; Jaquet 2004).

Population characteristics

Social Organization

Because social organization is thought to be important for the survival and wellbeing of sperm whales, particularly females and young, knowledge of social organization of sperm whales in the northern GOM population is important for management. Sperm whales have highly developed societies (Caldwell et al. 1966) and their strong social organization allows them communally to take care of calves and defend against predators. Females and immature sperm whales form long-term (>decades) associations of on average 10-12 individuals called units (Whitehead et al. 1991; Christal et al. 1998). These units usually associate with another unit for about one week to form what is commonly called the group or the nursery group (Whitehead et al. 1991; Christal et al. 1998).

To determine the pattern of sperm whale social organization in the GOM, we used the software SOCPROG (Whitehead 1999), especially developed for this purpose. The use of SOCPROG requires a large number of sperm whales photo-identified over a time span of several years. Although the SWSS project has now been running for three years, few identification photographs were taken in 2002; thus, most of the identification photographs were taken during a three-week period in 2003 and a seven-week period in 2004. Furthermore, in 2002 and 2003, it had not been possible to follow groups over consecutive days. Few individual whales were resighted during the course of the field season. Therefore, the data from 2004 are the only data that can be used to investigate the internal structure of groups and whether sperm whales follow the constant companions/casual acquaintances models found in the Pacific (Whitehead 2003). Therefore, the use of SOCPROG is still limited for our data set and the results are to be taken with caution. The results from SOCPROG using all SWSS identification photographs suggest that, in the GOM, sperm whales best fit a “constant companion” model.

Group size

Estimating group size in the field is difficult, as foraging sperm whales are spread over several nautical miles, and spend about 75% of their time underwater. Therefore, group size is usually estimated using identification photographs, and experience shows that, on average, two days are required for most individuals in a group to be identified (Whitehead 1999; pers. obs). Group sizes were very consistent; all groups followed for more than 10 hours had 9 to 11 individuals. This number is substantially smaller than in other areas where group size has been shown to be about 20 to 25 individuals (Whitehead 2003). Group size may be related to the size of prey patches that can be efficiently exploited. The analysis of fine-scale movements presented above is indicative of smaller prey patches, which is consistent with the smaller group size found here.

Aggregations (=two or more groups associating together for time periods of hours) were never seen in 2004, and only one aggregation was observed in 2003 (on the 18 July). Aggregations are thought to be related to large patches of food that are exploited simultaneously by several groups of sperm whales (Jaquet 1996). The absence of aggregations also suggests that prey patches in the northern GOM are small.

Length distribution

Knowledge of whale size (as related to age) is important to most ecological studies. Length measurements of individual whales can provide information on growth rate and allow estimation of population parameters such as pregnancy rate and age at maturity (Waters and Whitehead 1990). Measurement data can also reveal size-class segregation (Cubbage and Calambokidis 1987). Furthermore, changes in length distribution in whale populations can be used to indicate the degree of depletion of a stock, as highly exploited populations are likely to have fewer older and thus larger animals (Cooke and de la Mare 1983).

Over the three years of SWSS study, 153 good measuring photographs were taken of 78 different individuals. Therefore, we have obtained length measurements for almost half of the individuals that we have identified. Out of these 78 individuals, three were lone males and two were from a group of whales that was likely composed of bachelor males. The average length for these 73 females/immatures was 8.5 m (SD=0.85). This is much smaller than what would have been expected from the literature (Rice 1989). The length distribution for the GOM was then compared to the length distribution of female/immature of the Gulf of California (using the very same technique), and it was found that the whales in the GOM were on average two meters smaller than the one in the Gulf of California (average=10.5m, SD=0.85, n=154), and a t-test showed that the difference was highly significant (t-test: $p<0.001$).

Differences in length distribution can be due to a variety of factors, such as 1) differences in whaling histories; 2) closeness of the population to carrying capacity; 3) food resources and feeding conditions in an area; and 4) genetic differences. Sperm whales have not been hunted during the modern whaling period, and thus no whaling took place after the late 1800s. This whaling history is very similar to the one in the Gulf of California, and thus it is unlikely to be the cause of this size difference. We do not have enough data to determine whether the sperm whale population of the GOM is close to carrying capacity; therefore, we cannot yet comment on this hypothesis. Further data on population dynamic and foraging behavior will help in answering this question. Food resources in the GOM are very different from those in the Gulf of California. The Gulf of California is a very productive marginal sea, with some of the highest surface nutrient concentrations of any ocean of the world, while the deep waters of the GOM are characterized by lower primary and secondary productivity. However, the pattern of small-scale movements suggests high feeding success in the northern Gulf. It is possible that genetic differences are responsible for this difference in size, as it has been shown for other species of cetaceans. Preliminary results suggest that sperm whales in the GOM are different from all other populations which have been studied in details: their group size is about half the size of groups elsewhere, mature males seem to have either a different behavior or a different seasonality, groups of females/immature have a very high site fidelity comparable to bachelor males off Kaikoura but never described elsewhere for females/immatures, and they have significantly higher incidence of markings on their flukes compared to areas in the Pacific Ocean (annual report 2003). Furthermore preliminary genetic analyses suggest differences between individuals from the GOM and the rest of the Atlantic Ocean, and similarly, preliminary analyses of codas suggest differences in repertoires between the GOM and the rest of the Atlantic.

Acknowledgments

Funding for this study was provided by MMS, IAGC, IRFC and NFWF. We wish to thanks Ricardo Antunes, Steve Brown, Raul Diaz, Thomas Gordon, Christoph Richter, Trudi Webster as well as all the Gyre's visual and acoustic observers who greatly helped with the field work. This work was performed under NMFS OPR permit #821-1855-00.

References

Caldwell, K.D., M.C. Caldwell, and Rice, D.W. 1966. Behavior of the sperm whale, *Physeter catodon*. In: Norris, K.S. Whales, Dolphins and Porpoises. Berkeley: University of California Press**.** Pp. 677–717.

Christal, J., H. Whitehead, and E. Lettevall. 1998. Sperm whale social units: variation and change. Canadian Journal of Zoology 76:1431–1440.

Clarke, M. R. 1986. Cephalopods in the diet of odontocetes. In: Bryden, M.M. and R. Harrison. Research on Dolphins. Oxford: Clarendon Press. Pp. 281–321.

Cooke, J.G. and W.K. de la Mare. 1983. Description and simulation studies on the length-specific sperm whale assessment technique. Reports of the International Whaling Commission 33:741–745.

Cubbage, J. C. and J. Calambokidis. 1987. Size-class segregation of bowhead whales discerned through aerial stereophotogrammetry. Marine Mammal Science 3(2):179–185.

Hammond, P. 1986. Estimating the size of naturally-marked whale populations using capture-recapture techniques. Reports of the International Whaling Commission (Special Issue) 8:253–282.

Jaquet, N. 1996. Distribution and spatial organization of groups of sperm whales in relation to biological and environmental factors in the South Pacific. Dalhousie University.

Jaquet, N. 2004. Movements and vocal behavior of mature male sperm whales off Mexico. National Geographic Final Report. 34 pp.

Jaquet, N. and H. Whitehead. 1999. Movements, distribution and feeding success of sperm whales in the Pacific Ocean, over scales of days and tens of kilometers. Aquatic Mammals 25(1):1–13.

Jaquet, N., D. Gendron, and A. Coakes. 2003. Sperm whales in the Gulf of California: residency, movements, behavior, and the possible influence of variation in food supply. Marine Mammal Science 19(3): 545–562.

Kahn, B., H. Whitehead, and M. Dillon. 1993. Indications of density dependent effects from comparisons of sperm whale populations. Marine Ecology Progressive Series 93:1–7.

Kawakami, T. 1980. A review of sperm whale food. Scientific Reports of the Whales Research Institute 32:199–218.

Rice, D.W. 1989. Sperm whales (*Physeter macrocephalus*). In: Ridgway, S.H. and R. Harrison, eds. Handbook of Marine Mammals, Volume 4: River Dolphins and the Larger Toothed Whales. London: Academic Press. Pp. 177–23.

Waters, S. and H. Whitehead 1990. Population and growth parameters of Galápagos sperm whales estimated from length distributions. Reports of the International Whaling Commission 40:225–235.

Whitehead, H. 1990. Computer assisted individual identification of sperm whale flukes. Reports of the International Whaling Commission (Special Issue) 12:71–77.

Whitehead, H. 1999. Variation in the visually observable behavior of groups of Galápagos sperm whales. Marine Mammal Science 15(4):1181–1197.

Whitehead, H. 2003. Sperm Whales: Social Evolution in the Ocean. Chicago: University of Chicago Press.

Whitehead, H., S. Waters, and T. Lyrholm. 1991. Social organization of female sperm whales and their offspring: constant companions and casual acquaintances. Behavioral and Ecological Sociobiology 29:385–389.

Nathalie Jaquet is currently a Research Scientist at Texas A&M University at Galveston, TX. She completed her honor's degree in natural sciences at Lausanne University, Switzerland in 1986 and a M.S. in marine ecology at Aberdeen University, Scotland in 1988. She completed her Ph.D. with Dr Hal Whitehead at Dalhousie University, Halifax, Canada in 1996. From 1997 to 2001, she conducted post-doctoral studies at Otago University, Dunedin, New Zealand. She investigated the impact of whale-watching activities on the sperm whale population off Kaikoura, New Zealand. During this time she also initiated a research project on sperm whale distribution, abundance, and behavior in relation to jumbo squid density in the Gulf of California, Mexico. In 2001 she joined Texas A&M University at Galveston as a TIO postdoctoral fellow where she worked with the SWSS project.

Jonathan Gordon has studied sperm whales for the last 25 years. He did his Ph.D. work with sperm whales in the Indian Ocean with Hal Whitehead developing methods of working offshore from small boats that have now become the "traditional techniques" for observational studies of sperm whales. He ran a research boat for IFAW for many years, and this provided further opportunities for developing passive acoustic monitoring methods, many of which are being adapted and adopted as part of mitigation monitoring during seismic surveys. He has been involved as a consultant and a PI on both the SWAMP and SWSS research projects in the Gulf of Mexico and is currently based as the Sea Mammal Research Unit at the University of St. Andrews.

Bernd Würsig is Professor of Marine Biology at Texas A&M University at Galveston. He received his Ph.D. from the State University of New York at Stony Brook. His research interests focus on the behavioral ecology of marine mammals.

GULF OF MEXICO SPERM WHALES – A GENETIC PERSPECTIVE

Dan Engelhaupt, University of Durham

Background

Several fundamental genetic related aspects for endangered sperm whales occurring in the northern Gulf of Mexico (GOM) were assessed during the 2000–2004 SWAMP and SWSS cruises. A deeper understanding of the population structure and social structure of sperm whales using genetic techniques is presently being integrated with a variety of ongoing research projects such as digital acoustic recording tagging (D-tag), satellite-monitored radio tagging, distribution and abundance estimates, habitat use patterns and behavioral information to help establish realistic conservation and management strategies for these whales. In addition to providing important gender information for whales that have been satellite and D-tag tagged, our project provides essential data on social and population structure required to fully assess the impacts that the oil and gas industry and seismic exploration may or may not have on endangered sperm whales occupying potentially critical habitat areas in the northern Gulf. Sperm whales are highly social whales that occur in small clusters to large aggregations, in many cases, maintaining long-term bonds between female group members. Their dependence on acoustic communication between members and use of echolocation when feeding at depth make them vulnerable to anthropogenic noise. Could an outside noise influence disturb the dynamics of the group, or on a much larger scale, the population over time? The quantity and quality of knowledge gained from the combination of genetic (via degrees of relatedness among associates), satellite-monitored radio tagging, and behavioral studies provides the essential components to accurately describe social structure on a detailed scale. The original designation of a single Gulf sperm whale stock that is separate from the adjacent Atlantic and Caribbean is thought to be conservative. Stocks must be defined using several parameters including genetics. Once stocks are defined, human-caused disturbances or mortalities that occur to a stock can be managed appropriately. Such information is vital for creating meaningful management strategies for these animals in general, and relative to petroleum exploration and production in particular.

SWAMP & SWSS Cruise Sample Analyses

Tissue samples were collected during both SWAMP and SWSS cruises throughout 2000, 2001, 2002, 2003 and 2004. Overall, 117 individuals (including satellite-tagged, D-tag tagged, opportunistic, and stranded whales) were genotyped using both mtDNA and microsatellite techniques. Gender was determined for nearly all of these samples using molecular sexing techniques.

Results

Population Structure

A comparative analysis of matrilineal mtDNA and biparentally inherited nuclear genetic markers (microsatellites) have begun to show population structure for female lineages, which is expected given previous findings on social and reproductive behavior in this species. Nuclear DNA variation across oceans is generally non-significant, suggesting that males disperse and spread their genes to the more site-faithful females.

Group Structure

Members of 'groups' were predominately females, although some groups appeared to contain only males (suggesting that bachelor groups may reside in the Gulf). During the 2002 SWSS cruise, multiple members from two groups of whales (Group 3 & 5) were tagged with satellite transmitters and subsequently biopsy sampled for genetic analyses. Relatedness levels for each satellite-tagged group (and groups in general) suggest that the overall group is often unrelated, although groups did contain highly related whales (ex. parent/offspring). mtDNA analyses showed that groups are comprised of both single and multiple matrilines, which combined with the relatedness levels, may provide additional evidence to the idea of that sperm whale groups are composed of both 'constant companions and casual acquaintances.'

Future Recommendations

Genetic techniques supply a powerful set of detailed data that can be directly integrated with both the movements of satellite-monitored tagged whales and the dive profile data of D-tagged whales. The gender of a tagged whale may prove crucial to improving our understanding of movement patterns and dive profile data (i.e. do males and females react differently to anthropogenic noise influences?). Future work should continue to build on previous year's population and social structure results by incorporating biopsy sampling with both satellite-tagging and opportunistic sampling of whales (particularly focusing on whales of sexually mature size). This population has already been subjected to many years of human activity, and there is likely to be major oil-related activity offshore here for many years to come. Social organization is an important component for sperm whale survival yet seems vulnerable to disruption by disturbance. Understanding sperm whale social organization in this putative population before it is exposed to any more disturbance and exploring whether it is affected by offshore activity is thus a priority. To increase the resolution for population structure analyses, we recommend sampling sperm whales located in additional geographic areas like the Caribbean Sea and western North Atlantic Ocean in addition to sampling whales in the eastern, western, southern and northern GOM during the winter winter/spring months when large sexually and physically mature males may be present. A continuation of the genetic components previously described will maintain both the quality and quantity of information required for management purposes.

Dan Engelhaupt completed his Ph.D. at the University of Durham, England. His special field of study includes the assessment of population structure and social structure for endangered species, with a emphasis on sperm whales. Over the past five years, as part of the Minerals Management Service sponsored SWAMP and SWSS projects, he has examined the genetic variation and social structure of endangered sperm whales with a particular focus on putative 'populations' in the northern Gulf of Mexico, Mediterranean Sea, and the North Atlantic Ocean using a suite of molecular techniques. Mr. Engelhaupt is collaborating with a number of other researchers to provide an accurate sperm whale dataset so that management can effectively oversee sperm whale populations that exist in areas of anthropogenic noise.

THREE-DIMENSIONAL TRACKING OF SPERM WHALES USING PASSIVE ACOUSTICS

Aaron Thode, Scripps Institution of Oceanography

Introduction and Summary

Sperm whales are a very vocally active species, and detecting their signals, or "clicks," using towed passive acoustic arrays has become a standard procedure for locating and monitoring for the presence of these animals (Gillespie 1997; Gillespie and Leaper 1997; Barlow and Taylor 1998). Most passive array systems can also estimate the direction from which a particular sound is arriving by measuring the signal's arrival time difference at two hydrophones spaced a few meters apart. The range to a whale can be estimated by measuring how the measured bearings from a particular animal shift over time while the observation platform is moving. If the velocity of the platform is much larger than that of the animal, then the bearings will converge to a particular range over a 3–10 minute interval. Unfortunately, the speed of seismic vessels is not much greater than sperm whale swimming speeds, so at present there is no reliable way for ranging sperm whales using standard mitigation procedures. In addition, knowledge of the animal's depth becomes important for mitigation purposes whenever the animal of concern is deep-diving and the acoustic source is highly directional at certain frequencies, as is the case with seismic airgun arrays.

In 2003 and 2004 the SWSS project supported efforts to develop a three-dimensional tracking method for sperm whales using various combinations of towed acoustic gear. All methods rely on the fact that sperm whale sounds have such a short time duration that the surface-reflected acoustic path can often be distinguished in time from the direct path arrival. The basic concept was first demonstrated during the 2002 SWSS D-tag cruise, using data from two towed arrays (Thode 2004). Based on these results, both MMS and the International Association of Geophysical Contractors (IAGC) provided funds to build a dedicated towed array to demonstrate routine 3-D tracking of sperm whales during the 2004 SWSS S-tag cruise. The 400 m long "tandem" towed-array system was successfully deployed from the R/V Gyre during the entire cruise, and over two weeks of acoustic data were recorded, and a near real-time ranging algorithm was assembled in the field. Some initial 3-D tracks have been analyzed and their veracity checked using a variety of methods. The effects of ray-refraction from a depth-dependent sound speed profile have also been evaluated and to date seem to be negligible for ranges of 1 km or less. Aspects of these algorithms have been published in the peer-reviewed literature (Thode 2004), and currently plans are underway to develop and test a real-time tracking system during SWSS 2005.

Equipment

The MMS 3-D tracking effort uses signals collected across a large-aperture PAM system to estimate animal ranges and depths, while making no assumptions about an animal's signal characteristics. The total "tandem" array is comprised of six hydrophones on a single cable, arranged as two sub-arrays of three phones each, with the sub-arrays separated by 200m (Figure

2F.2) and the sub-array element spacing 1 m. Each sub-array also has a pressure transducer that permits the depth of each sub-array to be logged independently.

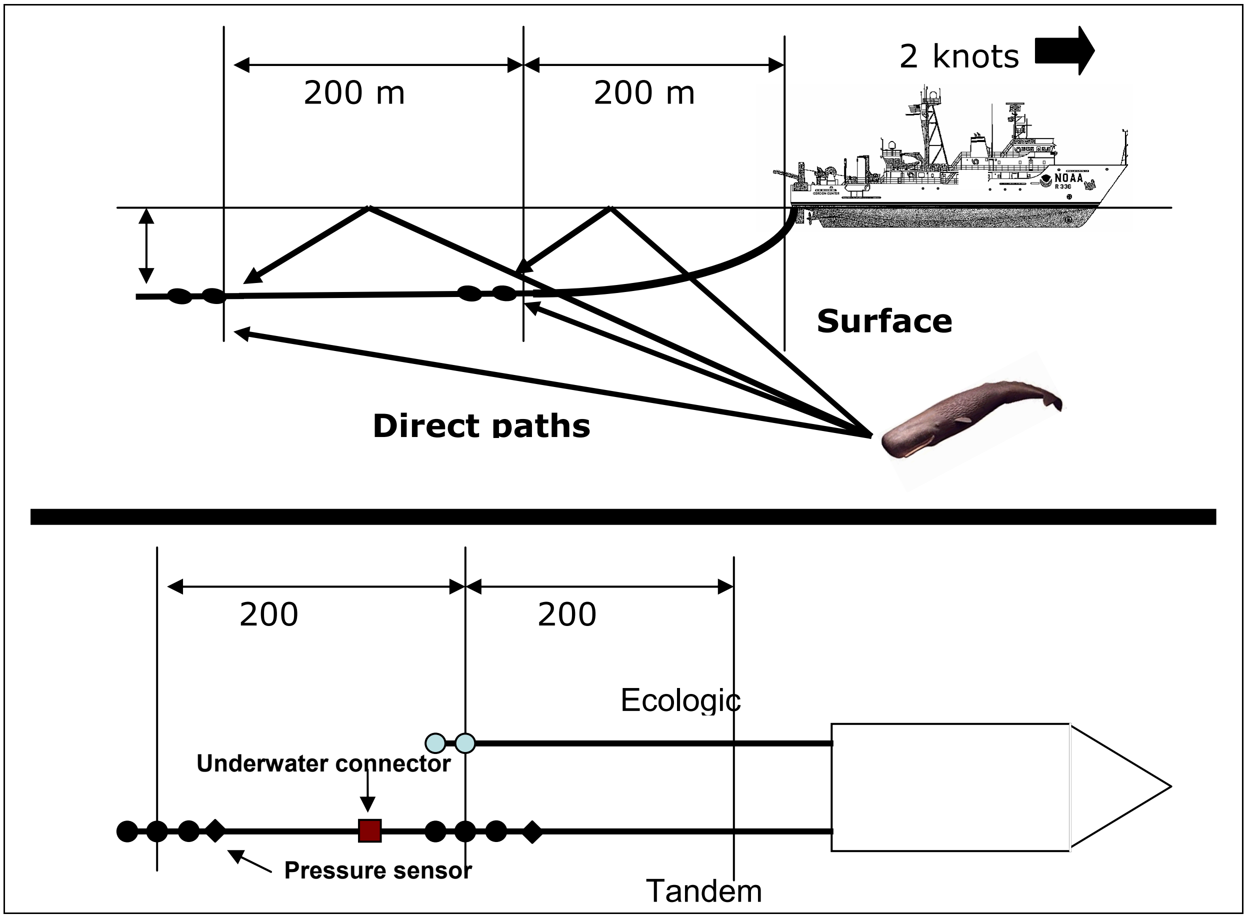


Figure 2F.2. Illustration of 2004 3-D deployment off R/V Gyre, using a tandem array specifically built for the project. <u>Top</u>: side view of tandem array during S-tag deployment. <u>Bottom:</u> View of S-tag array deployment from above, showing how tandem and ecologic array were deployed in parallel, which permits bearings of sounds to be determined without a port/starboard ambiguity. The total configuration permitted 3-D tracking data to be collected without interfering with S-tag requirements. Round circle: calibrated hydrophone; blue diamonds: pressure (depth) sensors; red square: underwater connector that would permit array aperture to be extended in 2005.

Concept

There are actually two separate algorithms for tracking the range and depth of a sperm whale using this array system. Technique "A" requires only two hydrophones, and was tested in 2002 and 2003 (Thode 2004). Technique "B," requires a third hydrophone, but seems considerably more robust to ship noise and uncertainties in hydrophone depths; was the focus of work in 2004. The "B" algorithm is described here. Figure 2F.3 illustrates the three measurements that permit tracking: the differences between the arrival times of the direct and surface-reflected paths($P_{ds,R}$) on the rear (R) hydrophone, the arrival time difference between the direct paths on both hydrophones (P_{dd}), and an estimate of the direct path bearing on the rear hydrophone (η_d). Given this information one finds the slant range from the forward hydrophone site to be

$$P_{d,F} = \left(\frac{1}{2}\right)\frac{2LP_{dd}\cos\eta_d - L^2 - P_{dd}{}^2}{P_{dd} - L\cos\eta_d} \tag{1}$$

from which the whale depth can be determined from

$$z_w = \frac{P_{ds,R}\left(2P_{d,F} + P_{ds,R}\right)}{4z_{a,R}} \tag{2}$$

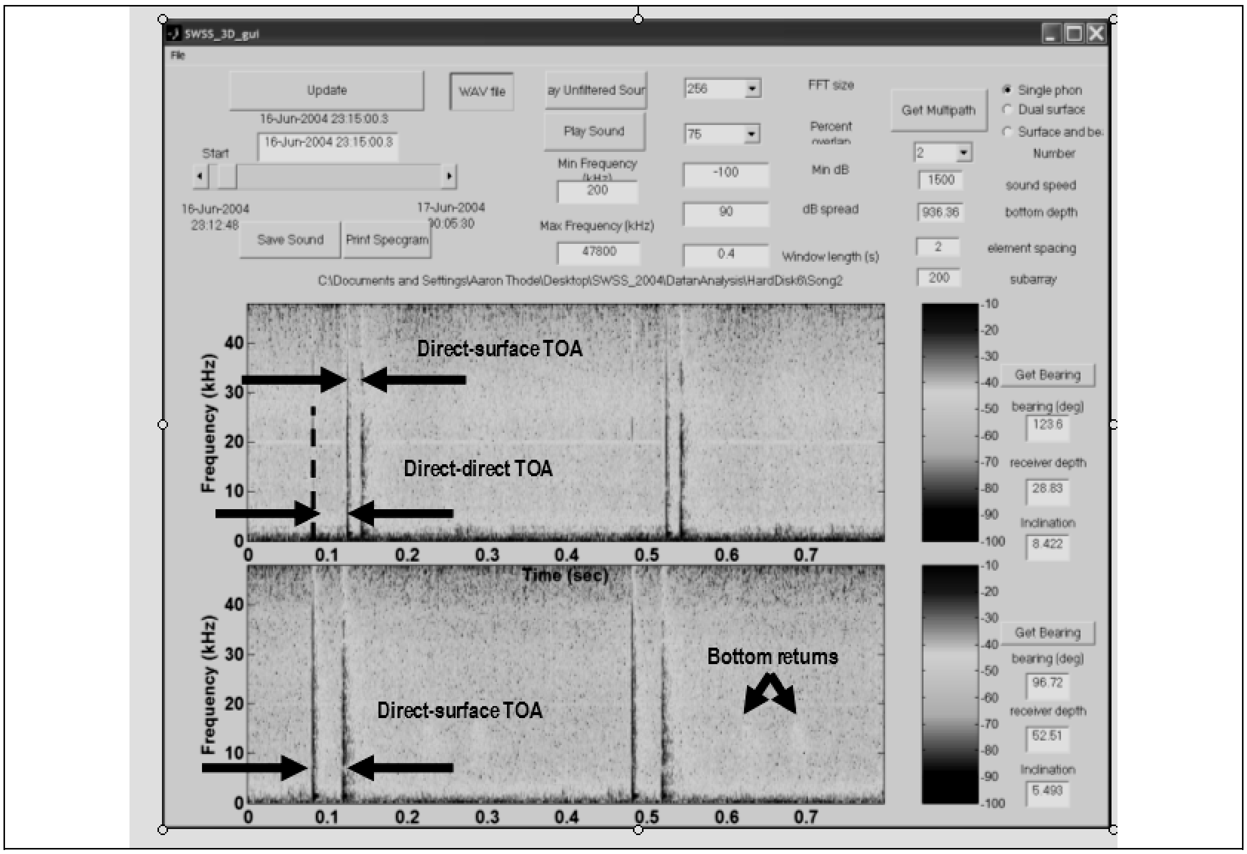


Figure 2F.3. Spectrograms of data collected during 2004 3-D tracking experiment, as viewed with a MATLAB graphical user interface. The top spectrogram displays a hydrophone of the forward sub-array, and the bottom spectrogram displays a hydrophone in the rear sub-array. The arrival-time differences indicated in the diagram can be used to obtain animal range and depth, if both array depths are known. Occasionally, bottom returns appear, which permit an independent check of the tracking algorithm. If the bearings of at least one the direct-path signals can be measured, then the direct-surface time-of-arrival (TOA) difference on the forward hydrophone is not required (i.e. tracking method "B" can be used instead of "A").

The method assumes that the local tilt of the rear subarray is equivalent to the effective tilt of the entire cable between the forward and rear hydrophone (i.e. the towed array cable is effectively straight between the forward and rear hydrophone). If this is not the case, expanded forms of Eq. (1) can be derived. The expression in the denominator of Eq. (1) indicates that the method will work as long as the animal is close enough such that the "wavefront" defined by the pulse is curved. Put another way, Eq. (1) should work as long as an acoustic bearing measured from the front hydrophone site differs from a bearing measured at the rear site.

Example

On the evening of 16 June a whale began a dive descent near the vessel. An example of data collected during this dive is shown in Figure 2F.3. In Figure 2F.4 the animal depth and range is shown for the two tracking algorithms, along with single-hydrophone fixes made by exploiting bottom multipath(Thode et al. 2002). All the methods agree until the ship changes course, as seen in the bottom plot, and Algorithm "B" becomes inaccurate.

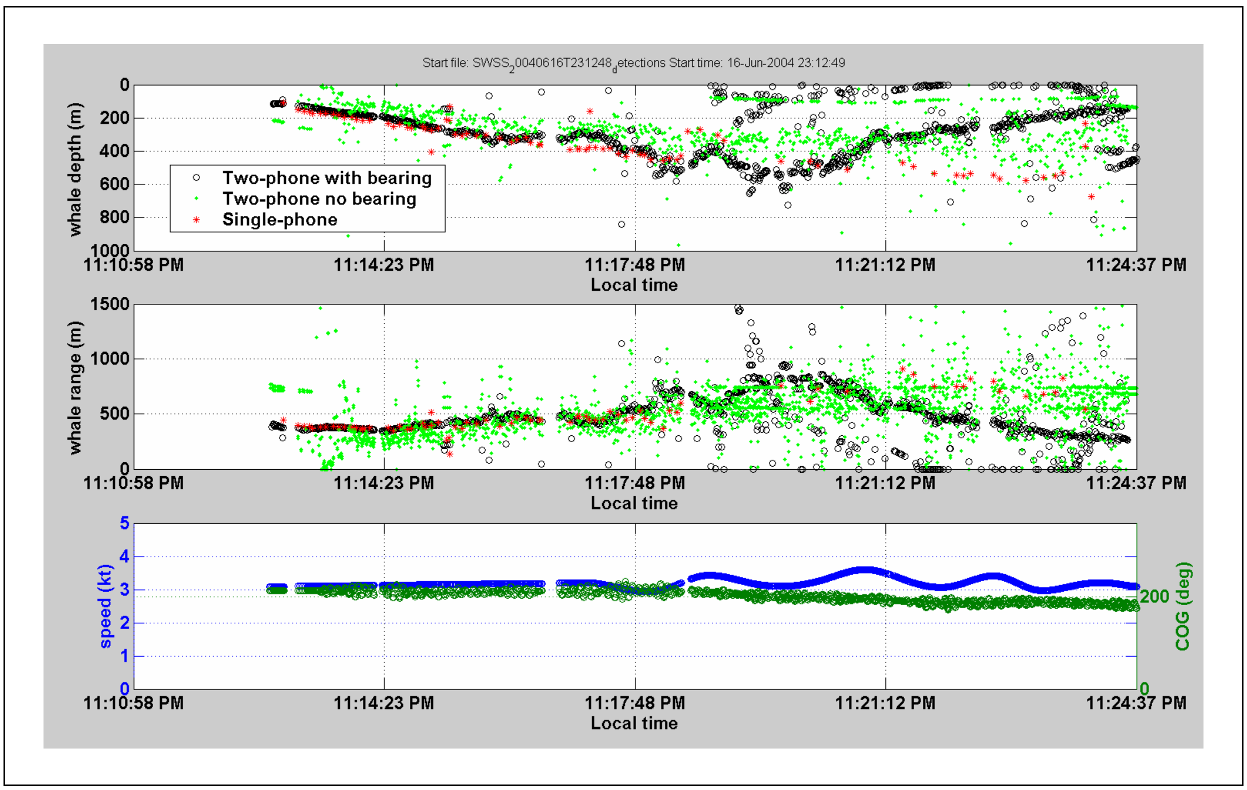


Figure 2F.4. Acoustic track of diving sperm whale on 16 June 2004: <u>Top</u>: Whale depth vs. local time using "A," "B," and single-phone tracking algorithms; <u>Middle</u>: Whale range vs. time for same algorithms; <u>Bottom</u>: Ship course and speed. Note divergence of "B" (black) algorithm once ship turns.

References

Barlow, J. and B.L. Taylor. 1998. Preliminary abundance of sperm whales in the northeastern temperate pacific estimated from a combined visual and acoustic survey. Cambridge: International Whaling Commission.

Gillespie, D. 1997. An acoustic survey for sperm whales in the Southern Ocean Sanctuary conducted from the RSV Aurora Australis. Reports of the International Whaling Commission 47:897–907.

Gillespie, D. and R. Leaper. 1997. Detection of sperm whales (Physeter macrocephalus) clicks, and discrimination of individual vocalisations. Research Cetaceans 10:87–91.

Thode, A. 2004. Tracking sperm whale (Physeter macrocephalus) dive profiles using a towed passive acoustic array. Journal of the Acoustic Society of America 116(1):245–253.

Thode, A., D.K. Mellinger, S. Stienessen, A. Martinez K. Mullin. 2002. Depth-dependent acoustic features of diving sperm whales (Physeter macrocephalus) in the Gulf of Mexico. Journal of the Acoustic Society of America 112(1):308–321.

Aaron Thode earned his Ph.D. at Scripps Institution of Oceanography in 1999, with his thesis work involving the acoustic tracking of blue whales. After a post-doc in the MIT Ocean Engineering Department, he attained his current research position at Scripps in 2002. That year he obtained the Office of Naval Research Acoustic Entry Level Faculty Award, currently being used to develop new types of passive acoustic tracking systems for marine mammals. In late 2004 he was awarded the A.B. Wood Medal by the UK Institute of Acoustics and the Acoustical Society of America, “for distinguished contributions in ocean acoustics/signal processing and marine mammal acoustics.”

PHYSICAL ENVIRONMENT OF THE NORTHERN GULF OF MEXICO DURING SUMMERS 2002–2004

Ann E. Jochens, Matthew K. Howard, Steven F. DiMarco, and Douglas C. Biggs, Texas A&M University

The Sperm Whale Seismic Study (SWSS) is a cooperative study of sperm whales in the Gulf of Mexico (GOM), their habitat, and their response to man-made noise. Scientists at Texas A&M University and the University of Colorado are conducting the habitat characterization study component of SWSS. Data collection includes *in situ* data during the cruises and remote sensing data before, during, and after the cruises. The *in situ* data, which are collected by the authors on the SWSS cruises, consist of currents from 153 kHz and 38 kHz acoustic Doppler current profilers (ADCP); temperature and salinity profiles using both conductivity-temperature-depth (CTD) sensors and expendable bathythermograph (XBT) probes; continuous, near-surface temperature, salinity, and fluorescence observations; and discrete chlorophyll data for calibration of fluorescence measurements into chlorophyll data. Remote sensing data consist of sea surface height (SSH) fields from satellite altimeter (Robert Leben of the University of Colorado), as well as ocean color fields from SeaWiFS (courtesy of Chuanmin Hu of the University of South Florida).

Data from the 2002–2004 field cruises were used to examine the dynamics of the circulation over the slope of the northern GOM, which has been the focus of the SWSS study area, and to consider the interaction of physical and biological components of the ecosystem. The circulation in the upper 1,000 m or so of the water column is forced mainly by mesoscale features such as the Loop Current, which enters at the Yucatan Channel and exists at the Florida Straits, Loop Current eddies (LCEs) that separate from the Loop Current, and slope eddies that are both anticyclonic (clockwise) and cyclonic (counterclockwise) circulating features. Wind-forcing of currents generally is weaker than that of the mesoscale forcing except during energetic atmospheric events such as hurricanes. Tidal currents in the Gulf are weak. Buoyancy driving from river input is significant on the northern shelves, but not over the slope or in deeper waters (see Nowlin et al. 2001 for a detailed discussion of the deepwater circulation in the GOM).

The fine-scale resolution of the ship surveys, when combined with the mesoscale resolution of remote sensing surveys of sea surface height and ocean color, document the summer-to-summer variability in the intensity and geographic location of Loop Current eddies, warm slope eddies, and areas of cyclonic circulation over the middle slope region of the northern GOM. These variations forced striking year-to-year differences in the locations along the 1,000-m isobath where there was on-margin and off-margin flow, and in locations where sperm whales were encountered along the 1,000-m isobath.

In summer 2002, an anticyclonically circulating warm slope eddy was present between 89°W and 91°W over the slope. Maximum speeds were about 70 cm/s near surface and decreased to 30–40 cm/s at 200 m. Flows at the eastern side of the anticyclone were directed off-margin and moved low salinity shelf waters out into deeper waters. The water here was green-brown, indicating biological productivity, rather than the oceanic blue water that occurred along most of the cruise track. A second region of off-margin flow was located west of 88°W and was associated with a weaker warm slope eddy located in the deepwater of DeSoto Canyon. Sperm whales were locally abundant in Mississippi Canyon and off the delta (see also Jochens and Biggs 2003).

In contrast, in summer 2003, a strong Loop Current eddy, LCE Sargassum, was moving onto the slope of the eastern Gulf during June. This resulted in very strong flows at the northern limb of the eddy as it encroached onto the slope. Maximum currents were about 120 cm/s near surface, 50 cm/s at 300 m, and 30 cm/s at 800 m. Over the Mississippi Canyon area, these flows resulted in the displacement of the usual lower-salinity, higher-chlorophyll waters with low-nutrient, low-chlorophyll "ocean desert" water of Caribbean origin. In July, the LCE moved back into deep water away from the slope taking the Caribbean-type waters with it. When there was strong on-margin flow into the Mississippi Canyon region in early summer 2003, sperm whales were very rarely seen or heard there. It is hypothesized that sperm whales usually seen in this area moved west and/or east out of this area during the time, in June 2003, that the LCE reached farthest north along the margin (see Jochens and Biggs 2004 for additional discussion).

For four weeks in May–June 2004, XBT probes were deployed and ADCP and fluorescence/temperature/salinity data were logged continuously while carrying out visual and passive-acoustic search for sperm whales as R/V *Gyre* surveyed along the 1,000-m isobath of the northern GOM. Several CTD casts were made, particularly when and where the XBT and ADCP data indicated that the ship track was passing into or out of the region of surface flow confluence set up by an anticyclonic-cyclonic slope eddy pair. The fine-scale resolution of the ship survey, when combined with the mesoscale resolution of remote sensing surveys of sea surface height and ocean color, indicated that this slope eddy pair entrained low salinity, high chlorophyll Mississippi River water, and carried this surface water off margin between 90°W and 88°W. Most of the 37 groups of sperm whales that were seen or heard in 13 different geographic locations in May–June 2004 were encountered in or near this off-margin flow, where SSH generally ranged from +2 to -4 cm. In contrast to most of the sperm whale encounters in previous years 2000–2003, however, only a few of the whale encounters were well inside the region of lower SSH that was representative of the interior of the cyclonic eddy (<-5 cm). Moreover, in summer 2004, most whales were encountered where surface chlorophyll was no higher than the 0.3 µg/L ensemble average along the 1,000-m isobath between 91°W–86°W.

References

Jochens, A.E. and D.C. Biggs, eds. 2003. Sperm whale seismic study in the Gulf of Mexico; Annual Report: Year 1. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-069. 139 pp.

Jochens, A.E. and D.C. Biggs, eds. 2004. Sperm whale seismic study in the Gulf of Mexico; Annual Report: Year 2. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-067. 167 pp.

Nowlin, W.D., Jr., A.E. Jochens, S.F. DiMarco, R.O. Reid, and M.K. Howard. 2001. Deepwater Physical Oceanography Reanalysis and Synthesis of Historical Data: Synthesis Report. OCS Study MMS 2001-064. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 528 pp.

Ann Jochens, Matt Howard, Steve DiMarco, and Doug Biggs are the Co-Principal Investigators (co-PIs) for characterization of biological and physical oceanography processes in the SWSS study area. They are from the Department of Oceanography at Texas A&M University (TAMU). They have collaborated as co-PIs on previous MMS-sponsored projects NEGOM, and DGoMB. Jochens, Howard, and DiMarco are physical oceanographers who also were co-PIs for the MMS-sponsored LATEX, Deepwater Historical Data Reanalysis, and Processes Maintaining Oxygen Levels in the Deepwater studies of the Gulf of Mexico. Biggs was a co-PI on the MMS-sponsored GulfCet-II project and helped define the oceanographic habitat of cetaceans for an MMS-NOAA-ONR study in summers 2000 and 2001 of Gulf of Mexico Sperm Whales and Acoustic Monitoring Program (SWAMP).

ANALYSIS OF THE MESOPELAGIC COMMUNITY IN AREAS OF FEEDING AND NON-FEEDING BY SPERM WHALES IN THE NORTHERN GULF OF MEXICO

John H. Wormuth, Department of Oceanography, Texas A&M University

Introduction

The objectives of the midwater trawling component of the Sperm Whale Seismic Study (SWSS) were to sample the potential prey fields at depths where sperm whales are known to feed and to sample areas where whales are actively feeding as well as areas where they are not observed to be feeding. In order to achieve these objectives, we used a 14.8 m^2 Isaacs-Kidd midwater trawl with an inner liner mesh of 4 mm terminating in a 0.333 mm mesh plankton net. The fishing intervals chosen were 0–400 m, 400–600 m and 600–800 m. The two deeper intervals were selected to partition the feeding depths of whales recorded in the previous field year. The 0–400 m interval was chosen to look at those components the trawl would sample on its way down to the deeper intervals. Depth and temperature were recorded with a Sea Bird TDR Model 39. Volume filtered was measured with a General Oceanics flow meter.

Tows were taken at night following the days' completion of over-the-side operations. This limited our ability to sample in "non-whale" areas, but reduced time lost to reacquiring whales prior to dawn. A total of 24 successful trawls were completed in cyclonic, anticyclonic and "other" regions. Samples were sorted into fish, crustaceans, and cephalopods. Displacement volumes (DV) were measured for each component. Temperature profiles for each of the three categories were plotted and showed a high degree uniformity with each category.

Previous reports have discussed analyses of the DV values, fishing characteristics of the trawl, and volumes filtered in the three depth intervals sampled. This report discusses results from the taxonomic work completed within the past year. A total of 84 crustacean taxa, 29 cephalopod taxa, and 11 fish taxa have been identified and counted. Crustacean and cephalopod taxonomy is completed. Fish taxa are incomplete, mainly in the Myctophidae. In this family there are 53 species in 17 genera that occur in the Gulf of Mexico (GOM). The identifications are going slowly, but the learning curve is getting less steep. In addition, there are many other fish in these samples, but their occurrence is very sporadic and unlikely to affect the analyses. In most of the correspondence analyses, the taxa that were the "outliers" were the infrequent taxa.

Results

Examination of the two temperature profiles that represented the extremes of the cyclone and the anitcyclone (IKMT #15 and IKMT #22) show only a small difference at the surface, maximum differences from 100–200 meters and less than 1.3 ^{o}C below 400 meters. Previously presented data also show no statistical differences in zooplankton biomass below 100 meters between cyclones and anticyclones (Wormuth et al. 2000).

The taxonomic data matrix is 123 taxa by 24 trawls. Correspondence analysis (CA) was selected as the statistical tool to handle such a large matrix (Greenacre 1993, Palmer 1993). Ordination techniques evolved from Principal Component Analysis through Factor Analysis to CA. The main advantage of CA is that the method of vector analysis allows both row and column categories to be plotted on the same set of eigenvalue axes. In Factor Analysis this cannot be done. Eight different analyses are summarized in Table 2F.2. The tabled values are the proportion of the total variance in each data set that is accounted for by the first, second, and third eigenvalues. The values for each of the first two eigenvalues for each taxa and trawl are then plotted. A visual inspection can help determine why a particular trawl or subset of trawls may differ from others.

The first analysis in Table 2F.2 used all trawls except #4, which briefly hit the bottom. Because of the sediment picked up, the specimens were quite damaged and most identifications were not possible. For the other 23 trawls, 116 taxa (of the total of 124 taxa) were used. Several taxa were combined because they were males and females of the same species. The total amount of variance explained by the first three eigenvalues was low (27%). Figure 2F.5 shows a plot of the first two axes of correspondence. Only trawls #12 and #24 stand out from the other trawls.

Analyses #2–4 in Table 2F.2 are for just the trawls from each of the three depth strata. Taxa that did not occur in any of the three trawls were eliminated from the analysis. Analysis #2 for the three 0–400 meter trawls show the trawls to be distinct from each other (Figure 2F.6). There is a cluster of taxa associated with each trawl with most other taxa falling inside the triangle formed by the trawls. Trawl #20 was in a cyclone, #21 was in an anticyclone, and #25 was in "other." Analysis #3 for the six trawls from 0–600 meters separates trawl #12 ("other") from the other five, but #14 and #23 are positive on CA2 as is #12. The other three (#6, #16 and #17) are all negative on CA1 and CA2 and are all cyclonic. There appear to be no discernable trends in Analysis #3.

Analysis #5 in Table 2F.2 is for 23 trawls and the 74 most abundant taxa with average concentrations > .04 indiv./ 1000 cubic meters water filtered. Trawls #12 and #24 group by themselves (both "other"), trawl #21 (anticyclone) is well separated from #12 and #24 and is somewhat separated from the rest of the trawls. Again, the amount of variance explained by CA1–CA3 is low, only 26%.

Analysis #6 in Table 2F.2 is also for 23 trawls; however, the species that were collected in the three 0–400m tows have been removed, leaving 83 taxa. The results are very similar to those of Analysis #5 with only slightly more variance explained. Analysis #7 is for 23 trawls with the restrictions of Analyses # 5 and 6 imposed. This left 50 taxa in this analysis. Again, trawls #12 and 24 separated themselves, but with no improvement in the amount of variance explained.

Analysis #8 is for only the 0–800 meter trawls and all of the less frequent (< 4 occurrences out of the 13 trawls) were eliminated. This left only 41 taxa. The first three eigenvalues accounted for a total of 44% of the total variance, the highest of all analyses. Only trawls #10 and 24 stood out from the others. The taxa that separated from the "central mass" of points were all euphausiids species with nut one exception.

Table 2F.2. Results of correspondence analysis runs for selected subsets of data.

ANALYSIS #1

Correspondence analysis Eigenvalues	1	2	3	
Percent Variance Explained	10	9	8	All 23 Trawls
Cumulative Percent	10	19	27	116 Taxa

ANALYSIS #2

Correspondence analysis Eigenvalues	1	2	0-400 meters
Percent Variance Explained	52	48	3 Trawls
Cumulative Percent	52	100	55 Taxa

ANALYSIS #3

Correspondence analysis Eigenvalues	1	2	3	400-600 meters
Percent Variance Explained	31	22	18	6 Trawls
Cumulative Percent	31	53	71	80 Taxa

ANALYSIS #4

Correspondence analysis Eigenvalues	1	2	3	600-800 meters
Percent Variance Explained	16	12	11	13 Trawls
Cumulative Percent	16	28	39	101 Taxa

ANALYSIS #5

Correspondence analysis Eigenvalues	1	2	3	All 23 Trawls
Percent Variance Explained	10	9	8	74 Taxa
Cumulative Percent	10	18	26	<.04 Averages Removed

ANALYSIS #6

Correspondence analysis Eigenvalues	1	2	3	23 Trawls (-#4)
Percent Variance Explained	12	10	9	0-400m Taxa Removed
Cumulative Percent	12	22	31	83 Taxa

ANALYSIS #7

Correspondence analysis Eigenvalues	1	2	3	23 Trawls (-#4)
Percent Variance Explained	11	11	9	50 taxa
Cumulative Percent	11	22	31	0-400m Taxa Removed
				<.04 Averages Removed

ANALYSIS #8

Correspondence analysis Eigenvalues	1	2	3	13 Trawls (-#4)
Percent Variance Explained	16	15	12	41 taxa
Cumulative Percent	16	32	44	0-400m Taxa Removed
				Freq <30% Removed

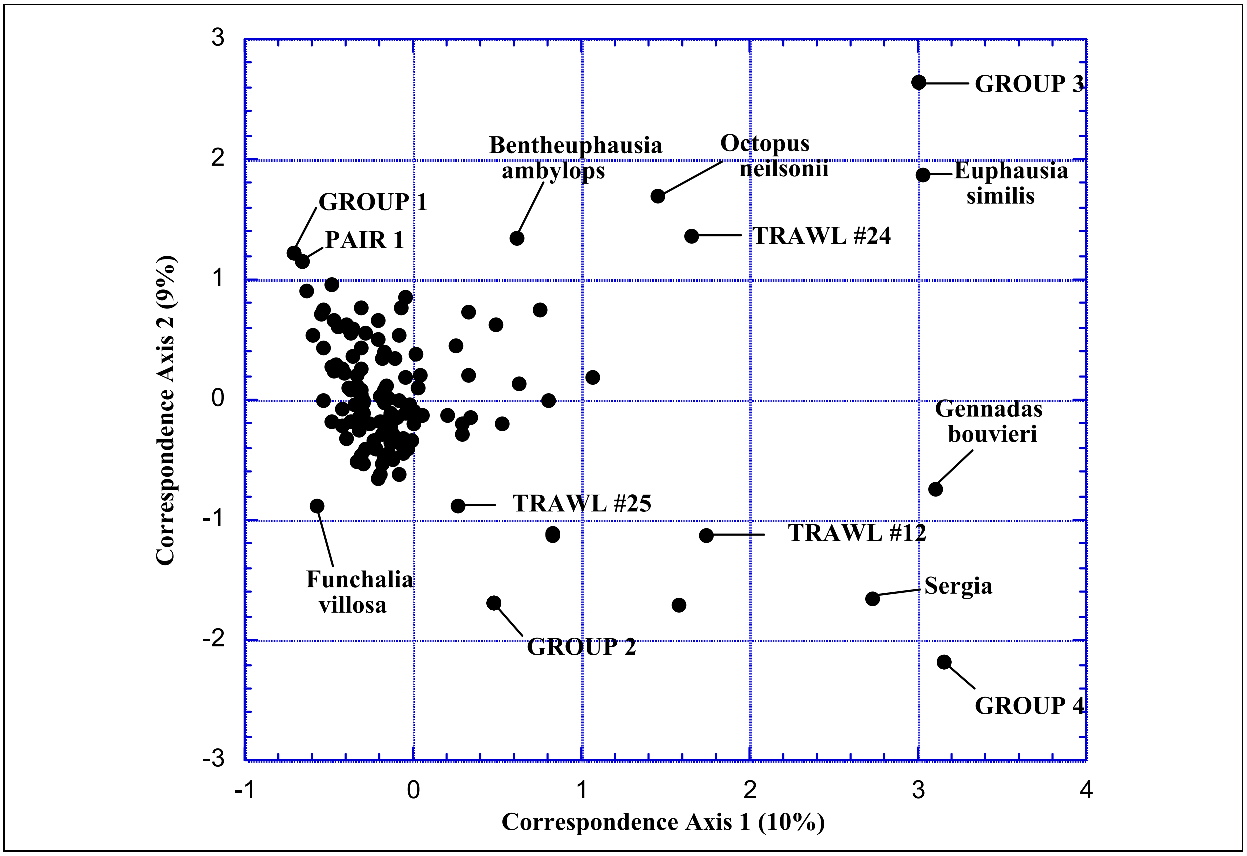


Figure 2F.5. Correspondence axes 1 and 2 for 23 trawls and 116 taxa. Group 1 includes *Sergestes atlanticus*, *Sergestes pectinat*us (sergestid shrimp) and Ommastrephidae unidentified (a squid family). Pair 1 consists of *Dantecia caudani* (an ophlophorid caridean) and *Pterygioteuthis* sp (a squid genus). Group 2 includes *Meningodora vesca*, *Oplophorus spinosus*, *Plesionika grandis* (crustaceans), *Galaiteuthis* sp., and *Sandalops* sp. (squid). Group 3 includes *Systellapsis cristata*, *Sergestes 'alanticus* group' sp 1, *Euphausia brevis*, and *Euphausia tenera* (all crustaceans). Group 4 is composed of *Sergestes* sp., *Euphausia mutica*, *Euphausia pseudogibba* (crustaceans), and *Haliphron mollis* (squid).

Discussion

With the exception of Analysis #2, the amount of variance explained by these analyses was disappointingly low. It is obvious from Table 2F.2 that the number of trawls is much more important than the number of taxa in determining the amount of variance explained. Further analyses with justified smaller sets of trawls have been undertaken. The analyses have shown, however, that a few trawls that stand out from the others. These distinctions will be pursued.

Overall, these results suggest that below 400 meters, the water masses are homogeneous and that differences in community structure do not exist for the most part. This is not surprising considering that analyses of zooplankton samples from the upper 200 meters in cyclones, anticyclones, and in other regions of the northern GOM show that differences exist, but only in the upper 100 meters of the water column (Wormuth et al. 2000).

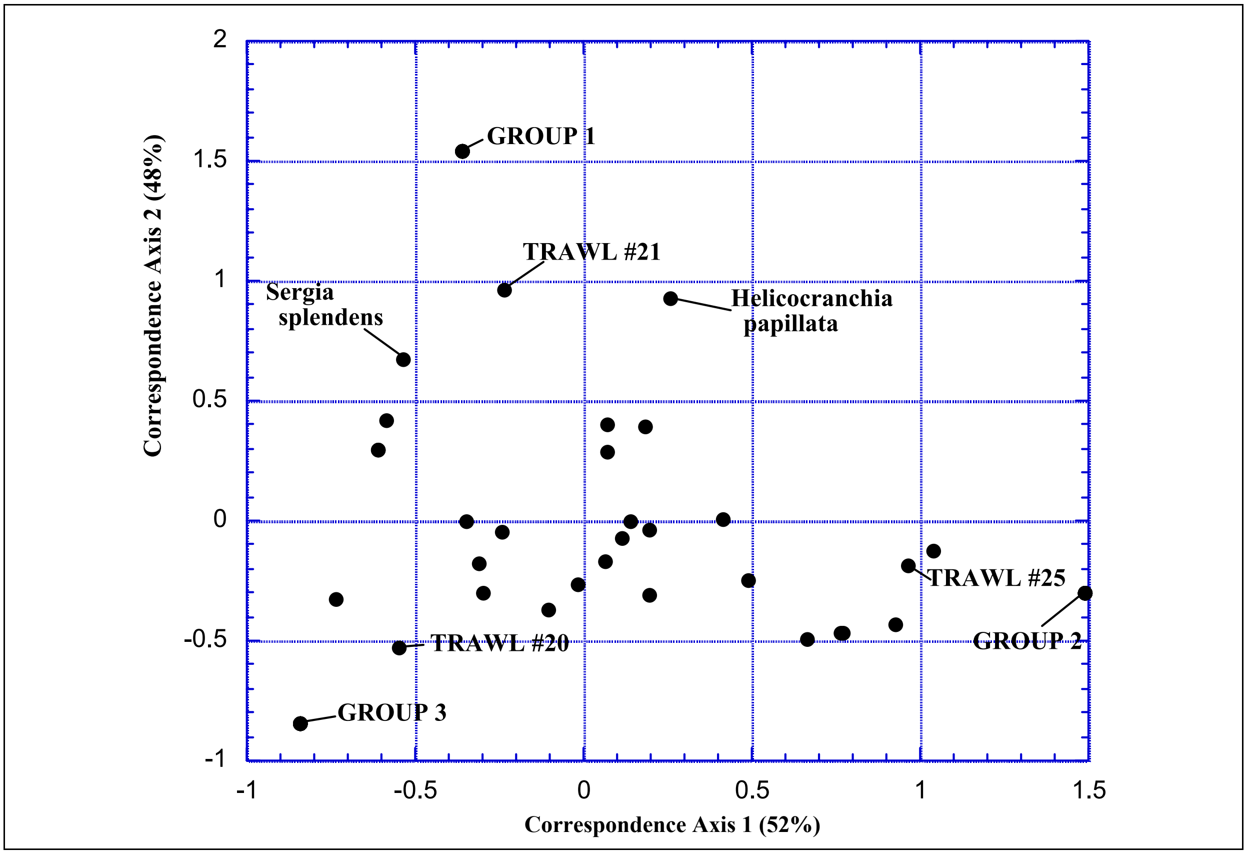


Figure 2F.6. Correspondence axes 1 and 2 for 3 trawls (0–400 meters) and 55 taxa. Group 1 includes *Systellaspsis pellucida*, *Gennadas bouvieri* total, *Thysanopoda monocantha* (Crustaceans), *Abralia atlantica*, *Heteroteuthis* sp., Pyroteuthidae, *Stenoteuthis pteropus* (squid), and *Sternoptyx diaphana* (fish). Group 2 consists of *Meningodora vesca*, *Oplophorus spinosus*, *Plesionika grandis*, *Sergia* sp., *Thysanopoda tricuspidata* (Crustaceans), *Galaiteuthis* sp., *Pyroteuthis margaritifera*, *Sandalops* sp., and Squid unidentified. Group 3 includes *Acanthephyra gracilipes*, *Sergia robustus*, *Sergia tenuiremi*, *Nematoscelis gracilis*, *Nematoscelis microps*, *Stylocheiron abbreviatum*, *Thysanopoda aequalis*, *Thysanopoda obtusifrons* (Crustaceans), Cranchiidae, *Histioteuthis arcturi*, and *Pterygioteuthis giardi* (squid).

From the standpoint of trophodynamics in the 400–800 meter community, the weights of the larger organisms are probably more important than their concentrations. Size frequency and weight data for hatchet fishes and *Gonostoma* have been completed. Weights have been measured on myctophids and *Cyclothoe*, but only as single values per trawl. These data will be supplemented with weights of other deep living species.

A set of trawls was made in October 1996 in the eastern area of the 2003 SWSS cruise using a 4 m2 MOCNESS with 4mm mesh. Each trawl collected seven discrete samples in the upper 400 meters of the water column. The data from these trawls will be used to further eliminate those taxa that occur in the upper 400 m.

The intriguing question that these results raise is: “Why do the whales occur more frequently in the cyclones when there appear to be no differences in the micronekton and nekton in the depths at which they feed?”

References

Greenacre, M.J. 1993. Correspondence Analysis in Practice. London: Academic Press.

Palmer, M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74:2215–30.

Wormuth, J.H., P.H. Ressler, R.B. Cady and E.J. Harris. 2000. Zooplankton and micronekton in cyclones and anticyclones in the Northeast Gulf of Mexico. Gulf of Mexico Science 18:23–34.

Dr. John Wormuth earned his Ph.D. from the Scripps Institution of Oceanography. After a one-year post-doc at Scripps, he came to Texas A&M as an Assistant Professor. He has led and participated in studies on zooplankton, pteropods, krill and squid in the North Atlantic, the Gulf of Mexico and the Antarctic. He has graduated twelve Ph.D. and eight M.S. students while at Texas A&M.

SESSION 1G

PLATFORM ECOLOGY

Chair: **Greg Boland, Minerals Management Service**

Co-Chair: **James Sinclair, Minerals Management Service**

THE FIDELITY OF RED SNAPPER (*LUTJANUS CAMPECHANUS*) TO PETROLEUM PLATFORMS AND ARTIFICIAL REEFS IN THE NORTHERN GULF OF MEXICO

Megan B. Peabody Westmeyer and Charles A. Wilson,
Department of Oceanography and Coastal Sciences,
School of the Coast and Environment, Louisiana State University

The habitat value of petroleum platforms for red snapper, *Lutjanus campechanus*, is poorly understood; however, it is widely recognized by both scientists and fishermen that the presence of platforms in the northern Gulf of Mexico (GOM) has affected the distribution and perhaps the abundance of red snapper by the addition of hard substrate habitat. The red snapper is the target of lucrative and heavily managed commercial and recreational fisheries, and the petroleum industry in the GOM is economically important to several of the Gulf States and the United States as a whole. The promulgation of effective management regulations both for the red snapper fisheries and for the petroleum industry must include information about the habitat preferences of red snapper as they relate to platforms. It is evident that platforms and artificial reefs (often toppled platforms) act as some sort of essential habitat for red snapper in the northern GOM, but the absolute importance of these artificial habitats to the red snapper population is as yet undetermined. To manage this species successfully, we must consider its use of platforms as habitat and determine the level of importance of these platforms to the ecology of red snapper. Advances in acoustic telemetry have resulted in a valuable technology that permits continuous tracking of specimens and yields more detailed and accurate information on red snapper usage of platforms. To address the question of the importance of petroleum platform habitats to red snapper, we monitored the fidelity of red snappers to standing and toppled platforms with acoustic telemetry.

In May 2003, 125 red snapper were captured with hook and line at several platforms in a 35 km^2 portion of the South Timbalier oil and gas lease blocks, 50 km south of Port Fourchon, Louisiana (Figure 1G.1). Following anesthetization with MS-222, an individually coded acoustic pinger (V8SC-2H from VEMCO Ltd., 100 Osprey Drive, Shad Bay, Nova Scotia, Canada B3T 2C1) was surgically implanted into the peritoneal cavity of each fish. Each fish was also fitted with a Floy® internal anchor tag (FM-95W) bearing a contact number and offer of reward for returned tags. The incisions were sutured and sealed with veterinary glue. After a short recovery period, the red snapper were released at five platforms in the study area. Presences of individual snapper were recorded with omnidirectional acoustic receivers attached to seven platforms and to one artificial reef, a toppled platform.

The majority of tagged snapper did not exhibit movement between or among receiver locations on a daily, weekly, or even a monthly basis, leading to a conclusion of high site fidelity over the short-term. A small number of tagged red snapper were recaptured outside the study area and displayed little movement in a uniform direction (Figure 1G.1). Of the red snapper that moved, those at liberty longer moved greater distances, as though they gradually dispersed from their area of origin over time. The results of a logistic regression on the probability of a red snapper being present at its site of release suggest that the longer-term (over a period of six months) site fidelity of red snapper is much lower than the short-term fidelity, perhaps approaching zero (Figure 1G.2). This result differs from previous studies that reported high fidelity over long time spans, though none of these studies were conducted at platforms off the Louisiana coast.

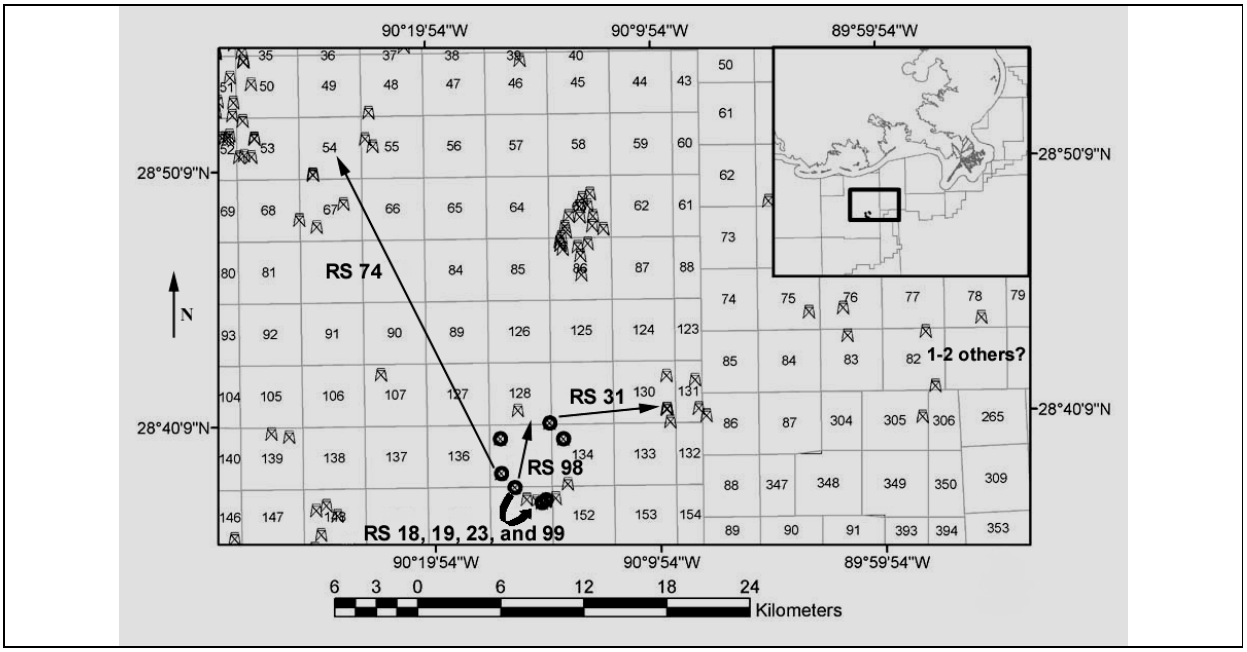


Figure 1G.1. Map showing the starting and ending points for the seven red snapper that were recaptured at locations other than their release sites. The unconfirmed location where one or two other red snapper may have been captured and released east of the study area is also shown.

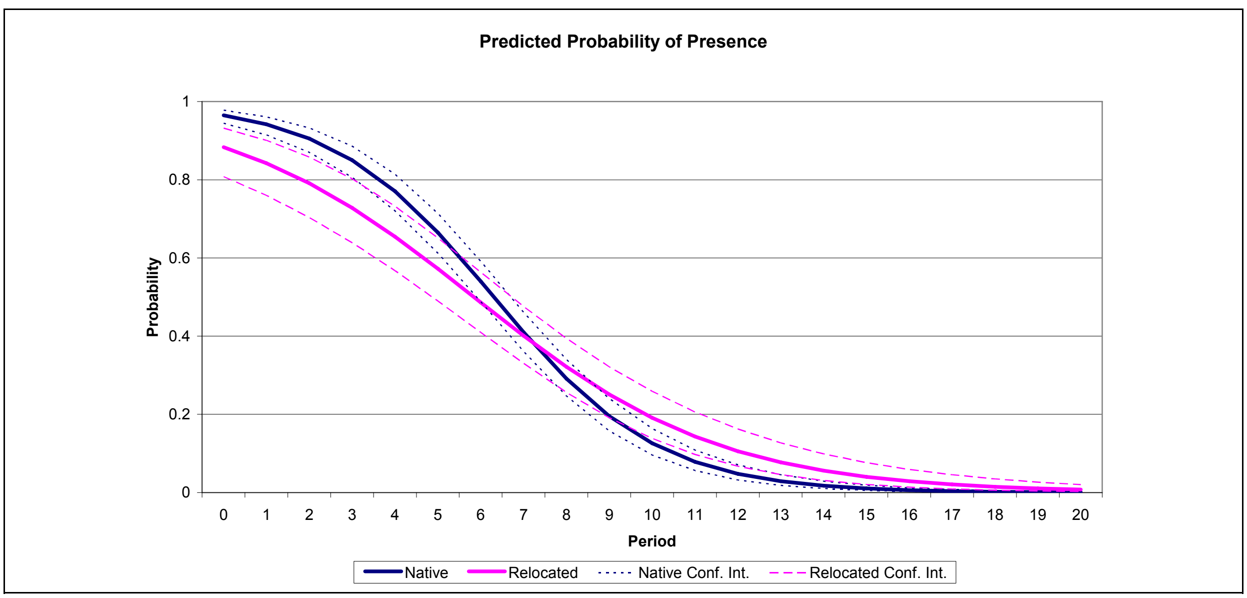


Figure 1G.2. Predicted probability of presence at release location for both native and relocated red snapper. Dashed lines are 95% confidence intervals.

A Fourier analysis revealed a diel pattern of movement away from the structures at night, most likely for offsite foraging on benthic organisms in the surrounding area (Figure 1G.3). A LOESS procedure revealed that this diel pattern took the form of a crepuscular movement, with red snapper moving away from the structures just before sunrise and at sunset. The red snapper appeared to take advantage of the overlap of diurnal and nocturnal organisms by venturing on intense feeding forays at dawn and dusk, with intermittent feeding forays throughout the night.

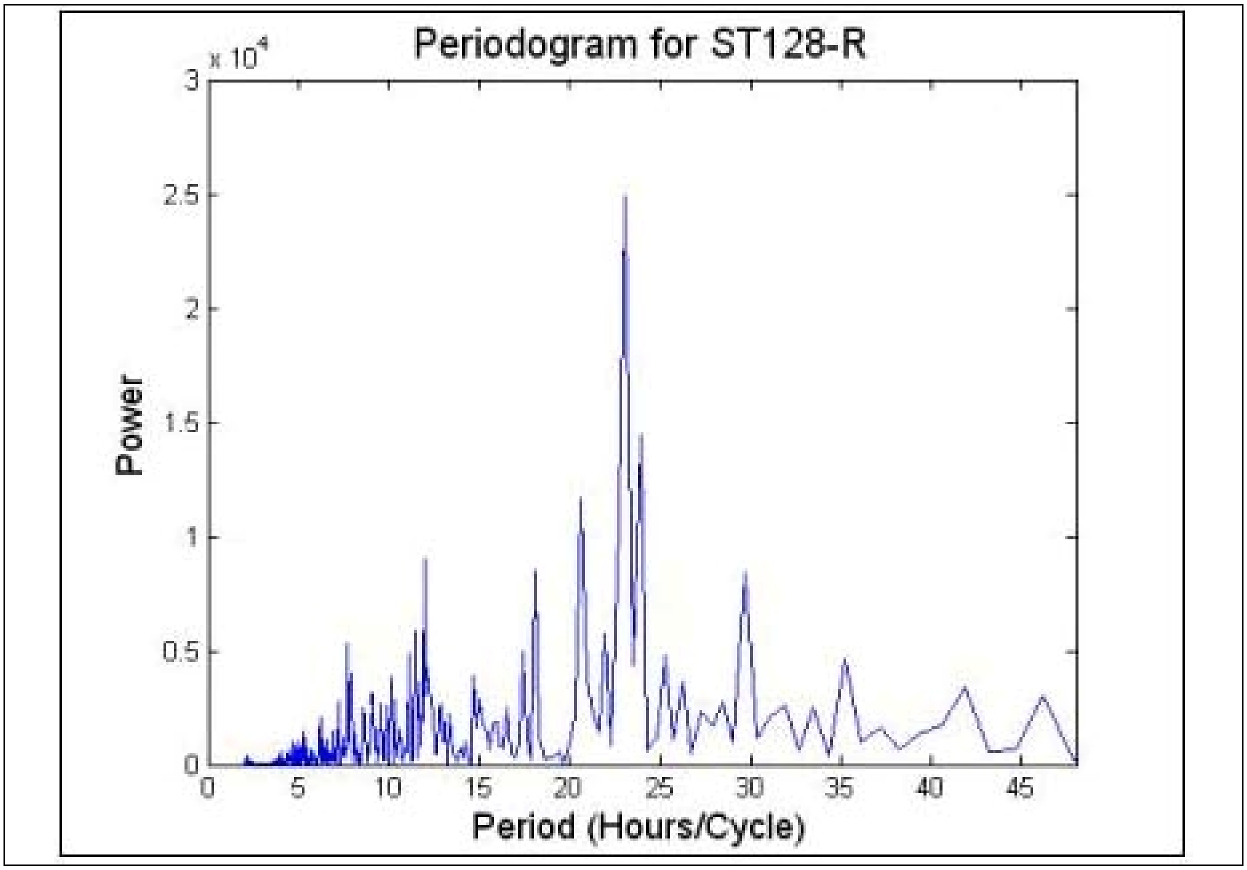


Figure 1G.3. Periodogram for South Timbalier 135-M showing the period and the power of the sine functions describing red snapper movement away from the platform.

Knowledge of red snapper fidelity to and movement around petroleum platforms will lead to more effective management of this species by clarifying both the specific function of these structures as habitat and their importance to the red snapper population in the GOM. There is much debate as to whether or not petroleum platforms should be toppled and left in the GOM as artificial reefs or removed completely. As this study has shown, red snapper are attracted to platforms and probably derive benefits from them; therefore, removal may hinder the recovery and rebuilding of this heavily exploited population. On the other hand it is important to remember that the catchability of red snapper at platforms may be higher than at natural hard-bottom because of the ease with which fishermen may locate platforms; an increase in catchability would likely lead to an undesirable increase in fishing mortality. If catchability is increased, platforms may not be as beneficial to the red snapper population as is currently thought by many. The effect of platform removal on the fisheries must also be considered: the decrease in easily available fishing opportunities could cause economic stress in the commercial and recreational fishing industries, both of which are very important to the states bordering the GOM.

Megan B. Peabody Westmeyer holds a B.S. degree from the University of South Carolina (2001) and an M.S. degree from Louisiana State University (2004). Her diverse background includes research on the climatological records preserved in the sediments of Lake Baikal, Russia, on the benthic eco-toxicology of pesticides on estuarine amphipods, on sea turtle nesting in North Carolina, and on the life history of important marine fishes. Megan is currently employed as the Program Coordinator for the Sustainable Seafood Education Project at the South Carolina Aquarium in Charleston (POB 130001, Charleston, SC 29413-9001).

Charles A. Wilson, III, is a Professor both in the Department of Oceanography and Coastal Sciences (DOCS) and in the Coastal Fisheries Institute, School of the Coast and Environment, Louisiana State University. During his twenty-year tenure at LSU, Dr. Wilson has also served as Chair of DOCS (1995–2002), Director of the Coastal Ecology Institute (2001–2002), and Vice Provost in the Office of Academic Affairs (2003–present). His diverse and rigorous research program on the biota of the northern Gulf of Mexico has resulted in over 70 publications in the primary literature and scores of technical reports.

THE BUCCANEER GAS AND OIL FIELD "RIGS TO REEFS" 1977–2004

Benny J. Gallaway, Larry R. Martin, John G. Cole, and Robert G. Fechhelm, LGL Ecological Research Associates, Inc.
Charles A. Wilson, Yvonne Allen, and Mark Miller, Louisiana State University

Introduction

The project "Platform Debris Fields: Extent, Composition and Biological Utilization" is being jointly funded by the Minerals Management Service (MMS) and the Texas Parks and Wildlife Department (TPWD). The study is being conducted by Louisiana State University (LSU) and LGL Ecological Research Associates, Inc. (LGL). Our objectives have been to conduct high-resolution side-scan sonar surveys of debris field associated with two sites where obsolete oil and gas platforms installed in the mid-1960s have been topped and left in place as artificial reefs. These surveys are being supplemented with ROV and hydroacoustic surveys to determine fish and megafaunal abundance associated with the debris fields. The sites are unusual in that extensive historical environmental and ecological investigations were conducted at these platforms in the late 1970s (Middleditch 1981).

Study Area and Methods

The structures in question (Platforms GA288 and GA296) are located about 27 nmi south of Galveston, Texas in 70 ft of water. Each site contained a 12-pile structure or production platform that was once attached by a catwalk to a four-pile structure that served as a quarter's platform. The structures were reefed using mechanical cutting methods. The decks were removed and transported to shore. The structures were cut at a depth of about 15 m (50 ft), and the top portions were cut into smaller sections that were placed within and around the base sections left in place. Each reef site is marked by a lighted buoy maintained by the TPWD.

We planned on conducting side-scan sonar, hydroacoustic and ROV surveys of the reef sites in the summer/fall period of 2003 and summer of 2004. The first cruise was conducted as planned in October 2003. Complete side-scan and hydroacoustic surveys were made at each reef site and at a nearby ridge thought to contain relict shell beds, habitat which is attractive to juvenile red snapper. ROV surveys began at the shell-ridge and documented that the area was mostly sand and shell-hash, not relict shell beds. The site did not have the habitat attributes attractive to juvenile red snapper. ROV surveys were not made at the reef sites due to adverse weather conditions which then prevailed for an extensive time period.

We next returned to the sites in August of 2004 and conducted hydroacoustic and synoptic ROV surveys at each reef. We plan to revisit the study area in spring or summer of 2005 and conduct side-scan, hydroacoustic, and ROV surveys at each artificial reef site.

Results

Below we summarize the side-scan sonar results from October 2003, hydroacoustic survey results from October 2003 and August 2004 and ROV survey results from August 2004. We also describe the fish communities present at the GA288 site in September 2003 based upon TPWD diver-surveys conducted by TPWD shortly after the rigs were topped and placed on the bottom.

Side-Scan Sonar Surveys. We obtained 100% side-scan coverage of the two sites in October 2003. Two debris fields are present at each site, one at the location of the 12-pile structure, and one at the location of the four-pile structure. Riprapp material covered a partially-buried segment of old pipeline at a location about 20- to 55-m east of the main debris pile at the GA296 site.

At GA288, bottom depth was on the order of 23 m, and the highest point of the debris field was on the order of 18-m deep. Maximum relief was thus about 5 m. Slightly greater relief was observed at GA296 (6 m) where the bottom depth was 22 m and the highest point of the debris field was about 16-m deep. At the GA288 site, the main debris field was mostly encompassed within a circle having a radius of 100 m whereas the four-pile structure debris field was largely contained within a circle having a radius of 50 m. Similarly, the main debris pile at GA296 site was contained within a radius of about 83 m, and the debris field at the old quarters platform at this site was within a radius of 55 m. Thus, the sites are similar in terms of size and relief.

Hydroacoustic Surveys

The hydroacoustic surveys showed that the debris fields comprised "islands" of relief extending above a relatively flat plain. "Clouds" of fishes hovered within and above the debris fields. The surrounding flat bottoms were virtually devoid of fish. Fish were abundant immediately above the reefs, and abundance declined rapidly within a 100-m distance away from the reefs. Fish targets were present throughout most of the water column. The population estimates at GA288 and GA296 in October 2003 were 8,292 fish (95% CI = 5,655 to 10,928) and 7,558 (95% CI = 5,461 to 9,654) respectively. In August 2004, 4,837 (95% CI = 2,799 to 6,874) fish were estimated to have been present at GA288, and 7,352 (95% CI = 5,596 to 9,109) were estimated to have been present at GA296.

ROV and Diver Surveys

We did not obtain ROV surveys at the study area reef sites in October 2003, but the small debris pile at the GA288 site was surveyed by TPWD divers in September 2003 shortly after the structures had been reefed. Five TPWD divers performed roving surveys at site GA-288. They initially dove to the bottom and worked their way to the surface recording the relative abundance of fishes observed. The abundance categories ranged from sightings of single fish of a species to an observation of groups of a species numbering from a few (2-10 fish), to many (11-100 fish) to abundant (>100 fish of a species). "Abundant" fishes included only the tomtate *Haemulon aurolineatum* whereas species represented in the "many" category included the sheepshead *Archosargus probatocephalus*, Atlantic spadefish *Chaetodipterus faber*, grey triggerfish *Balistes capriscus*, red snapper *Lutjanus campechanus*, and grey snapper *Lutjanus griseus*. Species in the "single" or "few" categories included the ling *Rachycentron canadum*, Almaco jack *Seriola rivoliana*, greater hammerhead shark *Sphryna mokarran* and the blue runner *Caranx crysos*.

The fish population at GA288 in August 2004 was dominated by red snapper (70%), sheepshead (12%), and grey triggerfish (6%). Tomtate and Atlantic spadefish, which had been highly abundant in September 2003, were scarce at this site in August 2004. This apparent decline corresponds to an overall population decline that was observed at GA288 between October 2003 and August 2004.

References

Middleditch, B.S. ed. 1981. Environmental effects of offshore oil production, the Buccaneer Gas and Oil Field study. Marine Science 14. Plenum Press, New York.

Benny J. Gallaway, Ph.D. is President of LGL Ecological Research Associates, Inc. His experience in the Gulf of Mexico spans more than three decades. Research interests have included artificial and natural reef ecology, continental shelf and slope ecology, and fisheries management. Dr. Gallaway has over 50 publications in the peer-reviewed literature and is author of hundreds of research reports.

Larry R. Martin is a marine biologist and diving scientist with LGL Ecological Research Associates, Inc. His Gulf of Mexico experience includes ecosystem analysis in relation to petroleum production activities, coral reef monitoring, ecological studies of the continental slope, and assessing effects of commercial shrimping on endangered and other key species taken as bycatch in that fishery.

John G. Cole has been a Vice-President and Data Analyst at LGL Ecological Research Associates, Inc. for the past 25 years. His research interests center around database design, and data integrity, review, and analysis. In recent years his work has been almost exclusively in the Gulf of Mexico, where he has consolidated data from various sources to create georeferenced data sets for the data from the LGL-led Gulf of Mexico continental slope study conducted in the 1980s, turtle interactions with the shrimping fleet, electronic logbook records of shrimp fleet activity and historical shrimp fleet observer data.

Robert G. Fechhelm, Ph.D. is a fisheries biologist/ecologist with LGL Ecological Research Associates, Inc. He has 24 years of experience conducting environmental research in the Gulf of Mexico. Research interests have included continental slope and shelf ecology, the effects of synthetic drilling fluid disposal, sea turtle ecology, fisheries, and bycatch issues. Dr. Fechhelm has authored 67 reports and technical documents for clients in industry, and state and federal agencies, and has published 25 papers in peer-reviewed scientific journals.

Charles A. Wilson, III**,** is a Professor both in the Department of Oceanography and Coastal Sciences (DOCS) and in the Coastal Fisheries Institute, School of the Coast and Environment, Louisiana State University (LSU). During his twenty-year tenure at LSU, Dr. Wilson has also served as Chair of DOCS (1995–2002), Director of the Coastal Ecology Institute (2001–2002), and Vice-Provost in the Office of Academic Affairs (2003–present). His diverse and rigorous

research program on the biota of the northern Gulf of Mexico has resulted in over 70 publications in the primary literature and scores of technical reports.

Yvonne Allen is a research associate in the Coastal Fisheries Institute at Louisiana State University. Ms. Allen received her M.S. degree in water resource management from the University of Wisconsin-Madison in 1990. Since then, she has worked on a variety of projects including large-scale food web manipulation, thermal habitat in large lakes, and invasive species in the Mississippi River.

Mark Miller is a research specialist in the Coastal Fisheries Institute at Louisiana State University. In his nine years there he has acquired extensive dive experience, ROV operations, and sonar experience. Mr. Miller also has had eight years' experience studying fish populations associated with oil and gas platforms.

POTENTIAL SPATIAL AND TEMPORAL VULNERABILITY OF PELAGIC FISH ASSEMBLAGES IN THE GULF OF MEXICO TO SURFACE OIL SPILLS ASSOCIATED WITH DEEPWATER PETROLEUM DEVELOPMENT

Mark C. Benfield and Richard F. Shaw,
Department of Oceanography and Coastal Sciences, Coastal Fisheries Institute, Louisiana State University, School of the Coast and Environment

Introduction

As petroleum exploration expands into and beyond the waters of the OCS, the potential exists, via accidental spills, to adversely impact pelagic recreational and commercial fisheries. Surface petroleum spills in pelagic waters of the OCS will primarily impact those species of fishes and crustaceans that inhabit the epipelagic zone of the open ocean. Members of this group include several species that command a high monetary and socio-economic value, as well as ecologically important or indicator species. Spills in the surface waters are also likely to impact floating *Sargassum* communities, which contain a diverse and often unique faunal assemblage of fishes and invertebrates and which also serve as important nursery habitats for many fishes.

Relatively little is known about the susceptibility of pelagic fishes from the Gulf of Mexico OCS to petrochemical spills. The magnitude of any impact will depend upon the spatial and temporal scale of the incident as well as the chemical properties of the spilled material. The spatial scale (location, depth and extent) of the spill combined with the temporal scale (timing and duration) will combine to determine the species and life history stages that are likely to be present in the impacted area. Unfortunately, information on the spatial and temporal distributions of pelagic fish stocks in the OCS is not readily available and is generally scattered throughout the peer-reviewed and non-peer-reviewed technical literature and databases.

This study was undertaken to synthesize what is known about the spatio-temporal distribution patterns of selected pelagic fish species. We have attempted to provide an estimate of what life history stages of these target species are likely to be present within the OCS waters on a seasonal (monthly) basis.

Methods

We delineated a study region of the north central Gulf of Mexico (GOM) that includes waters above the 200–2,000 m isobaths south to 26 ºN latitude. The study area was divided into four zones: western zone (96.4 ºW–92.0 ºW, 26.0 ºN–28.0 ºN), central zone (92.0 ºW–88.0 ºW, 26 ºN–28 ºN), eastern zone (88 ºW–84.3 ºW, 26.0 ºN–28.0 ºN), and a triangular northern zone with a base from 90.7 ºW-84.3 ºW at 28 ºN, and an apex at 87 ºW, 30 ºN (Figure 1G.4). The western, central and eastern zones correspond broadly to the MMS western, central and eastern planning areas. Species selected for study were: bluefin tuna (*Thunnus thynnus*), yellowfin tuna (*T. albacares*), blackfin tuna (*T. atlanticus*), blue marlin (*Makaira nigricans*), white marlin (*Tetrapturus albidus*), wahoo (*Acanthocybium solanderi*), dolphinfish (*Coryphaena hippurus*), two species of flyingfishes: *Cypselurus melanurus* and *C. furcatus*, blue runner (*Caranx crysos*), Ocean sunfish (*Mola mola*), and *Sargassum* community fauna**:** sargassumfish (*Histrio histrio*), planehead filefish (*Monocanthus hispidus*), tripletails (*Lobotes surinamensis*).

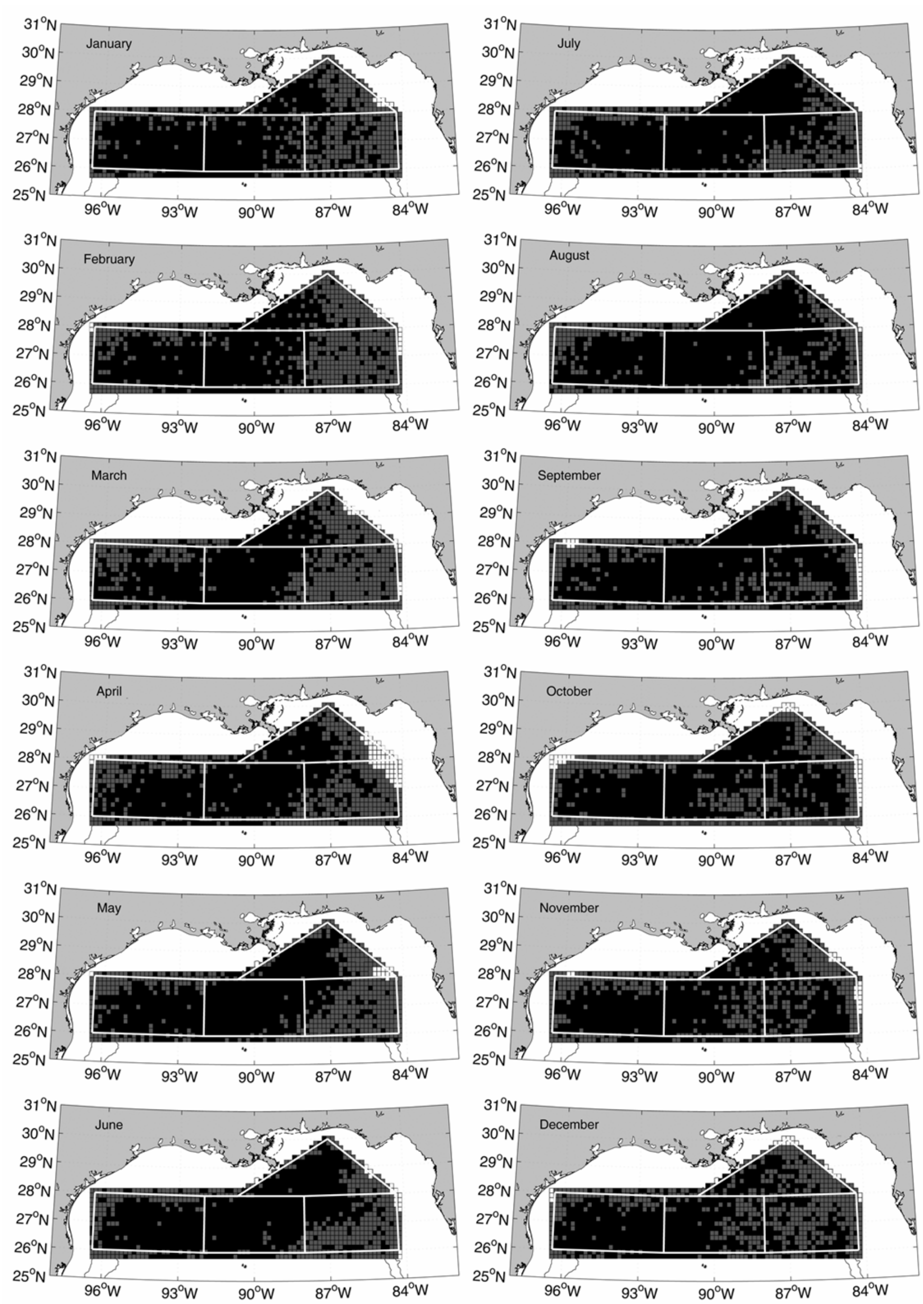


Figure 1G.4. Predicted distributions of adult yellowfin tuna in the study area from January through December. The presence of individuals in each grid cell is coded as confirmed (■), reasonable inference (■) or unreported (☐).

In addition to a comprehensive literature search of the available peer-reviewed literature, gray literature, and Internet websites, this report drew heavily on two datasets: the National Marine Fisheries Service (NMFS) long-line database and the Southeast Area Monitoring and Assessment Program (SEAMAP) ichthyoplankton surveys. Reported observations were sorted by month into a 10' longitude by 10' latitude grid (approximately 100 nautical miles^2 or 343 km^2). The potential presence of a particular stage in any of the cells within the grid was ranked according to three categories: confirmed, reasonable inference, and unreported. Confirmed presence was assigned when a physical sample of the relevant stage of a particular taxon had been reported as being present within a cell. Reasonable inference was assigned to any cells within which there was no confirmed presence, providing the cells were located within a radius of two cell distances (for adults) or one cell distance (for larvae/juveniles) of a cell with a confirmed presence. Reasonable inference was also assigned to any cells that were bounded by four or more cells also designated with the reasonable inference category. Finally, any regions within the study area that were completely surrounded by cells designated as confirmed or reasonable inference were also assigned reasonable inference. Finally, all cells that did not fall into the confirmed or reasonable were assigned an unreported category.
For each species, we have summarized the available distributional data on a monthly basis and have attempted to predict the distributions of larvae, adults, and juveniles (when possible) within the study region. Companion software in the form of Microsoft Excel spreadsheets allow the user to query the data to obtain probable distributions within specific locations defined by their longitude and latitude.

Results and Discussion

Distributional data are predicted for each month for adults and larvae/juveniles where possible. An example of these results is provided for yellowfin tuna. Comparable predictions are provided in the report but are not summarized here for the other taxa in the study.

Adult yellowfin tuna are likely present throughout the majority of the study area during all months of the year (Figure 1G.4). During winter, the majority of confirmed landings were in the western and western halves of the central and northern zones. By April, yellowfin expand their distribution in the northern zone towards the northeast, and this movement pattern continues through May and June. During April there is also an apparent movement into waters deeper than 200 m in the southeastern edge of the northern zone and the northeastern edge of the eastern zone. In summer, adults are present throughout most of the three zones, and during fall and early winter the epicenter of confirmed records shifts back to the western and central zones. The SEAMAP dataset contains extremely limited numbers of confirmed yellowfin larvae that were only present during May, June, and September. Predictions of larval distributions based on this dataset are restricted to these three months and do not provide much utility for estimating larval distributions. Limited data suggest that most spawning occurs near the Mississippi River plume frontal region with larval and juvenile yellowfin tuna present seaward and downstream (southwest) of the plume along the 200 m (Figure 1G.5). In the absence of juvenile distributional data, it is likely that their distributions overlap with the larvae.

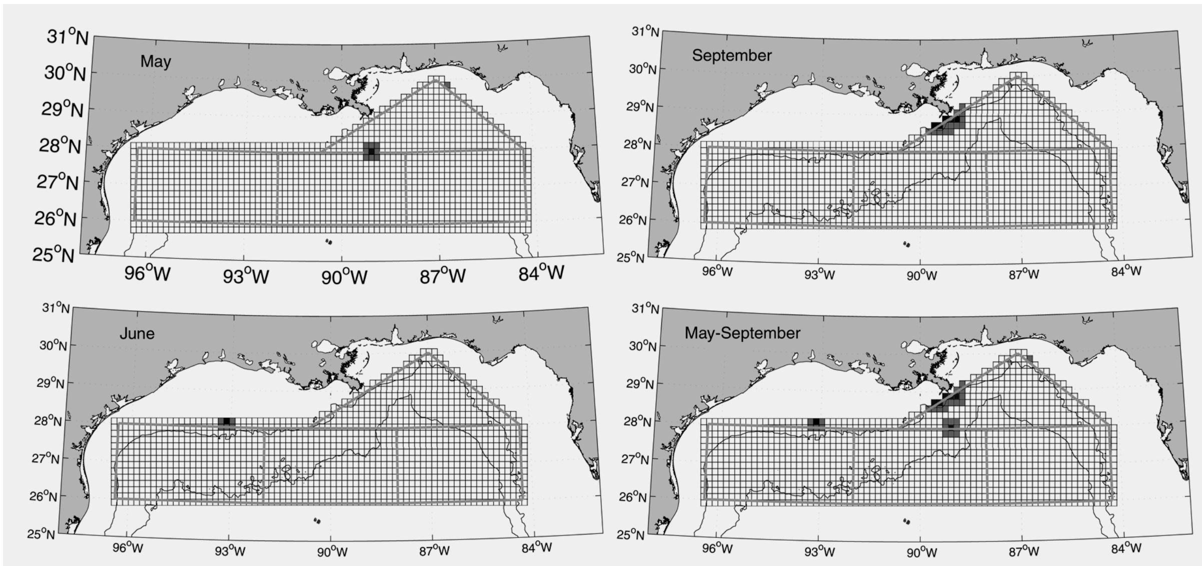


Figure 1G.5. Predicted distributions of larval yellowfin tuna in the study area during May, June, and September. These were the only months in which confirmed larvae were present. The presence of individuals in each grid cell is coded as confirmed (■), reasonable inference (■) or unreported (☐).

Data for each taxon and stage is provided in a Microsoft Excel spreadsheet with separate worksheets for each taxon and life history state. A series of files are provided for each month of the year. There is one set for adults and a second set for larvae/juveniles. Within each file there are worksheets for each species containing latitude and longitude coordinates, and a matrix of cells containing distributional data are encoded with values of 2 (confirmed), 1 (reasonable inference), or 0 (unreported). The cells corresponding to the study area are colored yellow. Within each monthly Excel spreadsheet for either larvae/juveniles or adults there is a worksheet called Distribution Calculator that provides a means of querying the data. Individual worksheets for each taxon are accessible via tabs at the bottom of the spreadsheet page. The Distribution Calculator worksheet allows the user to enter the western and southern coordinates of the location to be queried. The calculator will query each taxon for the month in question and return the predicted distribution of adults or larvae/juveniles of each taxon at the location of interest.

It is clear that for many taxa, substantial gaps exist in our understanding of their spatial and temporal distributions. Prediction of the distributions of larvae and juveniles is particularly problematic due to the limited amount of spatially explicit data available for these life history stages. Estimation of vertical distributions was also problematic for most stages and taxa. This study represents a useful first step for predicting the potential presence of target taxa and for identifying knowledge gaps to guide future studies.

Acknowledgments

The authors are extremely grateful to Elizabeth Burroughs-Loden for her diligent pursuit of the literature and data relevant to this project. We appreciate the assistance of Mr. Mark McDuff, National Marine Fisheries Service (NMFS) for providing access to the SEAMAP dataset and Dr. Jean Cramer, NMFS for providing access to the longline database for the GOM. Dr. Richard Pitman, NMFS generously provided access to his flyingfish data. Ms. Kathy Lang, NMFS provided data on distributions of larval yellowfin tuna. We thank the NMFS Library Staff in Miami for their assistance with our literature searches.

Mark C. Benfield is an Associate Professor in the Department of Oceanography and Coastal Sciences and the Coastal Fisheries Institute at Louisiana State University. He received his B.Sc. from the University of Toronto, an M.Sc. from the University of Natal, and a Ph.D. from Texas A&M University. He was a Postdoctoral Investigator in the Department of Biology at the Woods Hole Oceanographic Institution where he currently holds an appointment as a Guest Investigator. His research focuses on zooplankton ecology, feeding ecology of zooplanktivorous fishes, and the integration of optical, acoustical and direct sampling techniques to understand the ecology of zooplankton.

Richard F. Shaw is a Professor in the Department of Oceanography and Coastal Sciences and the Coastal Fisheries Institute at Louisiana State University. He received his B.A. from Merrimack College at Andover and his Ph.D. from the University of Maine at Orono. His research examines the early life histories of marine and estuarine fishes, larval transport, and the ecology of fishes in relation to natural and artificial reefs.

DETERMINATION OF TRACE ELEMENTS IN RED SNAPPER, *LUTJANUS CAMPECHANUS*, OTOLITHS USING ICPMS TO EVALUATE THEIR AFFINITY FOR OIL AND GAS PLATFORMS

Lauren Mione, James H. Cowan, Jr., and Richard F. Shaw,
Coastal Fisheries Institute, Louisiana State University
Robert Gauldie and Eric DeCarlo, Department of Oceanography,
University of Hawaii at Manoa

The Magnuson-Stevens Fishery Conservation and Management Act, the 1996 revision and reauthorization of the 1976 Public Law 94-265 (Act), requires that fishery management plans include an identification and description of essential fish habitat (EFH), adverse impacts on EFH (including the effects from fishing), and actions to conserve and enhance EFH (Gallaway et al. 1999). One of the most pressing federal fisheries management concerns in the Gulf of Mexico (GOM) region is the overfished status of red snapper *Lutjanus campechanus* (Schmitten, 1999). Red snapper support the most economically valuable finfish fishery in the GOM and are among the most targeted fishes by commercial and recreational fishers (Goodyear 1995). It has been demonstrated that as red snapper mature they show strong preferences for natural and artificial habitat with vertical relief. Examples of this habitat include coral, rocks, banks, outcrops, and manmade submerged objects such as oil and gas platforms and artificial reefs (Workman and Foster 1994). It is these areas that are considered by many to constitute red snapper EFH.

In the waters of the northern GOM there are over 4,000 functioning oil and gas platforms (Stanley and Wilson 1998). Due to the noted presence of red snapper around oil and gas platforms, recreational and commercial fishing efforts for red snapper have continually been concentrated in those areas. Artificial reefs, such as oil and gas platforms, may be useful tools for fishery managers if they increase fisheries production, but many researchers question whether or not they are a positive influence on reef stock dynamics. There have been doubts about whether or not they produce or attract fish and the resolution to this question is essential to the management of reef fish stocks. If they indeed constitute EFH for red snapper, then they can be considered as viable management tools. If they are simply attracting fish to the area, they may be merely promoting overfishing.

Existing oil and gas platform operations and their prior history of drilling operations are likely to produce trace amounts of residues of Lead (Pb), Barium (Ba), and Lanthanum (La) whose isotope ratio signatures will differ from those typical of the GOM seafloor. This can be used as a harmless 'tag' in the otoliths of the juvenile fish that have spent time in close association with oil and gas platforms. Fish otoliths have traditionally been used as a hard part to age fish, but more recent research indicates that they may also serve as ideal natural markers of individual fish or fish populations (Campana et al. 1994) The main objective of this study was to test whether association with oil and gas platforms impart a detectable "trace element fingerprint" in the otoliths of juvenile red snapper using Inductively Coupled Plasma-Mass Spectrometry (ICPMS).

Methods

A total of 115 red snapper were collected by hook and line on recreational charter boats from the fall of 2002 to the spring of 2004. Of those 115 red snapper, 35 were captured off coastal Louisiana on oil and gas platforms in the South Timbalier and Grand Isle Lease Blocks; 35 were captured from artificial reefs off Louisiana in the same location; and 45 were captured on artificial reefs off coastal Alabama in the Hugh Swingle Permit Area south of Mobile Bay. Multiple attempts were made to collect red snapper on oil and gas platforms off of coastal Alabama, but no fish could be caught. Upon collection measurements of fork length, total length, dorsoventral height, and sex were taken. Once specimens were returned to the dock, the heads were removed and returned to LSU. Otoliths were then removed in a clean laboratory in a HEPA-filtered air module, packaged, and sent to the University of Hawaii (UH) for ICPMS analysis. At UH the otoliths were dissolved in quartz-distilled nitric acid (HNO_3) using an MDS 2100 Microwave Digestion System. Once the otolith samples were dissolved they were processed in a VG PlasmaQuad mass spectrometer. A suit of 17 trace elements were analyzed in the otoliths. These consisted of Vanadium 51, Nickel 58, Cobalt 59, Nickel 60, Nickel 62, Zinc 64, Copper 65, Zinc 66, Silver 107, Silver 109, Cadmium 110, Cadmium 111, Cadmium 114, Lead 206, Lead 207, Lead 208 and Uranium 238. Raw data from the mass spectrometer was then standardized for use.

Currently, only the two red snapper samples collected from coastal Louisiana have been processed using ICPMS. Therefore, those 61 otolith samples were the only ones used in this analysis. Of those 61 observations, 30 were otoliths from oil and gas platforms and 31 were otoliths from artificial reefs. A number of statistical methods were used to analyze the standardized data. First, a simple linear regression was used to determine the relationship between otolith weight and fish weight. A multivariate analysis of variance (MANOVA) was used to determine the equality of the means of each element between the two different sites (site 1 = oil and gas platforms, site 2 = artificial reefs). A discriminant function analysis was performed to determine if the observations could be allocated to one or another set of classes (site 1 and site 2) in an optimal way with the least amount of misclassifications. A stepwise discriminant function was performed to determine the most influential elements in discriminating between oil and gas platforms and artificial reefs off of coastal Louisiana.

Results

Results from the simple linear regression showed a positive linear relationship between otolith weight and fish weight, which was to be expected. The regression had a high r-square value of 0.9507. When comparing the equality of the means of each element for each of the two sites it was determined that eight of the seventeen elements had significantly different means between oil and gas platforms and artificial reefs (Figure 1G.6). Zinc 64 ($p=0.0061$) and Zinc 66 ($p=0.0006$) were significantly higher on artificial reefs that on oil and gas platforms off of coastal Louisiana. Vanadium 51 ($p<0.0001$), Silver 107 ($p=0.0005$), Silver 109 ($p<0.0001$), Lead 206 ($p=0.0086$), Lead 207 ($p=0.0108$), and Lead 208 ($p=0.0109$) were all found to be significantly higher on oil and gas platforms off of coastal Louisiana.

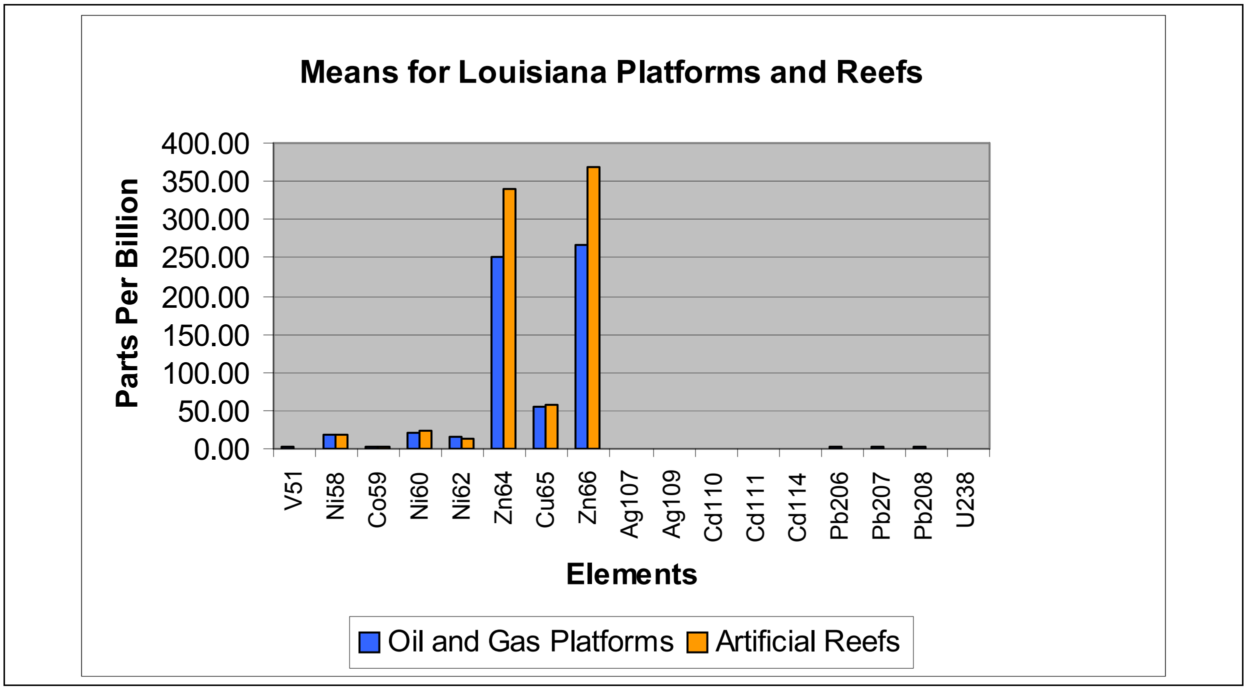


Figure 1G.6. Comparison of the mean differences of the 17 elements between oil and gas platforms and artificial reefs in Louisiana.

Discriminant function analysis was successful in differentiating between our two sites using all 17 elements that were analyzed with otolith microchemistry. Two approaches were used in the discriminant function analysis to estimate the misclassification rate of the 61 observations into site 1 (oil and gas platforms) and site 2 (artificial reefs). The first was the resubstitution approach. It correctly classified 29 of the 30 observations from site 1 but misclassified one observation into site 2. This approach also correctly classified all 31 observations from site 2. Therefore, this approach only had a misclassification rate of 1.67%. However, the resubstitution approach is known in general to be overly optimistic and the second approach used, the cross-validation approach, gives a more realistic misclassification rate. The cross-validation approach correctly classified 25 of the 30 observations from site 1 and misclassified five of them into site 2. It correctly classified 27 of the 31 observations form site 2 and misclassified 4 observations into site1. This approach has a more realistic misclassification rate of 14.78%. A stepwise discriminant function was then performed on the 61 observations, and it identified the most influential elements used to discriminate between oil and gas platforms and artificial reefs in Louisiana. The elements identified as the most important in the analysis were Silver 109, Zinc 66, Vanadium 51, Uranium 238, Lead 206 and Nickel 58. Using only these six elements to rerun the original discriminant analysis yielded a cross-validation approach misclassification rate of only 5%, reduced from the original estimate of 14.78%.

References

Campana, S.E., A.J. Fowler, and C.M. Jones. 1994. Otolith elemental fingerprinting for stock identification of Atlantic cod (*Gadus morhua*) using laser ablation ICPMS. Canadian Journal of Fisheries and Aquatic Sciences 51:1942–1950.

Gallaway, B.J., J.G. Cole, R. Meyer, and J.P. Roscigno. 1999. Delineation of essential habitat for juvenile red snapper in the northwestern Gulf of Mexico. Transactions of the American Fisheries Society 128:713–726.

Goodyear, C.P. 1995. Red snapper in U. S. waters of the Gulf of Mexico. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Miami MIA-95/96-05.

Schmitten, R.A. 1999. Essential fish habitat: Opportunities and challenges for the next millennium. American Fisheries Society Symposium 22:3–10.

Stanley, D.R. and C.A. Wilson. 1998. Spatial variation in fish density at three petroleum platforms as measured with Dual-Beam hydroacoustics. Gulf of Mexico Science 16:73–82.

Workman, I.K. and D.G. Foster. 1994. Occurrence and behavior of juvenile red snapper, *Lutjanus campechanus*, on commercial shrimp fishing grounds in the northeastern Gulf of Mexico. Marine Fisheries Review 56:9–11.

Lauren Mione is a Master's degree student in the Department of Oceanography and Coastal Sciences and the Coastal Fisheries Institute at Louisiana State University. Her major advisor is Dr. James Cowan, Jr. She received her B.Sc. (marine biology) from Auburn University in 2001.

James H. Cowan, Jr. is a Professor in the Department of Oceanography and Coastal Sciences and the Coastal Fisheries Institute at the Louisiana State University. He received B.Sc. (biology) and M.Sc. (biological oceanography) degrees from Old Dominion University, and M.Sc. (experimental statistics) and Ph.D. (marine sciences) degrees from the Louisiana State University. He has almost 20 years of experience conducting fisheries research in marine and estuarine ecosystems.

Richard Shaw is the Director of the Coastal Fisheries Institute and a Professor in the Department of Oceanography and Coastal Sciences at LSU. He has worked with ichthyoplankton since 1973 and received his Ph.D. in biological oceanography from the University of Maine in Orono in 1981.

Dr. R W Gauldie in 1977 published a paper looking at otolith chemistry as a potential stock marker. Some 100 publications later, he suspects that the core problem of otolith chemistry is

that all otoliths have the same chemistry in differing proportions, related to the physiology of individual fish and only in unusual circumstance related to the environment. The rig-recruit situation may well be the unusual circumstance in which otolith chemistry is sufficiently correlated to environment to overcome the background physiological noise in the chemistry of the otolith.

Dr. Eric Heinen De Carlo is a Research Professor in the Department of Oceanography at the University of Hawaii at Manoa. He is a faculty affiliate with the Honolulu District U.S. Geological Survey in Hawaii. He received a Ph.D. in chemistry in 1982 from the University of Hawaii at Manoa.

DISTRIBUTION OF CORALS COLONIZING OIL AND GAS PLATFORMS IN THE NORTHWESTERN GULF OF MEXICO: A PRELIMINARY REPORT

Paul W. Sammarco and Amy D. Atchison, Louisiana Universities Marine Consortium (LUMCON) and Department of Oceanography and Coastal Science, Louisiana State University
Gregory S. Boland, Environmental Section, Minerals Management Service

Abstract

The Flower Garden Banks (FGB), Gulf of Mexico (GOM), are highly isolated corals reefs. The surrounding continental shelf possesses ~3,800 oil/gas platforms. Questions: To what degree are corals expanding their geographic range through the Gulf via these platforms, and what are their genetic affinities to neighboring systems. Thirteen platforms were surveyed initially in the vicinity of the FGB. Coral settlement racks were deployed to determine levels of recruitment. Tissue samples of dominant corals were collected for genetic analysis and analyzed via AFLP. Recruitment on the platforms was compared with that from similar racks implanted on the FGB. Two cross-shelf transects were also taken off Port Aransas, Texas and Lake Sabine, Louisiana, to assess corals on platforms. Eleven coral species were found—nine hermatypic, and two ahermatypic—the most abundant being *Madracis decactis* and *Diploria strigosa,* and *Tubastraea coccinea,* respectively. Most species were characteristic of later sere communities; *Agaricia* and *Porites* spp. were notably rare or absent, respectively. There was no relationship between coral abundance and distance from the FGB. Abundance and diversity were correlated with platform age. Coral recruitment was high on the FGB but rare on the platforms. Spat species composition was normal on the FGB (*Agaricia* and *Porites* spp.) but atypical on platforms near the FGB, characterized by *Tubastraea coccinea* and *Madracis decactis.* The western limit of scleractinian corals on platforms occurred ~60 km SE of Port Aransas, Texas, at the shelf edge, but ahermatypic corals were abundant throughout this region. Ahermatypic corals abounded starting ~120 km offshore, with hermatypes occurring 180–210 km, near the shelf edge. No corals were found between 60 and 120 km offshore. Populations of *D. strigosa* on the FGB and platforms were highly self-contained, with minimum genetic connectivity. *M. decactis* populations were more genetically homogeneous. Contrary to current larval dispersal theory, this brooder was highly effective at dispersing to neighboring habitats; the broadcaster was not.

Introduction

Thirty-eight hundred oil and gas platforms are currently deployed in the northern GOM (Knott 1995; Dauterive 2000). They provide hard substratum which extends through the upper euphotic zone, where hard substratum has been rare in recent geological time (Curray 1965; Blum et al. 2001). The Flower Garden Banks (FGB) are coral reefs located 110 nm S-SE of Galveston, Texas (Rezak et al. 1985). Platforms surrounding these banks have recently been shown to possess scleractinian corals and other reef organisms (Bright et al. 1991; Adams 1996; Boland 2002; Sammarco and Atchison 2003; Sammarco et al. 2003, 2004; K. Deslarzes, pers. comm.). Here, we attempt to 1) determine the degree to which corals have colonized these platforms; 2) determine levels of coral settlement on the platforms in comparison with those on the FGB; 3) determine how these coral community variables relate to distance from the FGB, platform age, and depth; 4) determine their genetic affinities between the platforms, and between platforms and the FGB; and 5) determine the degree of coral colonization on platforms in the western GOM.

Materials and Methods

Coral distribution and abundance data were collected through visual surveys performed by SCUBA divers on 13 drilling platforms near the FGB, occurring within an ellipse extending 15 km W, 45 km E, and 15 km N of the banks. Coral recruitment was studied on the platforms by deploying two coral settlement racks (see Sammarco 1991) with terracotta plates (Harriott and Banks 1995; Maida et al. 1995) made of galvanized steel on each platform jacket at depths of 11-16 m. Nine similar racks were deployed on the East-FGB in sets of three, ≥10 m apart from each other, in a circular pattern. Plates were processed with a dissecting microscope. Coral spat were identified to genus and species. Information on platform age and area (for standardization purposes) was obtained from the platform owners.

Coral tissue was collected for DNA analysis from adults of the three dominant scleractinian corals—*Madracis decactis, Diploria strigosa,* and *Montrastraea cavernosa*—on the platforms and the FGB. Samples were analyzed for genetic affinity between populations using AFLPs—a DNA finger-printing technique recently applied to corals (Sammarco and Brazeau 2001; Barki et al. 2003; Brazeau et al., submitted). AMOVA (Excoffier et al. 1992) and AFLPOP (Duchesne and Bernatchez 2002) were used to analyze molecular genetics data.

Results

Distribution and Abundance

Twelve coral species were found on the platforms, including nine hermatypes and three ahermatypes. The most abundant species were *Tubastraea coccinea*, *Madracis decactis, Diploria strigosa,* and *Montrastraea cavernosa.* The others were *Colpophyllia natans, Madracis formosa, Millepora alcicornis, Oculina diffusa, Phyllangia americana, Porites astreoides, Stephanocoenia intersepta, and S. michelinii.* Most species were characteristic of later sere communities. *Agaricia* spp. were absent.

Relationship to Distance from the FGB

Coral community variables were generally not related to distance from the FGB, including density of all corals, *Madracis decactis,* and *D. strigosa,* as well as coral species diversity.

Relationship to Platform Age

Except for *D. strigosa* density, the above coral community variables were associated with platform age, increasing significantly with platform age in both depth categories.

Depth Distribution

All corals exhibited a significantly non-uniform depth distribution on the platforms. Total coral and *D. strigosa* density peaked at 10 and 20 m depth. *Madracis decactis,* however, peaked at ≥ 27 m, and *Tubastraea coccinea* at 15-18 m. Some species extended down to ≥36 m.

Coral Recruitment

Coral recruitment on the platforms was rare. Only nine spat were found—*Tubastraea coccinea* and *Madracis decactis*. No spat of pioneer species, *e.g. Agaricia* or *Porites* spp., were found.

Genetic Affinitie

Madracis decactis, a brooder, was widely represented on seven platforms in the vicinity of the FGB. AMOVA analysis indicated that there was no significant difference between the populations of the two banks. In many cases, there was no significant difference between populations on the FGB and the platforms or between the platforms themselves. The geographic pattern of non-significant differences was represented in a variety of directions (E, W, and N). *Diploria strigosa* (broadcaster) was only represented on three platforms and *Montastraea cavernosa* (broadcaster) on one; both species were represented on the FGB. AFLP analyses demonstrated that the populations were, on the whole, significantly different between the platforms and the FGB, and between the platforms themselves.

Coral Distribution in the western GOM

Three ahermatypic corals were commonly found SE of Port Aransas, extending to the shelf edge, 60 km offshore - *Oculina verrucosa, Phyllangia americana,* and *Tubastraea coccinea.* The only hermatype found there was *Madracis decactis*—only at the shelf edge, and very few at that. Many corals, both ahermatypic and hermatypic, were found off Lake Sabine. The above three ahermatypes were abundant starting 120 km offshore, but hermatypes were not evident until 150 km offshore. No corals were found between 60-120 km offshore.

Discussion and Conclusions

The coral species found on the platforms were all Caribbean, representing a subset of those occurring on the FGB (Rezak et al. 1985; Gittings 1992; Bright et al. 1984, 1991). The absence of common pioneer species was extraordinary when compared to those found on natural reefs. Due to the correlation between abundance of *Madracis decactis* and platform age, this species may be considered an indicator of stage of succession; *Diploria strigosa,* occurring at all stages of community development, may not. The presence of corals on the platforms indicates a geographic expansion of corals in this region (Sammarco et al. 2004). The lack of the relationship between coral abundance, diversity, etc. and distance from the FGB may be explained by the random distribution of platform age around those banks.

The varied depth distribution of these corals on the platforms may be due to several factors. Firstly, the preferred depth of larval settlement may vary between species (see Stake and Sammarco 2003) and settlement cues may vary with depth (Baird et al. 2003). Secondly, most corals occurred at depths <26-m. This is important because, although federal law requires platform removal one year after cessation of production, other related joint federal/state legislation allows conversion of retired platforms to artificial reefs through the "Rigs-to-Reefs" program, including removing the upper portion to 26 m depth and leaving the remainder in place.

The extraordinarily low levels of coral recruitment on the platforms are unusual for both coral recruitment levels and species composition when compared to the FGB (Sammarco et al. in progress), Caribbean reefs (Sammarco 1982, 1987), and Indo-Pacific reefs (Sammarco and Carleton 1982; Sammarco 1991, 1994, 1996). This anomaly may be partially due to the distance of the platforms from the FGB and the resultant effect of diffusion on the larvae after their release from that area. A comparison with data derived from the Helix Experiment on the Great Barrier Reef demonstrated that even those platforms closest to the FGB were sufficiently distant to invoke strong diffusional effects (Sammarco and Andrews 1988, 1989; Okubo 1994).

AFLP data suggest that *Madracis decactis* is highly effective at expanding its range and colonizing nearby habitats separated by kms to tens of kms, using an “island hopping” strategy (Futuyma 1998; Williams et al. 2003). By planulating up to ten times per year (Vermeij et al. 2003), its larvae may utilize a variety of multi-directional, seasonal currents, facilitating dispersal. Larvae from the broadcasting species, on the other hand, utilize a single spawning period, single current regime, and propagules that require days for development to settlement competency (Harrison and Wallace 1990; Sammarco 1994, 1996). They appear to be less effective for short-range dispersal (also see Atchison et al. 2004).

At a time when coral populations are suffering high levels of mortality on a global scale (Sammarco 1996; Pandolfi et al. 2003; Bellwood et al. 2004; McClanahan et al., in press), these oil and gas platforms, often considered an environmental liability (Birnie 1978; Menzie 1983; Ajao et al. 1996), may have become important environmental assets by providing habitat for settlement of corals in the GOM.

Acknowledgments

Many thanks to the people and organizations who assisted us in this study: US-DOI-MMS—S. Childs, L. Dauterive, T. Dempre, H. Leedy, J. Sinclair; LSU-CMI—L. Rouse; Anadarko Petroleum; Apache Oil; Coastal Oil and Gas; Devon Oil; Dominion Exploration and Production; El Paso Energy; Forcenergy/Forest Oil; Kerr-McGee Oil and Gas; Merit Energy; Newfield Exploration; Noble Energy; Offshore Energy; UNOCAL; Samedan Oil; Chevron-Texaco Exploration and Production; W&T Offshore; LSU-Oceanography—K. Wheelock, D. Woodall; Gulf Diving, Inc.—K. Bush, J. Byron, P. Combs, L. DeWeese, J. Dibble, D. Fanning, K. Foster, J. Heiser, Jason, S. Kerr, T. Kilpatrick, R. Widaman; USAF/NASA—Lt. Col. D. Perrenod; United Space Alliance—A. Knight; LUMCON—A. Barker, J. Collins, W. Hebert, C. Luke, S. Parrott, C. Salmonsen; GB-Undersea, Inc.—G. Bunch; Texas A&M at Galveston—J. Culbertson; Aquarium of the Americas—A. Sebastian; SUNO—D. Hill-House; C. Gentry, D. Marcel. Thanks to J. Benzie for the suggestion to use AFLPs on corals. We especially thank the U.S. Department of the Interior, Minerals Management Service, the Louisiana State University Coastal Marine Institute, and LUMCON for their support of this project through MMS Contract No. 1435-01-99-CA-30951.

References

Adams, C.L. 1996. Species composition, abundance and depth zonation of sponges (Phylum Porifera) on an outer continental shelf gas production platform, northwestern Gulf of Mexico. Final report and M.Sc. thesis, Texas A&M University–Corpus Christi, Center for Coastal Studies.

Ajao, E.A., E.O. Oyewo, and J.P. Unyimadu. 1996. A review of the pollution of coastal waters in Nigeria. Technical Paper Nigeria Institute for Oceanography and Marine Research 107. 20 pp.

Atchison, A.D., P.W. Sammarco, and D.A. Brazeau. 2004. Genetic affinities of coral populations between the Flower Garden Banks and oil and gas platforms in the northern Gulf of Mexico: Preliminary data. Proceedings of the Tenth International Coral Reef Symposium. Okinawa, Japan. (submitted).

Baird, A.H., R.C. Babcock, and C.P. Mundy. 2003. Habitat selection by larvae influences the depth distribution of six common coral species. Marine Ecology Progressive Series 252:289–293.

Barki Y., J. Douek, D. Graur, D. Gateno, and B. Rinkevich. 2003. Polymorphism in soft coral larvae revealed by amplified fragment-length polymorphism (AFLP) markers. Marine Biology 136:37–41.

Bellwood D.R., T.P. Hughes, C. Folke, and N. Nystroem. 2004. Confronting the coral reef crisis. Nature 429:827–833.

Birnie, P. 1978. Did failures in the North Sea legal regime contribute to the Ekofisk blow-out? In: Butler, H. and M.D. Paterson, eds. Fourth International Conference and Exhibition for the Offshore Industries, Oceanology 78, Brighton, UK.

Blum, M.D., T.J. Misner, E.S. Collins, D.B. Scott, R.A. Morton, and A. Aslan. 2001. Middle Holocene sea-level rise and highstand at 12 m, central Texas coast. Journal of Sedimentary Research 71:4.

Boland, G.S. 2002. Fish and epifaunal community observations at an artificial reef near a natural coral reef: Nineteen years at HI-A-389-A, from bare steel to coral habitat. In: McKay, M., J. Nides, and D. Vigil, eds. Proceedings: Gulf of Mexico Fish and Fisheries: Bringing Together New and Recent Research. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2002-004. Pp. 372–392.

Bright, T.J., G.P. Draemer, G.A. Minnery, and S.T. Viada. 1984. Hermatypes of the Flower Garden Banks, northwestern Gulf of Mexico: A comparison to other western Atlantic reefs. Bulletin of Marine Science 23:461–476.

Bright, T.J., S.R. Gittings, and Zingula R. 1991. Occurrence of Atlantic reef corals on offshore platforms in the northwestern Gulf of Mexico. Northeast Gulf Science 12:55–60 .

Curray, J.R. 1965. Late Quaternary history, continental shelves of the United States. In: Wright, Jr., H.E. and D.G. Frey, eds. The Quaternary of the United States, Princeton, NJ: Princeton University Press. Pp. 723–735.

Dauterive, L. 2000. Rigs to reefs policy, progress, and perspective. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-073.

Duchesne, P. and L. Bernatchez. 2002. AFLPOP: A computer program for simulated and real population allocation using AFLP markers. Molecular Ecology Notes 2:380–383.

Excoffier, L, P.E. Smouse, and J.M. Quatrro. 1992. Analysis of molecular variation inferred from metric distances among DNA haplotypes: Application to human mitochondrial DNA restriction data. Genetics 131:479–491.

Futuyma, D.J. 1998. Evolutionary Biology. Sunderland, MA: Sinauer Assocs.

Gittings, S.R. 1992. Long-term monitoring at the East and West Flower Garden Banks, Final Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 92-0006.

Harriott, V.J. and S.A. Banks. 1995. Recruitment of scleractinian corals in the Solitary Islands Marine Reserve, a high latitude coral-dominated community in Eastern Australia. Marine Ecology Progressive Series 123:1–3.

Harrison, P.L. and C.C. Wallace. 1990. Reproduction, dispersal, and recruitment of scleractinian corals. In: Dubinsky, Z., ed. Ecosystems of the World, Vol. 25, Coral Reefs. New York: Elsevier Press.

Knott, D. 1995. U.S. lessons for U.K. platform disposal. Oil and Gas Journal 93:17–18.

Maida, M, P.W. Sammarco, and J.C. Coll. 1995. Effects of soft corals on scleractinian coral recruitment. 1: Directional allelopathy and inhibition of settlement. Marine Ecology Progressive Series 121:191–202.

McClanahan, T., O. Hoegh-Guldberg, R.W. Buddemeier, and P.W. Sammarco. In press. Trajectory and predictions for coral reefs. In: Polunin, N., ed. Proceedings, Fifth International Conference on the Environment Future (ICEF), Zurich, Switzerland. EAWAG.

Menzie, C.A. 1983. Environmental concerns about offshore drilling—muddy issues. Oceanus 26:32–38.

Okubo, A. 1994. The role of diffusion and related physical processes in dispersal and recruitment of marine populations. In: P.W. Sammarco and M.L. Heron, eds. The Bio-Physics of Marine Larval Dispersal, American Geophysical Union, Washington, DC. Pp. 35–72.

Pandolfi J.M., R.H. Bradbury, E. Sala, T.P. Hughes, K.A. Bjorndal, R.G. Cooke, D. McArdle, L. McClenachan, M.J.H. Newman, G. Paredes, R.R. Warner, and J.B.C. Jackson. 2003. Global trajectories of the long-term decline of coral reef ecosystems. Science 301:955–958.

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. Reefs and Banks of the Northwestern Gulf of Mexico. New York: John Wiley & Sons. 259 pp.

Sammarco, P.W. 1982. Echinoid grazing as a structuring force in coral communities: Whole reef manipulations. Journal of Experimental Marine Biology and Ecology 61:31–55.

Sammarco, P.W. 1987. A comparison of ecological processes on coral reefs of the Caribbean and the Great Barrier Reef. In: Birkeland, C., ed. Comparison between Atlantic and Pacific Tropical Marine Coastal Ecosystems: Community Structure, Ecological Processes, and Productivity. University of the South Pacific, Suva, Fiji, 1986. UNESCO Reports Marine Science 46:127–166.

Sammarco, P.W. 1991. Geographically specific recruitment and post-settlement mortality as influences on coral community structure: The cross-shelf transplant experiment. Limnology Oceanography 36:496–514.

Sammarco, P.W. 1994. Larval dispersal and recruitment processes in Great Barrier Reef corals: Analysis and synthesis. In: Sammarco, P.W. and M.L. Heron, eds. The Bio-Physics of Marine Larval Dispersal, American Geophysical Union, Washington, DC. Pp. 35–72.

Sammarco, P.W. 1996. Comments on coral reef regeneration, bioerosion, biogeography, and chemical ecology: Future directions. Journal of Experimental Marine Biology and Ecology 200:135–168.

Sammarco, P.W. and J.C. Andrews. 1988. Localized dispersal and recruitment in Great Barrier Reef corals: The Helix Experiment. Science 239:1422–1424.

Sammarco, P.W. and J.C. Andrews. 1989. The Helix Experiment: Differential local recruitment patterns in Great Barrier Reef corals. Limnology Oceanography 34:898–914.

Sammarco, P.W. and A. Atchison. 2003. Coral communities and recruitment on offshore drilling platforms in the northern Gulf of Mexico: Summary. In: McKay, M. and Nides, J., eds. Proceedings: Twenty-second Annual Gulf of Mexico Information Transfer Meeting. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-073. Pp. 6–7.

Sammarco, P.W., A. Atchison, and G.S. Boland. 2003. Drilling platforms as environmental assets: Developing an assessment protocol using adult and juvenile corals. In: McKay, M. and J. Nides, eds. Proceedings: Twenty-first Annual Gulf of Mexico Information Transfer Meeting. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-005. Pp. 183–200.

Sammarco, P.W., A. Atchison, and G.S. Boland. 2004. Expansion of coral communities within the northern Gulf of Mexico via offshore oil and gas platforms. Marine Ecology Progressive Series 280:129–143.

Sammarco, P.W. and D.A. Brazeau. 2001. Genetic affinity between corals, including spat, at three tropical W. Atlantic sites: Where do the larvae go? Proceedings: Thirtieth Scientific Meeting of the Association of Marine Laboratories of the Caribbean (AMLC), La Parguera, Puerto Rico. P. 31.

Sammarco, P.W. and J.H. Carleton. 1982. Damselfish territoriality and coral community structure: Reduced grazing and effects on coral spat. In: Gomez, E.D., C.E. Birkeland, R.W. Buddemeier, et al., eds. The Reef and Man, Proceedings: Fourth International Coral Reef Symposium. Manila, Philippines 1:525–535.

Stake, J.L. and P.W. Sammarco. 2003. Effects of pressure on swimming behavior in planula larvae of the coral *Porites astreoides* (Coelenterata, Scleractinia). Journal of Experimental Marine Biology and Ecology 288:181–201.

Vermeij, M.J.A., E. Sampayo, K. Broeker, and R.P.M. Bak. 2003. Variation in planulae release of closely related coral species. Marine Ecology Progressive Series 247:75–84.

Williams, M., J.D. Floyd, M.J. Salas, D.J. Siveter, P. Stone, and J.M.C. Vinnier. 2003. Patterns of ostracod migration for the 'North Atlantic' region during the Ordovician. Palaeogeography, Palaeoclimatology, Palaeoecology 195:193–228.

Dr. Paul W. Sammarco is a professor at the Louisiana Universities Marine Consortium (LUMCON) and also an adjunct professor in the Department of Oceanography and Coastal Sciences at Louisiana State University. His background is in ecology and evolution, and he has been working in the field of coral reef science for many years. His research interests are interdisciplinary and include the interface of ecology (grazing, larval dispersal and recruitment processes, etc.) with physics (physical oceanography), chemistry (chemical ecology and natural products chemistry), geology (bioerosion, stable isotope geochemistry), and mathematics (modeling of competition in coral populations). He also has interests in environmental policy and science administration.

Amy Atchison is an M.Sc. student in the Department of Oceanography and Coastal Sciences at Louisiana State University and is working with Dr. Paul W. Sammarco at LUMCON. Her interests are in the areas of molecular genetics as applied to the population level; larval dispersal and recruitment processes, particularly in corals; and the impact of oil and gas platforms on coral populations in the Gulf of Mexico.

Gregory S. Boland is a biological oceanographer with the Department of Interior's Minerals Management Service (MMS) in New Orleans, Louisiana. His areas of interest include deep-sea biology, coral reef ecology, artificial reef ecology, and fishery biology. He began his research career at Texas A&M University in 1974 while pursuing his M.S. degree. Prior to his current position with MMS, he served as a principal investigator on numerous large Gulf of Mexico studies at LGL Ecological Research Associates in Bryan, Texas including offshore platform studies, deep-sea biology and coral reef monitoring projects. He also worked ten years with Gil Rowe at Texas A&M University's Department of Oceanography on a variety of benthic ecology studies worldwide, including the development and operation of a deep-sea benthic lander.

GENETIC AFFINITIES BETWEEN CORALS ON THE FLOWER GARDEN BANKS VS. OIL/GAS PLATFORMS IN THE NORTHERN GULF OF MEXICO: IMPLICATIONS FOR DISPERSAL

Amy D. Atchison and Paul W. Sammarco, Department of Oceanography and Coastal Science, Louisiana State University and Louisiana Universities Marine Consortium (LUMCON)
Daniel A. Brazeau, Pharmaceutical Genetics Laboratory, University of Buffalo

Introduction

The introduction of oil and gas platforms into the Gulf of Mexico (GOM) has provided substratum for colonization of a variety of marine organisms (Shinn 1973; Driessen 1989). Platforms extend through the euphotic zone, providing hard substrate in open water (Shinn 1973, 1974), that would otherwise be unavailable to sessile, epibenthic organisms, allowing them to expand their normal range of distribution. Several coral species (*Diploria* sp., *Porites astreoides*, *Madracis decactis*, etc.) have been found on GOM platforms (Bright et al. 1991; Sammarco and Atchison, 2004; Sammarco et al., 2003, 2004).

The Flower Garden Banks (FGB) are coral reefs that have developed on the surface of salt diapers. The banks are located in the NW GOM, ~110 miles SE of Galveston, Texas, and comprise two banks: the East and West Banks (Rezak et al. 1983) possessing 20 coral species (Bright et al. 1984; Gittings et al. 1992). Three hermatypic species found there dominate the coral community on the platforms surveyed in the vicinity of the FGB (Sammarco et al. (2003, 2004): *Madracis decactis* Lyman 1859, *Diploria strigosa* Dana 1846, and *Montastraea cavernosa* Linnaeus, 1767.

Madracis decactis, a hermaphroditic brooder (Diekmann et al. 2001; Vermeij et al. 2003), uses internal fertilization, and embryos develop within the parent for several weeks before they are released (Carlon 1999). Brooders typically planulate monthly, releasing larvae up to ten times a year (McGuire 1998). *Diploria strigosa* and *Montastraea cavernosa* are broadcast spawners, which release eggs and sperm for external fertilization and development. Both of these species participate in an annual mass spawning of gametes (Hagman et al. 1998a, b), occurring over seven to ten evenings during August and occasionally September (depending on mean SSTs).

To determine the level of inter-connectedness of corals in this offshore environment, we examined the degree of genetic affinity between populations of adult hermatypic corals on the FGB and seven platforms surrounding them (numbered here 1–7, W to E), using the above three dominant species – *Madracis decactis*, *Diploria strigosa*, and *Montastraea cavernosa*. We used AFLPs—a molecular genetic DNA-fingerprinting technique—to accomplish this.

Materials and Methods

Sample Collection

Adult coral tissue samples were collected from the three species from 0–30 m depth. The total number of samples collected per species varied between platforms, depending on abundance. SCUBA divers collected samples with a hammer and chisel from the edge of each colony. On shipboard, tissue samples were preserved in bags containing a high-salt buffer. Samples were stored at room temperature in ice chests and returned to the laboratory for DNA analysis.

Laboratory Procedures

In the lab, tissue was removed from the colonies with a scalpel and placed into 1.7 ml labeled centrifuge tubes. The DNA was isolated and purified using the Wizard® SV Genomic DNA Purification System (Promega Corp), following manufacturer's instructions for animal tissue. Pre-processed samples were then capped and stored at -20ºC.

AFLP analysis was performed according to the protocol of Vos et al. (1995). Complete procedural details may be found in Brazeau et al. (submitted). Products of the selective PCR were separated on a 5% polyacrylamide (sequencing) gel, and the banding patterns were analyzed using a Kodak Digital Image analysis software (Eastman Kodak Co. Scientific Imaging Systems).

Statistical Analyses

Two statistical analyses were used to analyze the banding data: Analysis of Molecular Variance (AMOVA, Excoffier et al. 1992), and AFLPOP (Duchesne and Bernatchez 2002). AMOVA estimates population differentiation directly from molecular data and tests hypotheses about such differentiation. AFLPOP uses AFLP data to calculate log-likelihood values for individuals derived from a reference population, based on banding patterns. A minimal log-likelihood difference of one was used in these AFLPOP analyses, indicating that the program will only allocate individuals to a particular population only if it is ten times more likely to occur or belong in that population than in any other. It is a conservative setting and often results in individuals not being assigned to any population.

Results

AMOVA

*Madracis decactis***.** Nine populations were analyzed—from Platforms 1–7, and the East and West FGB—using a bootstrap analysis of 1000 iterations. Firstly, the two FGBs were found to be genetically homogeneous. The *M. decactis* population from Platform 1 (platform furthest west) was significantly different from all others. The population from Platform 2 was significantly different from Platforms 1, 3, 5, 6, and 7. The West FGB was genetically homogeneous with all populations, except Platform 1. Platform 3 (located between the two banks) was significantly different from Platforms 1, 2, 4, and 6. The East FGB and Platform 4 were significantly different from Platforms 1, 6, and 7. Platform 5 was significantly different from Platforms 1, 2, and 6. The population from Platform 6 was significantly different from all populations, except the West

FGB. Platform 7 (platform furthest east) was significantly different from all populations, except the West FGB and Platforms 3 and 5.

Diploria strigosa. *D. strigosa* populations from the East and West FGB as well as Platforms 3, 5, and 7 were analyzed here. Again, the two FGBs were found to be genetically homogeneous. AMOVA analysis demonstrated that the West FGB population was significantly different from those on Platform 3. The population on Platform 3 was highly significantly different from those on the West FGB and Platform 5. In addition, Platform 7 was significantly different from Platform 5. The East FGB was genetically homogeneous with all other populations.

Montastraea cavernosa. Three *M. cavernosa* populations, East and West FGB and Platform 7, were analyzed. The two FGBs were highly significantly different from one another. Platform 7 was found to be homogeneous only with the West FGB.

AFLPOP

Madracis decactis. In comparison to *Diploria strigosa* and *Montastraea cavernosa*, a higher portion of the *Madracis decactis* colonies were identified as being heterogeneous when comparing populations at other sites, indicating high connectivity between sites. The EAST and West FGB had two of the lowest percentages of allocation of colonies back to the reef of origin, approximately 26% and 32% respectively. Platforms 1 and 6 exhibited the lowest levels of genetic affinity between *M. decactis* populations at their reference site *vs*. other sites; these populations were also shown to be significantly different from all other populations via the AMOVA analysis. They also had the lowest percentages of non-allocated individuals (individuals who were not assigned to any population), approximately 6% and 3% respectively. The populations on Platforms 3 and 4 had approximately 38% of the colonies allocated back to their respective reference populations, with 59% of the colonies not allocated to any population.

Diploria strigosa. By contrast, AFLPOP analysis allocated most of the *Diploria strigosa* colonies considered here back to their reference populations, indicating very low genetic affinity with other sites. Populations from the EAST and West FGBs showed the lowest degree of genetic affinity with *D. strigosa* populations at their reference site *vs*. other sites. *D. strigosa* at the two banks also had the highest percentage of non-allocated colonies, approximately 64%. Platforms 5 and 7, well to the east, were unique and had 100% allocation of colonies back to their respective reference populations.

Montastraea cavernosa. The *Montastraea cavernosa* had the highest percentages of colonies allocated back to the reference population when analyzed via AFLPOP. Both FG banks had a much higher rate of self-allocation than the other two species considered here. The population at Platform 12 had 74% of the colonies allocated to its population of origin with approximately 25% of the colonies not assigned to any population.

Discussion and Conclusions

When examining these three sets of genetic affinity patterns, one must take into account the reproductive mode that each uses in nature. *Madracis decactis* is a brooding species that releases fully developed larvae, swimming planulae once a month for up to eight to ten months of the year. In contrast, *Diploria strigosa* and *Montastraea cavernosa* are broadcast spawners that release eggs and sperm for external fertilization once per year via mass spawning during the late summer. Current coral larval dispersal theory would predict that the broadcast spawning species should be found over a greater geographic range than the brooders. This is because broadcast larvae should be able to colonize over long distances more readily than brooders, but this hypothesis was not borne out. The genetic signatures of *D. strigosa* and *Montastraea cavernosa* on the FGB and the platforms clearly indicated that populations at those sites were highly self-contained, with a minimum of genetic connectivity between them. This was indicated by the proportion of colonies that were allocated back to the reference population in each case. Only a nominal number of colonies were identified as similar at other sites.

Brooded larvae are expected to have shorter dispersal capabilities than to broadcast larvae due to the amount of time the latter larvae are obligated to spend in the water column. Brooders can settle within $\geq$ four hours, while broadcasters must spend a minimum of two to three days in embryonic development before they are competent to settle. Our results, however, do not support this concept. Here, the genets derived from a brooding species were found to be more widely dispersed throughout the ecosystem than those of a broadcasting one—at the meso-scale. The broadcast larvae, despite their ability to disperse widely over long distances, do not appear to be as effective as the brooded ones in colonizing broadly.

These results imply that a brooding species of coral is more effective in dispersing its progeny over a wider region than a broadcasting species by utilizing the "stepping stone" strategy (Kimura and Weiss 1964; MacArthur and Wilson 1967). That is, brooders, on the whole, release fewer larvae per planulation period and disperse their larvae over shorter distances in the short term. Since neighboring settlement sites are nearby, however, (within kms to tens of kms), they have a higher probability of successfully locating suitable substrata within a short period of time. Broadcast larvae, however, by the time they are competent to settle, have not only been dispersed through advection (currents) but have experienced strong diffusional effects as well (Okubo 1994; Sammarco 1994). Thus, the density of larvae will have been decreased greatly.

Based on these results, we conclude that, counter to current theory regarding larval dispersal in corals, populations of brooding species such as *Madracis decactis* are highly effective at dispersing their larvae over a wide region where suitable habitats are inter-dispersed at distances on the order of kms to tens of kms. They are able to carry this dispersal out via the "stepping stone" strategy common in many populations of organisms. Species such as this one appear to be more effective at this type of dispersal than broadcasting species, *e.g. Diploria strigosa* or *Montastraea cavernosa*. Future studies over a larger geographic range, *e.g.* hundreds to thousands of kms, will indicate whether broadcast larvae are more effective at dispersing over larger distances.

We also conclude that AFLPs are an appropriate and powerful tool by which to conduct DNA-fingerprinting studies on scleractinian corals and determine degrees of genetic affinity between populations within a species.

Acknowledgments

Special thanks to G. Boland, G. Bunch, C. Chauffe, J. Conklin, J. Culbertson, L. Dauterive, B. DeFelice, T. Dempre, D. Dowdy, T. Empey, S. Kolian, L. Logan, K. de Mutsert, G. Rainey, G. Speyrer, and J. Van der Ham for assistance in sample collection, Crew of the *M/V Fling* (Gulf Diving, Inc.), and Anadarko Petroleum, Apache Oil, Coastal Oil and Gas, Devon Oil, Dominion Exploration and Production, El Paso Energy, Forcenergy/Forest Oil, Kerr-McGee Oil and Gas, Merit Energy, Newfield Exploration, Noble Energy, UNOCAL, Samedan Oil, Chevron-Texaco Exploration and Production, and W&T Offshore. Thanks to J. Benzie for the suggestion to use AFLPs on corals. This project is funded in part by U.S. Department of Interior, Minerals Management Service, Louisiana State University Coastal Marine Institute, Louisiana Universities Marine Consortium (LUMCON), and J. Bennett Johnston Science Foundation.

References

Bright T.J., S.R. Gittings, and R. Zingula. 1991. Occurrence of Atlantic reef corals on offshore platforms in the northwestern Gulf of Mexico. Northeast Gulf Science 12:55–60.

Bright T.J., G.P. Kraemer, G.A. Minnery, and S.T. Viada. 1984. Hermatypes of the Flower Garden Banks, northwestern Gulf of Mexico: A comparison to other western Atlantic reefs. Bulletin of Marine Science 34:461–476.

Carlon, D.B. 1999. The evolution of mating systems in tropical reef corals. Trends in Ecology and Evolution 14:491–495.

Diekmann, O.E., R.P.M. Bak, W.T. Stam, and J.L. Olsen. 2001. Molecular genetic evidence for probable reticulate speciation in the coral genus *Madracis* from a Caribbean fringing reef slope. Marine Biology 139:221–233.

Driessen, P.K. 1989. Offshore oil platforms: Mini-ecosystems. In: Reggio, V.C., ed. Petroleum Structures as Artificial Reefs: A Compendium. Fourth International Conference on Artificial Habitats for Fisheries, Rigs-to-Reefs Special Session. Miami, FL. OCS Study MMS 89-0021. Pp. 3–6.

Duchesne, P. and L. Bernatchez. 2002. AFLPOP: A computer program for simulated and real population allocation using AFLP markers. Molecular Ecology Notes 2:380–383.

Excoffier, L., P.E. Smouse, and J.M. Quatrro. 1992. Analysis of molecular variation inferred from metric distances among DNA haplotypes: Application to human mitochondrial DNA restriction data. Genetics 131:479–491.

Gittings, S.R., G.S. Boland, K.J.P. Deslarzes, C.L. Combs, B.S. Holland, and T.J. Bright. 1992. Mass spawning and reproductive viability of reef corals at the East Flower Garden Bank, northwest Gulf of Mexico. Bulletin of Marine Science 51:420–428.

Hagman, D.K., S.R. Gittings, and K.J.P. Deslarzes. 1998a. Timing, species participation, and environmental factors influencing annual mass spawning at the Flower Garden Banks(Northwestern Gulf of Mexico). Gulf of Mexico Science 2:170–179.

Hagman, D.K., S.R. Gittings, and P.D. Vize. 1998b. Fertilization in broadcasting-spawning corals of the Flower Garden Banks National Marine Sanctuary. Gulf of Mexico Science 2:180–187.

Kimura, M. and G.H. Weiss. 1964. The stepping stone model of population structure and the decrease of genetic correlation with distance. Genetics 49:561–576.

MacArthur, R.H. and E.O. Wilson. 1967. The Theory of Island Biogeography. New Jersey: Princeton University Press. 203 pp.

McGuire, M.P. 1998. Timing of larval release by *Porites astreoides* in the northern Florida Keys. Coral Reefs 17:369–375.

Okubo, A. 1994. The role of diffusion and related physical processes in dispersal and recruitment of marine populations. In: Sammarco, P.W. and M.L. Heron, eds. The Bio-Physics of Marine Larval Dispersal. Washington, DC: American Geophysical Union. Pp. 35–72.

Rezak, R., T.J. Bright, and D.W. McGrail. 1983. Reefs and banks of the northwestern Gulf of Mexico: Their geological, biological, and physical dynamics: Final report. U.S. Dept. of the Interior, Minerals Management Service, Outer Continental Shelf Office, New Orleans, LA. MMS-GM-PT-83-015. 502 pp.

Sammarco, P.W. 1994. Larval dispersal and recruitment processes in Great Barrier Reef corals: Analysis and synthesis. In: Sammarco, P.W. and M.L. Heron, eds. The Bio-Physics of Marine Larval Dispersal. Washington, DC: American Geophysical Union. Pp. 35–72.

Sammarco, P.W. and A.D. Atchison. 2004. Coral communities and recruitment on offshore drilling platforms in the northern Gulf of Mexico: Summary. In: McKay, M. and J. Nides, eds. Proceedings: Twenty-second Annual Gulf of Mexico Information Transfer Meeting, January 2003. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, Kenner, LA. OCS Study MMS 2003-073. Pp. 6–7.

Sammarco, P.W., A.D. Atchison, and G.S. Boland. 2003. Drilling platforms as environmental assets: Developing an assessment protocol using adult and juvenile corals. In: McKay, M. and J. Nides, eds. Proceedings: Twenty-first Annual Gulf of Mexico Information Transfer

Meeting, January 2002. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, Kenner, LA. OCS Study MMS 2003-005. Pp. 183–200.

Sammarco, P.W., A.D. Atchison, and G.S. Boland. 2004. Offshore oil and gas platforms and expansion of coral communities within the Northern Gulf of Mexico. Marine Ecology Progress Series 280:129–143.

Shinn, E.A. 1973. Pipes, plankton, and pompano. In: Man-made oasis for fish. Shell Reprint 17, 1-463-6-73. Pp. 6–7.

Shinn, E.A. 1974. Oil structures as artificial reefs. In: Colunga, L. and R. Stone, eds. Proceedings of an International Conference on Artificial Reefs, March 1974. Houston, TX. TAMU-SG-74-103. Pp. 91–96.

Vermeij, M.J.A., E. Sampayo, K. Broker, and R.P.M. Bak. 2003. Variation in planulae release of closely related coral species. Marine Ecology Progress Series 247:75–84.

Vos, P., R. Hogers, M. Bleeker, M. Reijans, T. Vandelee, M. Hornes, A. Frijters, J. Pot, J. Peleman, M. Kuiper, and M. Zabeau. 1995. AFLP – A new technique for DNA-fingerprinting. Nucleic Acids Research 23:4407–4414.

Amy Atchison is an M.Sc. student in the Department of Oceanography and Coastal Sciences at Louisiana State University and is working with Dr. Paul W. Sammarco at LUMCON. Her interests are in the areas of molecular genetics as applied to the population level; larval dispersal and recruitment processes, particularly in corals; and the impact of oil and gas platforms on coral populations in the Gulf of Mexico.

Dr. Paul W. Sammarco is a professor at the Louisiana Universities Marine Consortium (LUMCON) and also an adjunct professor in the Department of Oceanography and Coastal Sciences at Louisiana State University. His background is in ecology and evolution, and he has been working in the field of coral reef science for many years. His research interests are interdisciplinary and include the interface of ecology (grazing, larval dispersal and recruitment processes, etc.) with physics (physical oceanography), chemistry (chemical ecology and natural products chemistry), geology (bioerosion, stable isotope geochemistry), and mathematics (modeling of competition in coral populations). He also has interests in environmental policy and science administration.

Dr. Daniel A. Brazeau is the Director of the Pharmaceutical Genetics Laboratory, Department of Pharmaceutical Sciences, University of Buffalo. His research interests lie in directing a lab that provides training and research support for a wide array of molecular genetic techniques to address a broad range of questions, including gene expression, bioinformatics, and genotyping in a broad array of organisms. His expertise includes the following techniques: Restriction fragment

length polymorphisms (RFLPs), multilocus fingerprinting (AFLPs, ISSRs), single nucleotide polymorphisms (SNPs), microsatellites, mRNA differential display, northern analysis, serial analysis of gene expression (SAGE), DNA microarrays, and real-time PCR.

SESSION 1H

SENSITIVE BIOLOGICAL HABITATS OF THE GULF OF MEXICO: WETLANDS TO CORAL REEFS

Chair: **James Sinclair, Minerals Management Service**

Co-Chair: **Herb Leedy, Minerals Management Service**

SEAFLOOR MAPPING IN THE FLOWER GARDEN BANKS REGION, NORTHWESTERN GULF OF MEXICO

Douglas C. Weaver, Emma L. Hickerson, and George P. Schmahl,
Flower Garden Banks National Marine Sanctuary,
National Oceanic and Atmospheric Administration
Christine Taylor, National Marine Sanctuary Program,
National Oceanic and Atmospheric Administration
Troy Holcombe, Department of Oceanography, Texas A&M University
Shepherd Smith, NOAA Ship *Thomas Jefferson*, NOAA Office of Coast Survey

The Flower Garden Banks National Marine Sanctuary (FGBNMS), which includes East and West Flower Garden Banks (FGB), is located approximately 185 km south of the Texas/Louisiana border. East and West FGB harbor the northernmost living coral reefs (17–50m) on the continental shelf of the United States and a diversity of deepwater (50 to 150m) marine habitats. The FGBNMS was designated in 1992 under the jurisdiction of the National Oceanic and Atmospheric Administration (NOAA). The FGB were first mapped in the 1930s, and have been the subject of geological and biological investigations since the 1950s. During the 1960s and 1970s, expeditions to the FGB by scuba divers and submersibles, funded by the Houston Museum of Natural Science, the Flower Gardens Ocean Research Center, and later by the Bureau of Land Management, led to the discovery of many unique features within the sanctuary, including remnants of drowned reefs, numerous natural gas seeps, and a modern brine lake and overflow canyon at East Flower Garden Bank.

Mapping efforts at the FGB began in 1937 by the U. S. Coast and Geodetic Survey, using leadlines. Contour maps of increasing resolution were produced over the next 60 years using single beam echosounders, with topographic detail increasing with decreased line spacing and more advanced equipment. During December 1997, The U.S. Geological Survey, the Ocean Mapping Group at the University of New Brunswick, and C&C Technologies conducted sea trials in the northwestern Gulf of Mexico using a Konsberg Simrad EM300 high-resolution multibeam echosounder (MBES). This survey provided the first complete coverage of the FGBNMS, including East and West Flower Garden Bank, and Stetson Bank, to water depths of 150m. New discoveries identified by the resulting high-resolution maps included a deep, anticline rim of patch reefs circling Stetson Bank, vast fields of patch reefs surrounding East and West FGB, various deepwater mounds associated with the banks, and extensive faulting that extended beyond the existing sanctuary boundaries. While the multibeam maps provided new insights into habitat distribution at FGBNMS, the area between the banks remained unmapped by detailed single beam or multibeam surveys.

Contour maps of the FGBNMS region produced by colleagues at TAMU, using existing single beam echosounder and leadline data archived in NOAA-NGDC data sets, identified numerous topographic features occurring between East and West FGB, and in deeper waters south of the region. These features corresponded with reported areas of drowned and buried patch reefs, salt diapirs and faults occurring between EFGB and West Flower Garden Bank. Despite the occurrence of these unique geological features, no detailed maps were available for this region. Bathymetric surveys of EFGB, WFGB, and Stetson Bank have been conducted since the 1930s using single beam echosounders, and were surveyed in the 1990s using high-resolution multibeam echosounders (MBES). However, areas of the outer shelf and upper slope surrounding the sanctuary were poorly mapped, and deepwater reef communities between East and West FGB were unknown.

During April 2004, a hydrographic survey was conducted aboard the NOAA Ship THOMAS JEFFERSON to provide information on habitat distribution and classification to the FGBNMS, and provide a source of bathymetry for updating existing National Ocean Service (NOS) charts. Data were acquired by the NOAA Ship THOMAS JEFFERSON using a Simrad EM1002 MBES and GPS-aided inertial navigation system. NOAA launches 1014 and 1005 acquired multibeam data with GPS-aided inertial navigation systems and RESON 8125 and RESON 8101 MBES, respectively.

High-resolution multibeam mapping of the mid- to outer continental shelf resulted in the discovery of previously unknown features on the seafloor. A series of mud volcanoes, a deep reef escarpment, a submarine canyon, and over 2,000 deep-patch reefs were identified, providing a continuous network of deep-reef communities between East and West FGB (Figures 1H.1 and 1H.2). Multibeam surveys of the coral cap also resulted in extremely detailed views of coral distribution (Figures 1H.3 and 1H.4). Multibeam bathymetry data were incorporated into Arcview 3.2 projects as geo-tiffs, and as 3D maps using Fledermaus Interactive Visualization Systems. Habitat polygons were visually traced in Arcview 3.2 to identify distribution of habitat types, and estimate total area of habitat types within the sanctuary and the region (Figure 1H.2).

Acknowledgments

We would like to thank the captain and crew of the NOAA ship *Thomas Jefferson* for their tremendous enthusiasm and efforts during the 2004 multibeam survey. We thank Dr. Jim Gardner, University of New Hampshire (formerly of USGS), for providing supplemental multibeam data. Figure 1H.1 was provided courtesy of International Mapping Associates, Ellicot City, MD and the National Marine Sanctuary Program Headquarters, Silver Spring, MD.

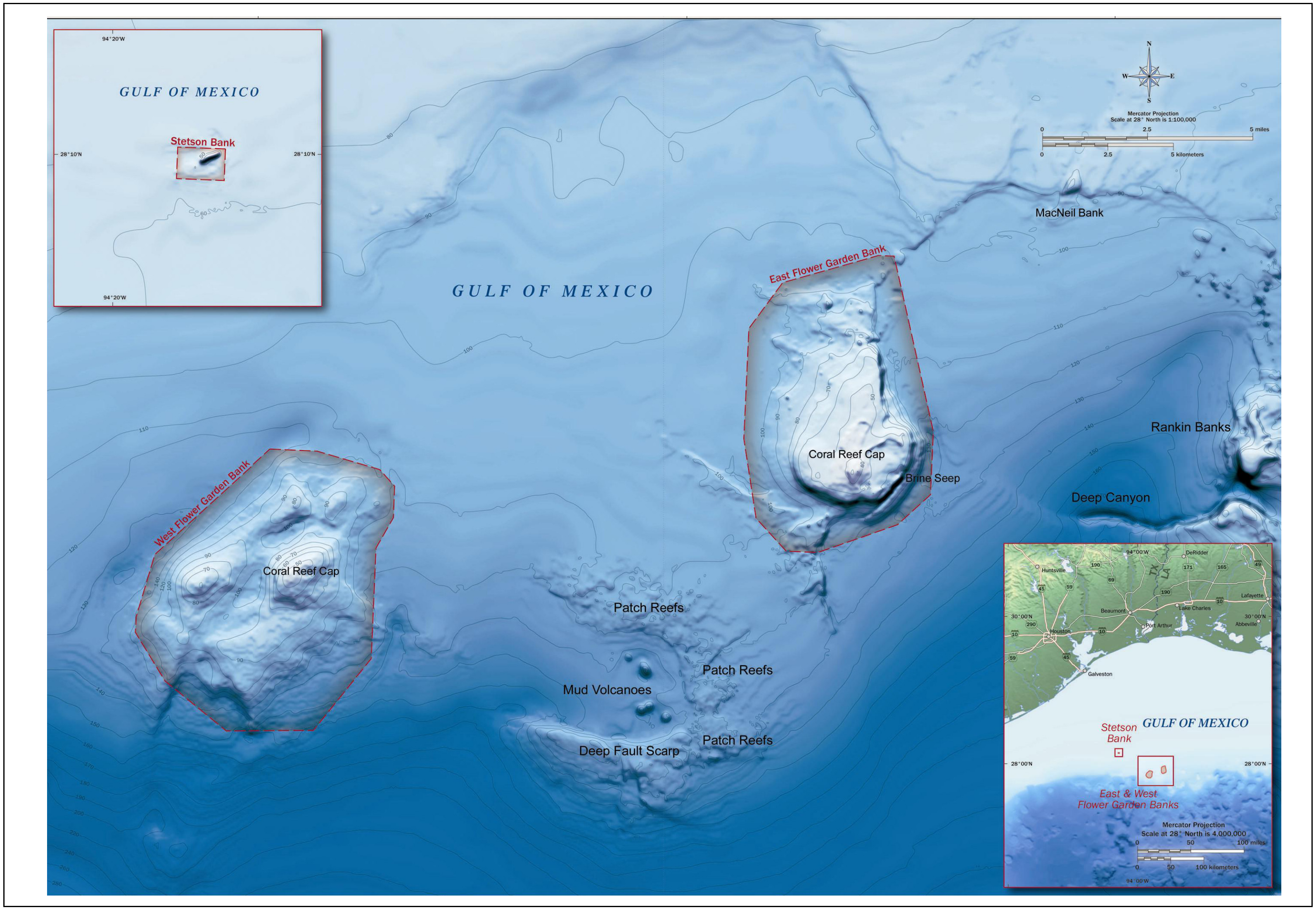


Figure 1H.1. Flower Garden Banks Region of the Northwestern Gulf of Mexico.

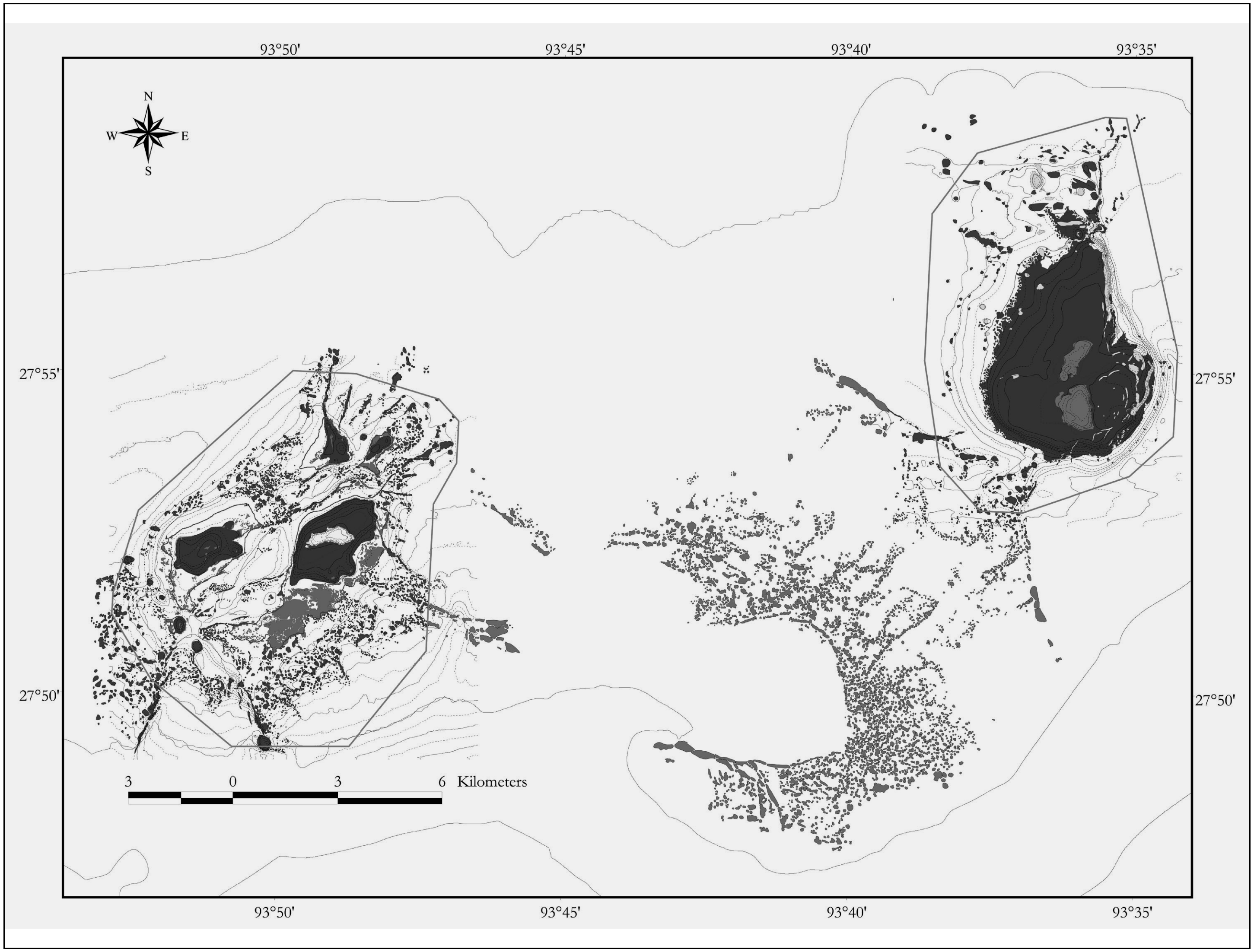


Figure 1H.2. Habitat Map of the Flower Garden Banks Region, showing distribution of hard-bottom and patch reefs, as interpreted from bathymetry and acoustic backscatter data.

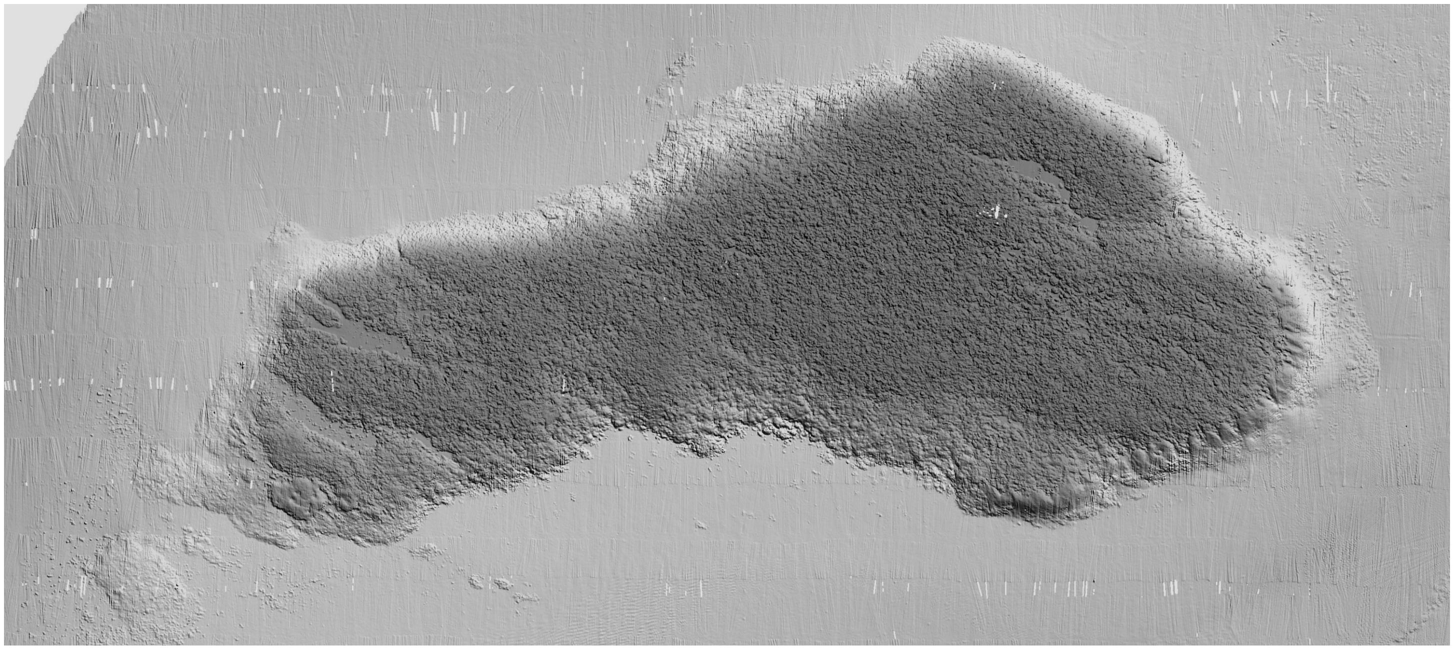


Figure 1H.3. Coral Reef Cap of the West Flower Garden Bank, interpolated at 0.5m resolution.

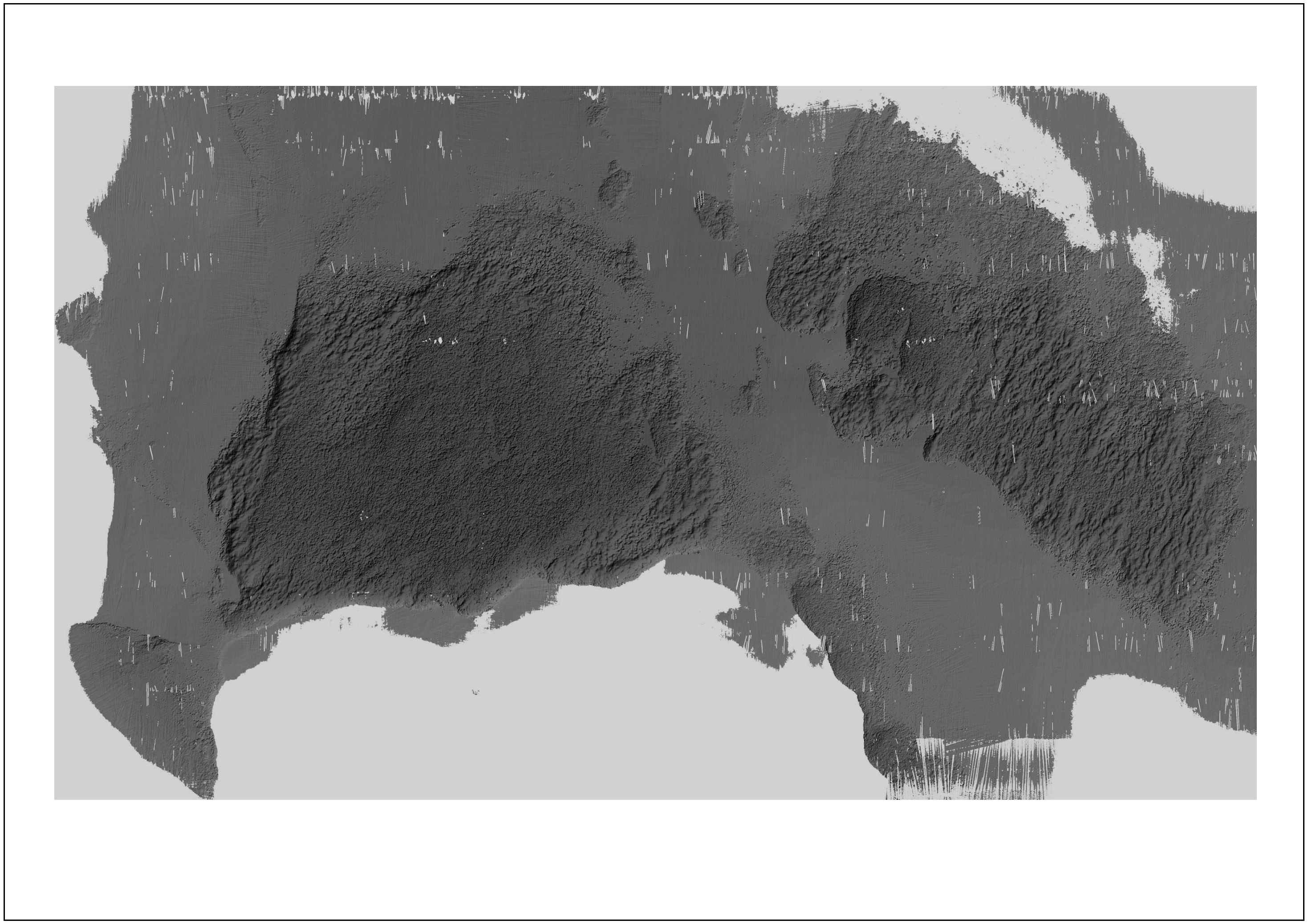


Figure 1H.4. Coral Reef Cap of the East Flower Garden Bank, interpolated at 0.5m resolution.

Douglas C. Weaver is a research biologist/GIS specialist at the Flower Garden Banks National Marine Sanctuary. He has over 18 years of experience in research in marine ecosystems. He has participated in over 50 research cruises as Research or Chief Scientist, including three multibeam mapping surveys, and has conducted over 800 SCUBA dives in the Gulf of Mexico and Florida. Mr. Weaver received his B.S. in marine biology from Millersville University, PA and his M.S. in zoology from the University of Florida. His main research interests are reef fish biology and ecology, seafloor mapping/ habitat characterization, and landscape ecology.

Emma Hickerson has held the position of research coordinator of the Flower Garden Banks National Marine Sanctuary since 1997. She began her career at the Sanctuary while still a graduate student at Texas A&M University, conducting satellite tracking studies on loggerhead sea turtles living on the reef. During her tenure in the current position with the Sanctuary, she has coordinated over 50 research cruises, including SCUBA, ROV, and submersible operations. Her interests have expanded beyond sea turtles, to include most ecological and biological aspects of the Sanctuary, with recent efforts being placed on the deepwater habitats of the Sanctuary, and adjacent areas.

G.P. Schmahl. has been the manager of the Flower Garden Banks National Marine Sanctuary since March 1999. Prior to that he served for eight years as the Lower Keys Regional Manager of the Florida Keys National Marine Sanctuary in Key West, Florida. As Sanctuary manager, he is involved with a broad array of Marine Protected Area management issues including research, education and resource protection. After obtaining a graduate degree in zoology from the University of Georgia, G.P. has held a variety of positions relating to marine research, coastal management, resource planning and environmental regulation. His primary interest is the ecology and management of coral reefs and associated ecosystems, and he has specific interest and expertise in the biology and ecology of marine sponges.

LONG-TERM REEF MONITORING OF THE EAST AND WEST FLOWER GARDEN BANKS: NEW SURPRISES

William F. Precht and Martha L. Robbart, Ecological Sciences Division, PBS&J
Richard B. Aronson, Dauphin Island Sea Lab
Ken J. P. Deslarzes, Marine Sciences Group, Geo-Marine Inc.
Les Kaufman, Center for Ecology and Conservation, Boston University

The Flower Garden Banks (FGB) coral reef monitoring program has been continuously funded since 1988 by the Minerals Management Service (MMS) and in partnership with NOAA's National Marine Sanctuary Program since 1996. Two sites, each 100 m x 100 m and 18–25 m deep, have been monitored over that period: one on the East FGB and the other on the West FGB. The two sites remain in excellent condition. Their status contrasts with reports of reefs in crisis throughout the southern Gulf of Mexico, the western Atlantic, and the Caribbean region.

Across the Caribbean, regional disease outbreaks have changed the structure and function of reefs over relatively short time scales, and while scientists observed the changes, they still do not completely understand the causes. Beginning in the 1970s and continuing up to the present, diseases or disease-like syndromes have appeared in many coral species throughout the western Atlantic and Caribbean. Although coral diseases are present on the FGB, their prevalence is low compared to that on most other reefs that have been surveyed. The short- and long-term impacts of coral diseases on populations remain difficult to assess, but disease is clearly a factor in the mortality of some corals on the FGB.

In addition to disease, widespread coral bleaching in response to anomalously high summer-season temperatures has become more frequent since the early 1980s. Bleaching episodes on reefs in the western Atlantic-Caribbean region, including the FGB, have generally been followed by recovery of most of the affected coral colonies (Hageman and Gittings 1992; Aronson et al. 2002). Other causes of coral mortality on the FGB include concentrated spot-biting by parrotfish, resulting in large lesions on head corals, as well as the impacts of damselfish territories, which result in patchy areas of coral mortality and algal growth on affected colonies.

Remarkably, no significant long-term changes have been detected in coral reef populations, total coral cover, or coral species diversity at the FGB since quantitative surveys of the reefs began in 1988. Percent coral cover on these reefs is among the highest measured at present in the entire region. Probable reasons for the exceptional condition of the FGB include 1) the water depth of the reefs, which buffers them from the effects of storm waves and anomalously high sea temperatures; 2) the lack of acroporid corals, which have suffered catastrophic levels of mortalities throughout the Caribbean; 3) the remote, offshore location of these reefs, which provides a water column characterized by oligotrophic, oceanic water; 4) healthy fish populations that include all trophic guilds; and 5) protective Federal regulations, which prevent hydrocarbon-related impacts, and impacts caused by fishing and recreational diving activities.

Corals are the dominant cover on both reefs, accounting for over 50% cover in both cases. A category comprising bare rock and turf-covered rock is the second-most prevalent at ~ 25%, followed by crustose coralline algae at ~15%. Macroalgae and filamentous algae are next in abundance at ~5%, followed by sponges, which account for ~1% of total cover. In addition to assessing benthic community structure, we are also measuring coral growth rates, incidence of coral mortality, associated mobile fauna, fish population structure, and water quality parameters. New additions to the monitoring program include the establishment of deep reef stations at the East Bank in 31–40m depth.

Recent surprises at the FGB include the first known colony of *Acropora palmata*, the first sighting of the exotic coral *Tubastraea coccinea*, the initial recovery of the sea urchin *Diadema antillarum* on the West Bank, and occasional outbreaks of plague-like coral diseases. As previously mentioned, reef condition at the FGB is currently exceptional and shows essentially no difference in species composition or total coral cover from early monitoring studies. Therefore, understanding the role of these reef environments in the context of the greater Caribbean is of critical importance. Continued long-term monitoring of these reefs will enhance our knowledge of community dynamics at the FGB in particular and provide insight about coral reefs in general.

William F. Precht is a carbonate sedimentologist by training, and has been studying coral reefs since 1978. His research interests include combining ecological and geological methodologies to decipher "change" in reef communities through time and space. Using this integrated approach, he (with collaborators Richard B. Aronson and Ian Macintyre) has been able to assess the geological and ecological novelty of many of the recent maladies affecting Caribbean coral reefs. This assessment includes deciphering local anthropogenic signals from overarching global effects. Specific research has included the effects of coral disease and coral bleaching on the trajectories of reef coral communities. Since completing his graduate degree in marine geology and geophysics from the University of Miami's Rosenstiel School of Marine and Atmospheric Science, Bill has worked as an environmental scientist specializing in the ecology of coastal systems. Presently, he is the chief scientist overseeing the long-term reef monitoring at the Flower Garden Banks National Marine Sanctuary. In addition, he developed cutting edge assessment and restoration strategies for reefs impacted by various anthropogenic sources, including providing expert assistance to a wide array of both national and international clients.

Richard B. Aronson received his A.B. in biological sciences from Dartmouth College in 1979 and his Ph.D. from Harvard University in biology in 1985. He is currently Senior Marine Scientist at the Dauphin Island Sea Lab in Alabama. Rich has been working on coral reefs for decades, focusing on disease, climate change, and other large-scale factors that cause turnover of reef faunas. He pioneered the use of videographic methods for surveying coral reefs, and he developed the univariate and multivariate statistical approaches needed to analyze the data. Rich's techniques are now being used by reef managers throughout the western Atlantic and

Caribbean region. Rich's research combines survey and monitoring work with paleoecology to understand the history, present status and future of coral reefs.

Dr. Ken Deslarzes is a Senior Marine Ecologist at Geo-Marine Inc. and has extensive experience in coral reef science with an emphasis on resource assessment studies conducted since 1988 (nine studies). His Ph.D. research while at Texas A&M was conducted at the Flower Garden Banks: "Long-term monitoring of reef corals at the Flower Garden Banks (northwest Gulf of Mexico): reef coral population changes and historical incorporation of barium in *Montastrea annularis*." Dr. Deslarzes has 32 publications (refereed papers, theses, reports, conference products), 23 of which are directly related to the FGB coral reefs. His most recent coral reef research dealt with identifying the source of luminescent banding in *Montastraea faveolata* at the Flower Gardens (submitted to *Coral Reefs*) and the dispersal of coral larvae from the Flower Gardens (2001 *Continental Shelf Research*).

Dr. Les Kaufman works on the scientific underpinnings for marine conservation and sustainability of the human enterprise in the world's oceans. Specifically, Dr. Kaufman's research has focused on the ecology of coral reef fisheries. These fisheries have had a profound impact not only on edible species but also on entire marine nearshore communities as well, via the cascading ecological effects of the removal of target biomass. In a series of studies, Dr. Kaufman's lab is developing the scientific basis for a shift from data-poor, single-species impact management, to information-rich, ecosystem-based management. One focus of this work includes field studies of fish movements in and out of protected areas using acoustic telemetry. To this end, Dr. Kaufman is studying the movements of individual cod and haddock in and around the Western Gulf of Maine Closure in the Stellwagen Bank National Marine Sanctuary (Massachusetts Bay) and in and out of Special Protected Areas in the Florida Keys National Marine Sanctuary. He is also conducting experiments on fish-habitat relationships, population modeling, and the development of non-demographic parameters for assessing the health of marine communities that support important fisheries. His work on nearshore fisheries has been supported by the Packard Foundation, the Pew Charitable Trusts, and NOAA. Dr. Kaufman is particularly interested in the movements of reef fish in and around the reefs of the Flower Garden Banks.

Martha L. Robbart is a scientist at PBS&J and has experience in coral reef biology, biochemistry and ecology. Her M.S. degree in biology from Smith College investigated thermal tolerance in scleractinian corals as expressed in heat shock proteins. With a strong background in coral reef ecology, she has been involved in coral reef assessment in Belize, San Salvador Bahamas, and now the Flower Garden Banks National Marine Sanctuary.

MONITORING AT THE FLOWER GARDEN BANKS: METHODOLOGY, EVOLUTION, AND FUTURE

Richard B. Aronson, Dauphin Island Sea Lab
William F. Precht, Ecological Sciences Division, PBS&J

The coral reefs of the Flower Garden Banks (FGB) are among the most sensitive biological communities in U.S. federal waters of the Gulf of Mexico. In 1973, the Minerals Management Service (MMS) established a program of protective activities at those reefs. Two sites, each 100 m x 100 m and 17–26 m deep, have been monitored since 1988: one on the East FGB and the other on the West FGB. MMS has been monitoring the coral populations at these sites on a long-term basis to detect incipient changes caused by oil and gas activities. The results are also helping to explain the rampant degradation of reef ecosystems observed in the wider Caribbean region over the last few decades.

The percent coverage of living coral within the study sites was assessed visually from 1978–1982 using the linear point-intercept (LPI) method. A diver swam along transect lines, recording the substratum components at set intervals. During the period 1988–2002, coral cover was estimated by taking still photographs along randomly placed, 10-m transects. In this technique, the estimates were derived by planimetry of the photographs. As part of a transition to digital imaging, beginning in 2002–03 we videotaped randomly positioned transects and derived estimates of coral cover from point counts on individually captured video frames. To compare the methods, we also estimated coral cover in 2002–03 using the LPI technique and planimetry of still photographs.

The total area analyzed from the videotapes was 30.24 m^2 per site per year (14 transects x 20 frames/transect x 1080 cm^2/frame). In contrast, the photographic technique covered more than twice the area, at 65.97 m^2 per site per year (14 transects x 17 frames/transect x 2,772 cm^2/frame). The LPI design is unidimensional, so there is no 'area' covered. Despite these differences in area covered and analytical technique, comparison of the videographic, photographic and LPI methods in 2002–03 showed that the three approaches gave very similar mean estimates of coral cover. Repeated measures analysis of variance (ANOVA) showed no significant differences among the estimates.

This result demonstrates that the three methods are interchangeable. A methodological change in the long-term monitoring program to digital videography, for which the analysis is far less labor-intensive than planimetry of still photographs, is entirely justified and will not compromise the utility of previous years' data. On the contrary, it is legitimate to compare estimates of coral cover from 2002–03 and future videographic transects to existing records from still images, and from the early LPI transects, without confounding our understanding of coral dynamics at the Flower Garden Banks.

Based on the video transects, the mean coverage of living hard corals exceeded 50% at the two banks in 2002–03, consistent with estimates of coral cover from the LPI data and still photographs in previous years. To determine the sensitivity of the videographic technique, we calculated δ, the minimum difference in coral cover detectable by ANOVA. The significance level was set at the conventional $\alpha = 0.05$ and the desired power at the conventional $(1-\beta) = 0.80$. For videographic surveys of two sites over two years, with 14 transects per site per year, $\delta = 0.074$. In other words, we can expect to be able to detect a 7.4% change in coral cover between any two years at the Flower Garden Banks, or a 7.4% difference in cover between the two banks in a two-year study.

The calculated δ agrees with values of 5.2–9.8% obtained using the videographic method to compare four sites in Florida and the Caribbean, with 10 transects per site and coral cover varying from 3–21%. The δ calculated in the present study is a few percent higher than the minimum detectable difference of 2.4–3.8% calculated for a comparison of three sites in the Florida Keys; however, that study used 30 transects per site and the sites had extremely low cover, both of which reduced the error variance and, therefore, reduced δ.

We also compared our results from 2002–03 to data collected during the same period on protected reefs within the Florida Keys National Marine Sanctuary. Low values of coral cover on the reefs in Florida illustrate how recent, catastrophic mortality of the formerly dominant *Acropora* spp. has led to the degradation of coral assemblages in the Caribbean. The FGB have remained in exceptionally good condition largely for reasons of physical geography. Their northern location has excluded the cold-sensitive acroporids, so the loss of acroporids throughout the region in the 1980s and 1990s did not affect coral cover at the FGB. A single colony of *A. palmata* has now appeared on the FGB, coincident with warming temperatures in the subtropical western Atlantic and northward expansion of acroporids along the east coast of Florida. The continuing, multidecadal baseline of reef condition generated by the monitoring program will enable managers to make informed decisions in the event of future changes to the biota of the Flower Garden Banks.

Richard B. Aronson received his A.B. in biological sciences from Dartmouth College in 1979 and his Ph.D. from Harvard University in biology in 1985. He is currently Senior Marine Scientist at the Dauphin Island Sea Lab in Alabama. Rich has been working on coral reefs for decades, focusing on disease, climate change, and other large-scale factors that cause turnover of reef faunas. He pioneered the use of videographic methods for surveying coral reefs, and he developed the univariate and multivariate statistical approaches needed to analyze the data. Rich's techniques are now being used by reef managers throughout the western Atlantic and Caribbean region. Rich's research combines survey and monitoring work with paleoecology to understand the history, present status and future of coral reefs.

William F. Precht is a carbonate sedimentologist by training, and has been studying coral reefs since 1978. His research interests include combining ecological and geological methodologies to decipher "change" in reef communities through time and space. Using this integrated approach, he (with collaborators Richard B. Aronson and Ian Macintyre) has been able to assess the geological and ecological novelty of many of the recent maladies affecting Caribbean coral reefs. This assessment includes deciphering local anthropogenic signals from overarching global effects. Specific research has included the effects of coral disease and coral bleaching on the trajectories of reef coral communities. Since completing his graduate degree in marine geology and geophysics from the University of Miami's Rosenstiel School of Marine and Atmospheric Science, Bill has worked as an environmental scientist specializing in the ecology of coastal systems. Presently, he is the chief scientist overseeing the long-term reef monitoring at the Flower Garden Banks National Marine Sanctuary. In addition, he developed cutting edge assessment and restoration strategies for reefs impacted by various anthropogenic sources, including providing expert assistance to a wide array of both national and international clients.

FEASIBILITY OF USING REMOTE SENSING TECHNIQUES FOR SHORELINE DELINEATION AND COASTAL HABITAT CLASSIFICATION FOR ENVIRONMENTAL SENSITIVITY INDEX (ESI) MAPPING

Katherine Born-Phillips, Chris Locke, and Jacqueline Michel,
Research Planning, Inc.
DeWitt Braud, Coastal Studies Institute, Louisiana State University

Introduction

Environmental Sensitivity Index (ESI) mapping refers to a shoreline classification and sensitivity ranking system that has been a vital component of oil spill contingency planning and marine environmental assessment programs nation wide for 25 years (Halls et al. 1997). The U.S. Minerals Management Service (MMS) currently uses ESI data and the ESI classification scheme for environmental assessment studies related to Outer Continental Shelf (OCS) activities.

Traditional ESI data development includes the interpretation of aerial photographs and mapped observations by coastal geologists during overflights. This method has been applied successfully to the majority of the U.S. coastline. The complex, rapidly changing shoreline of Louisiana, however, has made ESI mapping extremely difficult using traditional techniques. As a result, a coast-wide ESI shoreline classification has never been developed for Louisiana. This represents a major information gap, as oil spill risk and environmental consequences in Louisiana are great.

ESI classification efforts in Louisiana in the late 1980s relied on remotely sensed imagery with spatial resolution of 20-30 meters (Jensen et al. 1990). Although a useful land-use/land cover classification was achieved, the detail associated with the linear nature of shoreline features could not be resolved, and a true ESI shoreline classification was not possible. More recently, the barrier island beaches and other outer-coast features of Louisiana were classified using traditional ESI methods, as part of the Gulf-Wide Information System (G-WIS) project (MMS et al. 2001; Zengel and Hanifen 2001; Zengel et al. 2002). This effort was possible due to the linear configuration of the outer coast. Beyond this, most of the Louisiana coast remains unclassified and cannot reasonably be completed using traditional methods. Newer, high-resolution satellite imagery offers the best opportunity for coast-wide ESI shoreline mapping and classification in Louisiana and other similar areas with highly complex, rapidly changing shorelines.

The primary objective of this research was to develop remote sensing classification procedures to support ESI mapping efforts in Louisiana and elsewhere. Several questions comparing remote sensing techniques and traditional classification methods were of interest including:

1. Are remote sensing methods reliable, more cost and time effective, and do they provide as much information as traditional methods?
2. Is the spectral and spatial resolution of the IKONOS satellite imagery chosen for the project appropriate? Is the use of archived imagery for cost savings appropriate?
3. Can a viable land/water interface be created from the imagery? And finally,

4. Can an ESI-style product useful for spill response and coastal management be produced?

The saline areas of the Louisiana coastline from Port Fourchon to Lake Barre were chosen as the study site. Salinity boundaries were obtained from the 1997 Louisiana Coastal Marsh Vegetative Type Map (LDWF 1997) which included values of brackish, fresh, intermediate, saline, and water. In this data set saline was defined as salt marsh having typical vegetation of oystergrass (*Spartina alterniflora*), glasswort (*Avicennia germinans*), and saltgrass (*Distichlis spicata*). This area of coastal Louisiana has experienced high rates of land loss and rapid shoreline change that have made traditional ESI classification techniques difficult. However, the presence of extensive oil and gas infrastructure and highly sensitive habitats and natural resources in this area emphasizes the need for up-to-date maps for oil spill planning and response.

Methods of Study

The study methodology consisted of the following tasks: image acquisition, land/water interface production, *in situ* data collection, image classification, vector shoreline transfer, validation overflight, and an accuracy assessment. In contrast, a traditional ESI project methodology would consist of: identification of existing digital land/water or shoreline, overflight classification on topographic quads, field classification accuracy assessment, and on-screen ESI attributing of the digital shoreline.

Results

The results section describes ten ESI habitat types that were observed during the field work and traditional overflights. For each ESI habitat type, the habitat characteristics are described, and the technical performance of the imagery and classifications techniques are discussed. The text is followed by a sub set of the IKONOS imagery where the ESI habitat is present, a second images shows the imagery with the shoreline classification. An oblique aerial photograph, taken during the overflights, is shown for the same general area of the imagery, and finally a representative ground photograph is provided for each ESI habitat.

Results

The spatial and spectral resolutions of IKONOS imagery adequately captured four broad habitat classes but did not extract the same level of detail as traditional ESI mapping methods. The usefulness and applicability of these broad ESI classifications are dependent on the question at hand. For oil spill response, the relatively current imagery provides a valuable base map that is greatly improved over other available maps. This feature is particularly important in coastal areas experiencing rapid shoreline change. One of the biggest challenges of responders in these areas is access to maps that accurately reflect current conditions so that equipment and personnel can be deployed to appropriate cleanup sites. Currently, responders obtain oblique digital photography during overflights then print out the photographs to use as base maps for use in deploying equipment and mapping the distribution of oil. Recent imagery would provide a more uniform base map. A high resolution shoreline vector was also extracted from the imagery and served as the base for shoreline classes. Creation of an actual shoreline is also of value to spill responders, since miles of shoreline oiled is a common metric used to measure the spill impact on linear shoreline types and track cleanup progress.

Both archived and new-collect imagery were used in this study. The average price for archived imagery was $6.85 per km² whereas the average price for new-collect imagery was $12.89 per km². The archived imagery is significantly cheaper; however, the seasons and tides cannot be chosen and fieldwork cannot coincide with the collection of the imagery. On the other hand, it is still difficult to predict and plan for new-collect satellite imagery to coincide with the desired seasons, tides and cloud-free days, and the small swath width of the IKONOS satellite cannot collect imagery for a large area in a single pass.

General recommendations to improve the classification of all ESI habitat types include the use of more robust sensors, sensors that can extract vertical structures, ancillary elevation data, texture analysis, and an exposure index. The Compact Airborne Spectrographic Imager (CASI and CASI 2) and Light Detecting and Ranging (LiDAR) are robust airborne sensors that have the potential to extract ESI classes with greater detail. Larsen and Erickson (1998) used the CASI sensor to distinguish between substrate types such as course sand, mud, and gravel beaches and man-made features. LiDAR collects elevation data, which may be useful in classifying vertical structures. Applying an exposure index to the shoreline can further define the modified classes into sheltered and exposed.

References

Halls, J., J. Michel, S. Zengel, J.A. Dahlin, and J. Petersen. 1997 Environmental sensitivity index guidelines, version 2.0. NOAA Technical Memorandum NOS ORCA 115, Seattle, WA. 79 pp. plus appendices.

Louisiana Department of Wildlife and Fisheries, Fur and Refuge Division, U.S. Geological Survey, Biological Division's National Wetlands Research Center, and Department of Geology and Anthropology, Louisiana State University. 1997. 1997 Louisiana Coastal Marsh Vegetative Type Map NAD83, LDWF, NWRC, LSU (1997) [salinity]. Lafayette, LA: Louisiana Department of Wildlife and Fisheries, Fur and Refuge Division and the U.S. Geological Survey's National Wetlands Research Center.

Minerals Management Service, Louisiana State University, Louisiana Department of Wildlife and Fisheries, and Research Planning Inc. 2001. Gulf-wide information system, Louisiana: outer coast environmental sensitivity index (ESI). U.S. Minerals Management Service, New Orleans, LA . Arc/Info coverage and metadata.

Zengel, S. and J. Hanifen. 2001. Louisiana G-WIS: ESI, Wildlife, and Fisheries Components. 17th Annual Louisiana Remote Sensing and GIS Conference, Baton Rouge, LA, April 2–4, 2001.

Zengel, S., Z. Nixon, C. Plank, J. Hanifen, D. Sa, and D. Braud. 2002. Environmental Sensitivity Mapping and GIS: The Louisiana G-WIS Database. Fourth Biennial Freshwater Spills Symposium, Cleveland, OH, March 19–20, 2002.

DeWitt Braud is a researcher in the Louisiana State University Coastal Studies Institute. He has specialized in GIS and remote sensing research and applications involving major projects in Louisiana for over 20 years.

Katherine Phillips is a GIS/Remote Sensing Analyst at Research Planning, Inc. Katherine has a B.S. from the University of Western Australia and an M.S. in marine science from the University of South Carolina. Her expertise is in integrating coastal science and policy with spatial technologies for the comprehensive planning and management of limited coastal resources.

Jacqueline Michel is a geochemist specializing in terrestrial and marine pollution studies, coastal geomorphology, and environmental impact assessments. She is President of Research Planning, Inc., an environmental consulting firm with offices at the University of New Orleans and in Columbia, South Carolina, that offers services in Spill Response and Planning, Natural Resource Damage Assessment, and Geographic Information System Design and Analysis.

Chris Locke is a Geographic Information Systems and Remote Sensing Analyst with Research Planning, Inc. in Columbia, South Carolina. Over a ten-year span at RPI, he has worked on a variety of spatial and image applications for oil and gas emergency preparedness, risk planning, and environmental damage assessment. He received his B.A. and M.S. in geography from the University of South Carolina.

PIPELINE AND NAVIGATION CANAL IMPACTS AND MITIGATION EFFECTS ON WETLAND HABITATS OF COASTAL WESTERN AND CENTRAL GULF OF MEXICO

James Johnston, Donald Cahoon, Megan LaPeyre, Philippe Hensel, and Thomas McGinnis, U.S. Geological Survey, National Wetlands Research Center, Lafayette, LA

Project Goals and Approach

The study goal was to prepare a factual array of data and data analyses in order to quantitatively determine any direct and indirect effects of OCS pipelines and navigation canals on land loss and wetland habitat change in the western and central planning areas of the Gulf of Mexico. Specific goals included 1) to estimate changes in land area (land versus open water) and extent of fresh and non-fresh marsh in relation to OCS pipelines and navigation canals, and 2) to discuss construction and mitigation techniques used to mediate OCS pipeline and navigation canal effects on land loss through literature review and qualitative analyses of selected case studies. The project was organized into four major components 1) literature review, 2) GIS analysis: collection and collation of spatial data on locations and habitats of OCS pipelines and navigation canals, as well as generation of land loss and habitat change data sets within the immediate vicinity of pipelines and navigation canals, 3) analysis of land loss and habitat change: statistical analyses of trends in land loss, habitat change, and pipeline and navigation canal construction effects, and 4) mitigation effectiveness: an evaluation of mitigation techniques for ameliorating pipeline and navigation canal impacts.

The study area boundaries incorporated the coastal Western and Central Planning Areas of the Gulf of Mexico as designated by the Minerals Management Service. The study area was divided into five subareas based on geologic and political features: Texas Barrier Islands (TBI), Texas Chenier Plain (TCP), Louisiana Chenier Plain (LCP), Louisiana Delta Plain (LDP), and Mississippi/Alabama (MS/AL). Geographic Information System (GIS) investigations of habitat changes were performed using historical aerial photography, coupled with a literature review and interviews with agency and industry personnel. GIS data sets were obtained from the U.S. Geological Survey and U.S. Army Corps of Engineers. For each of the five subareas, habitats within the immediate vicinity of pipelines and navigation canals were analyzed over two time intervals (e.g., 1956 – 1978 and 1978 – 1988/90). Habitat change was determined among fresh marsh, non-fresh marsh, and open water. Two data sets were developed and analyzed: 1) subarea trend of land/wetland loss and habitat change within 300 m (150 m either side) of every pipeline and 1,000 m (500 m either side) of every navigation canal, 2) subwatershed trend of change in wetland habitats/open water located within 3,000 m (1,500 m either side) for three to five pipelines and two navigation canals in each subarea, subdivided into non-overlapping zones located at increasing distances from the centerline. Two statistical models were used: YEAR comparing fixed time intervals and PHASE comparing pre- and post-construction changes. If the PHASE model provided a better fit, changes in habitat were more likely related to pipeline construction than other time-dependent processes.

Summary of Findings

Finding 1. Land loss in Louisiana was consistently higher in the vicinity of all pipelines and navigation canals compared to subarea trends. This analysis was made only for Louisiana where regional loss data were available for comparison. In the LDP, the annual land loss rate (%) was two- to three-fold greater in the vicinity of pipelines (0.89 vs. 0.33, P = 0.003, 1956–1978; 0.74 vs. 0.28, P = 0.007, 1978–1988/1990) and navigation canals (1.08 vs. 0.33, P = 0.006, 1956–1978; 0.50 vs. 0.28, P = 0.056, 1978–1988/1990). In the LCP, the annual land loss rate (%) was 50–100 % greater in the vicinity of pipelines but only significantly greater for the 1978–1990 interval (0.41 vs. 0.19, P = 0.059). For navigation canals, the annual land loss rate (0.09–0.14 %) was not significantly different (P > 0.801). These findings suggest that pipelines and canals impacted regional land loss, although there are constraints to the data (see below).

Finding 2. The influence of pipelines and navigation canals on land/wetland loss and habitat change differed among the five subareas. In the LDP, LCP, TCP, and TBI, the high loss rates and changes in habitat were apparently related, in part, to pipeline and canal construction, although other time-dependent phenomena (e.g., subsidence) also influenced the trends. In Louisiana, local conditions (e.g., subsidence rates) likely influenced high loss rates in the LDP because pipeline numbers were high in both areas, and the same array of construction methods was used in each. In Texas, the difference in loss rates between the TCP and TBI was likely related, in part, to the pipeline construction/mitigation techniques used and local conditions (e.g., directional drilling in the TBI and higher subsidence in the TCP). In contrast to Louisiana and Texas, pipeline construction in MS/AL apparently had little or no effect on trends in habitat change or land loss, however, navigation canals apparently affected patterns of habitat change and land loss, although not to the extent they did in Louisiana and Texas. In MS/AL, pipeline impacts were negligible with only 10 pipelines constructed, mostly in a corridor with other pipelines to localize impacts or directionally drilled under the wetland habitats.

Finding 3. In Louisiana and Texas, habitat changes were more often related to pipeline construction date than to some other time-dependent variable, suggesting that pipelines had an effect on habitat change in those cases. Considered together, Findings 1,2, and 3 strongly suggest that pipelines affected wetland habitats in many instances. In Mississippi/Alabama, both YEAR and PHASE analyses indicate that pipelines likely had little effect on trends in wetland habitat change, although canals were associated with habitat change in some cases. However, our level of certainty regarding pipeline and canal construction influences on the trends in habitat change is constrained by a lack of knowledge of the regional trends in habitat change.

Finding 4. The effectiveness of mitigation techniques on land/wetland loss and habitat change differed by subarea. Some differences may be due to the variation in land loss by subarea. Pipelines in Mississippi/Alabama appear to have had little or no effect on trends in habitat change or loss, although three construction and three mitigation techniques were used. Of note, unlike the other subareas, most pipelines in Mississippi/Alabama were built within one of several pipeline corridors. In Texas, impacts varied by subarea, with less noticeable impacts in the Barrier Island subarea due to the construction techniques used, as both directional drilling and more mitigation were required in the more sensitive barrier islands. In Louisiana, with its high loss rates and changes in habitat, pipeline effects were difficult to tease apart from other phenomena (e.g., subsidence, marsh management, marsh restoration, development). Qualitative analyses were either inconclusive due to confounding effects of other phenomena along the pipeline route or showed potential evidence of saltwater intrusion and increased open water areas mostly from un-backfilled pipelines. In many cases, however, the 300 m reference and pipeline zones showed similar trends in habitat change.

Dr. James B. Johnston is the Section Chief, Spatial Analysis Branch of the National Wetlands Research Center in Lafayette, Louisiana. He serves as the Regional Coordinator for the Louisiana Coastal Ecosystem Program and principal advisor to the Regional Director and other Regional-level staff, and Departmental officials regarding multi-agency scientific investigations in Louisiana. In this position, he consults with high-level officials on the federal and state agency Louisiana Task Force on coastal restoration.

Dr. Megan La Peyre is Assistant Unit Leader of the Louisiana Cooperative Fish and Wildlife Research Unit at LSU. Her research interests include restoration and management of coastal/estuarine ecosystems, quantifying/identifying characteristics of fish habitat, and ecology of coastal vegetation.

Dr. Donald R. Cahoon is a research ecologist with the U.S. Geological Survey, Patuxent Wildlife Research Center located in Beltsville, MD. He received his B.A. with Honors in botany, from Drew University (1972), and his M.S. (1975) and Ph.D. (1982) degrees in Wetland Plant Ecology from the University of Maryland. His professional interests include wetland plant ecology, wetland accretionary processes, and wetland restoration and management. His research program is focused on three objectives: 1) determining the impacts of sea-level rise on long-term marsh stability through evaluations of marsh accretionary processes, 2) identifying the processes of wetland loss, submergence, and soil erosion in both natural and managed coastal marshes, and 3) evaluating the effectiveness of wetland restoration and management techniques. He worked on coastal management and research issues in Louisiana for 19 years before moving to Maryland in 2001.

Dr. Philippe F. Hensel is an ecologist with the U.S. Geological Survey, Patuxent Wildlife Research Center located in Beltsville, MD. He received his B.S. in biology degree, maxima cum laude, from the Catholic University of America (1988), his M.S. degree in marine, estuarine, and coastal sciences from the University of Maryland (1992), and his Ph. D. in oceanography and coastal sciences from Louisiana State University (1998). His main areas of interest include: 1) coastal wetland ecology, especially sediment dynamics and mangrove ecology, and 2) the development of analytical and statistical tools to field-based studies, especially regarding spatial components of variation.

Mr. Thomas E. McGinnis, II, a native of south Louisiana, is a General Biologist II with Johnson Controls, Inc. (JCI), contracted to the U. S. Geological Survey – National Wetlands Research

Center (NWRC) in Lafayette, LA. He earned a B.S. (aquatic and fisheries biology, 1994) and an M.S. (biology, 1997) from the University of Louisiana at Lafayette (ULL) where he developed an interest in geomorphologic processes in coastal marshes. After his M.S. degree, Mr. McGinnis continued at ULL as a research associate studying how oil-spill clean-up chemicals affect salt marsh soil function. He then joined NWRC as a JCI contractor (1999) to research the effects of OCS pipeline and navigation canals on coastal ecosystems. Mr. McGinnis has remained at NWRC researching the effects of global climate change and hurricanes on coastal wetlands in the tropics (mangroves) and sub-tropics (coastal marshes).

THE ASSOCIATION OF SALINITY PATTERN AND LANDSCAPE CONFIGURATION WITH OCS OIL AND GAS NAVIGATIONAL CANALS IN COASTAL LOUISIANA

Gregory D. Steyer and Brian C. Perez, USGS National Wetlands Research Center, Coastal Restoration Field Station
Charles Sasser, Louisiana State University Agricultural Center and The School of the Coast and Environment
Glenn Suir, Louisiana State University Agricultural Center, Department of Agronomy
Elaine Evers and Erick Swenson, Louisiana State University, Coastal Ecology Institute

Coastal Louisiana is a dynamic and ever-changing landscape. In the past 50 years, over 310,000 hectares of coastal wetlands have been lost due to a combination of natural and human-induced causes (LCWCRTF 1993). Subsidence, sea-level rise, freshwater and sediment deprivation, saltwater intrusion, the dredging of oil and gas canals, navigational canals, shoreline erosion, and herbivory are all contributors to wetland loss in Louisiana. Separating the influences of each of these factors is extremely difficult because of the wide range of spatial and temporal scales over which they occur. Direct impacts associated with an immediate physical conversion of habitat have been well described for coastal Louisiana (Boesch 1982; Turner and Cahoon 1988); however, the indirect impacts that are subtle and operate over longer time horizons (such as salinity intrusion) have been difficult to discern.

The degree of connectivity of the landscape influences movement of water from primary sources (canals, bayous, lakes, bays, etc.) to interior estuarine marshes and, can greatly influence vegetation distributions. Saltwater intrusion into marshes can be increased by the location of straight and deep canals that connect the coast with the interior marshes (Gosselink 1984). Thus, the extent of connectivity, percentage of water in the marsh, and the configuration of water bodies within the marsh landscape are useful indicators to evaluate marsh conditions (Sasser et al. 2002).

Ten major federal navigation canals up to 45 feet deep and 1,000 feet wide have been constructed in coastal Louisiana since the mid-1800s (Good et al. 1995). These channels are partly responsible for the severity of coastal wetland loss Louisiana is experiencing via direct/primary losses and by indirect/secondary losses including saltwater intrusion, hydrologic disruption, and shoreline erosion. Louisiana Department of Natural Resources (LDNR) has estimated that approximately 57,000 acres of coastal wetland habitat have been lost via shoreline erosion of the ten major federal navigation canals, a figure much greater than the original direct loss associated with construction (Good et al. 1995). Maintenance dredging and the deepening of existing channels to accommodate increased and larger vessel traffic also increases the movement of more saline waters farther inland (Wang 1988) further exacerbating the problem. Because of the adverse impacts of canals and OCS-related activities, there is a need to better quantify the secondary impacts of navigation canals as well as to gain a better understanding of the patterns of change and wetland loss to minimize future impacts.

The objective of this project is to perform a comprehensive evaluation of the extent that OCS waterways and navigation canals have contributed to changes in salinity and wetland landscape patterns in coastal Louisiana. Our approach includes 1) assembling and synthesizing all available salinity data, salinity management studies, and salinity models for coastal Louisiana; 2) conducting temporal and spatial analyses of available salinity data to determine changes in those variables relative to pre- and post-navigational canal construction and subsequent deepening events; and 3) relating salinity changes to hydraulic connectivity and associated habitat changes over time in selected study areas. The last element of our approach includes developing a water body configuration classification and fragmentation index to classify the study area marshes into multiple categories based on estimates of percentages of marsh and water, configurations of water bodies within the marsh, and connectivity of water bodies with selected OCS-related navigation canals.

Two study sites have been selected for analysis in this project: the Houma Navigation Canal (HNC) and the Freshwater Bayou system. The HNC study site is located in the Terrebonne Basin bordered on the north by the Gulf Intracoastal Water Way (GIWW), the south by the Gulf of Mexico, the west by Bayou DuLarge, and the east by Bayou Terrebonne. HNC construction began in 1958 and was completed in 1962 and extends from the GIWW at Houma to the Gulf of Mexico. The canal dimensions were originally 15 feet deep by 150 feet wide, and in 1974, the lower reaches near Terrebonne Bay were enlarged to 18 feet deep by 300 feet wide. The Freshwater Bayou site is bordered on the north by the GIWW, the south by the Gulf of Mexico, the west by Highway 82, and the east by the McIlhenny Canal. Construction of Freshwater Bayou was completed in 1968 and extends from the GIWW to the Gulf of Mexico. The authorized dimensions of the navigation channel were 12 feet deep and 125 feet wide, with approval to increase width to 250 feet in the Gulf approach.

A literature search of previous studies regarding salinity influence and patterns on the coastal Louisiana landscape has been completed. Variables investigated include forcing functions such as meteorological, climatological, freshwater input, and river discharge. These studies were used to evaluate coastwide and local patterns of salinity intrusion and effects of navigation canals on historic salinity patterns, wetland change, and wetland loss. The effects of salinity and the influence on vegetation establishment and spatial distribution have also been summarized.

Historic salinity data have been collected from as many long-term stations as possible (125 to date) in the identified study areas to determine patterns and pulses over different spatial and temporal scales. These data are being analyzed within natural and man-made channels and also in both channel types that have been dredged and not dredged.

Available information on the historic dredging activity of navigation canals within the selected study sites was obtained from various sources. These data sets and supporting attribute information (e.g., river mile locations), were processed and digitized into a geo-rectified vector layer. An assessment is under way that will try to discern if any salinity changes can be attributed to specific dredging events.

Photography and imagery will be used to evaluate land change and wetland landscape patterns as influenced by the OCS waterways HNC and Freshwater Bayou. Ideally, aerial photography selected for analysis will consist of dates that bracket canal construction and any major dredging activity (widening or deepening), will closely coincide with dates of supporting data (e.g. vegetation zones), and exhibit adequate quality, coverage, and ease of rectification.

Methods for establishing percentage of water, with configuration and connectivity of water bodies, within the marsh landscape are under development for evaluating the effects of OCS-related navigation canals on salinity and wetland landscape patterns. A water body configuration classification and fragmentation index will be used to classify study area marshes into multiple landscape categories. A search of habitat fragmentation and patch connectivity literature revealed numerous successful utilizations of fragmentation and patch analysis software, which described and predicted habitat patterns and change. Though this review produced important information regarding the feasibility of a "typical" fragmentation study, along with the accepted standard in fragmentation and patch analysis software (FRAGSTATS), it did not produce any literature on fragmentation analysis methods for a marsh landscape. Therefore, one of the purposes of this project is to establish, evaluate and improve methods of analyzing and classifying marsh fragmentation and configuration. Three test methods were proposed for this study 1) a holistic manual interpretation method, 2) a holistic computer-interpretation method, envisioned as a "moving window" class boundary delineation method, and 3) a FRAGSTATS grid-based method. Due to the shortcomings of both holistic approaches, we are currently working to develop a grid-based method of determining configurations using the FRAGSTATS computer software program. While the grid-based approach cannot be used to make determinations on the landscape as a whole, but as individual non-related tiles, it does provide reproducibility and potential as a packaged management tool. The FRAGSTATS grid method utilizes a land/water classified image and a two-part classification system 1) ratio of water to land, and 2) marsh water configuration and connectivity.

Scale emerged as a major factor in metric output and classification accuracy. A 1/8 km^2 scale process provided the most accurate results and seemed to better satisfy the one water/configuration class-per-grid tile criteria. Of the FRAGSTATS output statistics that were available and tested for suitability, three primary metrics appeared to demonstrate the greatest and most accurate control over class designation. These metrics are largest patch index, patch cohesion index, and clumpiness index. *Largest patch index* quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance, with values represented as a percentage. *Patch cohesion index* measures the physical connectedness of the corresponding patch type, reported as a percentage. The *clumpiness index* shows the frequency with which different pairs of patch types (including like adjacencies between the same patch type) appear side-by-side on the map, varying from -1 (totally disaggregated class) to 1 (maximally clumped). Besides using these stand-alone FRAGSTATS values, output variables were combined in an attempt to more accurately differentiate between configuration classes. Some combinations increased the precision of the classification, while others decreased the accuracy and were therefore discarded. The set of secondary metrics that appear to add precision to the classification scheme are adjusted patch density, ratio of number of patches to clumpiness index, and landscape shape index. Assessments continue to determine the most appropriate primary and secondary metrics for this study.

References

Boesch, D.F., ed. 1982. Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences and Options. U.S. Fish and Wildlife Service, Washington D.C. FWS/OBS-82/59. 256 pp.

Good, B., J. Buchtel, D. Meffert, J. Radford, K. Rhinehart, and R. Wilson, eds. 1995. Louisiana's Major Coastal Navigation Channels. Unpublished report. Baton Rouge: Louisiana. Department of Natural Resources, Coastal Restoration Division. 57 pp.

Gosselink, J.G. 1984. The Ecology of Delta Marshes of Coastal Louisiana: A Community Profile. U.S. Fish and Wildlife Service, Washington D.C. FWS/OBS-84/09. 134 pp.

Louisiana Coastal Wetlands Conservation and Restoration Task Force (LCWCRTF). 1993. Louisiana Coastal Wetlands Restoration Plan: Main Report and Environmental Impact Statement and Appendices. U.S. Army Corps of Engineers, U.S. Department of Agriculture, U.S. Department of Commerce, U.S. Department of the Interior, U.S. Environmental Protection Agency, and Louisiana Department of Natural Resources, Baton Rouge, LA. 256 pp.

Sasser, C.E., D.E. Evers, J.G. Gosselink, G.O. Holm, Jr., E.M. Swenson, and J.M. Visser. 2002. Ecological Evaluation of the CWPPRA Central and Eastern Terrebonne Basin Freshwater Delivery Project. Louisiana Department of Natural Resources, Baton Rouge, LA. 113 pp.

Turner, R.E. and D.R. Cahoon. 1988. Causes of Wetland Loss in the Coastal Central Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 87-0120. 400 pp.

Wang, F.C. 1988. Dynamics of saltwater intrusion in coastal channels. Journal of Geophysical Research 93:6397-6946.

Gregory D. Steyer received his B.S. from the University of Maryland in 1985, his M.S. in 1988 from the University of Louisiana in Lafayette and is currently a Ph.D. candidate at Louisiana State University in the Department of Oceanography and Coastal Studies. For the past 16 years he has worked for state and federal governments developing and implementing wetland mitigation plans, wetland vegetation planting programs, wetland restoration projects, and monitoring programs for the evaluation of wetland restoration projects. Greg is currently a wetland ecologist for the USGS National Wetlands Research Center, and his research is focused on developing ecological indicators, adaptive management approaches and ecological and landscape models for use in natural resource decision support.

Charles E. Sasser's professional preparation includes a B.A. in 1972, an M.S. in 1977 (both from LSU), and a Ph.D. in 1994 from the University of Utrecht. Charles has conducted environmental research at the LSU Coastal Ecology Institute, School of the Coast & Environment for over 25 years, focusing on ecology and management of coastal wetlands.

Brian C. Perez received his B.S. from the University of Alabama in 1992 and his Ph.D. from Louisiana State University in 2000 in the Department of Oceanography and Coastal Sciences. Brian is currently a wetland ecologist with the USGS National Wetlands Research Center where his research interests include wetland sedimentation and accretion dynamics, nutrient and sediment transport and retention within estuarine and wetland systems, coastal restoration and management, and the role that storms and other episodic event play in coastal management and sustainability.

Erick M. Swenson received his B.S. in geology in 1975 and his M.S. in earth sciences (oceanography concentration) in 1978, both from the Universality of New Hampshire. He joined the Coastal Ecology Institute, a research unit within the School of the Coast and Environment at Louisiana State University, as a Research Associate in 1978 as a Field Hydrologist. His research interests have focused on the investigations of the hydrologic regime of coastal wetland systems and their response to natural drivers and human impacts. Research interests include measurement (monitoring design, QA/QC) and analysis of water flows, water levels, and salinity in shallow water, coastal and estuarine systems. Mr. Swenson has worked on the analysis of long-term climate, water level, and salinity in the Louisiana coastal ecological systems with emphasis on wetland restoration and management. Mr. Swenson also serves as an academic advisor to the Environmental Working Group for the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA).

Elaine Evers received her B.S. in 1977 from the University of Houston and her M.S. in 1990 from LSU. She has worked for the past 26 years as a wetland ecologist with LSU, including benthic ecology and ecological work using GIS systems, including mapping vegetation species composition of flotant and non-floating marshes and wetland change over time.

Glenn M. Suir received his B.S. from the University of Louisiana at Lafayette in 1999 and his M.S. in 2002 from LSU, where he is currently a Ph.D. candidate in the Department of Oceanography and Coastal Studies. For the past five years he has worked for state and federal governments providing data management and spatial analysis support for wetland vegetation planting programs, wetland restoration projects, and coast-wide monitoring programs. Glenn is currently a research associate for Louisiana State University Agricultural Center Department of Agronomy, where his research is focused on water quality monitoring and modeling, and the use of GIS to assess landscape patterns and develop ecological and landscape models.

LOUISIANA COASTAL VEGETATIVE TYPE CHARACTERIZATION MAPS

Greg Linscombe, Louisiana Department of Wildlife and Fisheries
John Barras and Steve Hartley, USGS National Wetlands Research Center

Introduction

Coastal Louisiana has numerous data sets to conduct marsh change analyses. Most of these studies have used either the National Wetlands Inventory Data (1956, 1978, 1988) or the Vegetative Type Maps (1949, 1968, 1978, 1988, 1997) (Chabreck et al. 2001). Recently, the United States Geological Survey (USGS) Biological Resources Division (BRD)/National Wetlands Research Center (NWRC) and the Louisiana Department of Wildlife and Fisheries Fur and Refuge Division (LDWF) completed the development of the 2001 Vegetative Type Map for Louisiana. This data set and others are a cumulative effort to map and portray the ever-changing coastal vegetative types. Because of the technology used in the past to map the vegetative types, however, we can not reflect, within reason, the "true" amount of marsh acreages. To make better use of the 2001 and other (1978, 1988, 1997), a new methodology must be adopted to calculate marsh acreages.

Proposal Synopsis

Geographic information systems (GIS) will be used to develop a comprehensive land/water interface for coastal Louisiana using the 1998 Digital Ortho-Quarter Quadrangles (DOQQs). We propose to use this land/water interface and ancillary photography to classify LANDSAT imagery to the closest available corresponding vegetative marsh type map dates. The classified land/water data sets would then be merged with each corresponding vegetative marsh type map to produce improved vegetative data sets, which then could be used to show "true" marsh acreage changes.

Objectives

- Develop improved vegetative type databases and maps for 1978, 1988, 1997, and 2001 Louisiana coastal areas.
- Develop a detailed coast-wide land/water interface that can be used by numerous studies relating to habitat loss, pipeline erosion, and navigable waterways.
- Provide information that resource managers can utilize in a variety of applications related to their mission, such as:
    - Environmental Impact Statement Preparation
    - Pipeline Assessments
    - Natural Resource Damage Assessments
    - Vegetative Assessments
    - Navigable Waterway Assessments

Products

- Maps showing marsh types for each time period with associated acreage tables.
- Map showing marsh type change analysis.
- Visual animation file of coastal marsh change.
- Complete coverage of land/water interface digitized from the 1998 DOQQs.
- Digital copy of all classified and raw TM data.

References

Chabreck, R.H., G. Linscombe, S. Hartley, J. Johnston, and A. Martucci. 2001. Coastal Louisiana Marsh-vegetative Types: Report to Coastal Wetlands Planning, Protection and Restoration Act and the Louisiana Dept. of Wildlife and Fisheries. US Geological Survey, National Wetlands Research Center, Lafayette, LA.

Steve Hartley is a Senior Geographer at the USGS National Wetlands Research Center. He received his B.S. degree in 1985 from Louisiana Tech University and his M.S. in geology from the University of Louisiana at Lafayette in 2000. He is responsible for the installation, configuration and overall maintenance of software, hardware and networking for GIS operations. His specific duties include managing and coordinating GIS projects, performing image analysis, developing prototype GIS products, troubleshooting, quality control, personnel management and training, and client-interfacing and correspondence.

John Barras is employed as a Senior Geographer at the USGS National Wetlands Research Center. He received his B.S. in geology from Nicholls State University in 1984 and his M.N.S. in geography from LSU in 1991. He is responsible for managing the NWRC's Coastal Restoration Field Station (CRFS), housed on the Louisiana State University Campus in Baton Rouge, Louisiana. The CRFS provides applied GIS and remote sensing support for several state, federal, and academic partners involved in coastal wetland restoration and natural resource management activities via staff at LSU or on-site staff collocated with the partner agency.

Greg Linscombe has been employed by Louisiana Department of Wildlife and Fisheries since 1972 and is currently a Program Manager for the Fur and Refuge Division. He received his B.S. degree in forestry and wildlife management from LSU in 1970 and his M.S. in wildlife management from LSU in 1972. During his career he has been responsible for management on 230,000 acres of public wetlands (refuges and wildlife management areas) and is currently responsible for marsh ecology on 420,000 acres of these lands. He has published over 40 scientific papers dealing with furbearers and wetlands ecology and has produced four vegetative type maps of coastal Louisiana.

SESSION 1I

DEEPWATER PHYSICAL OCEANOGRAPHY INITIATIVE, PART I

Chair: **Alexis Lugo-Fernandez, Minerals Management Service**

Co-Chair: **Carole Current, Minerals Management Service**

SURVEY OF DEEPWATER CURRENTS IN THE NW GULF OF MEXICO – AMERICAN SECTOR

Evans Waddell, Science Applications International Corporation

In September 2003, the MMS awarded a contract to Science Applications International Corporation (SAIC) to conduct a 40-month study of circulation patterns and processes in the deepwater of the northwestern Gulf of Mexico (GOM).

Program Objectives

1. To collect current data to increase our deepwater database and knowledge of the deep circulation in the northwestern GOM.

2. To gather information to estimate oceanographic parameters needed to make experimental designs of full-scale physical oceanography studies in deepwater.

3. To provide information for use in oil-spill analyses, including the emerging deep-spill analysis and other ongoing studies; to help evaluate exploration plans; and to contribute to the preparation of NEPA documents.

To help focus the analysis and interpretation effort, the project science team identified 11 potential hypotheses that can be evaluated to support reaching the above goals.

The study area boundaries are defined by the EEZ on the south (approximately 26°N), the 200 m isobath on the west and north, and 93°W on the eastern edge (Figure 1I.1). The one-year ongoing measurement program began in March 2004 and is composed of thirteen full-depth instrumented moorings placed in various water depths. The instrumented moorings are supported by coordinated altimetry, radiometry and visual band remote sensing. After the program was initiated, the MMS chose to fund a proposed option involving placement of approximately ten Inverted Echo Sounders with Pressure (PIES) at appropriate locations relative to both the moorings and altimetry tracklines in the study area.(Figure 1I.2).

Using an empirically based analysis method, Gravest Empirical Mode (GEM), the travel time measured by the PIES can provide estimates of the depth of temperature, salinity, and density surfaces. Using density profiles and bottom pressures, geostrophic velocities can be computed and referenced with near-bottom velocities measured on the moored arrays. The directly measured and PIES-based information will combine to provide well-resolved characterizations of the temperature and salinity field within which the measured currents are occurring.

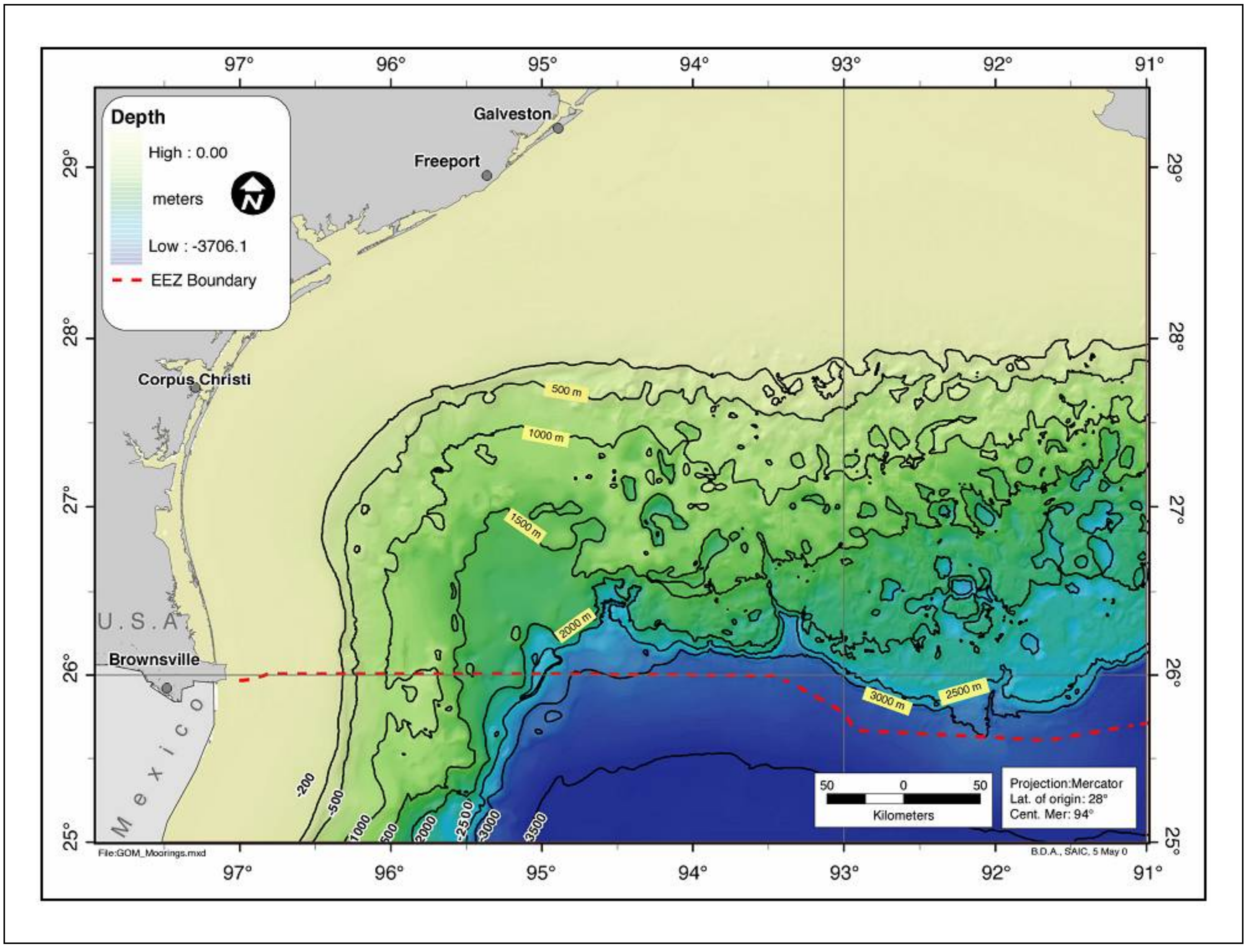


Figure 1I.1. General study area for NW Gulf Study – American Sector.

The general vertical placement of instruments is as follows:

Currents: Each full-depth moorings has an ADCP to measure currents in the upper portions of the water column. In water depths > 500 m, 75 kHz ADCPs are used. On the three 500 m moorings, 300 kHz ADCPs are used. Below the ADCPs and above 1,000 m, current meters are placed at $\Delta z \leq 250$ m,; below 1,000 m, current meters are placed at ≈ 500 m spacing. Depending on water depth, the lowest/deepest current meter is always approximately100 m above the local bottom.

Temperature and Conductivity: Appropriate sensors are attached to the wire above the ADCPs. All moorings have temperature sensors at ≈100, 150, 250, 375, and 500 m. All current meters/ profilers provide temperature sensors. Conductivity is measured with a MicroCat or SeaCat at 150 m in an effort to define the presence of the subsurface salinity maximum.

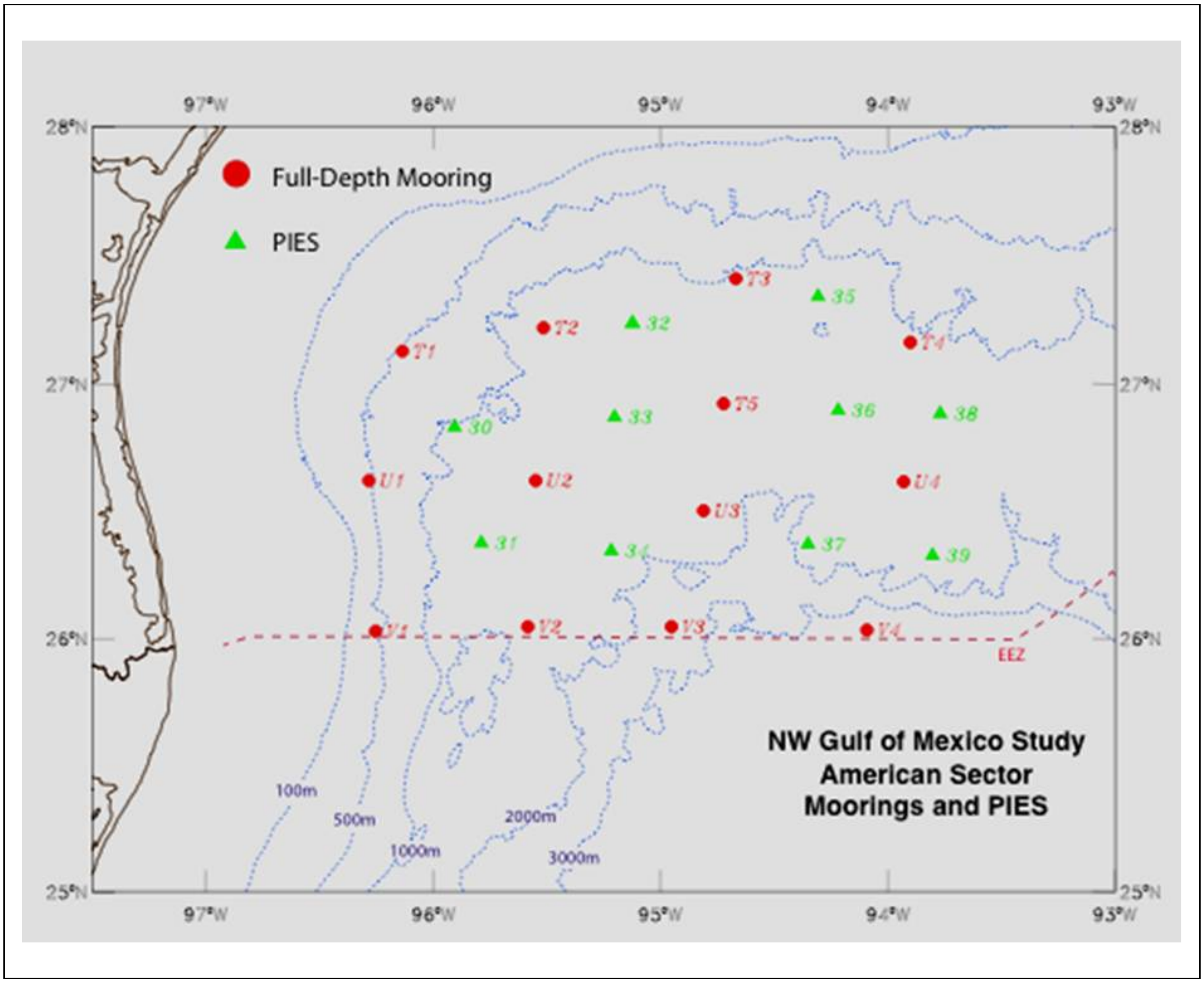


Figure 1I.2. Placement of American Sector Moorings (filled red circles), and PIES (filled green triangles).

PIES: PIES are self contained and positioned in a cradle on the bottom. Observations being made include acoustic round-trip travel time from the instrument to the water surface and precise bottom pressure measurements.

Key Project Team Members

Science

- Dr. Peter Hamilton – SAIC
- Dr. Robert Leben – University of Colorado
- Dr. Randy Watts – University of Rhode Island
- Dr. Kathleen Donohue – University of Rhode Island

Project

- Dr. Evans Waddell – SAIC

- Mr. James Singer – SAIC
- Mr. Paul Blankinship – SAIC

Science Review Group

- Dr. John Bane – University of North Carolina
- Dr. Tony Sturges – Florida State University
- Mr. David Driver – BP

Dr. Evans Waddell has worked at SAIC for approximately 28 years, most often as the manager of larger field measurement and analysis programs, often in the Gulf of Mexico. He is presently the Project Manager for the above program as well as the ongoing, MMS-funded Exploratory Study of Deepwater Currents in the Gulf of Mexico, which involves a broadly-based team of scientists involved in the acquisition, analysis, and interpretation of an extensive set of measurements over the deeper slope of the north central Gulf. He is also an Assistant Vice President and a Senior Oceanography for SAIC. Dr. Waddell received a B.A. and M.A. from the University of Virginia and a Ph.D. in marine science (physical oceanography) from Louisiana State University (1973). Prior to joining SAIC in 1977, he was an Assistant Professor of Marine Science at Purdue University and a Visiting Researcher at the Coastal Engineering Laboratory of the University of Tokyo.

SURVEY OF DEEPWATER CURRENTS IN THE EASTERN GULF OF MEXICO

Jeffrey M. Cox, Evans-Hamilton, Inc.

Recent deepwater oil and gas leases in the eastern Gulf of Mexico (GOM) extend beyond water depths of 1,600 m in an area that is periodically strongly influenced by the Loop Current (LC), Loop Current Eddies (LCEs), and associated LCE features such as frontal eddies and filaments. Bathymetry in the study area permits probably the most northerly movement of these features within the GOM (Figure 1I.3). Preliminary results presented by Dr. Peter Hamilton from the Exploratory Study in the central GOM also suggest that this area may be either a potential source region for certain wavelengths of topographic Rossby waves (TRWs) or an area traversed by them.

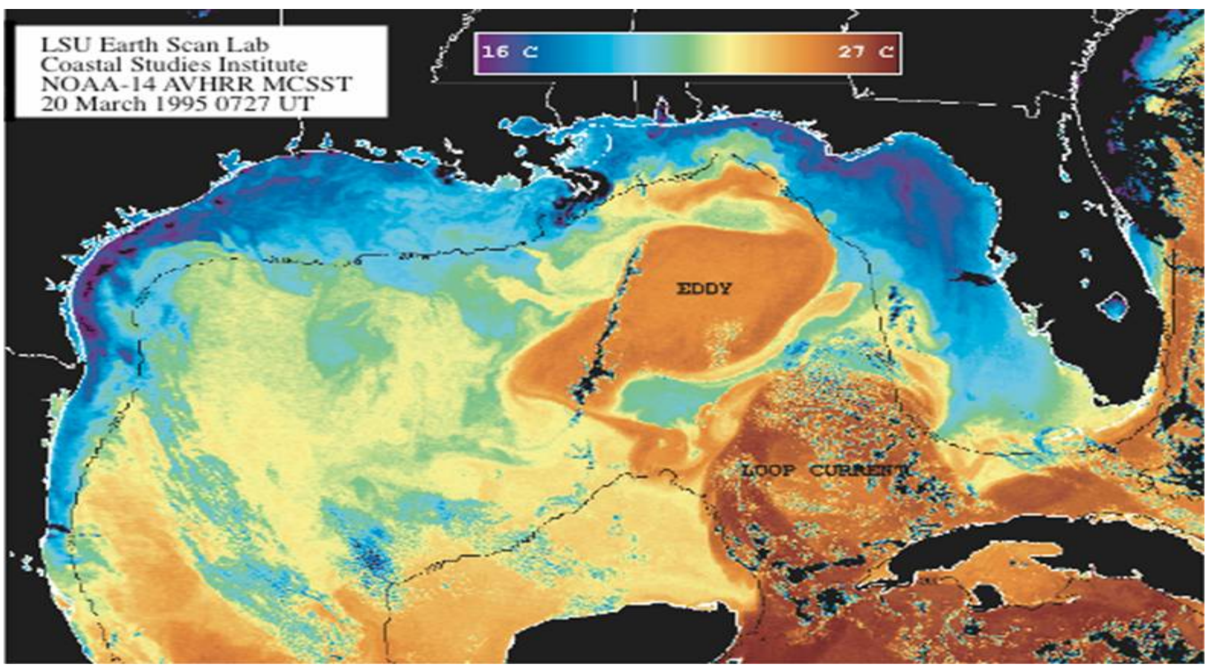


Figure 1I.3. Eddy Zapp with a frontal eddy/filament within the study area.

This area is sparsely measured for currents where water depths exceed 1,500 m (Figure 1I.4). For the MMS to fulfill its regulatory function proactively, more data on currents and a better understanding of the circulation in this area are needed. Specific study objectives are therefore to conduct measurements of deepwater currents using moorings to increase MMS's and the scientific community's database of ocean currents in the eastern GOM, and to improve understanding of the regional oceanography to help design future studies as well as to assist in the modeling of trajectories of released oil and its dispersion in this area.

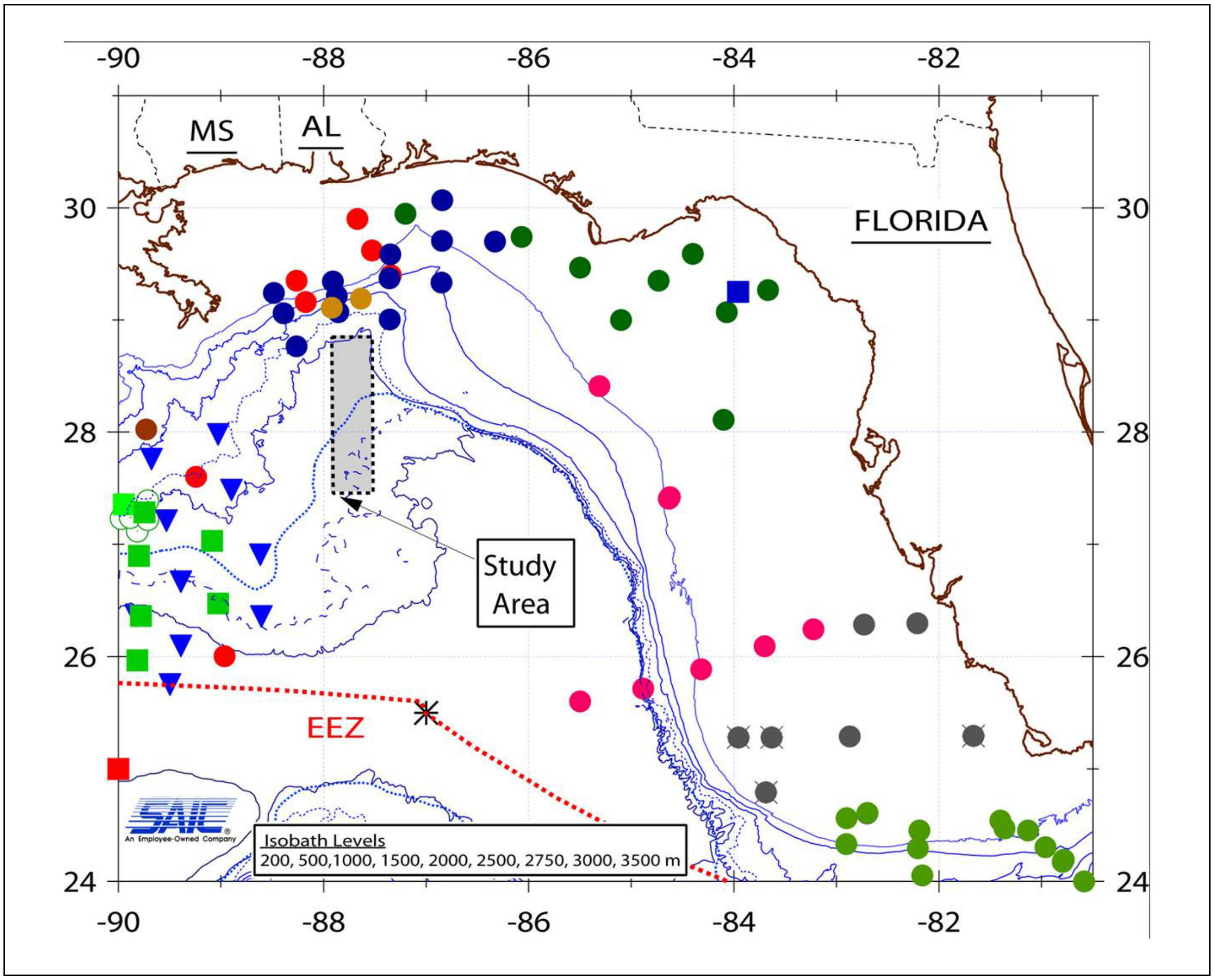


Figure 1I.4. Historical current measurement in eastern GOM vs. study area location.

Study Area

The study area is that area of the Eastern Gulf Lease Sale 181. This area lies off the mouth of DeSoto Canyon and is bounded approximately by the following coordinates:

NW Corner: 28.848°N, 87.918°W   NE Corner: 28.850°N, 87.523°W
SW Corner: 27.453°N, 87.907°W   SE Corner: 27.455°N, 87.516°W

The study area has multiple interesting bathymetric features potentially affecting circulation in this region, including that:

- The area is bounded to the north and northwest by slopes incised by hills and valleys.
- The steep West Florida Escarpment intersects a portion of the eastern boundary of the study area.

- The entrance to DeSoto Canyon lies adjacent to the northeast corner of the study area.

- Area contains primarily NNE to SSW oriented isobaths, rather than E-W isobaths.

- Area contains the farthest northward extent of the 2,000 m isobath in the GOM.

- The area lies within the area of the largest separation between the 2,000 and 3,000 m isobaths within the GOM. This area has a large, relatively flat bottom.

Circulation Processes of Interest

Following are the key circulation processes considered in the experimental design as potentially affecting the circulation in the study area:

- Loop Current (LC) & Loop Current Eddy (LCE) intrusions
- LCE frontal cyclonic and anti-cyclonic eddies
- Midwater jets
- LC/LCE dynamics
- Eddy-eddy interactions
- Eddy-topography interactions
- Baroclinic instabilities
- Geostrophic turbulence
- TRW Genesis by LC northward movement vs. LCE shedding
- TRW Propagation, Refraction & Reflection from Deep Water onto Slope
- Coupling or interactions between upper & lower layers

Measurement Program

The measurement program is designed to obtain an integrated set of current, hydrography, remote sensing, and ancillary measurements that will permit an excellent understanding of the regional scale circulation features affecting the study area. The hydrographic measurement program was also designed to be able to sample small scale (10–25 km) features should they occur in the study area during mooring deployment and hydrographic sampling cruises. All aspects of the measurement program are being coordinated with other MMS researchers to insure consistency in measurement instrumentation, techniques, and sampling intervals so as to maximize the inter-comparability of the measurements between MMS studies.

The measurement program consists of the follow key components:

- Three tall moorings reaching from 70 m depth to bottom at 2,600 or 2,800 m depths
- One short mooring reaching from bottom at 2,750 m depth to 2,500 m depth
- Seven PIES deployed surrounding and interspersed with the moorings
- Three hydrographic surveys (during deployment, servicing, and recovery cruises)
- Remote sensing altimetry and AVHRR imagery
- Ancillary measurements from NDBC buoys, local river runoff

Locations of the moorings and PIES (Figure 1I.5) were selected to maximize coverage of the study area while maintaining scales to conduct along and across isobath coherence analysis. Locating one mooring as far south as possible to maximize measuring the effects of the LC, or a LCE, ACE, or frontal eddy, was also a priority. The northernmost mooring was placed to also assess the potential intensification of the current along the Florida escarpment.

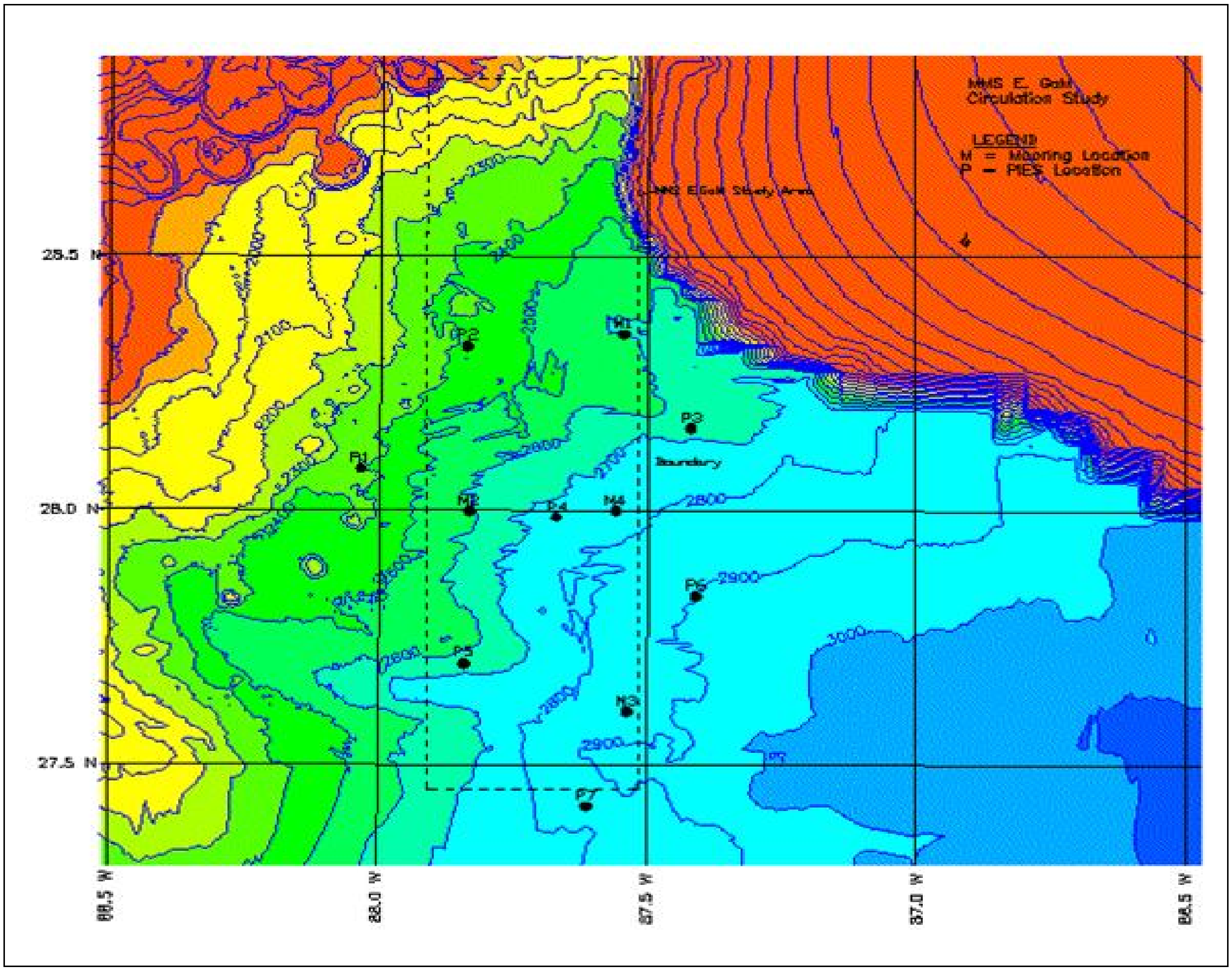


Figure 1I.5. Mooring (M1–M4) and PIES (P1–P7) deployment locations. Mooring M4 is the short mooring.

The current meter moorings were designed to provide excellent vertical resolution of currents throughout water column and to provide excellent temperature structure in the upper 500 m so as to measure the presence and strengths of LCE and ACE events to correlate to the remote sensing data. Instrumentation on the tall moorings consists of:

- Three moorings containing upward looking 75 kHz ADCP at 500 m depth, InterOcean S4 current meters at 750 m, and Aanderaa RCM7/8 meters at 1,000, 1,250, 1,500, 2,000, 2,500, & bottom +100m depths. Temperature is also measured on all current meters.

- All 3 moorings contain T/C/P measurements at 75, 150, and 225 m depths.

- All 3 moorings also contain T only measurements at 100, 190, 225, and 325 m depths, thus providing T measurements at a total of 14 depths per mooring.

The short mooring consists of two Aanderaa current meters placed at 100 m above the bottom and at 2,500 m depth for consistency with the three tall moorings.

Hydrographic measurements will be collected with a combination of CTD casts and XBTs. Deep CTD casts (to near-bottom) will be obtained at each mooring location, as well as each PIES location. Shallower (to 1,200 m depth) casts will be obtained at multiple additional locations. XBT's will be launched between CTD stations to provide ~10 km resolution of temperature. Remote sensing data will be viewed prior to each cruise to plan CTD and XBT measurement locations that can best cover any interesting circulation feature in the study are at the time of the cruise.

Shipboard ADCPs aboard the R/V Pelican will be operated during each mooring cruise to provide a better horizontal perspective of the circulation in the upper 500 m during the period of the cruises.

Study Schedule

PIES deployments occurred during December 19-22, 2004. The deployment of the four moorings and first hydrographic survey are scheduled for January 17-24, 2005. These have been successfully completed. Servicing of the moorings and the second hydrographic survey are scheduled for August 17-24, 2005. Recovery of the moorings and the third hydrographic survey are scheduled for late January 2006.

Study Team

The study team consists of the following key scientists. While the complete measurement data set will be made available to all PIs on the team, and all PIs will assist in interpreting the complete data set, there particular areas of responsibility are also listed below.

- Mr. Jeff Cox (EHI) – Project Manager
- Mrs. Carol Coomes (EHI) – Assistant Project Manager, Data Manager
- Mr. Keith Kurrus (EHI) – Chief Scientist on cruise, Sr. Instrumentation Specialist
- Dr. Peter Hamilton (SAIC) – PI – Upper/lower layer interactions, formation and effects of TRWs
- Dr. Robert Leben (University of Colorado) – PI – Remote sensing
- Dr. Steve DiMarco (Texas A&M) – PI – LCE/ACE/frontal eddy effects, upper/lower layer interactions
- Dr. George Forristall – PI – LCE/ACE/frontal eddy effects, slope intensification of currents, oil industry perspectives

- Drs. Randy Watts & Kathleen Donahue (University of Rhode Island) – PI – PIES, geostrophic flow

The study team was built to provide MMS consistency in the analysis of measurements between its major GOM measurement programs, as well as the historical data reanalysis project. The team also provides extensive knowledge of oil and gas industry perspectives. Initial results from this study will be available at the next MMS Information Transfer Meeting in 2007.

Jeffrey M. Cox is President and a Senior Oceanographer at Evans-Hamilton, Inc. He joined Evans-Hamilton in 1977, and has 27 years of experience conducting physical oceanographic, meteorological, and coastal water quality studies. Mr. Cox's present responsibilities include overall business development and company operations, as well as the planning and oversight of large complex and multidisciplinary physical oceanographic projects.

A CLIMATOLOGY OF OCEAN FEATURES IN THE GULF OF MEXICO

Fred Vukovich, Science Applications International Corporation

A climatology of certain ocean features in the Gulf of Mexico (GOM) was developed using satellite remote sensing data sets that span periods as long as 32 years and *in-situ* data and information. The satellite data that are used in this study include sea-surface temperature (SST) data from radiometers aboard TIROS-M, HCMM, SEASAT and the numerous NOAA polar orbiting satellites; ocean color data from the CZCS, which was aboard the Nimbus polar orbiting satellite, SeaWiFS, and MODIS; and altimeter data from the TOPEX/Poseiden and the ERS systems. These data were supplemented with *in-situ* data from ships of opportunity, from field programs in the GOM, and from the projects managed by the various oil and gas companies. Twelve (12) separate statistics were created, some of which described characteristics of the Loop Current, while others are involved with warm core rings that separate from the Loop Current and cold core rings. The specific statistics are:

1. Spatial frequency of Loop Current water in the Eastern GOM (EGOM). [Database period: 1976–2003];
2. Spatial frequency of warm water associated with major WCRs in the Western GOM. [Database period: 1977–2003]
3. Spatial frequency of centers of WCRs in the GOM (based on the location of the centers of both major and minor WCRs). [Database period: 1977–2003]
4. Frequency of the path of major WCRs in the Western GOM (based on three potential ring-path subdivisions [i.e., northern path, central path, and southern path]). [Database period: 1976–2003]
5. Frequency of the speed of major WCRs in the Western GOM [Database period: 1972–2003]
6. Mean decay of the size of the major WCRs (Ring Dissipation) [Database period: 1976–2003]
7. Frequency of the separation of major eddy shedding periods from the Loop Current. [Database period: 1972–2003]
8. Periods of oscillation of the Loop Current's Northern Boundary. [Database period: 1977–2003]
9. Frequency of the orientation of the Loop Current. [Database period: 1976–2003]
10. Spatial frequency of Loop Current water in the EGOM not directly associated with the Loop Current or with major WCRs (This water mass is, for the most part, associated with minor WCRs and with the advection of warm Loop Current water by cold core rings [CCRs]). [Database period: 1976–2003]
11. Spatial frequency of intrusions of Loop Current water onto the West Florida Shelf. [Database period: 1976–2203]
12. Spatial frequency of centers of CCRs in the GOM. [Database period: 1992–2003]

The principal data set, but, however, not the only data set, used to derive the statistics is monthly analyses of the fronts in the GOM, which were created using an integral of available satellite clear-sky images (i.e., satellite SST, ocean color, and altimetry imagery) and of any available information on ocean features and/or analyzed *in-situ* data for the month in question. These analyses provided the "characteristic" position of the fronts in the GOM for a given month. The LC front in these analyses was the approximate average front for the month unless a WCR separated from the LC during that month. Then, it was the position of front after separation has occurred. WCR fronts are the approximate average front for the month. If warm LC water mass not directly associated with the LC or with major WCRs was found in the EGOM in a given month, then it was represented in the frontal analysis by its most widespread effect in the EGOM for that month. If an intrusion of warm LC water onto the West Florida Shelf was found in the EGOM in a given month, then it was also represented by its most widespread effect on that shelf for that month.

It is hoped that the information derived from this integrated climatology may be useful in planning field programs, to marine biologists and oceanographers for processes studies in the GOM, and as background information for environmental impact statements (EISs). It has also been shown that the information from a climatology can useful in evaluating and directing improvements for models that calculate the ocean dynamics in the GOM.

Dr. Fred Vukovich is a Chief Scientist for Science Applications International Corporation. He has been involved in oceanographic studies using remote sensing data from satellites such as TIROS-N, NIMBUS, NOAA, HCMM, , GOES, TOPEX, SEASAT, ERS-1, ERS-2, SeaWiFS, and MODIS, for thirty years. His research has focused on the Gulf Stream off the southeast coast and on the Gulf of Mexico. For the last twenty-five years, he has focused on studies in the Gulf of Mexico.

CURRENTS AT THE SIGSBEE ESCARPMENT

Nan D. Walker, Coastal Studies Institute and Department of Oceanography and Coastal Sciences, Louisiana State University
Steven P. Anderson, Horizon Marine, Inc.
Robert R. Leben, Center for Astrodynamics Research, University of Colorado

Abstract

During the August 2001 through May 2002 period, strong surface currents (> 100 cm s^{-1}) resulted from an intrusion of the Loop Current over the mooring site, the separation and passage of Loop Current warm-core eddies, and flow intensification due to cyclone/anticyclone interactions. Relatively strong bottom currents were experienced nearly simultaneously with many of these dynamic surface current events. The timing of the bottom current events varied, as some occurred nearly simultaneously with surface events while others lagged the surface events by several days. During most events, flow direction was similar from surface to bottom. The integration of GOES SST composite imagery with contoured SSH data revealed that some of the strong southwestward currents at the bottom along the escarpment occurred when Loop Current frontal eddy cyclones moved rapidly into regions of well-developed cyclonic circulation near the mooring site. Other events appeared to be closely linked with rapid movements of the Loop Current toward the escarpment. The strongest bottom currents in the opposite direction, to the northeast, occurred as warm-core eddies moved southwestward, south of the mooring site. Thus, the bottom-currents, at least during this period, were closely linked with surface processes. The potential effects of bottom trapped topographic Rossby waves were not clearly revealed by this analysis and bottom currents were not as strong as those discussed by Hamilton and Lugo-Fernandez (2001) farther to the east along the escarpment.

Introduction

On 31 July 2001 a full water column mooring was deployed at a depth of 2,960m seaward of the southern section of the Sigsbee Escarpment at 26° 20.23'N and 90º 45.93'W (Figure 1I.6). Measurements included current speed/direction, temperature, conductivity, and pressure at eighteen discrete depths. The main objective of this research project is to characterize current behavior near the bottom as well as to investigate the relationships between the bottom circulation and surface circulation. Additional measurements obtained from satellites and drifting buoys are being used to interpret the current information. Remote sensing data include GOES night-time sea surface temperature (SST) composite images, satellite altimeter data of sea surface height (SSH), and ocean color measurements from Orbview-2 SeaWiFS and Oceansat-1 OCM. An extension to the project enabled the collection of an additional fourteen months of data from 19 April 2003 to 6 June 2004. This paper focuses on the first series of measurements that were made from 31 July 2001 2 to June 2002.

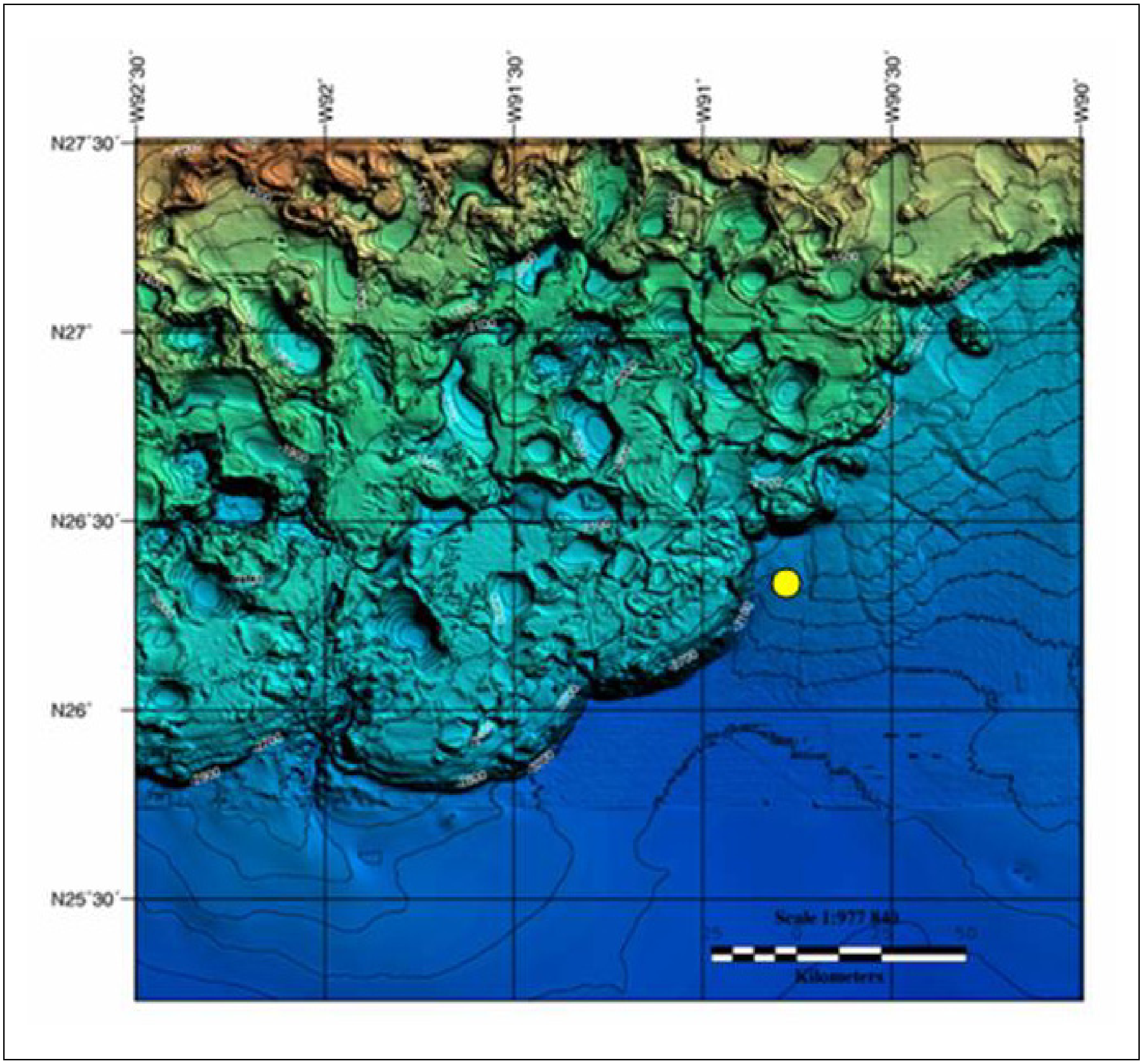


Figure 1I.6. Bathymetric contour map of the Sigsbee Escarpment and the location of the LSU mooring from 31 July 2001 to 2 June 2002.

Data Collection and Analysis

Current speed and direction were measured using Acoustic Doppler Current Meters (ADCPs) and Aanderaa RCM-7 and RCM-8 instruments. Upward-looking ADCPs were deployed at depths of 136m and 614 m. Ten Aanderaa current meters were deployed at depths of 146, 633, 878, 1128, 1378, 1628, 1878, 2128, 2578, and 2878m. Microcats were deployed at water depths of 148, 635, 978, 1278, 1630, and 2130m. Data return and data quality were excellent, and little editing of the data was needed. The currents were low-pass filtered using a 40-hour Butterworth filter to remove tidal and inertial frequencies. Data processing was performed using MATLAB and other graphic software.

Satellite imagery from the GOES GVAR, SeaWiFS, and OCM were obtained in real time and processed at the LSU Earth Scan Laboratory (*http://www.esl.lsu.edu*). GOES night-time SST composites were used extensively to detect and track ocean features with daily updates. The night-time compositing process enables removal of substantial cloud contamination by using a ten hour sequence of imagery (Walker et al. 2003) and the result is a daily update of SST information. Additional imagery from SeaWiFS and OCM revealed pigment patterns that were often helpful in detecting flow fields associated with eddies. Sea surface height (SSH) measurements from Dr. Bob Leben were superimposed on the SST composites as an aid to interpretation of eddy locations. In addition, an ongoing collaborative project with Horizon Marine Inc. has enabled the use of drifting buoy data that is also an important aid to interpretation of rapid changes in the eddy field at the study site.

Results and Discussion

The entire time series of low-pass filtered currents from all instruments are displayed in Figure 1I.7. Strongest currents were measured near the surface, where a speed maximum of 133 cm s^{-1} occurred in mid- February 2002. Surface current speeds exceeded 100 cm s^{-1} during four separate events in the February through April 2002 period. These strong currents resulted from the northwestward surge of the Loop Current over the study site and separation of Loop Current eddies, ‘Pelagic’ and ‘Quick,’ in rapid succession.

The graphic of current vectors (Figure 1I.7) clearly shows a coherence of currents in the top 650m of the water column, with minimum flow at 1,128 m. Near-surface currents for the 40–60m depth range averaged 38 cm s^{-1} over the entire time series. At 1,128m, currents averaged 5.9 cm s^{-1}. Current behavior was also quite coherent between 1,378m and 2,878m and weak bottom intensification was noted. At 2,878m, the mean current speed was 11.1 cm s^{-1} and the maximum speed was 37.4 cm s^{-1}. Current statistics, computed from the unfiltered data, are tabulated for selected depths in Table 1I.1.

Most of the bottom-current variability was in the northeast-southwest direction, an alignment that followed the escarpment, but not the bottom topography. The orientation of surface currents was variable in nature, with no dominant principal axis.

Ten along-escarpment bottom-flow events to the northeast and eleven to the southwest were observed in the record (Figure 1I.7). Bottom current reversals along the escarpment occurred every 14 days, on average. Several surface-intensified high-velocity flow events occurred during this time period, which were associated with a northwestward surge of the Loop Current, the separation of Loop Current eddies over the mooring, and associated cyclones.

The strongest surface and bottom currents occurred in early December 2001 and between mid-January and the end of May 2002, when the Loop Current, warm-core eddies, and cyclones were most prevalent in the study area. During several events, accelerations in bottom flow were correlated with surface flow and, in a few cases, current direction was consistent from surface to bottom. A brief discussion of six events follows.

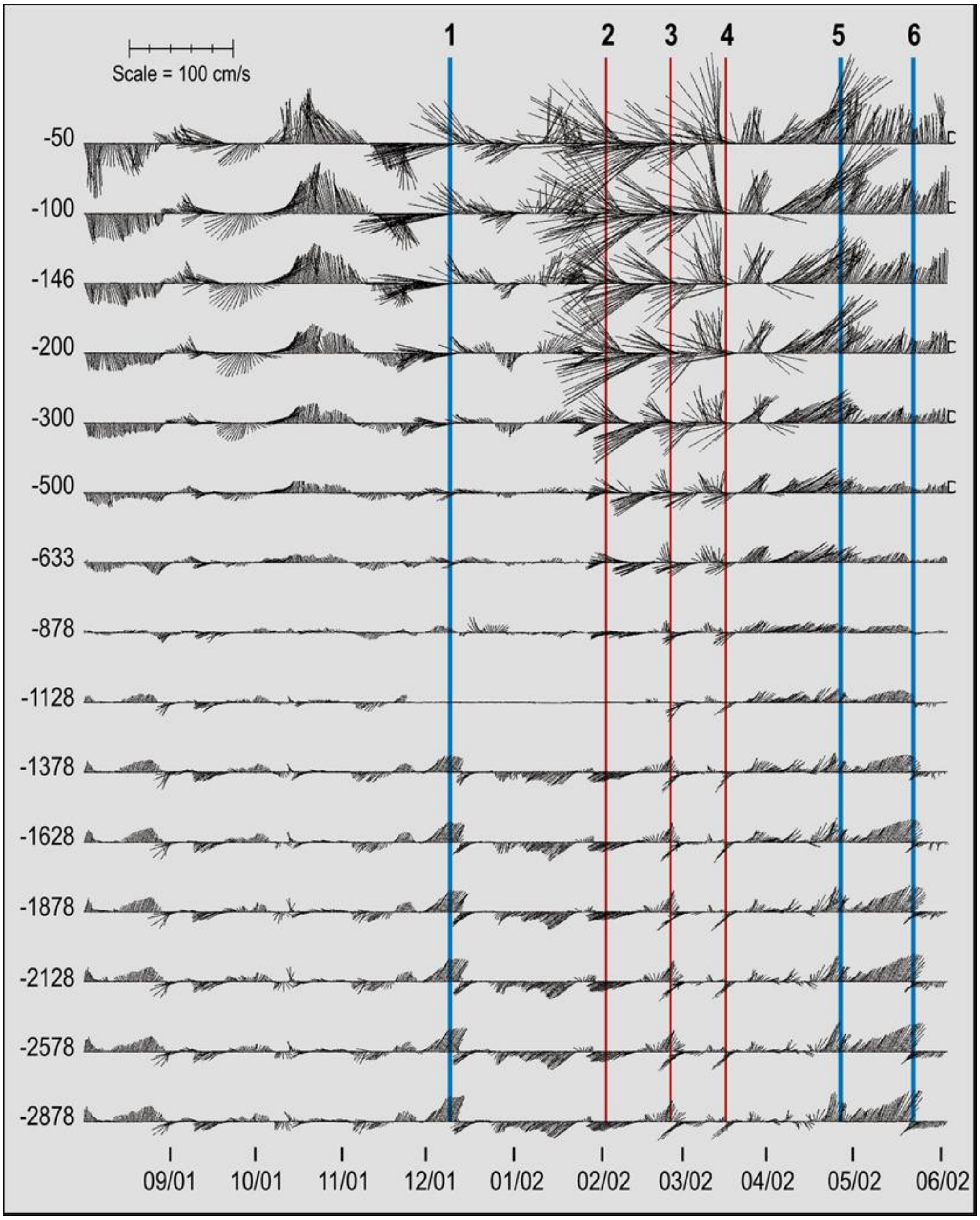


Figure 1I.7. Graphic showing stick vectors of low-pass filtered currents at selected depths from 31 July 2001 to 2 June 2002. The 50, 100, 200, 300, 500m bins are 20m averages from the ADCP measurements, that were adjusted for mooring blow-over. The blue lines depict along-escarpment flow events to the northeast and red lines depict along-escarpment flow events to the southwest.

Table 1I.1. Statistics of currents at selected depths. Scalar and vector speeds are in cm s^{-1}. No filtering or axis rotation was performed. Positive 'U' components show eastward flow and positive 'V' components show northward flow. The 'n' indicates number of observations. The 50, 100, 200, 300, and 500 m depths are 20m averages of ADCP currents.

Depth (m)	Mean (cm/s)			Max (cm/s)			Min (cm/s)			Standard Deviation (cm/s)		
	U	V	Speed	U	V	Speed	U	V	n	U	V	Speed
-50	-11.63	10.57	38.04	98.07	107.94	132.86	-115.63	-83.10	7336	29.96	27.84	21.74
-100	-7.64	10.01	37.84	93.33	99.96	119.58	-105.95	-76.30	7336	33.04	26.54	22.85
-200	-3.10	5.24	25.13	68.73	52.60	95.04	-82.60	-59.20	7336	23.04	17.59	15.68
-300	-2.11	3.17	19.41	52.25	44.25	73.90	-63.50	-44.35	7336	18.24	13.53	12.39
-500	-1.24	2.01	13.36	43.70	31.70	52.50	-45.40	-29.45	7336	12.94	9.12	8.82
-633	-1.26	1.98	11.07	31.20	26.02	37.42	-35.05	-23.50	7339	11.06	7.50	7.84
-878	-1.12	1.07	7.68	28.52	20.28	30.16	-27.36	-21.73	7340	7.79	5.21	5.59
-1128	-0.22	1.27	5.86	19.99	17.85	30.16	-28.79	-23.13	7339	6.44	4.85	5.69
-1378	-1.72	1.05	10.16	19.47	22.35	30.74	-23.85	-22.73	7339	8.41	7.85	5.75
-1628	-1.77	1.15	10.66	22.84	25.34	31.32	-24.15	-25.30	7339	8.82	8.68	6.63
-1878	-2.15	1.62	11.10	23.52	27.40	32.19	-25.70	-22.47	7340	9.50	8.80	7.19
-2128	-2.07	1.77	11.59	23.01	30.34	33.36	-24.63	-21.54	7336	9.26	9.29	6.71
-2578	-2.14	1.59	11.33	23.17	29.46	36.04	-23.71	-22.31	7339	9.09	9.44	7.11
-2878	-2.82	1.47	11.08	23.09	30.86	37.39	-24.14	-20.97	7339	8.38	9.47	6.87

Strongest bottom currents were measured in the along-escarpment direction, to the northeast (Figure 1I.7). During the two main events (labeled 1 and 6 on Figure 1I.7) warm-core eddies and associated cyclones passed in close proximity to the mooring. During event 1 in early December 2001, the center of a warm core eddy was located north of the mooring, and westward surface flow was experienced. Cyclones were located south of the eddy and farther west along the escarpment. Acceleration in surface and bottom currents occurred nearly simultaneously. Surface currents reached 78 cm s^{-1} and bottom currents reached 30 cm s^{-1}. During event 6 in May 2002, a larger warm-core eddy passed south of the mooring and surface currents were not much stronger than the bottom currents (46 and 36 cm s^{-1}, respectively). During event 1, bottom and surface currents were in opposition, whereas in event 6 they flowed in the same general direction. During event 5, in the latter part of April, acceleration in bottom currents lagged acceleration at the surface by about one week. This event coincided with the southwestward movement of Quick Eddy south of the mooring site (Figure 1I.8a). Geostrophic currents at the mooring site were maximized as a well developed cyclone abutted with the large warm-core eddy on its northwest margin. It is interesting to note that the currents within the 630 to 1,378m depth range were unusually strong (compared with the rest of the record) from mid-April to late May.

The strongest along-escarpment currents, to the southwest, occurred from January through March 2002. Two events (3 and 4 in Figure 1I.7) were short-lived events (3-days) and were characterized by speeds of 25–30 cm s^{-1} at 2,878m (Figure 1I.7). During both events, southwestward flow occurred throughout the water column, and surface and bottom flow intensified nearly simultaneously. The first of these short-lived events (event 3) was characterized by a rapid transition from northeast to southwest flow. The GOES image sequence from 24 to 27 February revealed a surge of the Loop Current towards the escarpment just prior to the onset of southwestward flow that was relatively strong from 27 Feb to 2 March 2002.

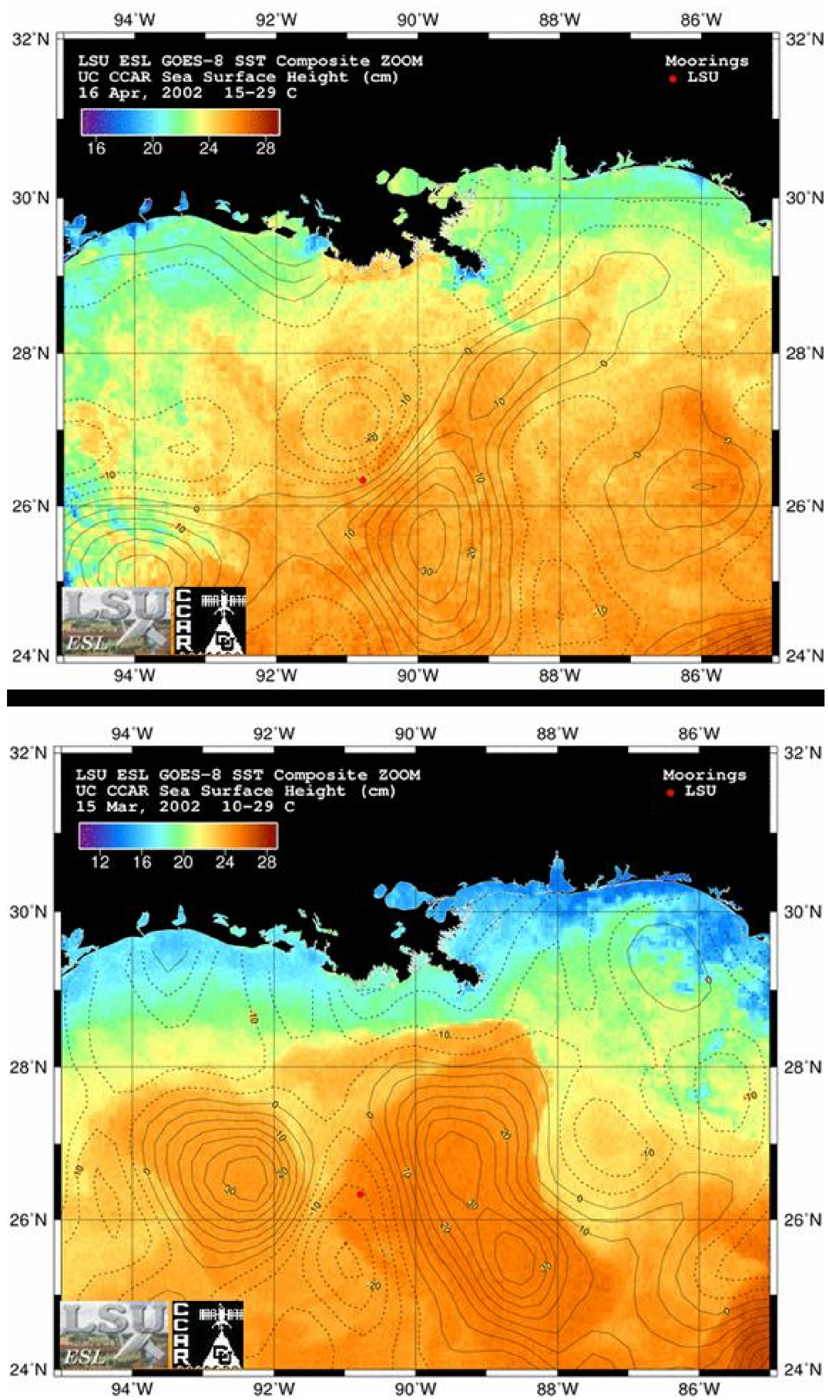


Figure 1I.8. Color enhanced GOES SST composite imagery superimposed with contours of SSH data for (top panel) 16 April 2002 and (bottom panel) 15 March 2002. The mooring site is shown with a red dot. Positive SSH are solid and negative SSH are dashed. The top panel shows Quick Eddy with a center southeast of the mooring and the bottom panel shows both Pelagic Eddy (to the west) and Quick Eddy, separated by a large cyclone.

The second of these short-lived events (event 4 in Figure 1I.7) was also studied in detail using GOES SST composites in tandem with SSH data. In mid-March 2002, the mooring was situated on the northeast flank of a cyclone (Figure 1I.8b). Strong geostrophic currents were indicated by the SSH data as the cyclone was adjacent to Quick Eddy, that had just recently separated from the Loop Current. A time history of GOES SST image composites revealed rapid northward movement of a frontal eddy cyclone along the western side of Quick Eddy. The GOES SST/SSH image for 15 March shows the location of Quick Eddy and the cyclone in relationship to the mooring site that is depicted with a red dot (Figure 1I.8b). The frontal eddy cyclone, located along the western margin of Quick Eddy, appears as a warm meander at the surface due to the entrainment of warm water away from the eddy. Strong bottom currents, to the southwest, occurred as the frontal eddy cyclone moved over the mooring, soon after intensification of surface flow. This event was relatively short-lived at the bottom, as southwestward currents lasted from 17 to 20 March.

Prior to these two strong short-lived events, a prolonged period of southwestward flow was experienced from 25 December to 22 January. It was associated with the extreme westward intrusion of the Loop Current and separation of Pelagic Eddy.

References

Hamilton, P. and A. Lugo-Fernandez. 2001. Observations of high speed deep currents in the northern Gulf of Mexico. Geophysical Research Letters 28(14):2867–2870.

Walker, Nan, S. Myint, A. Babin, and A. Haag. 2003. Advances in satellite radiometry for the surveillance of surface temperatures, ocean eddies and upwelling processes in the Gulf of Mexico using GOES-8 measurements during summer. Geophysical Research Letters 30(16):1854, doi:10.1029/2003GL-17555.

Dr. Nan D. Walker is an Associate Professor in the Department of Oceanography and Coastal Sciences and Director of the LSU Earth Scan Laboratory. She has 24 years of experience in the field of satellite remote sensing of coastal and ocean processes. Her research interests include estuarine-shelf circulation, coastal upwelling, Loop Current and eddy circulation, coastal sediment transport, physical-biological interactions, and ocean climatology. She received her B.S. in marine zoology from Duke University, M.S. in marine science from Louisiana State University, and Ph.D. in physical oceanography from the University of Cape Town, South Africa.

Dr. Steven P. Anderson is Chief Scientist at Horizon Marine, Inc. Dr. Anderson's research interests include air-sea interaction, upper ocean dynamics and ocean observing systems. Dr. Anderson received a B.S. in mechanical engineering from Lafayette College and a Ph.D. in applied ocean sciences from the Scripps Institution of Oceanography, University of California, San Diego.

Dr. Robert R. Leben received the B.S., M.S., and Ph.D. degrees in aerospace engineering sciences from the University of Colorado, Boulder in 1981, 1982 and 1986, respectively. Since 1986, he has been employed at the Colorado Center for Astrodynamics Research at the University of Colorado, Boulder, where he is an Associate Research Professor. His research interests include satellite altimetry and its application to monitoring ocean circulation.

SESSION 2G

DEEP GULF OF MEXICO CHEMOSYNTHETIC COMMUNITIES: CURRENT KNOWLEDGE FOR SITES BELOW 1,000 METERS

Chair: Greg Boland, Minerals Management Service

Co-Chair: James Sinclair, Minerals Management Service

HYDROCARBON SEEP REGIMES IN THE GULF OF MEXICO CHEMOSYNTHETIC COMMUNITIES, REMOTE SENSING, BIOGEOGRAPHY

Ian R. MacDonald, Texas A&M University – Corpus Christi

Twenty years of research in the northern Gulf of Mexico (GOM) have assembled an unequaled overview of the benthic chemosynthetic communities supported by fluid seepage in a marine basin. Sources of the chemical substrata these communities require include conate fluids, CH4 in free, dissolved, and clathrate form and high-molecular weight hydrocarbons in liquid and solid form. Recent findings from the Gulf document structural and taxonomic affinities that now span the entire basin.

Communities of tube worms including and undescribed escarpid and seep mussels (*Bathymodiolus heckeri*) were discovered among jointed carbonates and associated rubble at the base of the Florida Escarpment (3,270m water depth) in 1984 (Paull et al. 1984). In 1990, the similar species were found in a very similar setting, but on the opposite side of the basin at 2,800m in Alaminos Canyon (Brooks et al. 1990). Discovery of asphalt volcanism and associated chemosynthetic communities in the Campeche Knolls (3,000m) document a new seep process (MacDonald et al. 2004), but appears to have taxonomic affinity with the Florida Escarpment and Alaminos Canyon sites. Interestingly, the Campeche Knoll findings were partially anticipated by a 1971 photograph from the Sigsbee Knolls in the GOM abyss (Pequegnat and Jeffrey 1978). In contrast, the seeps of the Green Canyon in the northern at slope depths (500–2,000m) appear to comprise a distinct zoogeographic province, a broad depth range, and distinct geologic styles.

Satellite remote sensing of the GOM hydrocarbon system is a tool for filling in these gaps and extending the Gulf seep model to analogous areas in the Caribbean and West Africa. The current compilation of remote sensing targets—many of which having been confirmed by seafloor collections—confirm the basin-wide distribution (Figure 2G.1). They also illustrate that hydrocarbon seeps support a remarkable ecosystem. Major questions that are the subject of active research include determining the role of this ecosystem in the global and region carbon cycle. In other ocean settings, microbiologists are investigating the magnitude the so-called "deep, hot biosphere." The GOM hydrocarbon reservoirs should be investigated in this context. Finally, the role that the GOM basin has played in the evolutionary history of chemosynthetic fauna requires additional research.

From a management perspective, regulatory agencies can be confident that they have developed robust models to describe the variety and distribution of upper slope seep communities. However, preliminary findings indicate that there is a major gap in the occurrence of lush tube worm communities between ~1,000 and 2,000 m. This issue needs to be tested with additional survey and biogeochemical investigations.

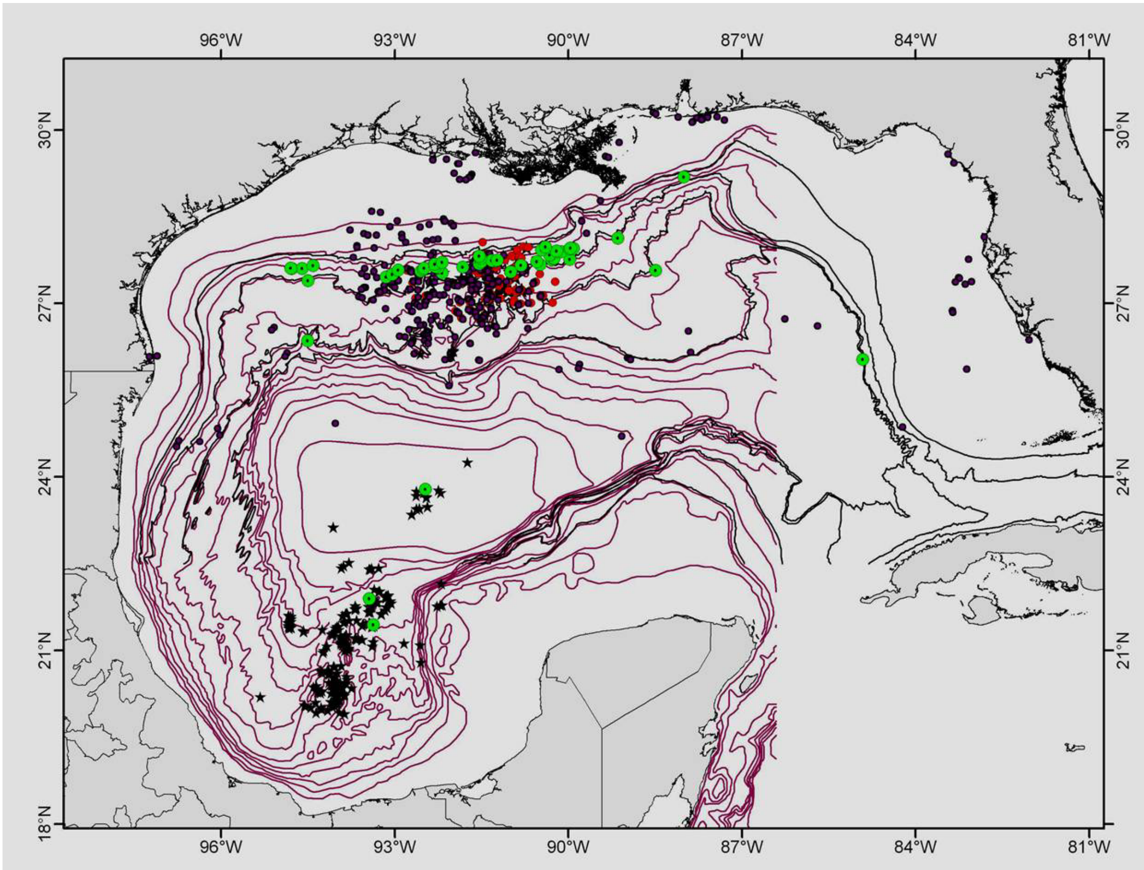


Figure 2G.1. Compilation of satellite remote sensing targets indicating robust oil seepage (solid dots) and sites where seafloor collections have confirmed the occurrence of chemosynthetic fauna (circles).

References

Brooks, J.M., D.A. Wiesenburg, H. Roberts, R.S. Carney, I.R. MacDonald, C.R. Fisher, N.L. Guinasso, Jr., W.W. Sager, S.J. McDonald, R.A. Burke, Jr., P. Aharon, and T.J. Bright. 1990. Salt, seeps, and symbiosis in the Gulf of Mexico. A preliminary report of deepwater discoveries using DSV Alvin. EOS, Transactions, American Geophysical Union 71(45):1772–1773.

MacDonald, I.R., G. Bohrmann, E. Escobar, F. Abegg, P. Blanchon, V. Blinova, W. Brückmann, M. Drews, A. Eisenhauer, X. Han, K. Heeschen, F. Meier, C. Mortera, T. Naehr, B. Orcutt, B. Bernard, J. Brooks, and M. de Faragó. 2004. Asphalt volcanism and chemosynthetic life in the Campeche Knolls, Gulf of Mexico. Science 304:999–1002.

Paull, C.K., B. Hecker, R. Commeau, R.P. Freeman-Lynde, C. Neumann, W.P. Corso, S. Golubic, J.E. Hook, E. Sikes & J. Curray. 1984. Biological communities at the Florida Escarpment resemble hydrothermal vent taxa. Science 226:965–967.

Pequegnat, W.E. and L.M. Jeffrey. 1978. Petroleum in deep benthic ecosystems of the Gulf of Mexico and Caribbean Sea. Contributions in Marine Science 22:63–75.

Ian R. MacDonald, Ph.D. is Professor of Environmental Science with the Physical and Life Sciences Department of Texas A&M University – Corpus Christi. After receiving simultaneous undergraduate degrees in environmental science from Friends World College in Huntington, NY, and Telemark District College in Norway, he was then employed by the International Ocean Institute and the Food and Agriculture Organization of the United Nations at postings in Malta and Rome. He completed his M.S. in fisheries sciences in 1984 from Texas A&M and then his Ph.D. in 1990. His doctoral dissertation was on the ecology of communities that flourish at natural oil seeps. Dr. MacDonald's research has entailed extensive use of such deep-diving submarines as *Johnson Sea-Link, Alvin*, and the Navy nuclear submarine *NR-1.* His particular interest is the application of advanced imaging technology to marine research; this includes satellite detection of oil slicks, as well as application of satellite image processing techniques to analyze images collected from submarines.

Samantha Joye (University of Georgia at Athens) and William Sager (Texas A&M University) contributed to this presentation.

CHALLENGES FOR INTERPRETATION OF SEAFLOOR GEOLOGY-BIOLOGY IN DEEP AND ULTRA-DEEP WATER, GULF OF MEXICO

Harry H. Roberts, Coastal Studies Institute, Department of Oceanography and Coastal Sciences, Louisiana State University

Geologic Framework and Need for a Deep Water Study

The northern Gulf of Mexico (GOM) continental slope covers an area of over 120,000 km^2 and is defined by the shelf edge at roughly the 200 m isobath to the upper limit of the continental rise at an approximate depth of 2,600 to 2,750 m (Bouma and Roberts 1990). The most complex part of the basin's continental slope occurs opposite east Texas and Louisiana. In this province, regional topography is dominated by domes or knolls associated with salt in the shallow subsurface and intervening basins. Seafloor slopes associated with these regional-scale features range from less than 1° on the dome tops and along the basin floors to over 20° on the side of domes and on basin flanks. Observable on this regional topography of domes and basins are smaller-scale geologic features that are associated with high variability in sediment type and local relief. Near-surface geology and topography of the upper continental slope in the northern GOM is highly influenced by cyclic episodes of shelf edge progradation and sediment input to deep water. In addition to filling mini-basins and mobilizing salt, sediment loading during periods of lowered sea-level activates faults. Faulting creates abrupt relief and steep slopes (some near vertical) on the modern ocean floor of the slope. Faults function as avenues of transport for fluids and gases to or near the modern seafloor. The process of fluid and gas expulsion has an important impact on the present surficial geology of the slope. Expulsion of large volumes of fluidized sediment results in the formation of mud volcanoes and mud flows (Neurauter and Roberts 1992; Kohl and Roberts 1994). Seepage and venting results in the development of highly populated communities of chemosynthetic organisms (Kennicutt et al. 1985), creation of brine pools and pock marks (McDonald et al. 1990), gas hydrate mound formation (Brooks et al. 1985), and precipitation of carbonates and other exotic minerals to form hardgrounds, chimneys, and mound-like buildups (Roberts and Aharon 1994). These various seafloor responses are all products of vertical flux of hydrocarbon gases, crude oil, and other formation fluids migrating to the ocean floor along faults. They have been documented over the slope's full depth range. However, well-studies sites the deep (mid-slope) and ultra-deep (lower slope-basin floor) are few.

Since the mid-1980s, researchers working on the continental slope of the northern GOM have studied the impacts of hydrocarbon seeps and vents on both the slope's surficial geology and biology. Although a few programs have spanned the full depth range of the slope (e.g. Brooks et al. 1990), most have been confined to the upper slope (< 100 m water depth). The reason for an upper slope focus relates to the availability of data for analyzing the surficial geology and also the availability of manned submersibles for directly observing, sampling, and deploying in situ instrumentation at seep and vent sites. In the early 1980s, vast amounts of geophysical and geotechnical data were collected to evaluate the upper slope for both oil-gas exploration and production. By the mid-1980s the exploration front had moved beyond the upper slope and 3D-seismic was being acquired in large tracks in mid and lower slope areas. At this same time, several manned submersibles, limited to a diving depth of 1,000 m, became available at a reasonable cost for the study of hydrocarbon seeps and their unusual chemosynthetic communities. Deeper diving submersibles, particularly ALVIN, were and still are difficult to schedule for GOM research.

The oil and gas exploration front has now moved to the deepest parts of the continental slope and deeper water of the continental rise. Studies of seafloor geology and biology related to hydrocarbon seeps and vents, that have characterized the upper slope for the last two decades, now need to be extended to deeper parts of the slope. As Figure 2G.2 clearly illustrates, geology of the continental slope changes from an extensional regime at the shelf-slope transition to a contractional setting at the lower slope to basin floor region. Fault patterns, intraslope basins, and salt masses all change as one progresses from the shelf edge to deep basin floor.

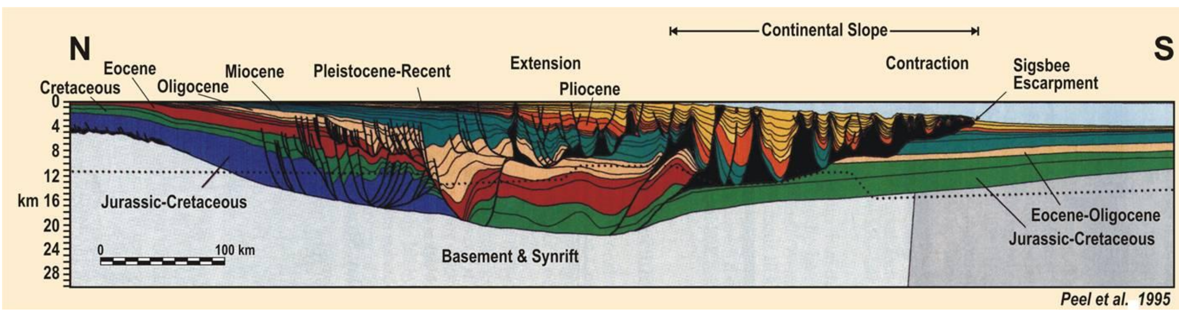


Figure 2G.2. Dip section across the western coast of Louisiana illustrating the changing structure and salt geometrics from onshore to the deep Gulf of Mexico basin floor (modified from Peel et al. 1995).

Differences Between the Shallow and Deep Slope

The shallow and deep parts of the northern GOM continental slope differ both in their geologic configuration as well as their oceanographic setting. The slope to a depth of approximately 1,000 m is periodically impacted by thermal and current forcing associated with direct contact with the Loop Current and its eddies. These Loop Current intrusions have been shown to destabilize surface and shallow subsurface gas hydrate deposits as well as erode sediments from the tops of salt-supported topographic highs. The upper slope is also characterized by deep-cutting growth faults and counter regional faults driven by sediment input from the shelf edge during sea level lowstands and by salt mobility. Salt masses range from stocks to canopies while the lower slope is dominated by salt nappes. Intraslope basins of the upper slope house thick sedimentary sequences that are not usually salt-floored. Most basins extend well unto the zone of overpressure. Breaches in this zone cause fluid and gas expulsion that occurs primarily at the flanks of these basins. Salt masses at the basin flanks focus fluids and gases to modern seafloor. In the lower slope province, intraslope basins commonly house comparatively thin sedimentary sequences, and the basins are generally salt-floored. Where they are not salt-floored, salt welds are evident. The compressional setting for the lower slope results in various types of anticlinal structures in the subsurface. Some of these structures become breached and thereby develop as obvious "leak points" to the modern seafloor. The recognition of bottom simulating reflectors (BSRs) running through the stratigraphy of the lower slope strongly suggests the presence of gas hydrate. However, mound-like features at the seafloor that could represent surface expressions of gas hydrate, as occur in the upper slope, are not commonly associated with the lower slope.

At the base of the slope, salt nappes extend over the basin floor creating the Sigsbee Escarpment. Slope instabilities and brine seeps are common. Whether the brine seeps also contain hydrocarbons and therefore support chemosynthetic organisms remains as a research question. Also, can "leak points" for hydrocarbons originating from beneath the salt nappes be clearly identified and perhaps recognized as being different from brine seeps associated with salt dissolution?

Greatest Challenges for Seep-Research in Deep and Ultra-Deep Water

The geologic framework for hydrocarbon seepage and venting clearly changes from the upper slope to the Sigsbee Escarpment at the continental slope-to-continental rise transition. So, in order to be successful in a study that focuses on surficial expulsion geology and related biology of the deep slope, the unique geologic framework of the lower slope must be understood from a petroleum systems point of view. Technology exists for collecting excellent data sets from deep water. However, data collection systems for deep and ultra-deep water are expensive and some systems, such as ALVIN, have very limited accessibility. Research in the deep slope environment is an expensive undertaking. Without a substantial financial commitment, a comprehensive and field-based deep water research program for both academic and government researchers cannot be truly successful.

References

Bouma, A.H. and H.H. Roberts. 1990. Northern Gulf of Mexico continental slope. Geo-Marine Letters 10:177–187.

Brooks, J.M., M.C. Kennicutt II, R.R. Bidigare, and R.A. Fay. 1985. Hydrates, oil seepage, and chemosynthetic ecosystems on the Gulf of Mexico slope, EOS, Transactions, American Geophysical Union 66:106.

Brooks, J.M., D.A. Wiesenburg, H. Roberts, R.S. Carney, I.R. MacDonald, C.R. Fisher, N.L. Guinasso, Jr., W.W. Sager, S.J. McDonald, R.A. Burke, Jr., P. Aharon, and T.J. Bright. 1990. Salt, seeps, and symbiosis in the Gulf of Mexico. A preliminary report of deepwater discoveries using DSV Alvin. EOS, Transactions, American Geophysical Union 71(45):1772–1773.

Kennicutt, II, M.C., J.M. Brooks, R.R. Bidigare, R.A. Fay, T.L. Wade, and T.J. McDonald. 1985. Vent-type taxa in a hydrocarbon seep region on the Louisiana slope. Nature 317:351.

Kohl, B. and H.H. Roberts. 1994. Fossil foraminifera from four active mud volcanoes in the Gulf of Mexico. Geo-Marine Letters 14:126–134.

McDonald, I.R., J.F. Rilly, II., N.L. Guinasso, Jr., J.M. Brooks, R.S. Carney, W.A. Bryant, and T.J. Bright. 1990. Chemosynthetic mussels at a brine-filled pockman in the northern Gulf of Mexico. Science 248:1096–1099.

Neurauter, T.W. and H.H. Roberts. 1992. Seismic and visual observation of seepage-related structures on the continental slope, northern Gulf of Mexico. In: Proceedings: Twenty-fourth Offshore Technology Conference, Houston, Texas, OTC 6850. Pp. 355–362.

Peel, F.J., C.J. Travis, and J.R. Hossack. 1995. Genetic structural provinces and salt tectonics of the Cenozoic offshore U.S. Gulf of Mexico: A preliminary analysis. In: Jackson, M.P.A., D.G. Roberts, and S. Snelson, eds. Salt Tectonics: A Global Perspective: American Association of Petroleum Geologists Memoir 65:153–195.

Roberts, H.H. and P. Aharon. 1994. Hydrocarbon-derived carbonate buildups of the northern Gulf of Mexico continental slope: A review of submersible investigations. Geo-Marine Letters 14:135–148.

Harry H. Roberts is the former director of Coastal Studies Institute (for 10 years) at LSU, a member of the Department of Oceanography and Coastal Sciences, and a Boyd Professor. He has had a career in marine geology that spans more than 30 years and has worked in many foreign countries as well as in the United States. Recently, he has focused his research on two areas: (a) deltaic sedimentation and processes, and (b) surficial geology of the northern Gulf's continental slope. The latter research thrust has concentrated on building an understanding of the impacts of fluid and gas expulsion on the surficial geology and biology of the slope. Gas hydrates constitute one of the unusual consequences of fluid and gas migration and expulsion in deep water.

BIOGEOGRAPHY AND BIODIVERSITY OF COLD SEEPS IN THE GULF OF MEXICO

Charles R. Fisher and Erik E. Cordes, Pennsylvania State University

Chemosynthetic communities are found wherever reduced chemicals (most often sulfide and/or methane) and oxygen co-occur. Environments range from mudflats and sewage outfalls to deep-sea hydrothermal vents and cold seeps. All chemosynthetic communities include free-living chemoautotrophic and/or methanotrophic bacteria, and often the communities include one or more species of metazoan (animal) that harbor chemoautotrophic and/or methanotrophic bacteria as symbionts. The easily visible fauna that comprise the chemosynthetic communities can be as simple as a bacterial mat or a few scattered clams, or as spectacular as the giant vestimentiferan tubeworm aggregations found at many of the worlds cold seeps and hydrothermal vents.

Defining a cold seep is somewhat problematic, as there are a wide range of chemosynthetic environments that could qualify for this designation. Some are actually warm (hydrothermal), some are more vent-like (high flow), and the geological drivers also differ in different places. For purposes of this summary, "cold-seeps" will refer to places where fluids containing reduced chemicals exit the sea floor as a result of geological processes other than superheating of pore fluids associated with magmatic interactions. Some of the first deep sea cold seeps to be discovered were in the Gulf of Mexico (GOM), on the Florida Escarpment and on the Upper Louisiana Slope (ULS) (Paull et al. 1984; Kennicutt et al. 1985). Since that time cold seeps have been discovered and sampled from most of the world's oceans and will likely be discovered in many other places yet to be explored (Sibuet and Olu 1998).

Cold-seep animal communities are most often dominated by one of three groups of animals with chemoautotrophic symbionts; vesicomyid clams (with sulfur oxidizing symbionts), siboglinid polychaetes or tubeworms (with sulfur oxidizing symbionts), or bathymodiolid mussels (with methanotrophic and/or sulfide oxidizing symbionts). Globally, vesicomyid clam communities are the most common, followed by mussels and then tubeworms (Sibuet and Olu 1998). Although macrofaunal communities associated with clam communities are not nearly as well studied as the communities associated with mussels or tubeworms, photographs and anecdotal reports suggest that clam-associated communities are not nearly as diverse or substantial as those associated with mussels and tubeworms (Gebruk et al. 2000; Levin et al. 2003). Communities associated with mussels at both vents and seeps have been quite well described, including those at the Florida Escarpment, Alaminos Canyon, and numerous sites on the ULS of the GOM (Turnipseed et al. 2003; Bergquist et al. 2005). Quantitative studies of the community ecology of seep tubeworm aggregations are largely limited to studies on the ULS (Bergquist et al. 2002; 2003a; 203b).

As a result of MMS, NOAA, and NSF funding over the past 20 years, the cold seeps of the upper Louisiana Slope of the GOM are arguably the best understood of any seep communities in the world. The physiology of the ULS mussels and tubeworms is better studied than that of any other seep fauna (for example Fisher et al. 1987; 1988; Page et al. 1989; Kochevar et al. 1992; Lee et al. 1992; Fisher and Childress 1992; Streams and Fisher 1998; Julian et al. 1999; Freytag et al.

2001), as is their life history (Nix 1995; Fisher et al. 1997; Young et al. 1996; Smith et al. 2000; Bergquist et al. 2000; Cordes et al. 2003; 2005) and community ecology (Bergquist et al. 2002; 2003a; 2003b; 2004; in press). Because the known vesicomyid clam communities on the ULS are much more sparse and rare than the mussel and tubeworm communities, much less is known about these communities. These clams are thought to dominate the deepest seep communities (Sibuet and Olu 1998), and a large dense bed of what appeared to be vesicomyid clams was seen about 500 meters from the main Alaminos Canyon seep site during the last two minutes of the last dive of a 1991 dive series; unfortunately, no time remained to obtain a sample (C. Fisher, pers. obs). It is quite possible that as we better explore the GOM seeps at depths greater than 1,000 meters, we will discover significant vesicomyid clam communities.

In the final report of the MMS Chemo II project and related publications, a qualitative model for the establishment, persistence, and succession of seep communities on the ULS is presented (Bergquist et al. 2000; MacDonald et al. 2002; Bergquist et al. 2003a). That model has since been expanded, and aspects such as the proposed successional sequences verified experimentally (Bergquist et al. 2003b; Bergquist et al. 2005). In addition, quantitative mathematical models of tubeworm aggregation establishment, growth, longevity, and interactions with free-living microbial consortia have been developed (Cordes et al. 2003; 2005). These models place constraints on the types of environments that will support rich and long-lived chemosynthetic communities, indicate the most important parameters to quantify to understand the systems, and also provide a variety of testable predictions concerning the communities of animals and bacteria associated with the tubeworms and mussels. This rich body of literature and knowledge provides a firm foundation for the design of surveys and experiments to provide a first-order understanding of chemosynthetic communities in the deeper waters of the GOM.

Although only a few communities from the lower slope (LS) chemosynthetic habitats of the GOM have ever been studied, and quantitative collections from below 1,000 meters in the GOM are sparse, some general trends (and testable hypotheses) are evident from these collections. There is very little overlap in the species composition between the communities on the ULS and the LS of the GOM. Our preliminary data suggests five potential shared species greater than one mm (of the 116 from the ULS seep communities and the 48 from the LS). However of these five, one (*B. childressi*) is represented by two distinct genetic populations (Craddock et al. 1995), three are undescribed species, and the last is a sipunculid with little easily apparent morphological criteria for distinguishing between species. Confirmation that any of these species are the same from both depths must await further molecular investigations, and the shallow and deep communities may prove to be completely genetically isolated from one another. On the other hand, there is significant species overlap between the communities at the Florida Escarpment (3,300 m depth) and Alaminos Canyon (2,200 m depth) where 13 of 21 common species are apparently shared. Interestingly, brittle stars (Ophioroidea), a group that are largely absent from collection on the ULS, dominated the associated fauna in several collections from the LS. In general, community diversity and evenness declines with depth, endemicity increases with depth, and the biomass of the associated faunal communities (standardized to habitable surface area) is similar across the depth gradient studied. Unlike the general trend for the background fauna, body size does not show any trends with depth, increasing in some taxa and decreasing in others. Together, our existing knowledge of the ULS and our preliminary surveys of LS chemosynthetic communities provide a substantial foundation for targeted research in the deep waters of the GOM.

References

Bergquist, D.C., F.M. Williams, and C.R. Fisher. 2000. Longevity record for deep-sea invertebrate. Nature 403:499–500.

Bergquist, D.C., I.A. Urcuyo, and C.R. Fisher. 2002. Establishment and persistence of seep vestimentiferan aggregations from the upper Louisiana slope of the Gulf of Mexico. Marine Ecology Progressive Series 241:89–98.

Bergquist, D.C., T. Ward, E.E. Cordes, T. McNelis, R. Kosoff, S. Hourdez, R. Carney, and C.R. Fisher. 2003a. Community structure of vestimentiferan-generated habitat islands from upper Louisiana slope cold seeps. Journal of Experimental Marine Biology and Ecology 289:197–222.

Bergquist, D.C., J. Andras, T. McNelis, S. Howlett, M.J. van Horn, and C.R. Fisher. 2003b. Succession in upper Louisiana slope cold seep vestimentiferan aggregations: the importance of spatial variability. PSZN Marine Ecology 24:31–44.

Bergquist, D.C., C. Fleckenstein, E. Smith, J. Knisel, and C.R. Fisher. 2004. Environment drives physiological variability in the cold seep mussel *Bathymodiolus childressi*. Limnology and Oceanography 49:706–715.

Bergquist, D.C., C. Fleckenstein, J. Knisel, B. Begley, I. R. MacDonald, and C.R. Fisher. In press. Variations in seep mussel bed communities along physical and chemical environmental gradients. Marine Ecology Progressive Series.

Cordes, E.E., D.C. Bergquist, K. Shea, and C.R. Fisher. 2003. High hydrogen sulfide demand of long-lived vestimentiferan tube worm aggregations modifies the chemical environment at deep-sea hydrocarbon seeps. Ecology Letters 6:212–219.

Cordes, E.E., M.A. Arthur, K. Shea, and C.R. Fisher. 2005. Modeling the mutualistic interactions between tubeworms and microbial consortia. Public Library of Science, Biology 3:e77.

Cordes, E.E., S. Hourdez, B.L. Predmore, M.L. Redding, and C.R. Fisher. Submitted. Succession of hydrocarbon seep communities associated with the long-lived foundation species *Lamellibrachia luymesi.* Marine Ecology Progressive Series.

Cordes, E.E., B.L. Predmore, C. Jones, P. Deines, G. Telesnicki, and C. R. Fisher. Submitted. Impact of ecosystem engineering tubeworms on the hydrocarbon seep habitat. Ecology.

Craddock, C., W.R. Hoeh, R.G. Gustafson, R.A. Lutz, J. Hashimoto, R.J. Vrijenhoek. 1995. Evolutionary relationships among deep-sea mytilids (Bivalvia: Mytilidae) from hydrothermal vents and cold-water methane/sulfide seeps. Marine Biology 121:477–485.

Fisher, C.R., J.J. Childress, R.S. Oremland, and R.R. Bidigare. 1987. The importance of methane and thiosulfate in the metabolism of the symbionts of two deep-sea mussels. Marine Biology 96:59–71.

Fisher, C.R., J.J. Childress, and N.K. Sanders. 1988. The role of vestimentiferan hemoglobin in providing an environment suitable for chemoautotrophic sulfide oxidizing endosymbionts. Symbiosis 5:229–246.

Fisher, C.R. and J.J. Childress. 1992. Organic carbon transfer from methanotrophic symbionts to the host hydrocarbon-seep mussel. Symbiosis 12:221–235.

Fisher, C.R., I. Urcuyo, M.A. Simpkins, and E. Nix. 1997. Life in the slow lane: growth and longevity of cold-seep vestimentiferans. PSZN Marine Ecology 18:83–94.

Gebruk, A.V., P. Chevaldonne, T. Shank, R.A. Lutz, R.C. Vrijenhoeck. 2000. Deep-sea hydrothermal vent communities of the Logatchev area (14 degree 45'N, Mid-Atlantic Ridge): diverse biotopes and high biomass. Journal of the Marine Biological Association of the United Kingdom 80:383–393.

Julian, D., F. Gaill, E. Wood, A.J. Arp, and C.R. Fisher. 1999. Roots as a site of hydrogen sulfide uptake in the hydrocarbon seep vestimentiferan *Lamellibrachia* sp. Journal of Experimental Biology 202:2245–2257.

Kennicutt M.C., J.M. Brooks, R.R. Bidigare, R.R. Fay, T.L. Wade, T.J. McDonald. 1985. Vent-type taxa in a hydrocarbon seep region on the Louisiana slope. Nature 317:351–353.

Kochevar, R.E., J.J. Childress, C.R. Fisher, and E. Minnich. 1992. The methane mussel: Roles of symbiont and host in the metabolic utilization of methane. Marine Biology 112:389–401.

Lee, R.W., E.V. Thuesen, J.J. Childress, and C.R. Fisher. 1992. Ammonium and free amino acid uptake by a deep-sea mussel containing methanotrophic bacterial symbionts. Marine Biology 113:99–106.

Levin, L.A., W. Ziebis, G.F. Mendoza, V.A. Growney, M.D. Tryon, K.M. Brown, C. Mahn, J.M. Gieskes, A.E. Rathburn. 2003. Spatial heterogeneity of macrofauna at northern California methane seeps: Influence of sulfide concentration and fluid flow. Marine Ecology Progressive Series 265:123–139.

MacDonald, I.R., N.L. Guinasso, G.A. Wolff, M.C. Kennicutt, R. Sassen, J.W. Morse, R. Arvidson, W. Sager, S. Macko, D.C. Nelson, E. Powell, R. Carney, P. Montagna, S. Joye, C.R. Fisher, S. Schaeffer. 2002. Stability and change in Gulf of Mexico chemosynthetic communities. Report for U.S. Department of Interior, Minerals Management Service. Contract #1435-01-96-CT-30813.

Nix, E., C.R. Fisher, K.M. Scott, and J. Vodenichar. 1995. Physiological ecology of a mussel with methanotrophic symbionts at three hydrocarbon seep sites in the Gulf of Mexico. Marine Biology 122:605–617.

Page, H.M., C.R. Fisher, and J.J. Childress. 1989. Filter-feeding and the nutritional biology of a deep-sea mussel with methanotrophic symbionts. Marine Biology 104:251–257.

Paull, C.K., B. Hecker, R. Commeau, R.P. Freeman-Lynde, C. Neumann, W.P. Corso, S. Golubic, J.E. Hook, E. Sikes, J. Curray. 1984. Biological communities at the Florida Escarpment resemble hydrothermal vent taxa. Science 226:964–967.

Sibuet M. and K. Olu. 1998. Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. Deep-Sea Research II 45:517–567.

Smith, E.B., K.M. Scott, E.R. Nix, C. Korte, and C.R. Fisher. 2000. Growth and condition of seep mussels (*Bathymodiolus childressi)* at a Gulf of Mexico Brine Pool. Ecology 81: 2392–2403.

Streams, M. and C.R. Fisher. 1997. Incorporation of methane by methanotrophic symbionts and symbiont digestion by their host mussel. Marine Biology 129:465–476.

Turnipseed M., K.E. Knick, R.N. Lipcius, J. Dreyer, and C.L. Van Dover. 2003. Diversity in mussel beds at deep-sea hydrothermal vents and cold seeps. Ecology Letters 6:518–523.

Young C.M., E. Vázquez, A. Metaxas, and P.A. Tyler. 1996. Embryology of vestimentiferan tube worms from deep-sea methane/sulphide seeps. Nature 381:514–516.

Charles Fisher is a Professor of Biology and Chair of the Graduate Program in Biology at the Pennsylvania State University. He received his BA from Michigan State University and his MS and PhD from the University of California in Santa Barbara. He is currently the Chair of the NSF Ridge 2000 Program steering committee and serves on numerous national and international committees including: the steering committees for the international mid-ocean ridge research coordinating program (InterRidge) and the Census of Marine Life Chemosynthetic Ecosystems (ChEss) program, the oversite committee for the Endeavour Ridge Marine Protected Area (Canada), and advisory boards for the NSF Centers for Ocean Science Education Excellence (COSEE) program and for the 11,000 meter Hybrid ROV (HROV) project. He has made 122 dives in research submersibles, spent 57 days at sea working with ROVs, participated in 53

oceanographic research expeditions and published more than 90 peer-reviewed papers on the biology of hydrothermal vent and cold seep animals.

Erik Cordes is a post-doctoral researcher at the Pennsylvania State University. He received his BS from Southampton College, his MS from Moss Landing Marine Laboratories, and his PhD from the Pennsylvania State University. He has accepted a post-doctoral position at Harvard University with Dr. Peter Girguis to study the microbial ecology of Juan de Fuca hydrothermal vents. He has participated in 9 research cruises over the past 10 years and has made 23 submersible dives, and has published 6 papers on the biology and ecology of cold seep and deep-sea coral communities, with 4 more in preparation or review.

DEEP GULF OF MEXICO CHEMOSYNTHETIC COMMUNITIES: CURRENT KNOWLEDGE FOR SITES BELOW 1,000 METERS. RECENTLY DISCOVERED ASPHALT VOLCANO AND ASSOCIATED CHEMOSYNTHETIC COMMUNITIES IN THE SOUTHERN GULF OF MEXICO

Elva Escobar-Briones, Universidad Nacional Autónoma de México, Instituto de Ciencias del Mar y Limnología

Introduction

The Gulf of Mexico (GOM) is an important hydrocarbon basin where salt tectonism controls development of hydrocarbon reservoirs. Efforts on the northern continental slope have extensively documented chemosynthetic life in association with hydrocarbon seeps, mud volcanism, gas hydrates and salt lakes. Over thirty years ago, cores containing hydrocarbons and asphalt pieces were collected and an asphalt deposit was photographed from the seafloor deep salt domes in the southwestern GOM and several other records of potential sites where petroleum could occur in deep benthic ecosystems of the GOM and the Caribbean (Pequegnat & Jeffrey 1979).

Materials and Methods

The preliminary results of this study are based on images from the abyssal seafloor of the southwestern GOM where an ocean floor observation system (OFOS) was deployed with the objective to visually locate active seep sites and identify potential seeps and chemosynthetic communities at abyssal depths. The OFOS system, a TV-guided sled equipped with a B/W video camera, two xenon lamps, a Benthos camera with flash, a SeaSnap 990 digital camera system for LLC high resolution images, three laser pointers and a CTD, was deployed in the Campeche Knoll area (Figure 2G.3) at sites where oil spills were detected by satellite imaging during five deployments (Stas. SO 174/2- 126 to 138 [re. OFOS 10 to 14]). The locations studied were defined guided by data from satellite imagery that showed evidence for persistent oil seeps in the region and where mapping with the German ship *RV SONNE* revealed isolated salt diapirs shaped as elongated 'pillows' averaging 5 by 10 km and having 450 to 800m of relief and slopes in an average of 10% (MacDonald et al. 2004).

The photo-sled revealed extensive surface deposits of solidified asphalt at some of the cratered knolls. The site with a large asphalt spill, named Chapopote was selected for this purpose and extensively documented. This seafloor observation program procedure included lowering OFOS to a few meters above the seafloor and towing the sled along a pre-defined track by the ship at a speed less than 1 kn. The distance between the seafloor and sled was manually controlled with the winch with the pictures taken in the manual option of the operating system. UTC time, ship position were recorded using the protocol software (Eisenhauer, et al. 2004).

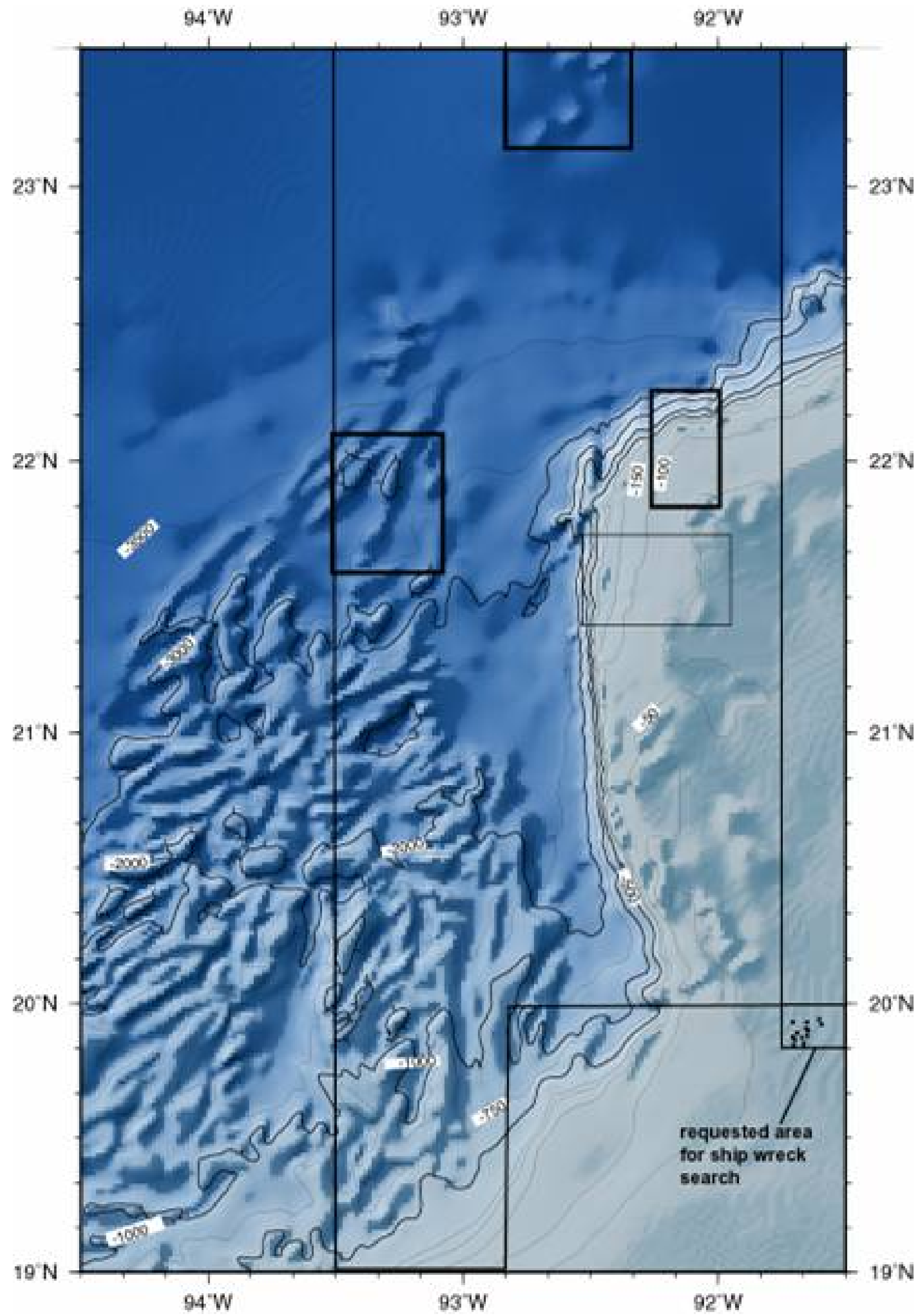


Figure 2G.3. The area of study in the southwestern Gulf of Mexico.

The Benthos camera held film roles of 800 slides each. Onboard every image recorded was logged in log and relevant features recorded with the UTM protocol software and added to a map. The film was processed in Germany and later on stripes cut and pictures scanned to 893x591 pixels with a Nikon CoolScan 4.0 ED with color activation. The scanned pictures were saved as individual files in TIF-format .tif with homogene size 1.71 MB each and ID coded by cruise number e.g. SO_174 station number e.g. STAT_138 and OFOS deployment number OFOS_140 followed by the picture number i.e. 12 (i.e. SO_174_STAT_138_OFOS_14012.tif). The pictures were qualitatively analyzed with Windows image viewer and a file with diverse worksheets (Table 2G.1) generated that recorded the following:

1. The type of bottom with six categories ranging from the relatively homogeneous soft bottom to the heterogeneous asphalt as the example of the presence of chemosynthetic activity, the relative occurrence of these two bottom types, the presence of bacteria.

2. The prevalence of biological activity with six categories of the presence, in the size and density of tracks, pellets and burrows.

3. The nature of materials exported from the coastal and pelagic zones with six categories and types.

4. Evidence of chemoautotrophic activity with five categories ranging from the presence of oil, bacterial mats their color and extension, gas bubbles, and fauna previously recognized for other chemosynthetic communities in the basin, associated to whale carcasses or hydrothermal vent sites (e.g. tubeworms, mollusk and squat lobster aggregations).

5. The presence of the diverse megafaunal groups to major taxa and group levels with 25 categories that were recorded both by their abundance and by their presence/absence.

A classification analysis based on the presence and absence (1/0) of features was performed in an initial phase to identify and classify the types of habitats and communities with potential chemosynthetic activity based on the resolution of the images.

Table 2G.1. Section of a worksheet that shows image identification in the Image field, and types of seafloor habitats identified and coded by the presence (1) or absence (0) of the feature for a later qualitative analysis.

Image	BSoft	BAsph	BSoft+Asph	BAsph+Soft	BGranul	BDark	LBurr
14324	1	0	0	0	0	0	1
14323	0	0	1	0	0	0	0
14322	1	0	0	0	0	0	0
14321	0	0	1	0	0	0	0
14320	0	0	1	0	0	0	0
14319	1	0	0	0	0	0	1
14318	1	0	0	0	0	0	0
14317	1	0	0	0	0	0	0

Results and Discussion

The seafloor visualization program in the Campeche knolls area recorded deeply-cratered salt domes with extensive slumps and mass-wasting at depths of more than 3,000m where abundant chemosynthetic life occurred associated to the deep soft sediment, the massive lava-like flow-fields of solidified asphalt and the ecotones found amid.

The levels of resolution of the visualization method allowed to processes images and classify them to community, types of habitats and major taxonomic group presence/absence.

The largest number of deployments concentrated in the area south of central crater. The total number of images analyzed was 1,469 for the five OFOS deployments where almost half of the images recorded asphalt and hydrocarbon seep related features.

The soft sediments and the hard substrates were the two types of communities recorded. The soft sediments were subdivided as non-chemosynthetic and as chemosynthetic (Figure 2G.4). The former were characterized by non-perturbed hemipelagic type of sediment and by bioturbated hemipelagic with a series of tracks and burrows. The latter were of four types black (dark) sediments, oily bacterial mats, granulated bottoms and soft sediments with shell deposits.

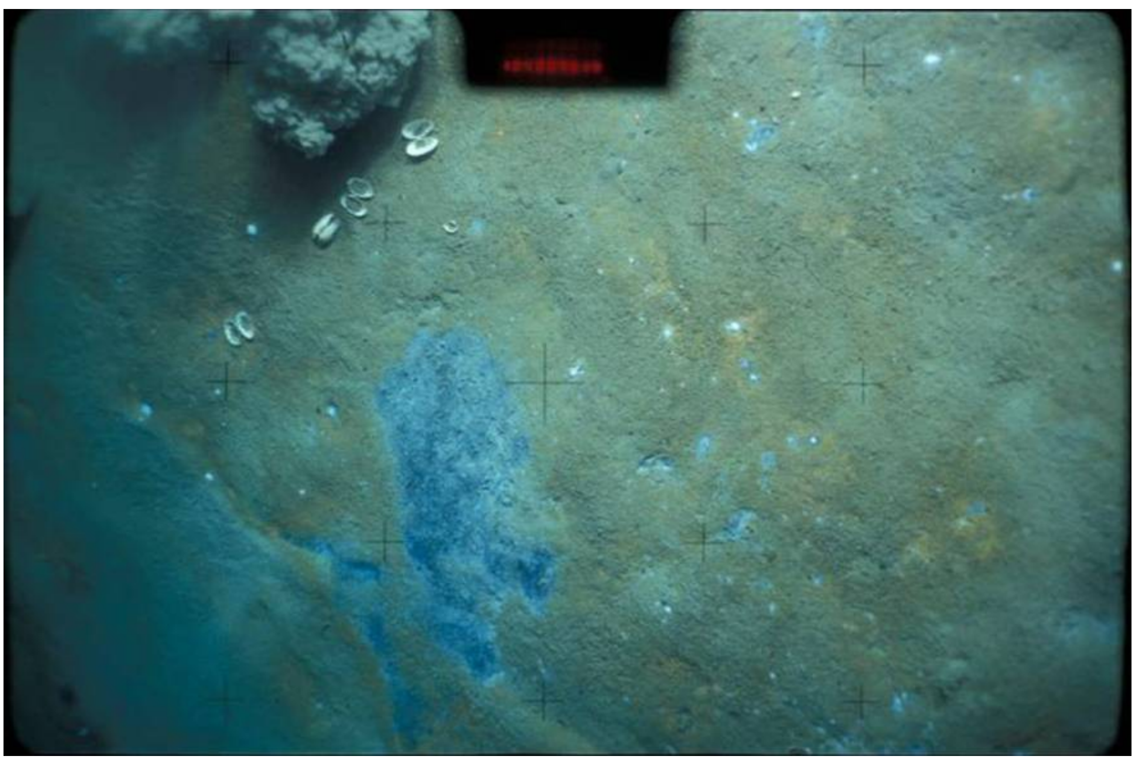


Figure 2G.4. Image of a soft sediment type of habitat with chemosynthetic activity. It depicts a yellow type of bacterial mat and a few open bivalve shells.

The hard substrates recorded in the images were subdivided into those hard substrates (asphalt) that were in contact with soft sediments and those where hard substrate or asphalt prevailed. The soft sediment to asphalt ratio and size of these hard substrate formations was quantified at each image as percentage coverage and was of relevance and had influence to the type and abundance of associated fauna (Figure 2G.5). The hard substrates that were in contact with soft sediments were identified as fields with pillow formation, predominance of rubble, large boulders, and blocks. The hard substrate formations were identified by their roughness, relief and texture as primary flow dikes, secondary flow blankets, surfaces with high relief and texture, and hard substrates without relief or texture.

Figure 2G.5. Image of a hard substrate rubble with associated chemosynthetic fauna.

The asphalt deposits varied in appearance and coverage in relation to the typical abyssal soft-bottom topography, establishing diversity at the landscapes, community, habitat levels. Samples obtained from these habitats recorded the occurrence of subsurface thick, liquid petroleum dispersed in veins and pockets throughout, the presence of plates of authigenic carbonates with layers of oil pooled beneath and gas hydrate many of which were associated to the diversified substrates where white films of bacterial mats resembling *Beggiatoa* occur (MacDonald et al. 2004). Among the megafaunal groups recognized are bacterial mats in different forms, colors and extension over the seafloor and asphalt, sponges, epizoid hydroids, corals, free living anemone, spaghetti worms, tubeworm aggregations, bivalve clusters, limpets, scaphopods, gastropods, shrimps, crabs, asteroids, crinoids, ophiuroids holothurids tunicates, several types of fish and others not identified.

The biological characterization of the communities associated to this asphalt volcanism suggest chemosynthetic activity and complex biogeochemical interactions through the presence of chemosynthetic fauna identified i.e. vestimentiferan tubeworms (c.f. *Lamellibrachia* sp.) that aggregate at the sediment/asphalt interphase under bitumen deposits or down into fractures within flow fields in densities that vary from single specimens scattered on the soft sediments near asphalt rubble fields to mostly small clusters and larger aggregations with over 50 individuals on the edges and folds of massive asphalt flows. Shells and living specimens of chemosynthetic mussels (c.f. *Bathymodiolus* sp., cf. Vesicomyidae, trails and tracks and a few living individuals of clams (c.f. *Calyptogena*, sp.) Samples recovered from these locations provided with specimens of bivalves of the genus *Solemya* sp heavily coated in oil. Heterotrophic fauna represented by galatheid crabs (*Munidopsis sp.,* shrimp resembling *Alvinocaris* sp., and other non-endemic deep-sea invertebrates (i.e. sponges, tunicates, hydroids, dense aggregations of echinoderms of the genera *Benthodytes* sp., *Psychropotes* sp., *Pterasterias* sp. that seem to feed on bacterial mats) and abyssal fish. From the photographs on the seafloor, it is clear that the asphalt site is an oasis of life with a large diversity of habitats generated by the asphalt flow. From the results we can preliminarily identify that communities are similarly assembled to other communities occurring in the basin where chemosynthetic activity has been recorded. Similar functional components occur among habitats and have a wide range in size, i.e. tubeworms and were less abundant in these abyssal habitats than when found at upper slope seeps. The ecotones (asphalt/soft sediment borders) between communities play an important role in structuring the chemosynthetic faunal components and their complexity. The bacteria were less prevalent on rocks and/or soft sediments. A large number of filter feeder epizoids and other free living forms co-occurring on the asphalt formations suggest resuspension or export of biogenic carbon to seafloor.

Acknowledgments

This study was financially supported by the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung; grant nos. 03G0174A and 03G0566A); the NOAA Office of Ocean Exploration, NSF grant no. OCE-0085548, the Harte Research Institute; the U.S. Department of Energy, National Energy Technology Laboratory, and PAPIIT UNAM grant IN. 224503 and support SEP-CONACyT 2002 no. 40158. People I would like to acknowledge: G. Bohrman, GEOMAR and I. MacDonald, TAMUCC.

References

Eisenhauer, A., I. MacDonald, F. Abegg, and O. Pfannkuche. 2004 Visual seafloor observation. In: Bohrmann, G. & S. Schenck, eds. RV SONNE cruise report SO 174 OTEGA II Gashydrate im Geosystem. GEOMAR. 108pp.

MacDonald, I.R., G. Bohrmann, E. Escobar, F. Abegg, P. Blanchon, V. Blinova, W. Brückmann, M. Drews, A. Eisenhauer, X. Han, K. Heeschen, F. Meier, C. Mortera, T. Naehr, B.

Orcutt, B. Bernard, J. Brooks, and M. De Farago. 2004. Asphalt volcanism and chemosynthetic life in the Campeche Knolls, Gulf of Mexico. Science 304:999–1002

Pequegnat, W.E. and L.M. Jeffrey. 1979. Petroleum in deep benthic ecosystems of the Gulf of Mexico and the Caribbean. Contributions in Marine Science 22:63.

Elva G. Escobar-Briones has been a Professor with the Institute of Marine Sciences and Limnology (ICML) of the National Autonomous University of Mexico (UNAM) since 1993. Dr. Escobar-Briones received an undergraduate degree in biology from the Metropolitan Autonomous University (UAM) in 1981, completed a master's degree in fisheries and ocean sciences at UNAM in 1984, and defended a doctoral dissertation in biological oceanography in 1987, also from UNAM, on the structure and function of benthic communities in the southwestern Gulf of Mexico. Dr. Escobar-Briones has been recognized on the study of the biology of benthic communities with some 55 peer-reviewed articles and over 50 reports and articles on related topics co-authored with both Mexican students and colleagues and international collaborators. Dr. Escobar-Briones has been Head of the Academic Unit in Coastal and Ocean Systems since 1999 and is active teaching graduate and undergraduate levels at UNAM. She coordinates the research program in deep-sea benthos of the southwestern Gulf of Mexico at ICML UNAM, a program that is financed by UNAM's program PAPIIT and the Mexican funding agency CONACyT.

RECOVERY OF DISTURBED DEEP-SEA COMMUNITIES

Craig M. Young, Oregon Institute of Marine Biology, University of Oregon

Because populations only increase when birth and immigration exceed death and emigration, reproductive rate (know variously as fecundity, birth rate, clutch size, etc.) is a major component of all population models. Indeed, the familiar Leslie matrix models, which predict the number of individuals in each age class, life-history stage or time increment, require age- or stage-specific knowledge of two kinds of transitions: survival and reproduction. Most marine populations, including those occupying deep-sea chemosynthetic ecosystems, are best modeled as fragmented metapopulations in which local persistence depends on rates of immigration from other source populations in the region. It follows that recovery potential is greatest in a regional system with numerous potential sources of migrants. Thus, predicting the recovery of a deep-sea population depends on a knowledge of 1) regional reproductive rate and 2) dispersal potential of offspring.

In marine animals, migrants are generally microscopic larvae that drift in the water column for hours, weeks, or months. In shallow water, small feeding (planktotrophic) larvae virtually always disperse much more widely than non-feeding (lecithotrophic) larvae. This greater dispersal capacity of feeding larvae confers greater longevity in evolutionary time and wider distributions in geographic space. Because planktonic algal foods are absent or rare in deep water, it has long been predicted that deep-sea animals should produce non-feeding larvae. Exceptions are known (e.g., some abyssal snail larvae migrate all the way to the euphothic zone to feed), but planktotrophic development is nevertheless the exception in deep water. One is tempted to infer from this that dispersal distances (and therefore geographic ranges and species longevities) should also be lower in deep water, but biogeographic evidence indicates that many deep-sea species with lecithotrophic larvae have very broad geographic distributions. The unexpectedly high dispersal potential of deep-sea lecithotrophic larvae can probably be attributed to lower metabolic demands in cold water. A case in point is the dispersal potential of vestimentiferan tubeworms. The yolky eggs of all known species are very similar in volume and energy content, yet the larvae of the vent worm *Riftia pachyptila*, which disperses at 2^{o}C, remains in the water column 40% longer than the larvae of the seep tubeworm *Lamellibrachia luymesi*, which disperses at 8-15^{o}C.

In the relatively well-studied chemosynthetic communities of the bathyal Gulf of Mexico (GOM) (less than 1,000m), many species have planktotrophic development and planktotrophic larvae. These include the mussel *Bathymodiolus childressi*, the snail *Bathynerita naticoidea,* the "ice worm" *Hesiocaeca methanicola,* and the seep orbinid *Methanoaricia dendrobranchiata*. Notable lecithotrophic species include the vestimentiferan worms and file shells of the genus *Acesta.*

Many species at slope depths reproduce seasonally like their shallow-water counterparts. Surprisingly, this includes some seep species, such as *Bathymodiolus childressi*, that have access to a continuous source of chemical energy. This seasonality can probably be explained by mixotrophy; these mussels are known to supplement methanotrophic nutrition by filtering ultraplankton and seston. Most seasonal animals from cold seeps in the GOM breed in mid-winter and produce planktotrophic larvae that presumably take advantage of the spring plankton bloom. The known lecithotrophic species are mostly, but not all, continuous breeders. It is expected that the incidence of continuous breeding will increase with depth in the GOM as it appears to in other systems, but empirical data in support of this hypothesis are not available.

In general, fecundity decreases with depth, presumably because photosynthetic food becomes less abundant in deeper water. For example, the gonadal indices of sea urchins (gonad weight as a proportion of total body weight) are one to two orders of magnitude higher in shallow-water species than in slope species. However, this generalization probably does not hold for deep-sea species with access to continuous sources of chemical energy. Thus, tubeworms breed continuously and produce hundreds of thousands of eggs at any given time. Moreover, some of the seep tubeworms from the GOM may produce eggs for hundreds of years. We suspect that these may have some of the highest lifetime fecundities of any marine organisms.

Like other biological rates, the rate of gametogenesis (egg production) might be expected to decline with lower temperatures in the deep sea. However, recent work with the electron microscope reveals that many deep-sea species, including a number of species from the GOM, have specialized mechanisms for fast egg production. Such mechanisms include blood vessels, trabeculae and ovarian acini that transport nutrients directly to eggs for the production of yolk. Mechanisms that facilitate rapid egg production, which appear to be especially common in vent species, are also found in highly disturbed intertidal environments (e.g, sabellariid polychaetes and some limpets on rocky shores) and may be adaptive responses to variable environments.

In summary, life-history studies give us reasons to suspect that deep-sea chemosynthetic animals might be particularly resilient to local environmental perturbations. Assuming that chemosynthetic communities are sufficiently widespread in the deep GOM to form substantial regional pools of larvae, we can hypothesize that the life-history attributes of high dispersal potential, continuous breeding, high fecundity, and rapid gametogenesis could facilitate the rapid reestablishment of perturbed chemosynthetic metapopulations in this region. These ideas require testing, and such tests would best be done in conjunction with studies on growth rates, survival and community assembly.

Craig Young received his B.S. and M.S. from Brigham Young University and his Ph.D. from the University of Alberta in 1982. After a three-year stint on the faculty at Florida State University, he moved to Harbor Branch Oceanographic Institution in Florida, where he worked as a research scientist and professor for 17 years. His appointment as the new director of the Oregon Institute of Marine Biology began in June 2002. He has published more than 120 scientific papers and has edited several books. Professor Young currently serves as an Honorary Fellow at the Southampton Oceanography Center in the UK, as Visiting Professor of Biology at Kings College London, as a member of the NSF Ridge-2000 Steering Committee, as a member of the board of directors of the Pacific Institutes of Marine Science, and as a member of the steering committee for CHESS, the chemosynthetic ecosystems program of the Census of Marine Life.

DEEPEST GULF OF MEXICO HYDROCARBON SEEP CHEMOSYNTHETIC COMMUNITY IN BLOCK AC 818 AND OTHER ROV OBSERVATIONS IN THE DEEP GULF

Dan Allen, ChevronTexaco Gulf of Mexico Operations

In February 2004 operator ChevronTexaco captured video images of the deepest chemosynthetic community observed to that time in the Gulf of Mexico (GOM). The community was observed at the Tiger prospect in Alaminos Canyon Block 818 at a water depth of ~2,749 m. The well was drilled from the Transocean drill ship Discoverer Deep Seas, and the video imagery was recorded by a camera aboard the Subsea 7 ROV *Hercules* operating from the ship. The work class *Hercules* is a 120 hp unit powered and controlled via an umbilical tether which limits the effective reach of its watch circle to ~200 m from the well location.

What appears most noticeable about the Tiger community is its similar composition to other chemosynthetic communities found at considerably shallower water depths in the GOM. Though this community is patchy, species include mussels, vestimentiferan tube worms, sponges, soft corals, crabs, starfish, holothurians, isopods, sea urchins and anemones frequently encountered elsewhere in the Gulf. Sediments across the site are fine sands littered with shell hash and abundant foraminiferan shells.

In addition to the chemosynthetic community at Tiger, the author also showed video clips of other animals not previously known in the GOM or, in one case, one never before observed alive. The latter, a long-nosed chimaerid fish, *Harriotta raleighana*, was filmed in Mississippi Canyon at a depth of approximately 2,130 m. The specimen's length, estimated at 2 m, makes it the largest specimen known, and it is the only one known to be seen alive.

At a different location in Mississippi Canyon in November 2003 a sleeper shark, tentatively identified as the Greenland sleeper *(Somniolus microcephalus)* was observed at a water depth of about 2,650 m. The specimen was estimated to be about 3–4 m long. The nearest previous record of this species was from a 1988 ROV sighting off the coast of Georgia in 2,200 m of water. That specimen was estimated at 6 m in length.

At a 3,048 m site in Alaminos Canyon an as-yet unnamed squid was captured on video. The squid is unusual in that it appears to swim using two very large fins. It also carries ten identical arms angling downward and away from the axis of its body at about 45°; trailing from the tip of each arm is a long, delicate tentacle which appears to be coated with a sticky mucous, as they have been observed to appear to get stuck when they come into contact with subsea structures. There have been numerous sightings of similar squid in most of the world's oceans in the past few years, and they are thought to represent mature specimens of a species recently named Magnapinnida pacifica from some juveniles caught off Hawaii. The specimen we observed was estimated to be about 4–5 m long.

In closing, oil and gas activities, in the deep GOM have illuminated biological discoveries during routine ROV operations and at least some operators have actively contributed them to the scientific community. Hopefully such sharing will become more commonplace as information-exchange networks between operators and scientists mature and grow more robust.

Dan Allen is a marine biologist who has been with ChevronTexaco (CVX) for twenty-four years. He has worked on many projects related to interactions between oil and gas exploration, production and transportation activities and the marine environment, including FADs, rigs-to-reefs, use of active facilities by fish and sea turtles, mariculture, and effects of anthropogenic sounds on marine animals. Since 1997 he has supported CVX's deep water Gulf of Mexico development where he has also been able to acquire many ROV video images of chemosynthetic communities and other deep sea life and share them with the broader scientific community.

SESSION 2H

LOUISIANA OIL SPILL RESEARCH AND DEVELOPMENT PROGRAM (OSRADP)

Chair: **Rusty Wright, Minerals Management Service**

Co-Chair: **Don Davis, Louisiana State University**

SURVEY OF LOUISIANA SEABIRD COLONIES TO ENHANCE OIL SPILL RESPONSE

Jenneke M. Visser, Coastal Ecology Institute, School of the Coast and Environment, Louisiana State University

Louisiana's coastal marshes and barrier islands support significant breeding populations of colonial seabirds. Because seabird nesting habitat is highly vulnerable to erosion from tropical and winter storms, the locations of these seabird (particularly Black Skimmer, Least Tern, and Forster's Tern) colonies are subject to annual changes. Due to their location and ground nesting habits, seabird colonies are also extremely vulnerable to oil spills during the nesting season. The locations of seabird colonies along the Louisiana coast have been surveyed in 1976 1983 by the U.S. Fish and Wildlife Service, and in 1990 by the Louisiana Department of Wildlife and Fisheries. Other partial surveys (1993, 1994, 1995, 1996; unpublished) are incorporated in the GIS database of the Louisiana Natural Heritage Program (LNHP) of LDWF. However, these recent surveys are based solely on aerial observations. Aerial surveys provide good estimates of colony size and nesting activity for wading bird colonies but are less reliable for seabird colonies because nesting birds cannot always be distinguished from resting birds.

We performed a ground survey of nesting seabirds in Louisiana in 1997 and compiled a database of Louisiana seabird colonies from 1976 to 1997. The number of breeding birds of each species was estimated by taking the average of the estimate of two independent observers. The number of nesting adults present at the colony closely mirrors the number of breeding pairs for most species. Because not all birds start nesting at the same time, our estimates for the total number of breeding birds is a conservative one. Additional notes were taken on habitats and parts of islands used. The period in which the colony was used by breeding birds, and was therefore most vulnerable to harm from oil spills, was based on the species present in 1997 and the activity window reported for these species.

We surveyed a total of 215 colonies and found 101 active colonies, of which 18 were new. Eighty-three historic colonies were inactive in 1997 and 30 historic colonies had disappeared, since they were located on islands that no longer exist. We found 11 different species of seabirds, of which the Herring Gull has set a new breeding record in Louisiana. The Laughing Gull was the most abundant seabird nesting in Louisiana in terms of total number of nesting birds (137,808) as well as number of colonies (52). The Common Tern was found at only one colony on a mud lump near the Mississippi River Delta's South Pass with an abundance of 400 nesting birds. The Common Tern was previously only found with one pair of nesting birds on Curlew Island in 1988. The Sooty Tern, a species that has previously nested at Curlew Island in 1988, was not found during our survey. Colony size varied from a minimum of ten to a maximum of 48,530 nesting seabirds. Approximately half (51%) of the colonies were smaller than 500 birds, with 21% of the colonies containing less than 100 birds each. Seabirds in Louisiana use four habitats: 1) vegetation, 2) wrack, 3) shell, and 4) sand. Forster's Tern and the Common Tern were always found nesting on wrack. The Brown Pelican, Herring Gull, and Laughing Gull were almost always found nesting in vegetation. The Gull-billed Tern showed the least consistent use of habitat, although half of the Gull-billed Tern colonies were found on shell. The Black Skimmer, Least Tern, Royal Tern, Caspian Tern, and Sandwich Tern were always found using either shell or sand for nesting habitat.

The six largest colonies are all located on relatively large barrier islands, and these islands represent the majority (69%) of all seabirds nesting in Louisiana. An oil spill on any of these islands during the nesting season would be a disaster. Only the Least Tern, Black Skimmer, Forster's Tern, and Laughing Gull are located in more than 15 colonies. These species are, therefore, less likely affected by the loss of one colony than other species. All other seabird species contain at least 10% of their Louisiana breeding population in each colony. The loss of a colony containing Royal Tern, Caspian Tern, Gull-billed Tern, Sandwich Tern, Brown Pelican, Herring Gull, or Common Tern would therefore have a much larger impact.

The atlas of Louisiana seabird colonies compiled in this study should help remediators make informed decisions about how to protect nesting seabirds from oiling. Although we hesitate to give advice about where to concentrate oil spill response efforts, we suggest that measures be taken to prevent oiling of active colonies. For planning purposes, colonies that have been present in at least one of the last ten years should be considered active. Colonies that have not been active for more than ten years, probably reflect unsuitable habitat at the present. Due to the ephemeral nature of many seabird colonies, we recommend that the Louisiana Oil Spill Coordinator's Office fund an aerial survey each year to verify the compiled seabird data. We also recommend that a ground survey be conducted every fifth year.

Jenneke Visser is an Associate Professor Research in the Coastal Ecology Institute of the School of the Coast and Environment at Louisiana State University. She holds a Ph.D. in marine sciences from Louisiana State University and the equivalent of a M.Sc. in biology from the University of Amsterdam. Her research interests include Louisiana wetland restoration, wetland ecology, and seabirds.

LOUISIANA PETROCHEMICAL PIPELINES: STATUS OF AN INVENTORY OF GAS, AND HAZARDOUS MATERIALS PIPELINES IN THE STATE

Robert Paulsell, Louisiana Geological Survey, Louisiana State University

These digital pipeline data are intended to supplement emergency response and planning for hazardous materials spills emanating from petrochemical transmission pipelines within the state of Louisiana. The thousands of miles of pipelines within the state constitute a major source for oil spill and other pipeline related emergencies. Assessment of digital petrochemical pipeline data is crucial for effective energy planning, environmental monitoring, disaster prevention, and emergency preparedness.

Any pipeline leak, large or small, can be dangerous to the public. These dangers include the obvious, volatile commodities exploding to inhalation hazards, and the not-so-obvious, small leaks that can seep through the permeable geology that lie beneath the pipelines and into the aquifer systems. The resulting damage could be irreversible and detrimental to potable water supplies throughout the region. The data developed can be used for emergency response as well as environmental and urban planning.

Accurate pipeline maps and a Geographic Information System (GIS) will enable increased response efficiency by allowing emergency response teams to quickly assess the product, diameter, and operator of specific pipelines. In addition to oil, gas, and refined product transmission pipelines, chemical and other hazardous materials transported by pipeline have been included in the GIS spatial data. Emphasis was on transmission pipelines rather than those associated with gathering or distribution systems. Generally, the investigators considered transmission pipelines to be those with diameters of three or four inches and greater. Documentation on pipelines is difficult to acquire due mostly to the attacks on the United States by terrorists. Also, many operators feel their data is proprietary and opt not to share data.

The Louisiana Geological Survey (LGS) has been compiling a digital pipeline database for the state for many years. Numerous maps and other geographic data concerning pipelines have been collected and cataloged. Most of these data have been in hard copy format, maps and other diagrams submitted by pipeline operators. Many of these submissions have poor spatial control and are not suitable for input into a GIS. Those data with good control were digitized. All submitted maps were helpful reference materials in the development of the spatial data.

Source data gathered by the LGS fell into three categories: large-scale or engineering diagrams with geographic control suitable for digitization, maps of small scale and poor geographic control that were not digitized (useful as reference material), and undocumented pipelines. Some 1,600 operator submitted maps are cataloged in the LGS inventory. One source of hard copy data, however, was found to be very helpful in route planning and pipeline feature development. The DTC Industrial Atlas, Houston, Texas, clearly shows most of the pipeline infrastructure within the parishes. The small scale of these maps, however, introduces errors of up to half a mile in some areas. These maps are copyright protected and were used solely as reference material. Other hard copy references were of limited use for they were out of date.

A method to digitally correct and create pipeline features has been developed by the LGS, utilizing Global Positioning System (GPS) technology. Point data were collected on pipeline witness posts locations that were observed near pipeline crossings of public roads. These records contained accurate positional data, information on pipeline operator, emergency contact telephone number, and information on the commodity transported by the pipeline. These data were compared to existing hard copy maps and digital pipeline data. Those data that did not conform to project guidelines were brought into compliance by comparison with GPS point data and aerial imagery. Pipeline features were developed utilizing aerial and satellite imagery, GPS point data, digital and hard copy maps or diagrams submitted by operators, and reliable third party maps.

Creating a GIS of hazardous materials pipelines is detail intensive. The initial task was to determine the scope of in-house data. Evaluating the existing digital and hard copy data submitted by pipeline operators was first on the list of many tasks. Digital as well as traditional hard copy maps were intensively examined to determine spatial integrity. Third-party maps were very useful in determining location of and commodities transported by many pipelines. Most of the existing LGS pipeline data needed to be further developed to conform to the digital mapping standards set forth by the National Pipeline Mapping System (NPMS). These data standards were adopted by the LGS for our pipeline mapping efforts.

The U.S. Department of Transportation, Office of Pipeline Safety, had created the National Pipeline Mapping System to "support the development of a reasonably accurate digital pipeline system" (*www.npms.rspa.dot.gov*). Generally, these data have very good spatial control; however, some data sets were found to contain errors, spatially and in their feature tables. However, the NPMS will not release or allow the LGS to release any of their data. Much concern has been placed on pipeline safety, and the Department of Homeland Security considers pipelines as part of our critical national infrastructure. This obstacle required the investigators to develop data that were initially to be included in deliverables "as submitted" by pipeline operators.

The initial focus was to develop nonexistent data, but data acquisition problems and spatial uniformity problems (mostly feature segmentation) required feature development for all pipeline operators (i.e. all pipeline features were developed by the investigators with no operator developed data in the deliverables). The LGS uses the digital NPMS data and operator submitted data as reference materials only. We have developed digital pipeline data uniformly for all operators following guidelines created by the NPMS. Also, the NPMS is concerned with interstate pipelines, while the data developed at the LGS include intrastate lines also. Cooperation from pipeline operators has varied and is reflected in the available research data.

The standards for data submission created by the NPMS allow for no more than a 500-foot margin of spatial error for pipeline data. The standards request that data be provided in digital format with accompanying metadata. If digital data are not available, then the operator may submit hard-copy data. All submissions are to contain geospatial data (location data), attribute data (descriptive information), and metadata (description of the content, quality, condition, and other characteristics of the submitted data).

Through funding from the Oil Spill Research and Development Program (OSRADP), a method to develop pipeline features and to adjust any spatially incorrect data has resulted in comprehensive petrochemical pipeline spatial data for East Baton Rouge, Calcasieu, and Ouachita Parishes along with the Greater New Orleans and Shreveport areas. These densely populated areas are considered high consequence areas (HCA) by the U.S. Department of Homeland Security. Spatial data covering pipeline crossings of navigated waterways is also being developed with this methodology. OSRADP projects include metropolitan pipeline data as well as river crossing pipeline data, also considered an HCA for the transportation infrastructure. These mapping efforts include cooperative pipeline GIS development with Dr. Michael Camille of the University of Louisiana at Monroe (ULM). Dr. Camille and his team have developed pipeline data for the Monroe and the Shreveport metropolitan areas.

The following outlines the method used in digital pipeline feature development.

I. Data collection route planning.
   A) Study existing data for potential stops (design a route plan)
   B) Examine aerial imagery for confirmation or other stops
   C) Review traffic scenarios (try not to be a hazard to the public or yourself)

II. GPS data collection and compilation
   A) Compile data dictionary
   B) Complete route plan
   C) Ensure that all data is collected and documented thoroughly

III. Data projection and conversion
   A) Upload GPS point data to GIS
   B) Export features as ArcGIS Shapefile
   C) Load shapefiles into ArcGIS Project

IV. Spatial feature GIS overlay and analysis
   A) GPS point data theme
   B) LGS digital pipelines theme
   C) NPMS digital pipeline data
   D) DOQQs and other themes from LaGIS CD to aid in analysis

V. Database normalization and quality assurance
   A) Review digital attribute tables
   B) Ensure database integrity (Quality Control)

VI. Create CD and hard copy (report and maps)

VII. Assessment of spatial accuracy of digital pipeline data
   A) Load digital point and linear pipeline data per operator into one view
      1. GPS point data shapefiles developed per operator/commodity
      2. Pipeline features, LGS and NPMS, per operator
      3. Analysis unique to each operator and commodity
   B) Develop pipeline features for data utilizing DOQQs, GPS point data, and third party maps

Group layers within ArcMap were created for each operator and populated with requisite aerial imagery, GPS point data, existing digital pipeline data, road data, and other helpful themes. Pipeline features were created utilizing heads-up digitizing technology in ArcMap. Referencing digital and hard copy data, attributes were carefully populated into the pipeline feature tables.

The analysis of digital pipeline data revealed many problems with spatial data accuracy. The most notable problems are a result of inadequate data. Most of the problems encountered were with submitted maps of inadequate scale and detail level. Data digitized at less than 1:24,000 scale lead to excessive spatial displacement. In some areas, this displacement has been close to a mile. The many corporate mergers, acquisitions, and divestures in the pipelines industry also created difficulties in resolving data collection issues. Many observed witness posts did not match any digital or hard-copy data.

The compilation and spatial analysis of digital pipeline data for the state of Louisiana is a complex process that will take years to accomplish. Although funding is the biggest obstacle to pipeline GIS development, the quantity and quality of data sources and the unique geographic parameters of each inhibit rapid development of a full-scale pipeline GIS for the state. Assessment of digital data, field investigations and the development of undocumented data are important to the statewide implementation of a pipeline GIS. The most prominent problem with existing digital data is spatial accuracy. Other problems have arisen through the conflicts between operator-supplied data and warning-post data in regard to transported commodities. Most of the digital data, digitized by the LGS or submitted by the operators, were incorporated into the GIS and displayed numerous problems associated with spatial accuracy. These issues were addressed by developing each pipeline feature utilizing GPS technology for spatial control. The GPS point data were also used to verify pipeline operator's names, commodities transported, and emergency contact telephone numbers.

The data developed through this and future pipeline mapping projects will eventually provide a comprehensive pipeline GIS for the state of Louisiana. As more operators develop and submit pipeline data and as the LGS and cooperative partners develop pipeline GIS, we will eventually have a comprehensive pipeline GIS for the state. However, no plans exist for the maintenance and updating of these critical data. With the constant corporate restructuring and economic growth, these data will need regular updating at least once a year.

GPS technology is very useful in pipeline mapping. Eventually, with this and other pipeline mapping efforts sponsored by OSRADP and other agencies/programs, the puzzle of pipelines in Louisiana will be put together.

Robert Paulsell is a Research Associate 4 with the Louisiana Geological Survey, LSU. He graduated from LSU with a B.S. degree in geography with emphasis in mapping. He has been with the survey for fourteen years and has been active in pipeline mapping for eight years.

CHEMICAL ADDITIVES IN OILED FRESHWATER LABORATORY MICROCOSMS: TOXICITY TO AQUATIC ORGANISMS, RELATIONSHIP BETWEEN HYDROCARBON MEASUREMENTS AND TOXICITY, AND THE INFLUENCE OF CHEMICAL ADDITIVES ON HYDROCARBON DISAPPEARANCE

Paul L. Klerks, Department of Biology, University of Louisiana at Lafayette

1) Toxicity and temporal changes in toxicity of freshwater-marsh-microcosms containing South Louisiana Crude (SLC) or diesel fuel and treated with a cleaner or dispersant were investigated using *Chironomus tentans*, *Daphnia pulex*, and *Oryzias latipes*. Bioassays used microcosm water (for *D. pulex* and *O. latipes*) or soil slurry (for *C. tentans*) taken 1, 7, 31, and 186 days after treatment. SLC was less toxic than diesel, and both chemical additives enhanced oil toxicity (with the dispersant being more toxic than the cleaner). Toxicities decreased gradually over time. Toxicities were higher in the bioassay with the benthic species than in those with the two water-column species. A separate experiment showed that *C. tentans*' sensitivity was intermediate to that of *Tubifex tubifex* and *Hyallela azteca*. Freshwater organisms, especially benthic invertebrates, thus appear seriously affected by oil under the worst-case-scenario of our microcosms. Moreover, the cleaner and dispersant tested were poor response options under those conditions.

2) This research investigated the extent to which various common hydrocarbon measures can be used to predict toxicity to freshwater aquatic organisms due to fouling by oil. Actual toxicity results on laboratory freshwater marsh microcosms using two water-column species and a benthic species were described earlier. The hydrocarbon measures used were TPH_g, TPH_{FID}, TPH_{MS}, TTAH (sum of 41 target aromatic hydrocarbons), principal components of 41 TAHs, and each individual TAH. In general, toxicity was more closely related to TPH_{MS} levels than to TPH_{FID} and (especially) TPH_g levels. The strongest relationships were found for TTAH levels and for the principal components of the TAHs. Regressions of toxicity on many individual TAHs were also strong, with a single group of compounds explaining as much as 59% of the variation in survival. While the various regressions were highly significant statistically and at times able to accurately predict broad differences in toxicity, the high variation in survival at a specific hydrocarbon concentration indicates that these hydrocarbon measures can not substitute for actual toxicity determinations in accurately ranking the toxicity of samples from oiled freshwater marshes.

3) We evaluated the effects of a cleaner and a dispersant on changes in hydrocarbon concentration over time in 288 microcosms containing freshwater marsh soils. Microcosms received no hydrocarbons, South Louisiana crude, or diesel; and no additive, dispersant, or cleaner. Microcosms were divided into water and sediment fractions 1, 7, 31, or 186 days later so that hydrocarbons could be extracted with dichloromethane. We determined the concentrations of four gross hydrocarbon measures and 44 target hydrocarbons to assess temporal changes and effects of additives on hydrocarbon concentrations. Hydrocarbon concentrations declined 24% to 97% after six months, but were unaffected by additives. This

study indicated that Corexit 9500 and Corexit 9580 should not be used to accelerate hydrocarbon disappearance, but could be used without fear that they subsequently slow hydrocarbon disappearance, in wetland soils dominated by *Panicum hemitomon*, which occur throughout South America and the southeastern United States.

Paul L. Klerks is Associate Professor of Biology at the University of Louisiana at Lafayette. He obtained his Ph.D. from SUNY Stony Brook in 1987 and joined UL Lafayette after post-docs at the University of Toledo and the Chesapeake Biological Lab. He is an ecotoxicologist focusing on the long-term effects of environmental contaminants in aquatic systems.

HISTORICAL ANALYSIS OF OIL SPILLS IN LOUISIANA

George Wooddell, University of Louisiana – Lafayette

Decision makers in government and industry need fast access to the facts about oil spills. But, current databases of oil spill characteristics are huge and unwieldy. The Louisiana Oil Spill Coordinator's office has sought to rectify that situation. Thus, the current work is to present a simple, fast, self-contained**,** free CD database program for desktop computers that makes accessible to non-technical users massive amounts of information about actual oil spills. This paper describes the program its use and its uses. The data are a modified version of those collected by the National Response Center.

For some years the authors have been studying Louisiana oil spills. Lately we have been immersed in massive and complex databases that must be manipulated by expensive and difficult-to-master database programs installed on high-end computers. Even with all of that, these databases have often crashed our machines and sometimes our brains. Still, we have learned a great deal by sifting through hundreds of thousands of records of spills.

Most decision makers in matters of oil spill preparedness and prevention are not as well equipped as the authors and not so peculiarly trained. Yet the more we learned the more we saw that the daily decision makers in industry and government are the very people who need most to access and analyze this particular information about oil spills. Thus we are now trying to make the facts more widely available by means of a simple, intuitive, free computer program on a CD.

This presentation introduces a simple, free, stand-alone computer program that makes the data accessible to a broad variety of oil spill decision makers. Starting sometime in 2004, those who ask the Louisiana Oil Spill Coordinator will be given the program on a CD (Figure 2H.1). This stand-alone program enables interested parties to query a large database of hazardous spills, to generate tables, and to do their own customized analyses. We submitted the program to the Office of the Louisiana Oil Spill Coordinator in August of 2003.

Two years ago (2001) the authors downloaded and reassembled the data of the National Response Center (NRC), creating a relational database of seven tables, each composed of detailed descriptions of hazardous spills—including petroleum spills—from 1992 through 1999. As mentioned, it was big and complex. While we had it in that form we added latitudes and longitudes to about 87% of the spills that had occurred in Louisiana so that we could map them on computers. We converted the spill amounts to gallons, added an "Fyear" (file year) variable to denote the year designation on the downloaded NRC files, standardized county (parish) names and did some other superficial cleaning up.

Figure 2H.1. The Louisiana Oil Spill Database opening screen.

Table 2H.1. The 30 variables used in the database.

Received	Parish
Complete	Zip
Call Type	Rad
Resp. Company	Bio
Resp. City	Oil
Description	FYear
Spill Type	Longitude
Cause	Latitude
Date	CHRIS CO
Location	CAS Number
Address	UN Number
Street1	Gallons
Street 2	AMT
Nearest City	Unit
State	Name

To make the data for the CD we drew thirty variables from multiple tables in the larger database and merged them into a single table, as shown in Table 2H.1, for use by the CD program. The variables were drawn from the NRC data (described more fully in the Appendix) and the latitudes and longitudes table developed by the authors for the Louisiana Oil Spill Research and Development Program. Along with the appendix in this document, the "About" and "Help" buttons in the program (pictured in Figure 2H.1) should answer most questions the user is likely to have.

Dr. George Wooddell is an Associate Professor of Sociology in the Department of Sociology and Anthropology at the University of Louisiana at Lafayette in Lafayette, Louisiana. He has served as principal investigator on research projects with the Louisiana Applied Oil Spill Research and Development Program (OSRADP). His areas of research interest are environmental sociology, minority groups, crime, and risk analysis. He obtained his B.A. in sociology from the University of Southwestern Louisiana in 1983, his M.A. from Louisiana State University in 1993, and his Ph.D. from Louisiana State University in 1999.

AERIAL VIDEO SURVEYS ON INTERACTIVE DVDs 2001 COASTAL LOUISIANA AND THE LOWER MISSISSIPPI RIVER – ARKANSAS TO THE GULF OF MEXICO

Karen A. Westphal, Louisiana State University

For 20 years, the LSU Aerial Video Survey Program (AVSP) has been collecting aerial video imagery of a part of the northern Gulf Coast for use in shoreline change studies, oil spill contingency planning, and environmental studies or resource management. Historically, the imagery has been collected and disseminated on analog video tapes, requiring large amounts of storage and time to find and view selected footages. Through OSRADP, the AVSP developed a methodology for digitizing these analog records and organizing them on interactive DVDs to make storage and access less cumbersome and to provide a more efficient reference tool.

Three surveys were committed to DVDs in this manner: 2001 imagery of coastal Louisiana, 1996 imagery of the lower Mississippi River from Baton Rouge to the Gulf of Mexico, and 2003 imagery of the lower Mississippi River from Baton Rouge to the Louisiana/Arkansas state line.

The oblique, aerial videotape imagery was acquired from a helicopter in SVHS format. On the bottom of the video image, realtime navigation data from a Global Positioning System unit (GPS) was presented so that each image was referenced with latitude, longitude, compass heading of the aircraft, date and time. On-board audio was recorded to provide additional information or clarify features observed. The analog video imagery was then converted to digital data, compressed, and divided into manageable segments.

The 2001 coastal video data was a simple, one-shoreline system and was divided into sections based on geography to fit on eight DVDs. The GPS data acquired during videotaping was downloaded and used as the data line from which video segments were indexed and chosen. Clicking within delineated areas on an image of the Louisiana coastline brings up subdirectories for that area showing a section of the coastline with place names. Clicking on a specific spot along the subdirectory shoreline initiates a digital playback of imagery for that area of the shoreline.

The 1996 and 2003 video data of the lower Mississippi River was a more complex project involving a two-shoreline system. This two-year project produced a set of DVDs containing easily accessed aerial video imagery of both banks of the Mississippi River from the Arkansas/Louisiana state line to the Gulf of Mexico. Whenever possible, imagery of pipelines, facilities and other features were identified and linked to maps and lists by River Mile. Both banks were linked, so that either side can be viewed at a particular stretch of the river.

Although the realtime navigation data from a GPS unit was presented on the bottom of the video image, location along the river was more difficult to determine. An additional label was added on the video image near the GPS line at every half-mile to indicate which bank of the river was being viewed, the approximate half-mile, and the direction of river flow to the Gulf of Mexico.

Because the 2003 video includes both Louisiana and Mississippi shorelines, the label on the 2003 imagery includes place names and state affiliation of the river shoreline. At every mile and major crossing, a link has been provided to the other side of the river at that location. A series of tables that lists features of interest along the Mississippi River is linked to the video imagery to provide an alternate method of accessing the data.

Karen Westphal earned her B.S. in zoology from LSU in 1978. She is now a coastal scientist and the manager of the LSU Aerial Video Survey Program at the School of the Coast and Environment Special Programs, Baton Rouge, Louisiana. She has been working with coastal issues and aerial video within the Louisiana coastal zone for over 25 years, with research efforts aimed at coastal change, coastal vegetation, bio-geomorphology, and habitat delineation.

DISPERSANT EFFECTS ON MARSH VEGETATION: TOXICITY EVALUATION AND OIL REMEDIATION

Qianxin Lin, Wetland Biogeochemistry Institute, Louisiana State University

Oil spills in nearshore or estuarine environments may eventually move into coastal marshes by currents, tides and winds, strand inside marshes, and impact coastal marsh organisms. Preventing oil from stranding and coating coastal sensitive habitats is an important step in protecting these habitats. Dispersants, which have received considerable attention for open, deep water oil spills, may be a candidate, but require evaluation for oil spill countermeasure in the nearshore and in wetlands. One strategy for habitat protection and oil remediation might be to apply dispersants to the spilled oil before the oil drifts into coastal marshes. However, little information is available on the toxicity and effects of dispersants on marsh habitats and the strategy of dispersant-use in the nearshore to protect sensitive coastal habitats.

The overall goal of the project was to determine the potential use of dispersants as an oil spill countermeasure in nearshore environments in which spilled oil may move into coastal marshes and impact these sensitive habitats. Specifically, the objectives of this study were to 1) evaluate the toxicity of dispersants on coastal marsh plants by determining the dose-response of plants to dispersants, per se; 2) evaluate different dispersed oils (crude oil and diesel fuel) on coastal marsh plants by determining the dose-response of plants to dispersed oils in the soil; and 3) compare the effect of dispersed oils (diesel and crude) in simulated nearshore dispersant application on marsh habitat protection.

Dispersants used today are more effective and much less toxic than those used previously. In this research, we used dispersant JD-2000. The dispersant JD-2000, manufactured and marketed by Van Waters and Rogers in 2001 and listed in the National Contingency Plan, is especially effective for South Louisiana crude oil for both salt and fresh water. The dose-response of the fresh marsh plant *Sagittaria lancifolia* and salt marsh plant *Spartina alterniflora* to the dispersant JD-2000 indicated that plant tolerance to dispersants, per se, was relatively high. The marsh plant *S. lancifolia* was not impacted by the dispersant JD-2000 at dosages ≤ 4,000 ppm based on plant photosynthetic rate, plant mortality rate, and plant aboveground biomass. *Sagittaria lancifolia* and *Spartina alterniflora* were able to recover at dispersant dosages as high as 16,000 ppm because the toxicity of the dispersant decreased during time the ten-month experiment.

In the experiments that determined the dose-response relationship and toxicity of dispersed oils to the fresh marsh plant *Sagittaria lancifolia* and salt marsh grass *Spartina alterniflora*, different concentrations of the JD-2000 dispersed diesel or crude oil (at the dispersant to oil ratio of 1:20) were applied to the soil. The plant photosynthetic rate, plant mortality rate, and plant aboveground biomass were negatively affected by the JD-2000 dispersed diesel applied to the soil substrate at high concentration. The $LC_{50\ (6\ weeks)}$ of dispersed diesel to *Sagittaria lancifolia* was estimated at 20,000 ppm. The $LC_{50\ (6\ weeks)}$ of dispersed diesel to *Spartina alterniflora* was estimated at 14,000 ppm. However, dispersed south Louisiana crude oil did not detrimentally affect *Sagittaria lancifolia* even at an oil dosage of 145,800 ppm. This indicated that the toxicity of the dispersed oil primarily resulted from the oil itself, not from the dispersants.

In an experiment that simulated oil dispersed before coming in contact with marshes, the dispersant JD-2000 greatly relieved the adverse effect of both diesel and crude oil. When both diesel and crude oil without the dispersant contacted the leaves, photosynthetic rate was significantly decreased and mortality increased even at a 50-ppm dosage. Two thousand ppm of diesel without the dispersant resulted in > 60% mortality of aboveground components of fresh marsh plant *Sagittaria lancifolia*. In addition, one thousand ppm of diesel without the dispersant resulted in > 90% mortality of aboveground components of salt marsh grass *Spartina alterniflora*. In contrast, neither the dispersed crude nor dispersed diesel significantly affected *Sagittaria lancifolia* and *Spartina alterniflora* compared to the no-oil control.

Therefore, dispersant application greatly reduced oil impact on marsh vegetation, indicating the potential of using dispersants as an alternative countermeasure for oil spills in nearshore or estuarine environments.

Qianxin Lin is the Assistant Professor, Wetland Biogeochemistry Institute, Louisiana State University. His research primarily focuses on fates, effects, and remediation of oil spill in coastal wetlands, particularly in bioremediation, phytoremediation, *in-situ* burning, dispersant application and remediation of oil spills in wetlands.

DESIGN, IMPLEMENTATION, OPERATION AND MAINTENANCE OF AN OCEAN OBSERVING SYSTEM OFF COASTAL LOUISIANA AND APPLICATION TO OIL SPILL CONTINGENCY

Gregory Stone, Coastal Studies Institute, Louisiana State University

Here we present the WAVCIS (WAVe-Current-Surge Information System) program and its usefulness for oil spill contingency. We emphasize the development of the program to assist in oil spill related issues, an important facet of a multi-faceted application. We also concentrate on further developing data processing techniques, product creation, quality control, data archiving and dissemination on the World Wide Web, integrative GIS web design and integration with other data bases, all of which are important for oil spill contingency along coastal Louisiana. Data obtained during tropical cyclones (Claudette and Bill), are also summarized as a gauge of the success of the program during extremely hazardous conditions in the Gulf of Mexico (GOM). New products discussed will provide numerous benefits to LOSCO, including enhancement of trajectory and circulation modeling, quantification of local currents required for the use of alternative technologies such as dispersants and *in-situ* burning, provision for rapidly obtaining critical information that would otherwise take precious hours to obtain by the conventional methods of aerial observations, and drifter buoy deployments.

WAVCIS measurements include wave height, wave period, wave direction, directional wave spectra, current speed, current direction, conductivity, turbidity, water depth, surge, sea temperature, air temperature, wind speed, wind direction, visibility, humidity, salinity, chlorine, and dissolved oxygen. Data measured offshore are transferred to the WAVCIS data processing laboratory via satellite cellular telecommunication. After post-processing, the data are archived in a SQL database and available to users via the World Wide Web in near/real-time basis. The WAVCIS array is also being developed to serve as a workbench for numerical wave, current and surge models for the scientific and engineering community. However, identified WAVCIS users include federal and government agencies, military, the scientific and engineering communities, students, the offshore industry, and recreation and sports groups. Usage has exceeded 50,000 logons over a five-hour period during tropical cyclone activity.

At present, six stations are online off the Louisiana coast (Figure 2H.2), and additional funding has been secured through federal agencies to support and expand the instrumentation array and necessary hardware. The ultimate objective of WAVCIS is to support Louisiana's ability to anticipate and prepare for emergencies offshore (oil spills, hurricanes, winter storms, shipping accidents, etc.), enhance homeland security, and assist numerical modeling efforts during storm events by measuring important oceanographic and meteorological information and making it available in real time, or, after archiving for 24-hour and one-month options, as a time series. The short-term goal, however, is to develop an online program that will be consistent with the needs of LOSCO. The entire effort is being coordinated with several other ocean observatories in the GOM to enhance geographic coverage. Current efforts are to continue refining a workbench for multiple applications and fine tuning this effort for oil spill contingency.

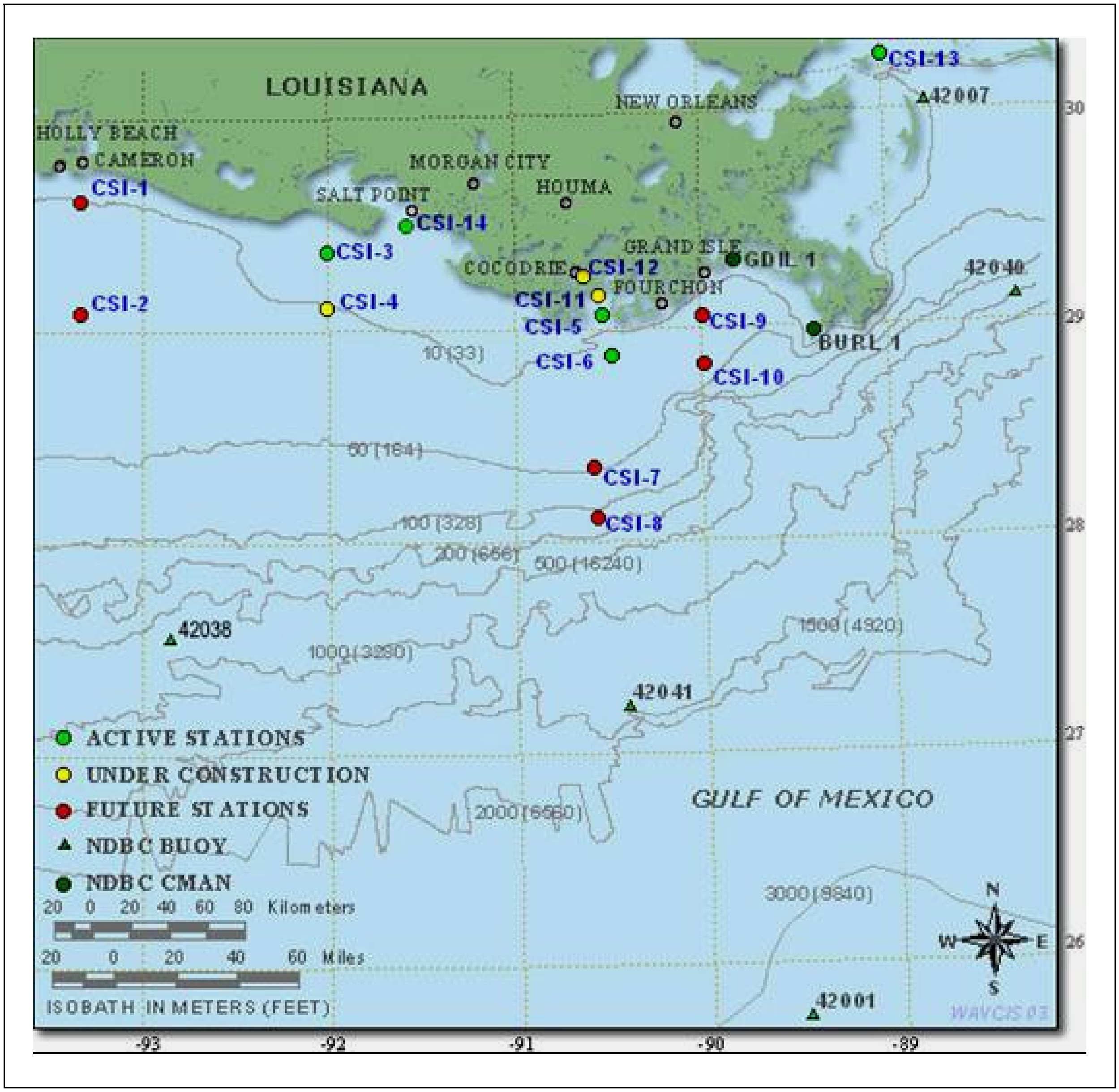


Figure 2H.2. Location of currently active WAVCIS stations along the northern Gulf of Mexico.

Dr. Gregory W. Stone is an expert in coastal processes and coastal erosion issues in Louisiana and elsewhere along the northern Gulf of Mexico. His doctoral research was conducted at the University of Maryland and focused on coastal morphodynamics. He has studied coastal problems for over two decades and is actively engaged in several erosion mitigation projects in coastal Louisiana. He is also an expert in measuring coastal processes and beach impacts due to storms and hurricanes. Dr. Stone is the Director of the Coastal Studies Institute at Louisiana State University where he was recently named the James P. Morgan Distinguished Professor. He is also a Professor in the Department of Oceanography and Coastal Sciences at LSU and Director of the WAVCIS (Wave-Current-Surge Information System—(*www.wavcis.lsu.edu*)) ocean observing system. He has published over 150 scientific papers/reports on coastal systems and serves as Deputy-Editor-in-Chief of the Journal of Coastal Research.

SESSION 2I

DEEPWATER PHYSICAL OCEANOGRAPHY INITIATIVE, PART II

Chair: **Alexis Lugo-Fernandez, Minerals Management Service**

Co-Chair: **Carole Current, Minerals Management Service**

DEEPWATER MOORING AT 87°W AND 25.5°N

Masamichi Inoue, Susan E. Welsh, and Lawrence J. Rouse, Jr.,
Department of Oceanography & Coastal Sciences and
Coastal Studies Institute, Louisiana State University

Introduction

In the Gulf of Mexico (GOM), the upper-layer circulation is dominated by the Loop Current (LC) in the eastern GOM and the Loop Current eddies (LCE) in the central and western GOM. Despite the fact that the deepwater in the GOM is isolated below the sill depths (~800 m in the Florida Strait and ~1,900m in the Yucatan Channel), deepwater in the GOM appears to be well ventilated, suggesting some energy propagation from the upper layer to deepwater inside the GOM. Cyclonic eddies in deepwater (e.g., Hurlburt and Thompson 1982) and topographic Rossby waves over the northern continental slope region (e.g., Hamilton 1990; Hamilton and Lugo-Fernandez 2001) have been suggested as agents of energetic forcing in deepwater in various numerical model studies as well as in observations. As a continuing effort to measure and monitor variability in energy level and water mass characteristics in the deep eastern GOM, a third deployment of a deepwater mooring was successfully completed, and the preliminary results are presented here.

Methods

A deep-water mooring strategically located to monitor the LC rings on their generally westward journey toward the western GOM was deployed at 87°W and 25.5°N at a water depth of 3,356 m. The mooring was equipped with two ADCPs, one upward-looking at 140 m and the other downward-looking at 3,200 m, and six Aanderra current meters set at 155, 750, 1500, 2500, 3000, and 3200 m to sample the entire water column. The initial deployment took place on 1 June 2000. The mooring was successfully turned-around in 1 August 2001, and was subsequently recovered on 3 June 2002. The third deployment took place on 19 April 2003, and the mooring was successfully recovered on 11 June 2004.

Results

Data from the third deployment show the dominance of the LC in the upper layer (Figure 2I.1). The water column sampled behaves basically like a two-layer system with an interface located near 750~1,000 m. In comparing to the altimeter data archived at the University Colorado (TOPEX/ERS-2 observations), several energetic events observed in the upper layer correspond to the time when the high-speed core of LC was sweeping past the mooring site. Currents in the lower layer are generally weaker than those in the upper layer and often appear to be decoupled from the upper layer currents. Currents in the lower layer are vertically coherent below the interface. Deep currents can typically reach speeds of 30~ 40 cm/s. Deepwater currents were significantly stronger during deployment three than deployments one and two (Figure 2I.2), while the upper layer currents appear to be comparable between one, two, and three.

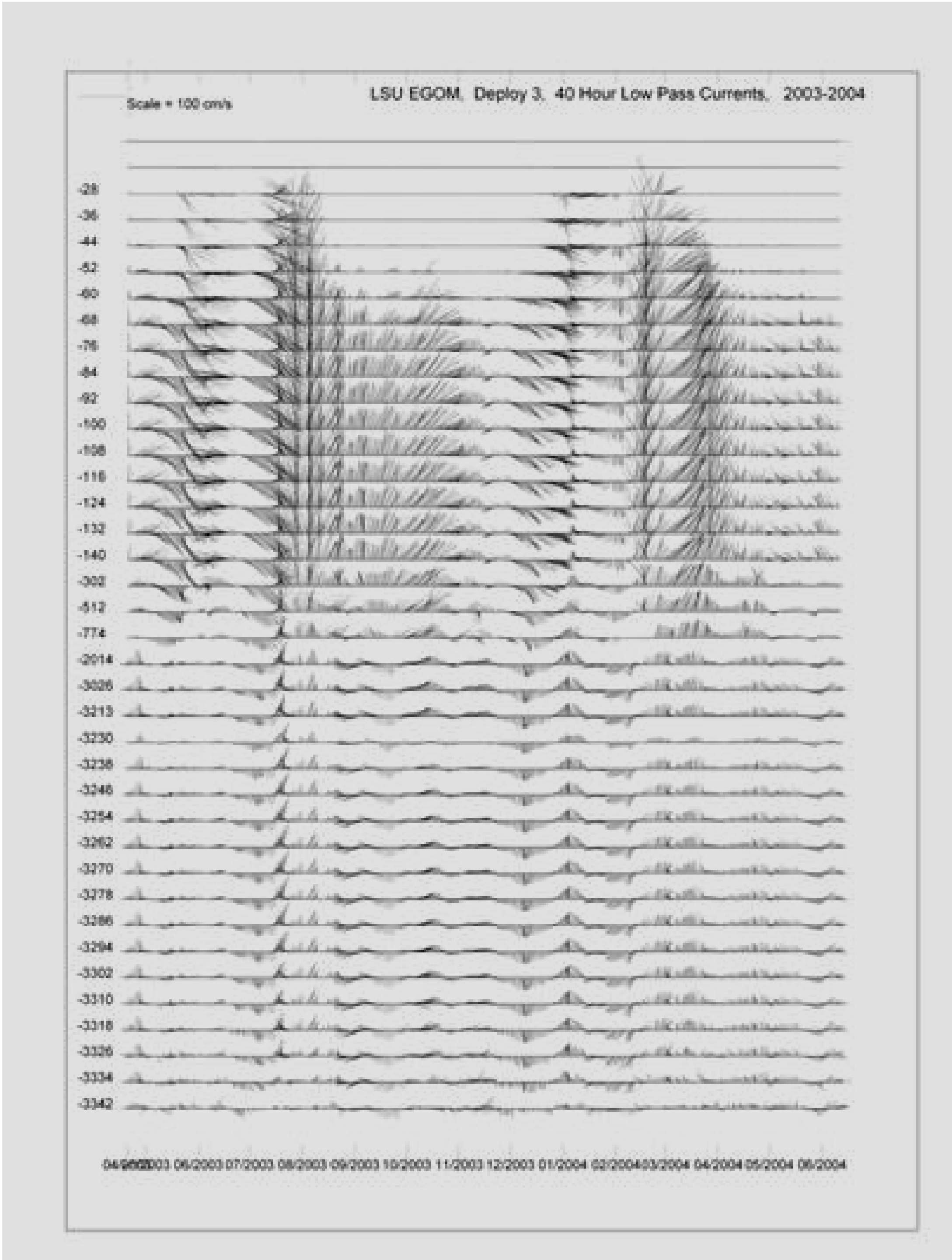


Figure 2I.1. 40-hour low pass filtered ADCP and current meter data at each instrument on the Deep Gulf Mooring for the period April 2003–June 2004.

For the first time, very strong currents exceeding 50 cm/s speeds were observed in deepwater in the eastern GOM. This two-day extreme event occurred between 18 and 20 July 2003, when currents in the upper and lower layers were well coupled, i.e., vertically uniform one-knot currents appeared to extend well into the upper layer. As a result, the entire water column at the mooring site was moving northward. The near-surface currents were significantly faster than one knot. However, it is difficult to estimate the actual current speeds near the surface due to a notable blow over of the mooring exceeding 300 m. Concurrent TOPEX/ERS-2 observations suggest that this extreme event coincided with the passage of the western wall of the LC over the mooring site. Current speeds measured at three different depths in deepwater (Figure 2I.3) suggest that currents at 2,000 m strengthen first, followed by currents at progressively deeper depths (3,000 m and 3,200 m). This extreme event resulted in the introduction of a colder and saltier water mass at 2,000 m (Figures 2I.4 and 2I.5). The vertical extent of the newly-introduced water mass in deepwater cannot be estimated due to the lack of temperature and salinity measurements with sufficient resolution below 2,000 m. Abrupt replacement of water mass extended into the upper layer, and colder and saltier water appeared even at 800 m. At 300 m and 150 m, this extreme event coincided with cooling and freshening of water mass, indicating that the mooring moved outside of the LC. At 2,000 m, the newly-introduced colder and saltier water appears to persist for more than two weeks, while water mass characteristics at shallower depths appear to rebound quicker. The characteristics of the newly-introduced water mass at 2,000 m suggest this type of extreme event might represent a mechanism to introduce colder and saltier inflow of deepwater from the Caribbean Sea that presumably takes place near Cuba at Yucatan Channel (McLellan and Nowlin 1963) into the interior region of the eastern GOM.

In terms of variability of water mass properties in deepwater, significant differences are observed between above sill depths (~1,900m) and below. Figure 2I.6 shows temperature measurements at 1,500 m during deployments one and two. Significant low frequency variability (20 days ~ several months) is present at 1,500m located above sill depths. Near sill depths at 2,000 m, less low frequency energy is observed (Figure 2I.7). At 2,500 m well below sill depths, most of the energy is contained in shorter frequency variability with significant short bursts of strong events (Figure 2I.8). These observations suggest that below sill depths, mixing of water mass is dominated by short-duration (lasting ~ 2 days) events, while above sill depths horizontal advection of different water masses (presumably flowing in from the Caribbean Sea) passing the mooring site manifests itself as longer frequency (20 days to several months) variability of water masses. Identity of the short-duration energetic events in deepwater still needs to be established.

Conclusions

The first direct observations of extreme currents exceeding one knot in deepwater were made in the central eastern GOM below the LC. This extreme event coincided with the passage of the western wall of the LC over the mooring site. This event lasted only two days. However, during this event, the entire water column was moving northward. Moreover, this event resulted in the introduction of colder and saltier water mass in deepwater. It appears that these extreme events might represent a mechanism by which to introduce colder and saltier inflow of deepwater from the Caribbean Sea into the interior region of the eastern GOM.

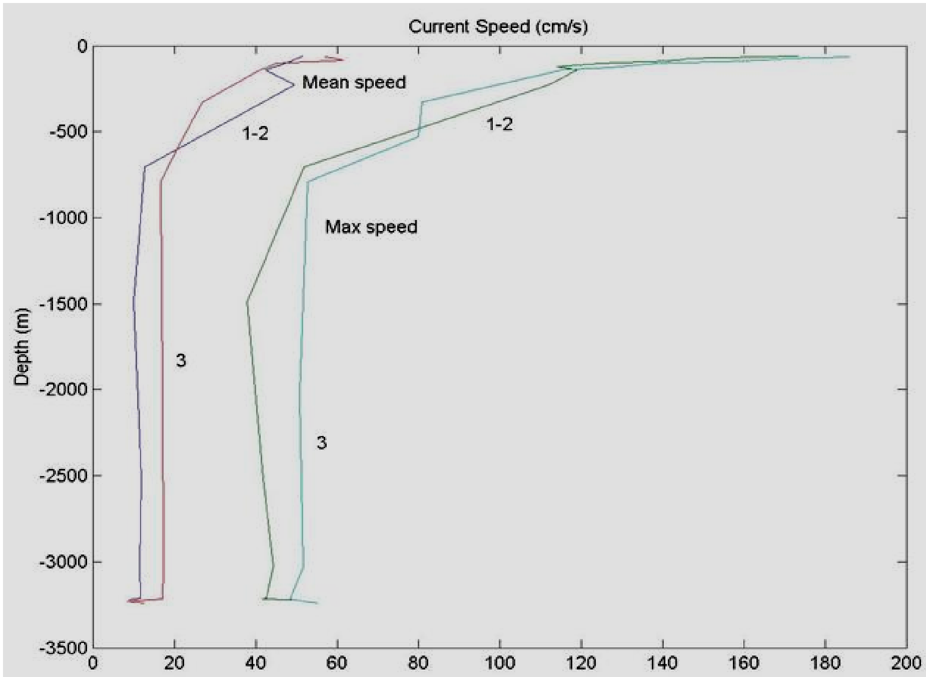


Figure 2I.2. Vertical profile of current speed (mean and maximum) measured during the deployments one and two and deployment three. During deployment three, deepwater currents were much stronger in both mean and maximum than deployments one and two.

Figure 2I.3. Hourly current meter data at 2,000 m, 3,000 m and 3,200 m on the Deep Gulf Mooring in July 2003.

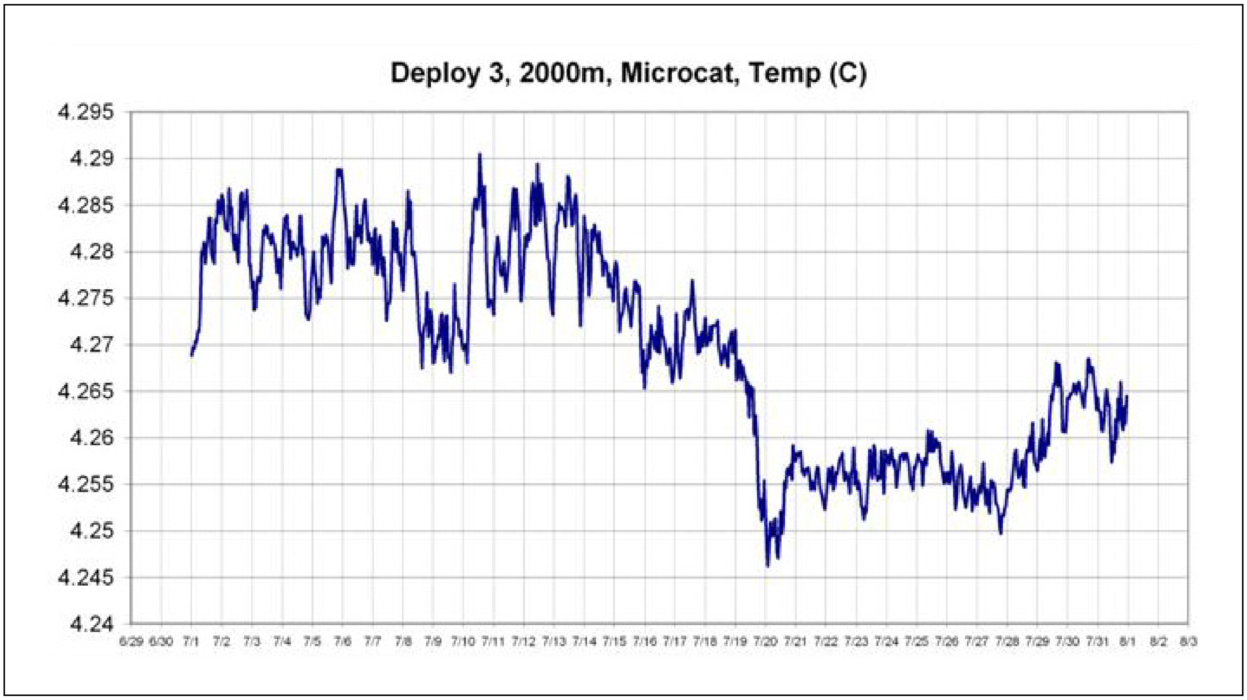


Figure 2I.4. Hourly temperature data at 2,000 m in July 2003.

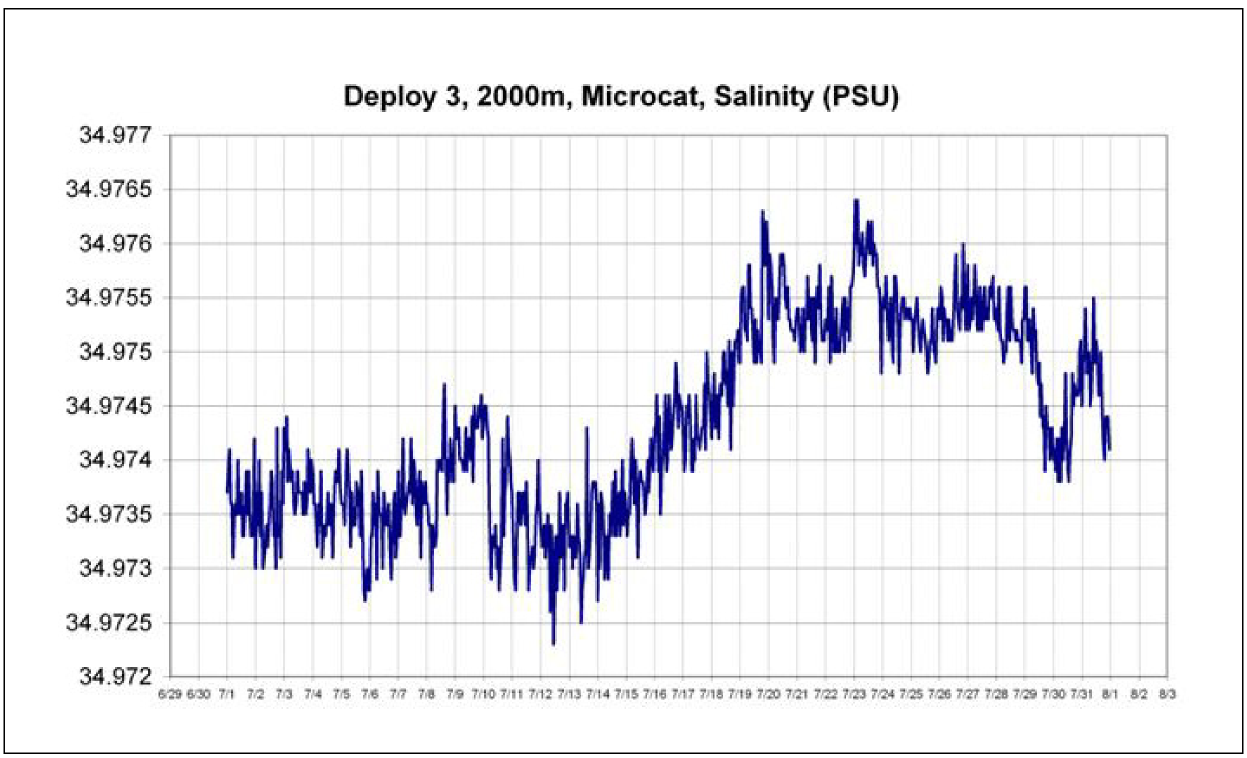


Figure 2I.5. Hourly salinity data at 2,000 m in July 2003.

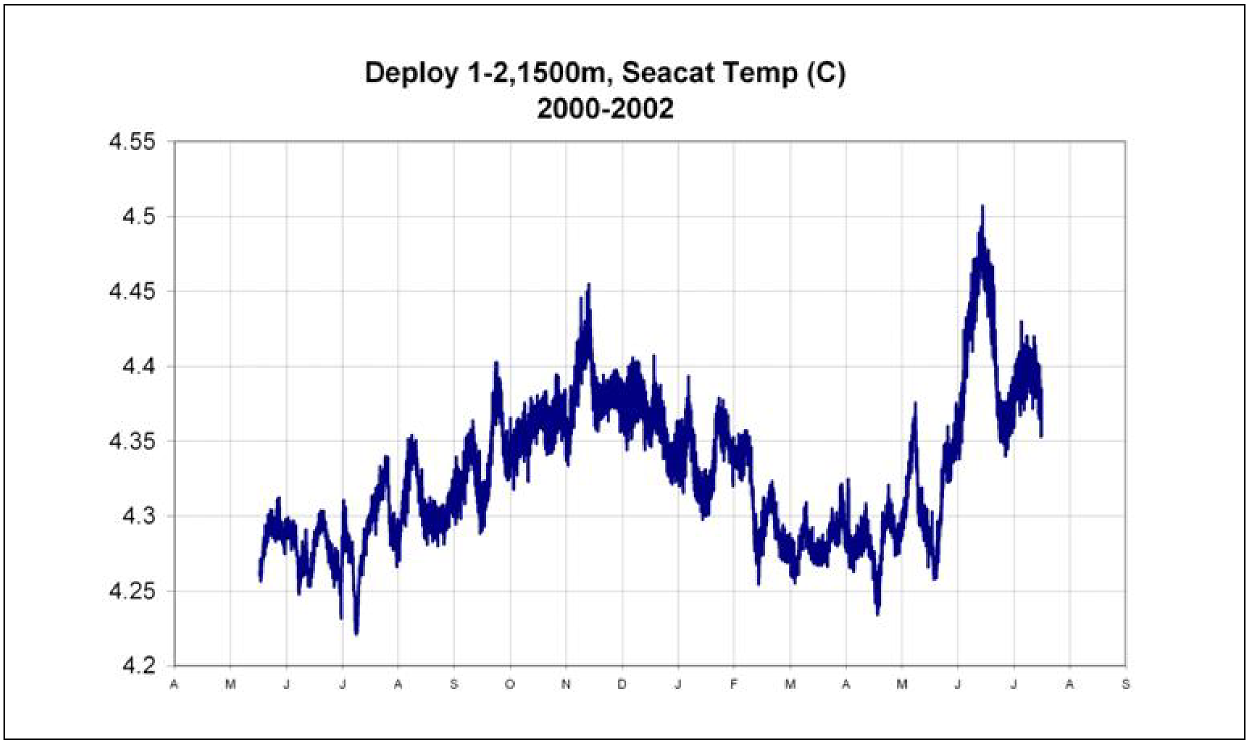


Figure 2I.6. Hourly temperature measured at 1,500 m during deployments one and two.

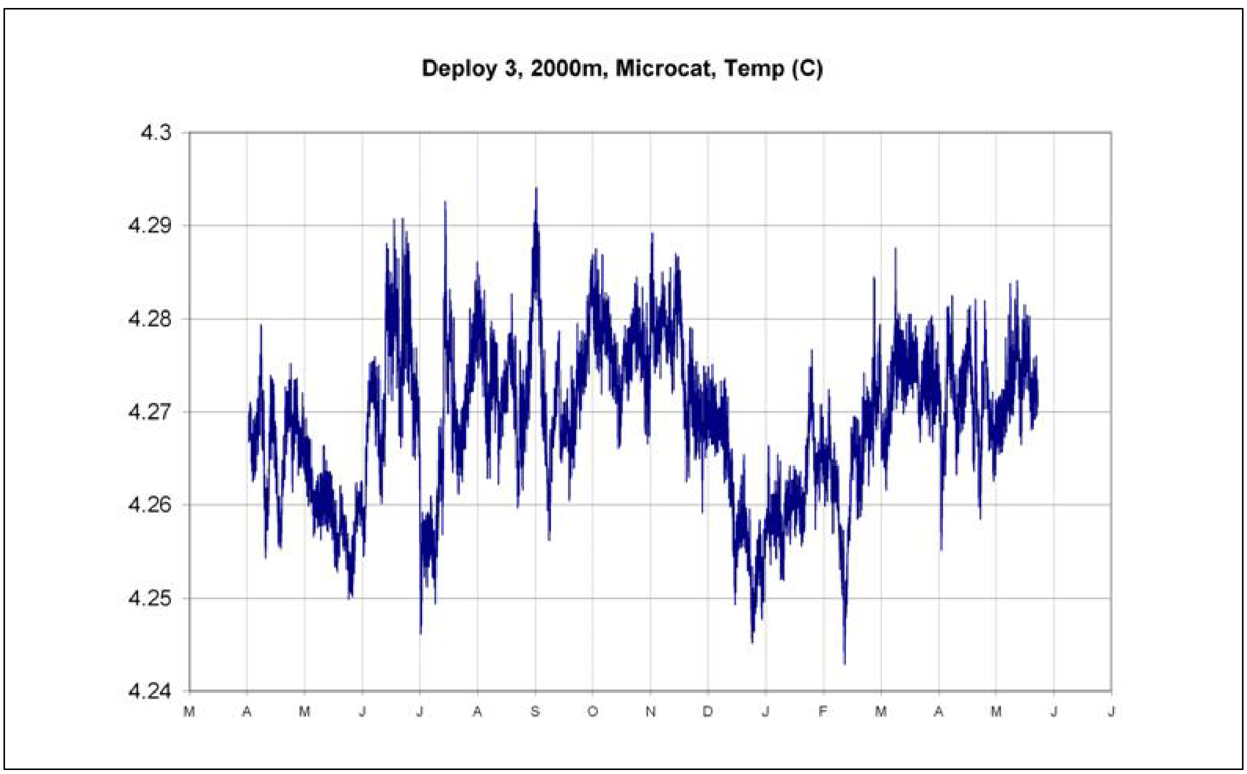


Figure 2I.7. Hourly temperature measured at 2,000 m during deployment three.

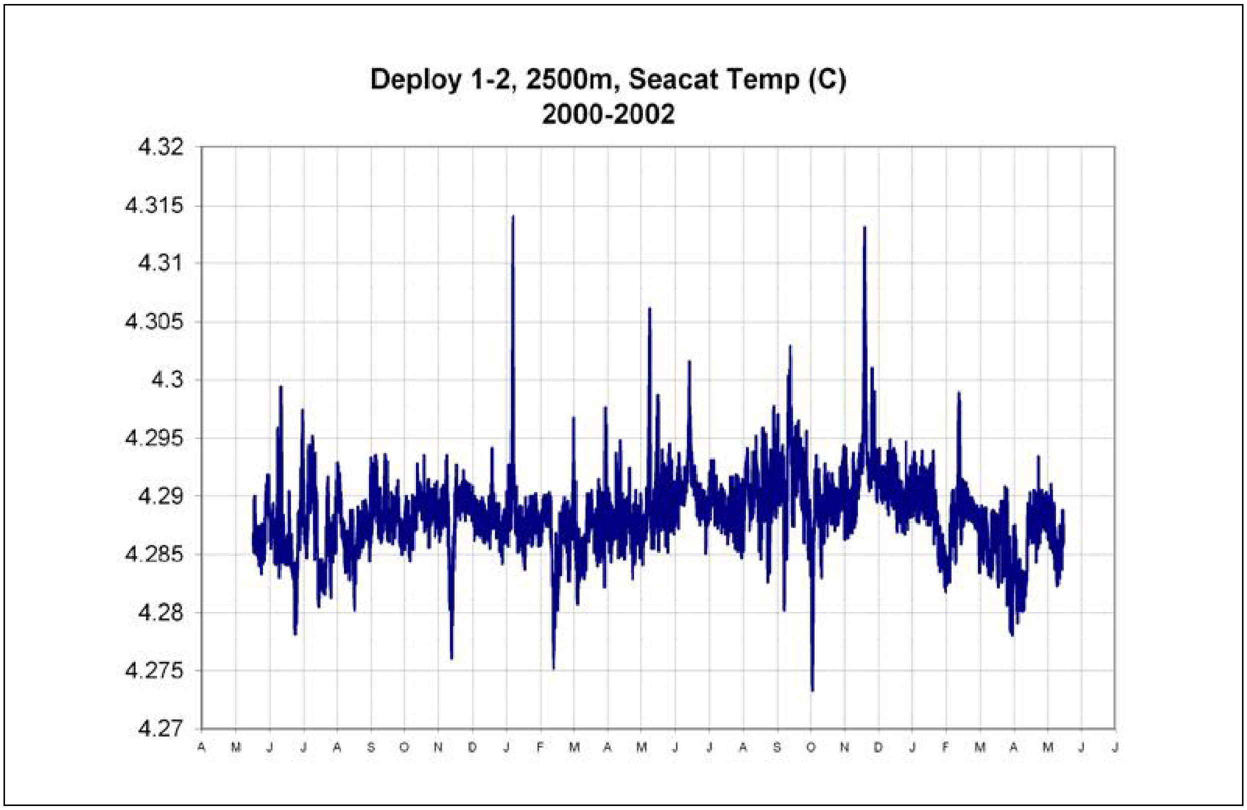


Figure 2I.8. Hourly temperature measured at 2,500 m during deployments one and two.

These observations suggest that interannual variability of deepwater currents in the eastern GOM can be significant, and in order to establish climatology of deepwater currents extended measurements of deepwater currents are required.

References

Hamilton, P. 1990. Deep currents in the Gulf of Mexico. Journal of Physical Oceanography 20:1087–1104.

Hamilton, P. and A. Lugo-Fernandez. 2001. Observations of high-speed deep currents in the northern Gulf of Mexico. Geophysical Research Letters 28(14):2867–2870.

Hurlburt, H.E. and J.D. Thompson. 1982. The dynamics of the Loop Current and shed eddies in a numerical model of the Gulf of Mexico. In: Nihoul, J.C.J., ed. Hydrodynamics of Semi-Enclosed Seas. Elsevier. Pp. 243–298.

McLellan, H.J. and W.D. Nowlin. 1963. Some features of the deep water in the Gulf of Mexico. Journal of Marine Research 21:233–245.

Dr. Masamichi Inoue has worked at Florida State University and at Australian Institute of Marine Science. He has been at Louisiana State University for the past 17 years and is Associate Professor in the Department of Oceanography & Coastal Sciences and at the Coastal Studies Institute. His research interests include ocean circulation and transport processes. Dr. Inoue received his B.E. in naval architecture from Tokai University, M.S. in ocean engineering from University of Rhode Island, M.E. in civil engineering and Ph.D. in oceanography from Texas A&M University.

Dr. Susan Welsh has worked in the Coastal Studies Institute for the past 15 years as a scientific programmer/modeler, a graduate assistant, a post-doctoral researcher, an assistant professor-research and presently as a Research Associate. Her areas of research are physical oceanography, numerical ocean models, and Gulf of Mexico circulation. Dr. Welsh received her B.S. in earth and planetary sciences from the Johns Hopkins University, her M.S. in oceanography from the Florida State University, and her Ph.D. in geology from Louisiana State University.

Dr. Lawrence Rouse is the director of the Coastal Marine Institute and Chair of the Department of Oceanography & Coastal Sciences at Louisiana State University. He is also an Associate Professor in the Department of Oceanography & Coastal Sciences and at the Coastal Studies Institute. His research interests are in coastal and shelf circulation, estuarine-shelf exchange, and remote sensing analysis of these processes. He received his Ph.D. in physics from Louisiana State University in 1972.

DEEPWATER EULERIAN OBSERVATIONS OF CURRENTS

Peter Hamilton, Science Applications International Corporation

Introduction

The observational part of the yearlong MMS Exploratory Program was completed in April 2004. The moored array was located over the central part of the northern Gulf of Mexico (GOM) slope, between water depths of 1,000 and 3,000 m, and consisted of 27 Inverted Echo Sounders with Pressure (PIES), 15 short lower-layer and 4 full-depth current meter moorings. Six near-bottom current meter moorings, deployed by the oil industry across the Sigsbee Escarpment, and two single full-depth moorings, deployed by CICESE and LSU, respectively, supplemented this array (Figure 2I.9). The study also has extensive remote sensing and deep Lagrangian float program elements designed to observe the large-scale phenomena influencing the fixed position array. In this paper, only the measurements that pertain to deep lower-layer flow events are discussed.

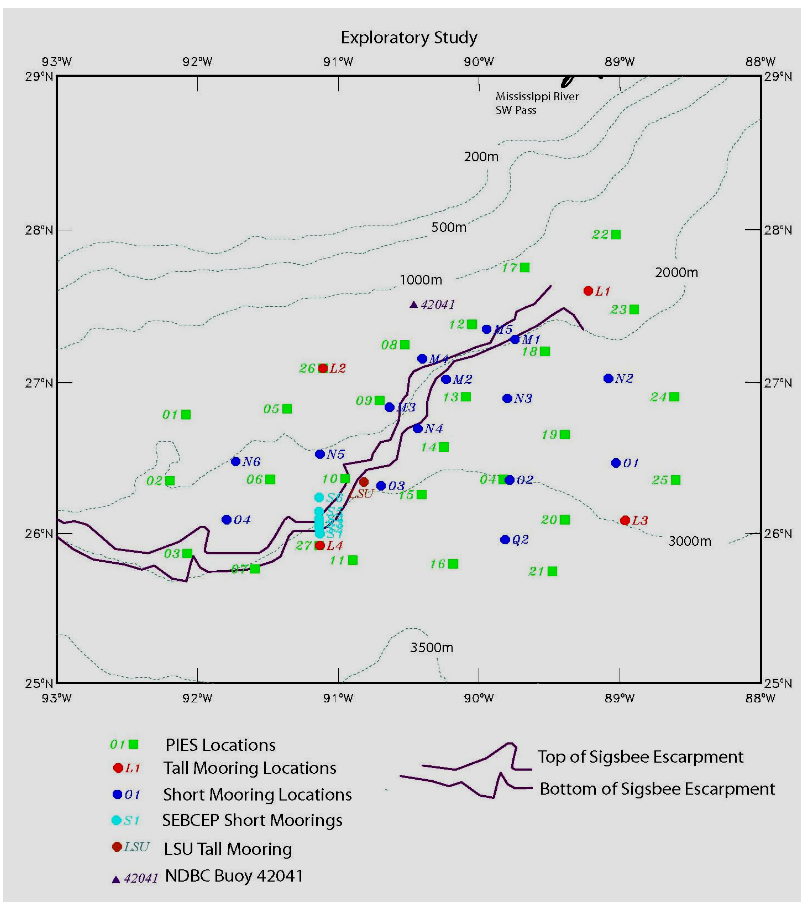


Figure 2I.9. Map of mooring positions for the Exploratory, SEBCEP (Industry) and LSU programs. The top and bottom of the escarpment are separated by about 500-m depth.

Previous current observations below 1,000 m in the GOM have established that flows are dominated by Topographic Rossby waves (TRW) (Hamilton 1990; Hamilton and Lugo-Fernandez 2001). TRWs are dispersive planetary waves, controlled by the slope of the local seabed, that have periods of ~ 7–100 days, wavelengths of ~ 100–200 km, and propagate at ~ 10–20 km d^{-1} in a direction such that shallower water is to the right (e.g. westward in the northern Gulf). Motions are highly coherent in the vertical and bottom intensified. When upper-layer eddy activity is minimal, TRW motions can penetrate weakly up to within a few 100 m of the surface (Hamilton 2005). Normally, however, the vigorous eddy circulations in the upper 800 to 1,000 m of the Gulf have little apparent connections with the deep TRWs. Model studies indicate that TRWs are generated by Loop Current (LC) fluctuations and the translation of LC anticyclones across the central and western Gulf. The processes of TRW genesis are yet to be elucidated and have not been clearly observed. It is suspected, in analogy with the Gulf Stream in the Northwest Atlantic, that the LC is a major source of TRWs with wave energy propagating towards the slope of the northern central Gulf. The steep Sigsbee escarpment (500 m depth change in 10 to 20 km) meanders across the study region with depths at the bottom of the slope ranging from 2,000 m in the east to 3,000 m in the west (Figure 2I.9). This major topographic feature must influence the propagation of the TRWs by refraction and/or reflection, and different period waves will have different propagation characteristics. A central question is whether the escarpment acts as barrier to energetic motions on the middle and upper northern Gulf slope, by reflecting deep TRWs south into the deep Gulf basin. This topic is the main subject of the preliminary analysis reported here.

Deep Currents

Previous studies established that the region near 90°W at the base of the escarpment (near M1 in Figure 2I.9) had high energy current fluctuations (a near-bottom maximum of 90 cm/s was reported by Hamilton and Lugo-Fernandez (2001)) that were interpreted as TRWs with unusually short periods (~ 10 to 12 days) and wavelengths (~ 70 km) compared to deep basin measurements further west, which had dominant periods ~ 20–30 days and current magnitudes of 10–20 cm/s (Hamilton 1990). Furthermore, current measurements above the escarpment at 90°W showed the strong flows rarely penetrated into shallower water. Thus, it appeared that the escarpment was blocking the transfer of wave energy to the slope above the escarpment. Therefore it was concluded that most TRW energy at these short periods was reflected from the escarpment with the possibility of some being transferred to enhanced mean flows over the escarpment. The present study sheds more light on this process by placing it in a regional context.

The fluctuation kinetic energy was calculated from the yearlong velocity records that have been filtered with a 40-hour low pass (HLP) Lanczos kernel, as is shown in Figure 2I.10. The majority of the records were about 100 m from the bottom; however, for a few moorings, velocities at 500 m above the bottom were used. There is a clear reduction in energy from east to west across the escarpment, and there are two regions on the deep side of the escarpment with high variance: one in the northeast corner (L1, M1 & N2), and the second further west around O3 and N4. Furthermore, mean velocities close to the escarpment are enhanced and directed along the escarpment towards the west. This kind of westward deep mean current along the base of the continental slope has been observed in model studies. Industry measurements at S3 were the only ones made above the boundary layer in the middle of the escarpment slope, and compared to nearby mean flows above (at S6) and below (at L4) the escarpment, the mean current is more than twice as strong (~ 14 cm/s). Examination of the 40-HLP velocity record at S3 shows that the fluctuations are directed westward and parallel to the slope and rarely reverse, unlike lower-layer, low-frequency fluctuations at other locations. Therefore, over this transect at ~ 91°8'W, there is a westward directed jet centered over the escarpment, which is probably a result of transfer of a portion of the fluctuation kinetic energy of the TRWs to the mean.

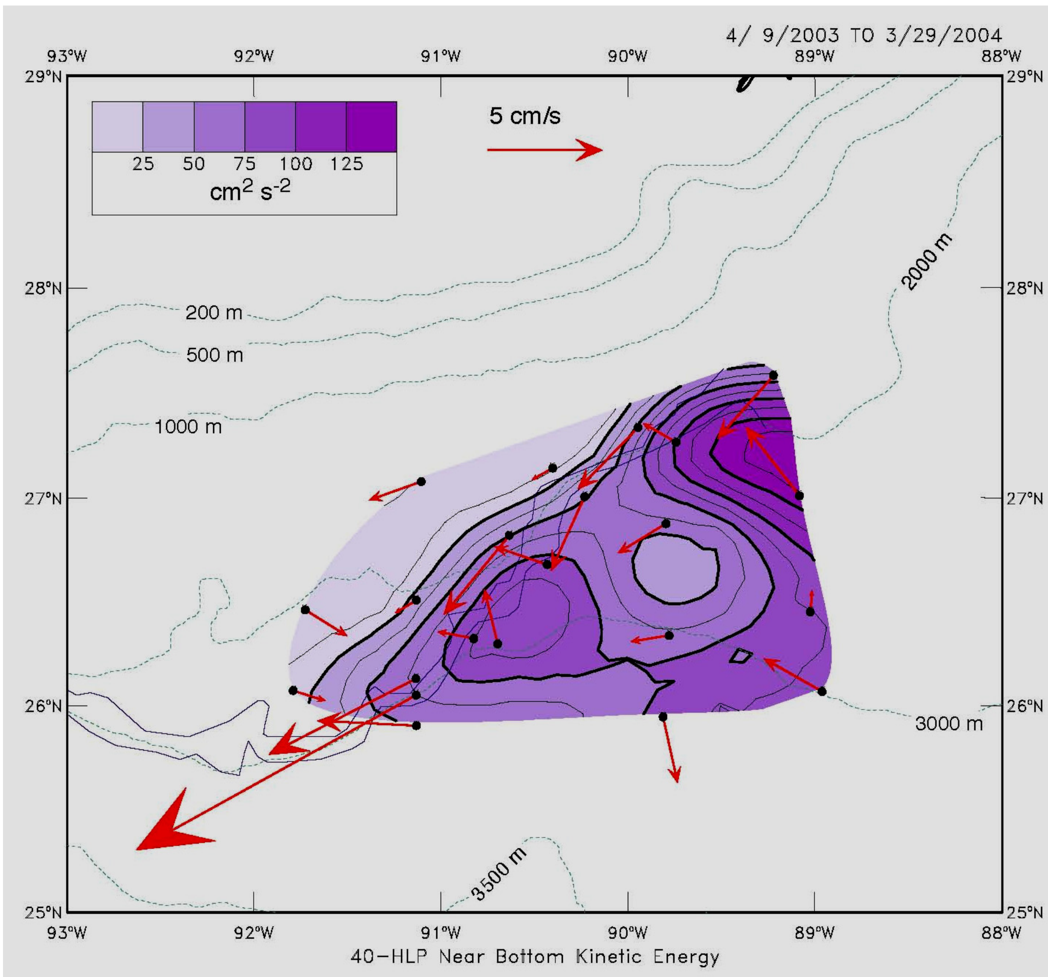


Figure 2I.10. Contours of 40-HLP mean kinetic energy, overlaid with 40-HLP mean velocity vectors, for near bottom current meter data. Averaging interval is one year.

The kinetic energy spectra, in variance preserving form where equal areas under the curve represent equal variances, are shown for lower layer currents at three of the tall moorings in Figure 2I.11. All three moorings show increases in energy with increasing depth of the measurement, except for the 2,925 m currents at the L5 (LSU) mooring, which is probably within the bottom boundary layer. This bottom intensification is typical of TRW motions. The spectra at the different locations have different characteristics and energy levels. In the southeast corner at L3, the major peak is at 12.5 days, with less energetic peaks at ~18 and 40 days. At L5, which is further west and close to the base of the escarpment, the ~20 day peak dominates though there is also substantial energy at ~ 40 days. The 12.5-day motions are largely absent. In the southwest of the array at L4, only the ~ 40 day peak is present, and it shows much less variance than at L5. Kinetic energy spectra for the other moorings (not shown) show similar changes in the periods of the dominant motions for differing locations as well as the changes in total variance across the escarpment seen in Figure 2I.10. Generally short period motions of ~ 8 to 14 days periods are important on the east side of the array and not observed in the west, where longer period fluctuations dominate. At M1, large amplitude fluctuations with periods ~ 10 days dominate similar to previous measurements in this region reported by Hamilton and Lugo-Fernandez (2001).

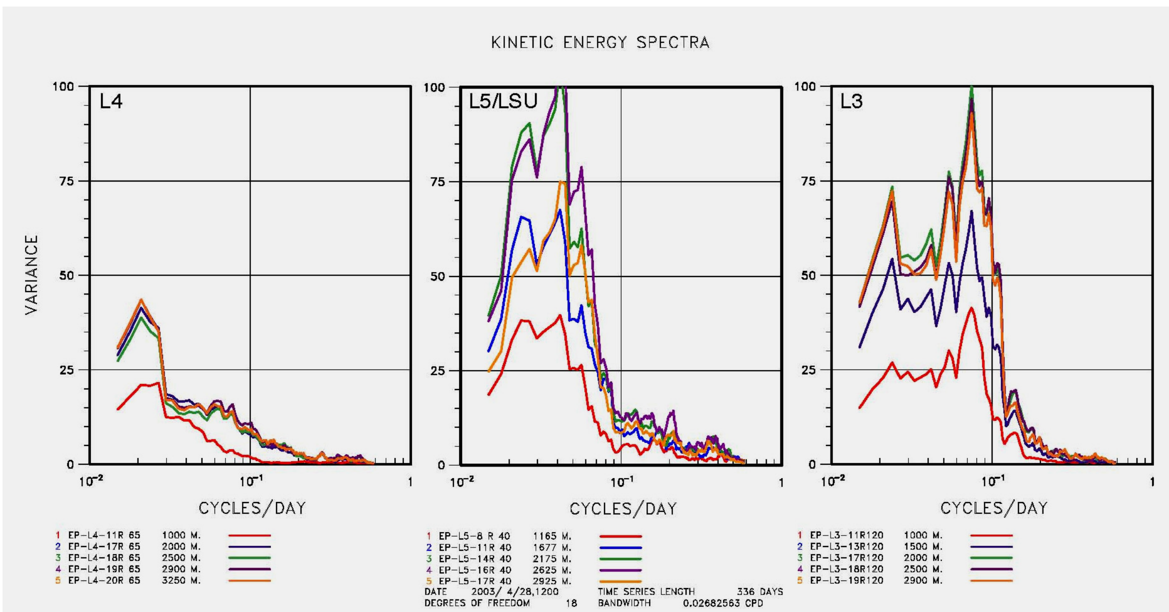


Figure 2I.11. Kinetic energy spectra of 40-HLP currents at selected depths below 1,000 m for the tall moorings L3, L5 (LSU) and L4.

An explanation of the complex mixture of periods that dominate the currents in different parts of the array that is south of the escarpment is that TRWs of different frequencies have different paths and possibly different sources. Thus, long period waves propagate more nearly parallel to the isobaths and are unable to penetrate into shallower water depths. The short-period waves propagate across the isobaths and appear to be trapped in the northeast corner of the array. This is illustrated in Figure 2I.12 where near-bottom current fluctuations in two frequency bands are analyzed using frequency domain EOFs. The first-mode fluctuations, which account for ~ 50% of the total variance of all the data, describe the dominant coherent signals along with their phase propagation. The lowest frequency band, which has most of the variance at L4, indicates that most of the fluctuations with the largest amplitudes are in the southern part of the array with little penetration above the escarpment and east of ~ 90.5°W along the escarpment. Wavelengths of TRWs were calculated from the phase differences of the mode using the four locations in the southeast corner (L3, O1, O2 and Q2) and a propagation path calculated using the ray tracing equations (Pickart 1995). Rays were calculated both backward and forward of the initial position for the center frequency of the mode. The result is shown in Figure 2I.12 and shows that the refraction keeps the energy in the southern part of the array. The ray path, however, is predicted to cross the escarpment. If the wave is reflected when it reaches the escarpment, the path, given by the dashed line, is more in accordance with the energetic fluctuations observed along the bottom edge of the escarpment. If this long period wave is traced backwards, then it shows that its origin could have been under the Loop Current about 10 to 15 days earlier. The EOF analysis of the short period (17–11 day) motions show that the higher amplitudes are found on the eastern side of the array and along the escarpment east of ~ 91°W (Figure 2I.12). It is noted that the major axes of the fluctuation ellipses are parallel to the escarpment for the locations immediately below the steep slope and perpendicular to the escarpment at M3 and N5 above the slope. This indicates that this short period TRW has different characteristics above and along the escarpment and again along the TRW ray path, initialized using the M1, M2 and N3 phase differences, corresponds better to the observations if the wave is reflected at the slope. The 13.4-day period ray paths are halted when the bottom slope becomes small south of the 3,000-m isobath. This seems to indicate that short period, short-wavelength TRWs are generated fairly locally to 90°W and remain trapped by the topography in this region (Hamilton 2005).

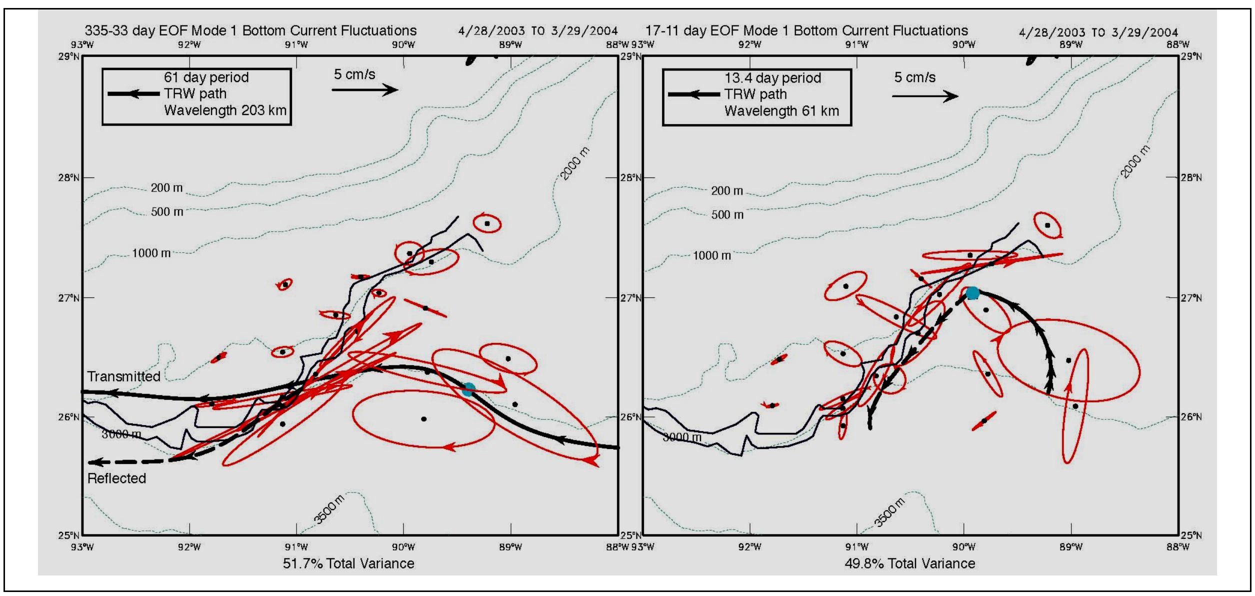


Figure 2I.12. First frequency domain EOF modes shown as amplitude ellipses (red) where the relative phase is given by the arrowhead. LH panel: 335-33 day motions; RH panel: 17-11 day motions. The heavy black lines are TRW propagation paths calculated by ray tracing forward and backwards from the blue dots using the indicated periods and wavelengths as initial conditions. Arrow heads on the paths are at five-day intervals.

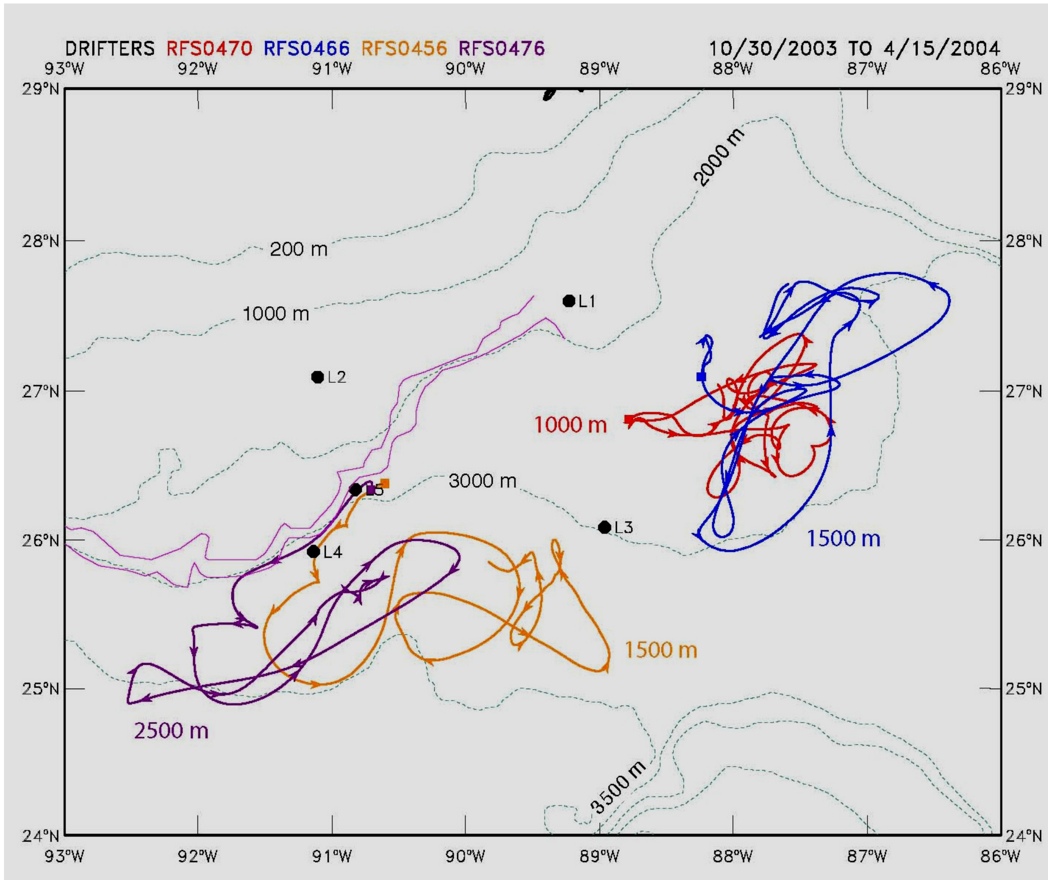


Figure 2I.13. Smoothed Lagrangian RAFOS trajectories for the indicated floats. The deployment depths of the floats are indicated and the arrowheads are at 10-day intervals.

The spatial variability of the low-frequency content of the lower-layer current observations have been discussed in terms of propagating dispersive planetary waves. It would be difficult to explain these observations in terms of lower-layer eddies moving through the region, because even if the eddies were steered by the topography of the escarpment, the signal content at the different positions south of the escarpment would be very similar, contrary to the observations. One crucial difference between eddies and waves is that westward propagating eddies transport mass as well as momentum. If this were the case, then the deep Lagrangian float trajectories would translate westward accompanied by cyclonic or anticyclonic circular or elliptical rotations similar in manner to surface floats deployed in Loop Current anticyclones. Lagrangian trajectories of deep TRW motions would be similar to the elliptical or rectilinear vector hodographs in Figure 2I.12 with little translation in the mean unless mean currents are large, such as at S3 over the escarpment. Four trajectories from the RAFOS float program are given in Figure 2I.13. One pair remains south of the array and the other pair east of the array for the ~ 5months of data coverage. Even though the floats are at different depths, each of the pairs had similar paths. For the eastern pair the 1,000-m float has smaller amplitude displacements than the deeper 1,500-m float, as is expected for bottom-intensified fluctuations. For the southern pair, the displacements are similar in magnitude and both floats have initial westward displacements caused by the mean flow over the escarpment. The trajectories have similar period fluctuations, which are both cyclonic and anticyclonic, to those found in the nearby current meter records, discussed above (e.g. L4 for floats 0456 and 0476, and L3 for 0470 and 0466 (Figure 2I.13)). Thus, the float displacements, in the region of the moored array, have more in common with TRWs than translating lower-layer eddies.

References

Hamilton, P. 1990. Deep currents in the Gulf of Mexico. Journal of Physical Oceanography 20:1087–1104.

Hamilton, P. 2005. Deep current variability near the Sigsbee Escarpment in the Gulf of Mexico. Journal of Physical Oceanography.

Hamilton, P. and A. Lugo-Fernandez, 2001. Observations of high speed deep currents in the northern Gulf of Mexico. Geophysical Research Letter 28:2867–2870.

Pickart, R.S. 1995. Gulf Stream-generated topographic Rossby waves. Journal of Physical Oceanography 25:574–584.

Dr. Peter Hamilton is a Senior Oceanographer with Science Applications International Corporation. He has served as a Principal Investigator on many MMS programs in the Gulf of Mexico and other coastal seas. He received his Ph.D. from the University of Liverpool (UK) in 1973.

PIES MEASUREMENTS IN THE DEEP GULF OF MEXICO

Kathleen Donohue, D. Randolph Watts, and Karen L. Tracey,
Graduate School of Oceanography, University of Rhode Island

Introduction

A mesoscale-resolving array of twenty-seven inverted echo sounders with pressure gauges (PIES) and fifteen deep current meters deployed in March 2003 and recovered in April 2004 constitute part of the Exploratory Study of Deep Water Currents in the Gulf of Mexico funded by Mineral Management Services (Figure 2I.14). Round-trip acoustic travel time measured by the inverted echo sounder is converted to vertical profiles of temperature, salinity, and density via an empirical relationship determined by historical hydrography. Comparisons between estimated and directly-measured mooring temperatures indicate that the empirical relationship holds well in the Gulf of Mexico (GOM). Key circulation processes in a deep-water region in the GOM are identified by quantitative mapping of the regional circulation. Coherent deep-eddy structures are associated with shifts in the Loop Current and Loop Current eddies. During the measurement time period, the Loop Current extended northward into the eastern portion of the array. In June, a Loop Current Eddy formed and subsequently reattached to the Loop Current by the end of the month. Another Loop Current Eddy, Eddy Sargassum, formed in late July and remained detached. Immediately after Eddy Sargassum detached the deep pressure field shows a burst of strong eddy activity comprising topographic Rossby waves and cyclones and anticyclones. Elevated deep energy levels occur at this time.

PIES Instrumentation

PIES is a bottom-mounted instrument which emits 12 kHz sound pulses, measures round trip travel times of acoustic pulses to sea surface and back and measures bottom pressure. A PIES mooring consists of a 17" glass sphere with a 150 lb anchor stand (Figure 2I.15). A sample burst of twenty-four 12-kHz pings is transmitted every half hour; the quartile value of each travel time burst becomes the tau measurement. Experience has shown that pressure drift is greatly reduced by preconditioning. The sensors were subjected to pressures of 3,000 dbar for one to two months in the laboratory prior to the first deployment. Tides are removed from the pressure records. Finally, an exponential-plus-linear drift curve is determined by a least-squares fit and then removed from the measurements. Within the array, the maximum drift was 0.25 dbar, fifteen PIES had drifts less than .05 dbar and twenty PIES had drifts less than 0.1 dbar.

The PIES are capable of acoustic pulse-delay telemetry. This method encodes the data as the delay in arrival time between two acoustic pulses. Advantages include low power requirements and high reliability balanced against the disadvantage of relatively slow speed. The instrument internally processes data using typical post-processing techniques and saves the processed value for each 24-hour day. One day of yearday, pressure, and tau measurements takes about 20 seconds to transmit between the instrument and the acoustic receiver aboard the ship. Data were successfully telemetered mid-experiment (September 2003) during mooring turn-around. The internally saved processed data and the telemetered data agree well with post-processed data.

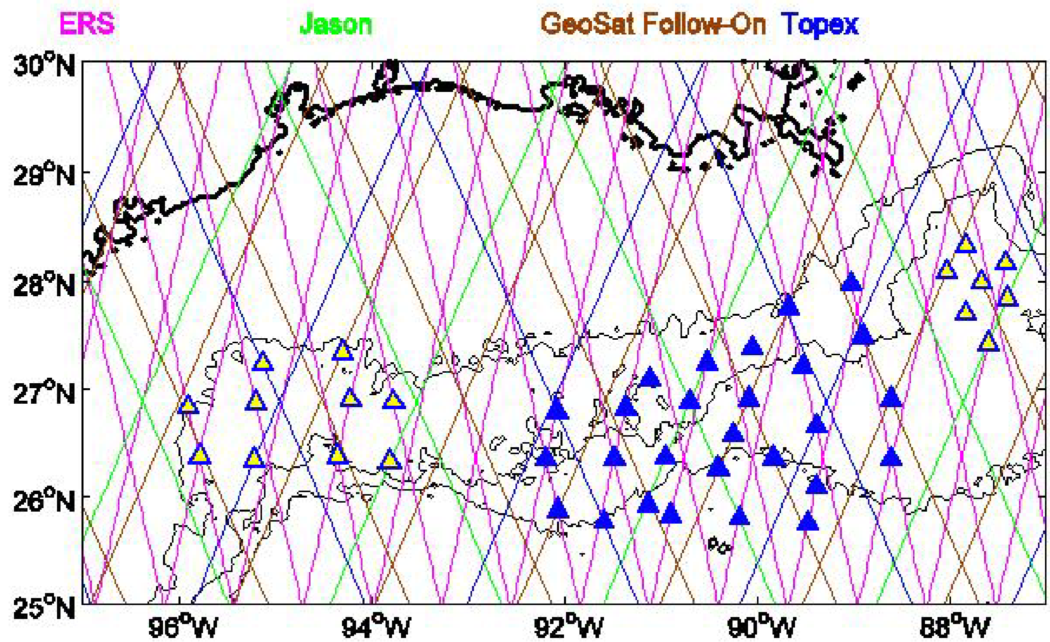


Figure 2I.14. Three arrays of inverted echo sounders equipped with pressure gauges (PIES) have been deployed in the Gulf of Mexico. Western Gulf array deployed October 2004 with an anticipated recovery August 2005. Central Gulf array deployed March 2003 and recovered April 2004. Eastern Gulf array deployed December 2004 with an anticipated recovery December 2005. Satellite altimetry tracks are superimposed on the bathymetry from Smith and Sandwell (1997) which is contoured every 1,000 m depth.

Figure 2I.15. The pressure-recording inverted echo sounder (PIES) is an ocean-bottom instrument housed in a single 17" glass sphere containing the controller/data logger, acoustic release, and relocation radio/strobe light. The PIES is released from the ocean bottom after it receives a coded acoustic command. The anchor stand is dropped; the PIES returns to the surface and emits an acoustic beacon—a relocation radio and a strobe flasher—for tracking.

PIES Array

The mesoscale-resolving array consists of twenty-seven PIES and fifteen deep-current meters. Near-bottom current meters deployed between the PIES in "triangles" allow the bottom-pressure records to be leveled. One constant is determined for each bottom-pressure record under the requirement that the mean leveled pressure records agree with the streamfunction determined from the mean near-bottom currents. PIES were placed along satellite altimetry tracks and at cross-over points to allow direct comparison between satellite- and PIES-derived sea surface height and to evaluate the baroclinic and barotropic components of sea surface height. The broad extent of the array, nominally 92W to 88W, 26N to 28N, and the eddy-resolving PIES spacing enables a quantitative mapping of the regional circulation.

Gravest Empircal Mode—A Look-Up Table

Experience in strong-jet environments such as the Gulf Stream and Antarctic Circumpolar Current indicates that a strong empirical relationship exists between tau and vertical profiles of temperature, salinity, and density. This relationship is coined Gravest Empircal Mode, or GEM, and yields a look-up table between tau and various ocean variables. We have created a GEM field for the GOM; the methodology is described below.

First, a regional hydrographic data set was assembled. We utilized CTD hydrocasts from the MMS-funded Deepwater Reanalysis supplemented with CTD data from SAIC. The northwestern GOM is well sampled; hydrocasts represent about 20 years of sampling; hydrocasts sample most of the annual cycle, except December; the bulk of casts extend between 1,000 to 2,000 dbar with relatively few casts below 2,000 dbar.

Second, a reference tau index was chosen to be the round-trip travel time between 1,000 dbar to 100 dbar. The lower limit was determined by the historical data set. The upper limit was chosen to be below the mixed layer to avoid contamination from the seasonal cycle. Future work will include a seasonal correction in the GEM field.

The hydrographic data (temperature, salinity, and specific volume anomaly) were sorted by the tau index, linearly interpolated to a uniform 25 dbar grid, and at each pressure level a cubic smoothing spline was fit to the hydrography (temperature, salinity and specific volume anomaly) as a function of the tau index. Root-mean-square residual, rms, for each curve provides an indication of the departure any individual profile might have from the GEM curve. The rms values for temperature, salinity, and specific volume anomaly are small and decrease with increasing pressure. There is little structure in the temperature and salinity GEM fields below about 1,000 dbars and this reflects the uniform deep water properties observed on the GOM. The GEM field provides a look-up table; given a reference tau value profiles of temperature, salinity, and specific volume anomaly can be determined.

The PIES-measured taus are then converted to the same index as the look-up table. We assume that tau at any deep pressure is linearly related to tau at any other deep pressure. Historical hydrography established the slope and calibration CTDs taken during turn-around telemetry cruise determined the intercept of this linear relationship.

Comparisons with Observations

Four tall moorings embedded within the PIES array directly measured temperature, salinity, and current at discrete depths during the experiment. Only one PIES was coincident with a tall mooring, so temperature estimated from the PIES was mapped to tall mooring locations and then compared to mooring measurement. Figure 2I.16 shows one set of comparisons for the tall mooring L1 located in the northeastern portion of the array. Here the comparison is excellent: estimated and measured temperature time series track each other well and the variance explained is greater than 84%. Considering all four moorings, the percent variance explained in thermocline is 83%.

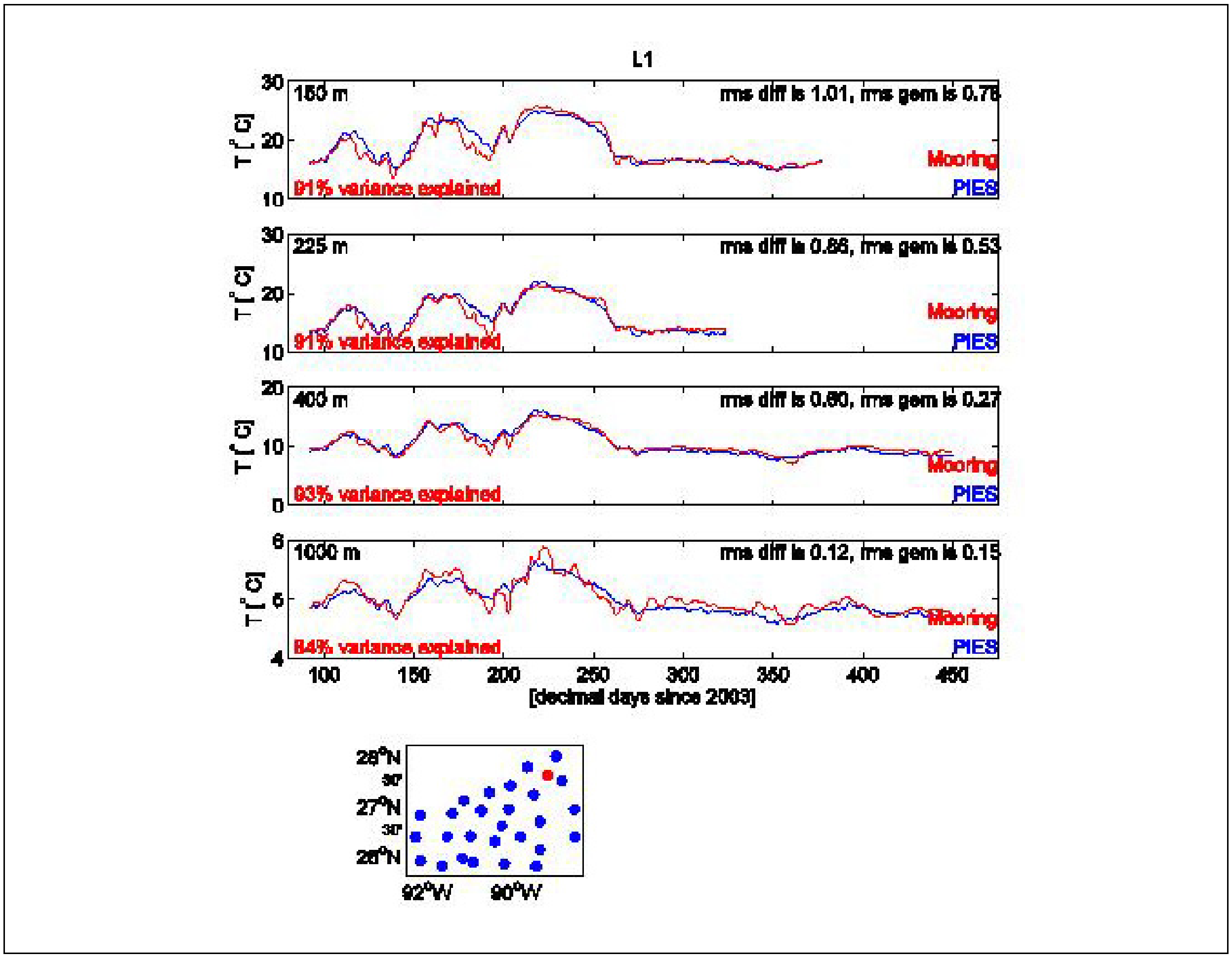


Figure 2I.16. Upper four panels compare PIES-estimated (blue) and directly-measured temperatures (red) at the L1 mooring whose location is shown in the bottommost panel by the red circle. The root-mean-square difference between the records is noted in the upper right corner of each panel and can be compared to the root-mean-square of the historical hydrography used to construct the GEM field.

Initial Results

Tau measured by the PIES shows strong coherence between nearby sites, and multiple space and time scales are evident. This multiplicity of scales was expected as upper-ocean eddies have a range of length and time scales: Loop Current and Loop Current Eddies range 200–500 km, slope eddies scales are 100–150 km, and frontal cyclonic eddies scale near 50–150 km. Maps of the upper-ocean circulation provide a framework in which the observations can be interpreted. For example, mapped temperature at 300 m (Figure 2I.17) shows frontal cyclones along the periphery of the Loop Current/Loop Current Eddy and a small anticyclone generated during ring pinch-off.

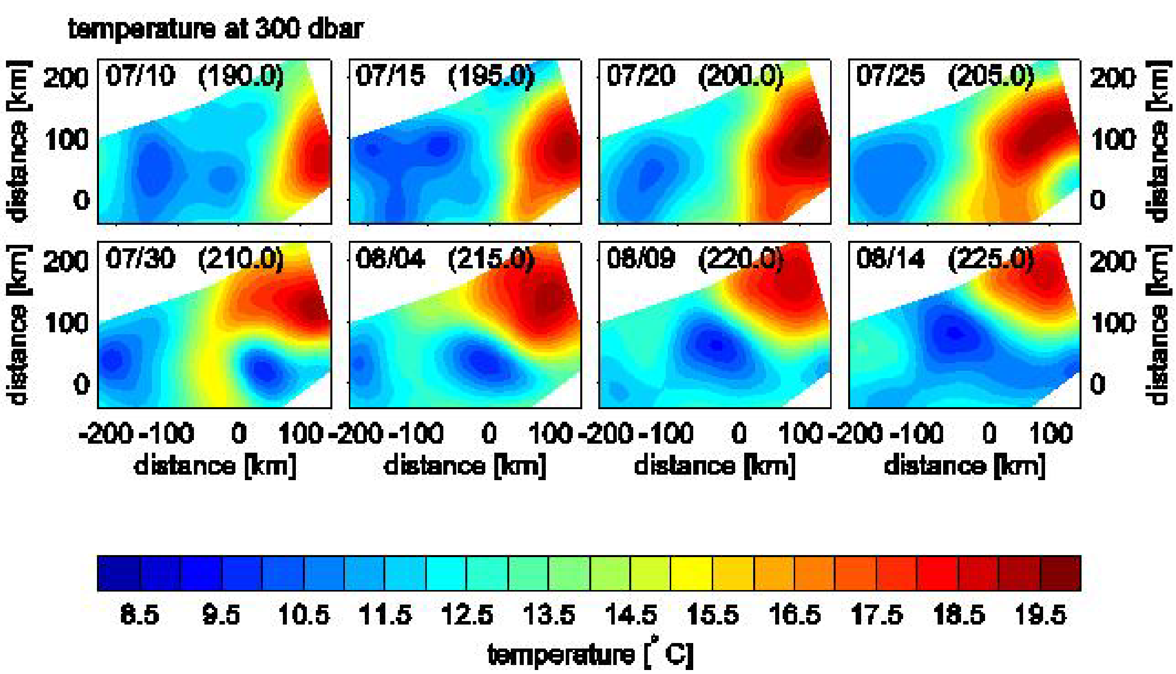


Figure 2I.17. Mapped temperature at 300 dbar shows frontal cyclones along the periphery of the Loop Current and Loop Current ring and a small anticyclone generated during ring development.

In addition, several deep features are revealed. A coherent 16-day oscillation in deep pressure with 5 cm peak-to-peak amplitude exists throughout the array.

There is increased variability south of escarpment and during the detatchment of Eddy Sargassum. There are clearly westward propagating topographic Rossby waves along the escarpment, but locally generated features are also apparent. Scales in the deep ocean are smaller than those in the upper ocean indicating that deep scales are set by the interaction of the upper-ocean circulation with complicated topography in the region.

Future Work

Future analysis of the central Gulf PIES array includes developing a better understanding of the upper-lower layer coupling, comparison between altimeter and PIES sea-surface height, and combining maps and float trajectories. Currently, there are two PIES arrays in the Gulf. In the Western Gulf 10 PIES centered near 26.7N, 95W will be recovered in late summer 2005 after an approximately six-month deployment. In the Eastern Gulf 7 PIES centered near 27.9N, 87.7W have been deployed in December 2004 and will be recovered in December 2005.

References

Smith, W.H.F. and D.T. Sandwell. 1997. Global sea floor topography from satellite altimetry and ship depth soundings. Science 277:1956–1962.

Kathleen Donohue received a Ph.D. degree in physical oceanography from the University of Rhode Island in 1995. She has worked as an assistant Marine Research Scientist at the Graduate School of Oceanography, University of Rhode Island, since 2000.

D. Randolph Watts received a Ph.D. degree in physics from Cornell University in 1973. He is a Full Professor at the Graduate School of Oceanography, University of Rhode Island.

Karen L. Tracey received her M.S. degree in marine sciences from the University of North Carolina, Chapel Hill in 1981. She has worked at the Graduate School of Oceanography, University of Rhode Island as a Marine Research Specialist since 1981.

DEEPWATER LAGRANGIAN OBSERVATIONS OF CURRENTS IN THE GULF OF MEXICO

Kevin D. Leaman, Division of Meteorology and Physical Oceanography, Rosenstiel School of Marine and Atmospheric Science, University of Miami

As part of the MMS-funded exploratory study of deep currents in the Gulf of Mexico (GOM), two types of subsurface, acoustically tracked Lagrangian drifters were launched into the central GOM for trip durations of up to one year. The first type of drifter, called RAFOS, was deployed in two groups: 1) an initial set of 30 drifters to be tracked for one year; and, 2) a special set of six drifters to be deployed as an "event" experiment. The initial set were deployed along three longitudes: 089° 00'W, 089° 45'W, and 090° 30'W from roughly 26° N to 28° N. These floats were deployed at depth intervals of 500m from 1,000m to 3,000m where topography permitted. At the end of their voyage they surface and transmit pressure, temperature, and acoustic tracking data via ARGOS. All RAFOS floats for this experiment were ballasted isobarically (that is, to stay on a given pressure, as opposed to density, surface).

The second set was deployed along 090° 30'W at depths of 1,500m and 2,500m "upstream" of the Sigsbee Escarpment, with a planned trip duration of seven months. Three floats were deployed at each depth with close horizontal separations. The intent of this experiment was to watch the progress of the floats as they moved through the complicated "downhill" topography of the Escarpment.

The second type of float, named "PALFOS," was acoustically tracked similarly to the RAFOS floats. However, these floats include a CTD sensor that will operate in a profiling mode; every ten days these floats will surface while making a CTD profile at vertical resolutions of from 50m (from the 1,000m rest depth to which they were deployed to 250m) to 10m (from 250m to the surface). While on the surface, the floats transmit CTD and acoustic tracking data to shore via ARGOS and are in turn navigated by ARGOS. After transmission the floats sink back to their rest depth. Two floats were deployed on each of the longitudes indicated above during March and April 2003 at the start of the experiment. Three of these floats are still functioning and transmitting data to shore. One float "escaped" from the GOM and "hopped" its way up the Straits of Florida, where it appears to have been finally picked up by a local boater. Since its transmitter disappeared from view, we suspect it is sitting in the boater's garage.

Acoustic tracking was provided by commercially manufactured sound sources moored at three locations in the northern GOM during the initial mooring cruise. These sources transmit every eight hours in a staggered pattern; extremely accurate clocks on the floats and sources permit range information to be determined. Unfortunately, two of the three sources failed partway through the experiment due to a mechanical failure, thereby resulting in the loss of several months of tracking data in the middle of the experiment. However, since the PALFOS floats were transmitting to ARGOS every ten days, positions of these floats could still be determined at ten-day intervals. Fortunately, we were able to borrow two sources from a colleague, Dr. Walter Zenk at the Institut fur Meereskunde in Kiel, Germany, allowing us to complete the last six to seven months of tracking, including complete tracking of the "event" floats.

Several general observations can be made from an inspection of the float tracks:

1. Floats tended to migrate preferentially to the east or west; very few remained in the central portion of the GOM, and those that did were usually deployed in the deeper (southern) part of the basin;

2. Once floats moved to the east or west, they exhibited long residence times over the Sigsbee Plain (west) or over the eastern basin. (This region appears not to have a formal name; however, we are referring to the deep region east of the north-south topographic restriction at about 088° W.);

3. A moderate majority of the floats moved to the west. However, there is little correlation between the direction floats moved, and the deployment line (east-middle-west). That is, some floats deployed along the easternmost line moved west, and vice versa;

4. Floats that moved eastward tended to exhibit eddying motions in the interior of the eastern basin, with no tendency to crowd the steep topography on the eastern side of the basin. Conversely, floats moving to the west tended to follow topographic contours and "funnel" along the western, steep-walled boundary. A few floats tracked along the walls of bathymetric features in the west, such as the Alaminos Canyon;

5. Floats near shallow topography showed more eddying behavior and cross-isobath flow (a few, in fact, ran aground);

6. Floats in the central region are clearly responding to spatial variability on extremely small scales. Two floats launched less than 15nm apart at 1,500m during the event experiment went in exactly opposite directions, one east and one west.

The picture that emerges from the above is that the deep circulation in the GOM is characterized by two large counter-rotating gyres, a stronger, cyclonic gyre with westward intensification in the western Sigsbee Basin (also seen by others), and a weaker, anticyclonic gyre in the eastern basin. Considerable small-scale horizontal, turbulent exchange may be taking place in the central part of the basin, in the region where the floats were launched. The eastern gyre shows a much more broadly distributed eddy activity across the eastern basin. Over the course of one year no floats managed to exit the basin via the Yucatan Channel, although other (e.g., current meter) data suggest that backflow into the Caribbean is taking place in this channel at deeper levels.

Dr. Kevin Leaman received his B.S. and M.S. degrees in meteorology and oceanography from the College of Engineering at the University of Michigan in 1970 and 1972, respectively. He was awarded a Ph.D. in physical oceanography in 1975 in the Joint Program in Oceanography of the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology. He has worked at the University of Miami's Rosenstiel School of Marine and Atmospheric Science since 1976, where he is now Professor of Physical Oceanography. He served as Chair of the Division of Meteorology and Physical Oceanography from 1995 to 2000. He has served for the last four years as the Co-Chief Editor of the Journal of Atmospheric and Oceanic Technology of the American Meteorological Society. His research interests have included oceanic internal waves, large-scale ocean circulations, western boundary currents, deep water formation, and biophysical interactions. He has also been involved with the development and design of oceanographic instrumentation. In the process of carrying out this research he has served as Chief Scientist on more than forty research cruises in the North and South Atlantic Oceans, Pacific Ocean, Caribbean Sea, Gulf of Mexico, Straits of Florida and the Mediterranean Sea. He has also developed and carried out bilingual training programs for oceanographic technicians and scientists from Latin America.

HIGH RESOLUTION MODELING OF THE GULF

Susan E. Welsh and Masamichi Inoue, Coastal Studies Institute, School of the Coast and Environment, Louisiana State University

Introduction

The outer continental shelf and slope of the Gulf of Mexico (GOM) provide valuable economic and environmental resources including fisheries, oil and gas production, hydrocarbon seeps, and gas hydrates. Offshore oil and gas exploration and production in the GOM have moved seaward into water depths greater than 300 m, which is defined as 'deepwater' for the creation of operating regulations. In the last decade there has been a continued increase in deepwater exploration, drilling, and production. There is a commitment by industry to continue exploring the outer continental shelf and slope for mineral resources and to develop and improve technology for safe operation of deepwater facilities. Current meter measurements made near the 2,000-m and 3,000-m isobaths in the northern GOM indicate occasional strong flows of least 50 $cm \cdot s^{-1}$. To the west of the Mississippi Delta in water depths of approximately 3,000 m, deep furrows have been observed on the continental rise. The size, morphology, and orientation of these sedimentary furrows may be attributed to strong currents (near 1 $m \cdot s^{-1}$) near the bottom. Numerical simulations of the GOM circulation predict deep strong flows near the boundaries resulting from energetic eddies impinging along steep topography.

Previous Modeling Studies

Recent current data sets in water depths of nearly 2,000 m to greater than 3,000 m (Oey and Hamilton 2000) are being analyzed as part of an MMS-funded program entitled, 'Modeling and Data-Analyses of Subsurface Currents on the Northern Gulf of Mexico Slope and Rise: Effects of Topographic Rossby Waves and Eddy-Slope Interaction.' This ongoing study is one of four major modeling programs funded by MMS and is designed primarily to look at the energetics of deep wave and eddy fields. A numerical study of TRW propagation in the northern GOM by Oey and Hamilton (2000) indicated that there is a concentration of kinetic energy in the 20 to 100 day band along the 3,000-m isobath extending westward from under the LC. There is a concentration of relatively high-eddy kinetic energy in bands along the slope below 2,200 m in the model study of Welsh and Inoue (2002). Slight bottom intensification of the kinetic energy in these bands is consistent with TRW propagation. Detailed analysis of the model 15-year mean velocity and hydrographic fields at each level in the deep also suggests mean cyclonic flow around the perimeter of the central and western GOM.

Welsh and Inoue (2002) implemented the Lagrangian technique of seeding and tracking tracer particles in the model to examine detailed transport and mixing processes and to identify potential processes responsible for ventilation of the deep water. The model was seeded with tens of thousands of inert particles that drift freely within the model domain in response to the velocity field. Several different experiments were designed with different starting positions of the tracer particles corresponding to the region or process of interest. The positions of the tracers were recorded and later analyzed to identify characteristic flow paths and to assess the effects of physical processes on the individual particles. This same method will be employed in the present study, but we will focus on the behavior of the particles near the boundaries. This will be facilitated by using a much smaller horizontal grid size and five-fold increase in the vertical resolution.

Methods

The numerical model to be employed in this study has now been in use for over 30 years and was first described by Bryan (1969) and programmed by Cox (1984); thus, it has been referred to as the "Bryan-Cox Model." MOM1 (Pacanowski et al. 1991), which succeeded the Bryan-Cox model, retains the basic physics of the Bryan-Cox code but was modified for more efficient use with a UNIX operating system and included faster, more efficient numerical solvers. The model grid will be derived from the Global Sea Floor Topography with two-minute horizontal resolution (Smith and Sandwell 1997). The data have already been acquired for free and are superior in accuracy to the bathymetry that has been employed in our previous GOM modeling efforts. In order to simulate realistic deep cyclones, it is necessary to resolve important small-scale bottom topographic features, such as a narrow deep channel connecting the eastern and the central basins. We propose to use a model grid with at least 7.5 km horizontal resolution and lower values for viscosity and diffusivity ($\leq 50\ m^2\ s^{-1}$). There will be 100 vertical levels with 20 m thickness in the upper 10 levels and 40 m thickness in the lower 90 levels. The fine horizontal resolution combined with extremely high vertical resolution in the model grid will greatly reduce the potential for topographically-induced numerical noise in the model fields.

The model will be initialized with the Levitus 3-D temperature and salinity fields for the GOM and western Caribbean. The Levitus surface salinity data will be used for the surface boundary condition on salinity. A more realistic surface temperature field derived from AVHRR estimates will be used for the surface boundary condition on temperature (which will coordinate in time with the wind stress field). The model domain includes the entire Caribbean west to 59°W and north to 31°N. A natural inflow condition through the Yucatan Channel is accomplished by forcing the flow through the eastern Caribbean at approximately 65°W to acquire the observed seasonal variation in the shear and geostrophic transport of the Caribbean Current. In order to implement a realistic vertical shear of the inflow, the temperature and salinity fields used to force the inflow will be examined. The Levitus climatology in the Venezuela Basin will be compared to all available hydrographic data. Adjustments in the vertical profiles will be made if the comparison turns out be unrealistic. Realistic shear in the Caribbean Current will directly improve the vertical structure of the LC rings in the GOM.

Incorporating the entire Caribbean will greatly improve the natural variability of the inflow to the GOM, as well as the generation of LC rings. Not only will the internal boundary for generating the Caribbean Current be moved far from the Yucatan Channel, but wind-forced circulation in the Caribbean can be incorporated. Oey et al. (2003) have proven the importance of the wind-forcing and eddy-forcing on the shedding behavior of LC rings using a numerical model of the northwest Atlantic Ocean. Results from this model indicate that shorter shedding intervals can result from wind-induced transport fluctuations through the Greater Antilles. Oey et al. (2003) also observed that longer shedding intervals can result from the arrival of Hispaniola eddies at the Yucatan Channel. The Hispaniola eddies are generated by the local wind-stress curl and have a characteristic time scale of 100 days.

The previous model study by Welsh and Inoue (2000) featured Hellerman and Rosenstein monthly wind forcing, which resulted in realistic seasonal variations in many surface circulation features. The proposed model will continue to use the Hellerman and Rosenstein winds for the spin-up of the model. For the production runs of the model, either the ETA winds (Black 1994), NCEP or ECMWF re-analysis winds will be implemented over a multi-year period (at least five years). The purpose of using real winds is to have realistic variability in the time and space scales associated with the surface momentum flux. This variability, which is not inherent in the climatological winds, may be important in producing more realistic LC ring separation and migration.

The method used to track the particles (Pacanowski 1995) features 3-D interpolation of each particle position at each time step followed by integration of the particle position in space using the 3-D components of velocity. Velocity at the position of a particle is constructed by 3-D linear interpolation. The particle trajectory is integrated forward for one time step taking convergence of meridians into account. Any component of the trajectory is prevented from entering land by resetting it to its previous value if it does cross over to land, thereby simulating free slip conditions. The analysis of the tracer particles will include both Lagrangian particle motion and Eulerian particle displacements. The vertical velocity will be examined to differentiate between vertical advection of the particles and Stokes drift.

Summary

The initial goals of this project are to develop a high-resolution OGCM of the GOM and compare and contrast the model deep circulation at high resolution to previous modeling studies. We will examine current-topographic interaction along the slope and rise of the GOM. Both energetics of the velocity field and the transport of Lagrangian particle tracers in the deep layer will be studied. We will determine the probability of mean cyclonic flow in the deep central and western portion of the GOM.

The proposed model will improve on the previous study by using smaller grid size to resolve small-scale topographic features on the shelf and slope, real winds, and a greatly expanded domain to improve the inflow condition. The expanded domain will hopefully result in more realistic inflow through the Yucatan Channel by including exchange through the Greater Antilles, as well as wind-driven eddies formed in the Caribbean. The expanded domain also provides the opportunity to move the artificial forcing of the Caribbean Current to the far eastern Caribbean and expand the region acted on by the wind stress—which is considerably stronger in the Caribbean. The enhanced vertical resolution to 100 levels will greatly improve the ability to represent the bottom topography, as well resolve the flow in the transition region between the surface and deep layers.

References

Black, T.L. 1994. The new NMC mesoscale Eta model: Description and forecast examples. Weather and Forecasting 9:265–278.

Bryan, K. 1969. A numerical model for the study of the world ocean. Journal of Computational Physics 4:347–376.

Cox, M.D. 1984. A Primitive Equation Three-dimensional Model of the Ocean. Technical Report #1. Geophysical Fluid Dynamics Lab, NOAA. Princeton, NJ. 250 pp.

Oey, L.-Y. and P. Hamilton. 2000. Modeling and data analyses of subsurface currents on the northern Gulf of Mexico slope and rise: Effects of topographic Rossby waves and eddy-slope interaction. In: Proceedings of the Workshop on the Physical Oceanography Slope and Rise of the Gulf of Mexico. 12–14 September 2000. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana.

Oey, L.-Y., H.-C. Lee, and W. Schmitz. 2003. Effects of winds and Caribbean eddies on the frequency of Loop Current eddy shedding: A numerical model study. Journal of Geophysical Research 108:3324.

Pacanowski, R., K. Dixon, and A. Rosati. 1991. The GFDL Modular Ocean Model User's Guide Version 1.0. GFDL Ocean Group Technical Report #2. Princeton, NJ.

Pacanowski, R. 1995. MOM 2 Documentation, User's Guide, and Reference Manual, Version 1.0. GFDL Ocean Group Technical Report #3. Princeton, NJ.

Smith, W.H.F and D.T. Sandwell, 1997. Global sea floor topography from satellite altimetry and ship depth soundings. Science, 277:1956–1962.

Welsh, S. and M. Inoue, 2000. Loop Current rings and the deep circulation in the Gulf of Mexico. Journal of Geophysical Research 105:16,951–16,959.

Welsh, S.E. and M. Inoue. 2002. A particle tracing study of circulation, transport, and vertical exchange in the Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2002-064. Pp. 51.

Dr. Susan Welsh has worked in the Coastal Studies Institute for the past 15 years as a scientific programmer/modeler, a graduate assistant, a post-doctoral researcher, and an Assistant Professor/ Research. She is presently working half-time as a Research Associate V. Her areas of research are physical oceanography, numerical ocean models, and Gulf of Mexico circulation. Dr. Welsh received her B.S. in earth and planetary sciences from the Johns Hopkins University, her M.S. in

oceanography from the Florida State University, and her Ph.D. in geology from Louisiana State University.

Dr. Masamichi Inoue has worked at the Florida State University and at the Australian Institute of Marine Science. He has been at Louisiana State University for the past 17 years and is Associate Professor at the Coastal Studies Institute and in the Department of Oceanography & Coastal Sciences. His research interests include ocean circulation and transport processes. Dr. Inoue received his B.E. in naval architecture from Tokai University, M.S. in ocean engineering from University of Rhode Island, M. E. in civil engineering and Ph. D. in oceanography from Texas A&M University.

INDEX

J

K

L

M

N

O

P

R

S

ATTENDEES

Jarvis B. Abbott
MMS
381 Elden Street, MS 4023
Herndon, VA 20170
(703) 787-1866
jarvis.abbott@mms.gov

Thomas E. Ahlfeld
MMS
Environmental Sciences Branch (4041)
381 Elden Street
Herndon, VA 20170-4817
(703) 787-1711
thomas.ahlfeld@mms.gov

Dan Allen
Ecologist
Chevron Texaco
935 Gravier St., Room 1454
(504) 592-6769
allj@chevrontexaco.com

David T. Allen
University of Texas
Center for Energy and Environment
10100 Burnet Road
Austin, TX 78758
(512) 232-6470
allen@che.utexas.edu

Yvonne Allen
LSU
Baton Rouge, LA 70808
(225) 578-6507
allenyc@lsu.edu

Tasha D. Anderson
MMS, ITD/TSB
381 Elden Street
Herndon, VA 20170
(703) 787-1501
tasha.anderson@mms.gov

Thomas R. Armstrong
USGS
150 National Center
Reston, VA 20192
(703) 648-6917
tarmstrong@usgs.gov

Richard B. Aronson
Dauphin Island Sea Lab
6704 Dorchester Drive
Dauphin Island, AL 36528
(251) 861-7567
raronson@disl.org

Amy D. Atchison
LUMCON
8124 Hwy. 56
Chauvin, LA 70344
(985) 223-7416
aatchison@lumcon.edu

Diane E. Austin
Researcher
University of Arizona
Bureau of Applied Research in Anthropology
Anthropology Bldg., Room 316
Tucson, AZ 85701
(520) 621-6282
daustin@u.arizona.edu

Buddy Ayers
127 Carina Circle
Slidell, LA 70458
(504) 232-1878
budbon@charter.net

Alyson Azzara
Texas A&M University
College Station, TX 77845

Arturo J. Baez
T. Baker Smith & Sons
P O Box 2266
Houma, LA 70361
(985) 223-9265
arturob@tbsmith.com

Jeff Baguley
University of Texas
Marine Science Institute
750 Channel View Drive
Port Aransas, TX 78373
(361) 749-6817
jeffb@utmsi.utexas.edu

Kyle P. Baker
DOC / NOAA / NMFS
9721 Executive Center Drive North, Suite 102
Saint Petersburg, FL 33702
(727) 570-5312
kyle.baker@noaa.gov

William Bankston
LSU
126 Stubbs Hall
Dept. of Sociology
Baton Rouge, LA 70803
(225) 578-5103
sobank@lsu.edu

Jim A. Barkaszi
GeoCet
7341 Glenwood Rd.
Cocoa, FL 32927
(281) 325-1080
jim@geocet.com

Mary Jo A. Barkaszi
GeoCet
7341 Glenwood Road
Cocoa, FL 32927
(281) 325-1080
maryjo@geocet.com

Carrie S. Barry
NOAA Fisheries
3209 Frederic Street
Pascagoula, MS 39567
(228) 762-4591
carrie.barry@noaa.gov

Kevin P. Barry
NOAA Fisheries
3209 Frederic Street
Pascagoula, MS 39567
(228) 762-4591
kevin.barry@noaa.gov

Mike Barton
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2555

Warren J. Barton
Environmental Scientist
MMS
1201 Elmwood Park Blvd., MS 5440
New Orleans, LA 70123
(504) 736-2731
warren.barton@mms.gov

Melissa A. Batum
MMS
1520 North Pointe Drive, Apt. 002
Reston, VA 20194
(703) 787-1646
melissa.batum@mms.gov

Richie Baud
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
richie.baud@mms.gov

Toni E. Bazer
Arthur J. Gallagher of LA
111 Veterans Blvd., Suite 1130
Metairie, LA 70005
(504) 888-1100
toni.bazer@ajg.com

Steve Bech
Project Engineer
Chevron Environmental Management Company
935 Gravier St
New Orleans, LA 70112
(504) 592-6670
sbech@chevrontexaco.com

Charles A. Bedell
Murphy Exploration & Production Company
P.O. Box 61780
131 S. Robertson St.
New Orleans, LA 70161-1780
(504) 561-2449
chuck_bedell@murphyoilcorp.com

Mark Benfield
LSU Coastal Fisheries Institute
2179 Energy, Coast & Environment Bldg.
Baton Rouge, LA 70803
(225) 388-6372
mbenfie@lsu.edu

Lee Benner
Oceanographer
MMS
6508 Summerton Way
Springfield, VA 22150
(703) 787-1710
lee.benner@mms.gov

James F. Bennett
MMS
381 Elden Street, MS 4320
Herndon, VA 22070
(703) 787-1660
jbennett@mms.gov

Richard Bennett
Biologist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2853
richard.bennett@mms.gov

Loretta Y. Beoh
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
loretta.beoh@mms.gov

Landry J. Bernard
National Data Buoy Center
1100 Balch Blvd
Stennis Space Center, MS 39529
(228) 688-3394
landry.bernard@noaa.gov

Douglas C. Biggs
Professor
Texas A&M University
Dept. of Oceanography
TAMU Mail Stop 3146
College Station, TX 77843-3146
(979) 845-3423
dbiggs@ocean.tamu.edu

Richard S. Billings
Eastern Research Group, Inc.
1600 Perimeter Park Drive
Morrisville, NC 27560
(919) 468-7812
richard.billings@erg.com

Thomas W. Bjerstedt
Geoscientist
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-5743
tom.bjerstedt@mms.gov

Dr. John P. Blaha
Oceanographer
Naval Oceanographic Office
1002 Balch Blvd
Bay Saint Louis, MS 39522-5001
(228) 688-5187
blahaj@navo.navy.mil

Brian Blanchard
Research Associate
LSU Coastal Studies Institute
Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
(225) 578-2961
bblanc5@lsu.edu

Earl Boatman
LNC
4931 Morano Road
New Orleans, LA 70129
(504) 258-2592

Mary Boatman
Oceanographer
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2781
mary.boatman@mms.gov

Del Bohnenstiehl
Lamont Doherty Earth Observatory
P.O. Box 1000
61 Route 9W
Palisades, NY 10964
(845) 365-8382
del@ldeo.columbia.edu

Gregory S. Boland
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2740
gregory.boland@mms.gov

Ronald C. Bowser
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2640
ronald.bowser@mms.gov

Brian E. Boyer
Vice President
COMM Engineering, Inc.
P.O. Box 53463
Lafayette, LA 70508
(337) 237-4373
brian@commengineering.com

Cosmin V. Bozenovici
University of New Orleans Conference Services
1610 Robert E. Lee, Apt. 20
New Orleans, LA 70122
(504) 288-7841
aquire44@hotmail.com

Vernessa J. Bradford
Shell E&P Co.
P.O. Box 61933, Suite 2900
New Orleans, LA 70139
(504) 728-4426
vernessa.bradford@shell.com

DeWitt H. Braud
LSU Coastal Studies Institute
331 Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
(225) 578-6177
dbraud1@lsu.edu

Darice Breeding
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2966
darice.breeding@mms.gov

Gary D. Brewer
Biologist
U.S. Geological Survey
11700 Leetown Rd
Kearneysville, WV 25430
(304) 724-4507
gary_brewer@usgs.gov

Ron Brinkman
Geophysicist
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2720
ronald.brinkman@mms.gov

James M. Brooks
TDI-Brooks Int'l Inc.
1902 Pinon Drive
College Station, TX 77845
(979) 696-3634
drjmbrooks@aol.com

Robert “Allen” Brooks
USGS
7920 NW 71st St.
Gainesville, FL 32653
(352) 264-3478
allen_brooks@usgs.gov

Harmon Brown
LSU Coastal Fisheries Institute
Baton Rouge, LA 70803
(225) 326-8016
hbrow11@lsu.edu

Patricia Bruce
Regulatory Specialist
Devon Energy Corporation
1200 Smith Street, Suite 3300
Houston, TX 77002-4313
(713) 286-5861
patricia.bruce@dvn.com

William R. Bryant
Professor
Texas A&M University
Dept. of Oceanography
Texas A&M University
(979) 845-7211
wbryant@ocean.tamu.edu

Carolyn Burks
Biologist
National Marine Fisheries Service
3209 Frederic St.
Pascagoula, MS 39567
(228) 762-4591x 286
carolyn.m.burks@noaa.gov

Daewon W. Byun
University of Houston
Dept. of Geosciences, College of NSM
312 Science & Research Bldg. 1
Houston, TX 77204-5007
(713) 743-0707
dbyun@mail.uh.edu

Donald R. Cahoon
USGS, Patuxent Wildlife Research Center
11510 American Holly Drive
Laurel, MD 20708
(301) 497-5523
don_cahoon@usgs.gov

Jack Caldwell
Geophysical Consultant
314 Greenpark Drive
Houston, TX 77079-6414
(281) 679-6716
jgcaldwell@sbcglobal.net

Robert W. Cameron
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2766
bob.cameron@mms.gov

Jereld Cammack
University of New Orleans Conference Services
New Orleans, LA 70148

Manuel L. Cano
Shell Chemicals LP
3333 Highway 6 South
Houston, TX 77082
(281) 544-7897
manuel.cano@shell.com

Jane M. Carlson
105 Montgomery Circle
Stephens City, VA 22655
(540) 869-7220
carlsonja@adelphia.net

Robert S. Carney
LSU Coastal Ecology Institute
Coast, Energy & Environment Bldg.
Baton Rouge, LA 70810
(225) 578-6511
rcarne1@lsu.edu

Anthony Chasar
GeoCet
1735 Bluebird Ct.
Melbourne, FL 32935
(440) 364-1323
tony@geocet.com

Dennis Chew
Chief, NEPA/CZM Unit
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394
(504) 736-2793
dennis.chew@mms.gov

Charles Christ
CJ Christ Consultant
P.O. Box 10037
Houma, LA 70363
(985) 872-2843
cjcuboat@netscape.net

Joe Christopher
Chief, Environmental Assessment Sec
MMS
1201 Elmwood Park Blvd., MS5400
New Orleans, LA 70123
(504) 736-2759
joseph.christopher@mms.gov

Jamie Christy
University of Houston
1313 Peden
Houston, TX 77006
(713) 942-9086
jamiechristy@hotmail.com

James Cimato
Oceanographer
MMS
Environmental Services Branch
381 Elden St., MS 4041
Herndon, VA 20170
(703) 787-1721
james.cimato@mms.gov

Rodney E. Cluck
Sociologist
MMS
381 Elden St., MS 4042
Herndon, VA 20170
(703) 787-1087
rodney.cluck@mms.gov

Doris Cochennic
Schlumberger
Cut Off, LA 70345
(985) 693-3661

Joffery Cochennic
Schlumberger
Cut Off, LA 70345

Craig E. Colten
LSU Dept. of Geography & Anthropology
Baton Rouge, LA 70806
(225) 578-6180
ccolten@lsu.edu

Rick R. Combs
Science Applications International Corporation
1140 Eglin Parkway
Shalimar, FL 32579
(850) 609-3459
combsro@saic.com

Richard E. Condrey
LSU Dept. of Oceanography and Coastal Studies
2161 Energy, Coast and Environment
Baton Rouge, LA 70803
(225) 578-6456
coecnd@lsu.edu

Mike Conner
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2663
george.conner@mms.gov

Kimberley Cook
MMS
1201 Elmwood Park Blvd., MS 5411
New Orleans, LA 70123
(504) 736-1720
kimberley.cook@mms.gov

James J. Corbett
University of Delaware
305 Robinson Hall
Newark, DE 19716
(302) 831-0768
jcorbett@udel.edu

Vicki Cornish
DOC / NOAA / NMFS
9721 Executive Center Drive North, Suite 102
Saint Petersburg, FL 33702
(727) 570-5312
vicki.cornish@noaa.gov

Daniel P. Costa
University of California Long Marine Lab
100 Shaffer Road
Santa Cruz, CA 95060
(831) 459-2786
costa@biology.ucsc.edu

David Cottingham
Marine Mammal Commission
4340 East West Hwy., Suite 905
Bethesda, MD 20814
(301) 504-0087
dcottingham@mmc.gov

James Cowan
LSU Coastal Fisheries Institute
Baton Rouge, LA 70803
(225) 570-9400
jhcowan@lsu.edu

Jeffrey M. Cox
Evans-Hamilton, Inc.
4608 Union Bay Pl. NE
Seattle, WA 98105
(206) 526-5622
jeff@evanshamilton.com

Eric Crecelius
Battelle Marine Sciences Lab.
1529 West Squim Bay Road
Coastal Resource & Ecosystem M
Sequim, WA 98382
(360) 681-3604
eric.crecelius@uh.edu

John Crusius
USGS
384 Woods Hole Road
Woods Hole, MA 02543
(508) 457-2353
jcrusius@usgs.gov

Eurico J. D'sa
Louisiana State University
320 Howe-Russell Geoscience Complex
Coastal Studies Institute
Baton Rouge, LA 70803
(225) 578-0212
ejdsa@lsu.edu

Donald W. Davis
Administrator
LA Oil Spill R&D Program
258A Military Science Bldg
LSU
(225) 578-3481
osradp@attglobal.net

Gary DeMarsh
Director
DEMEX
7144 Dummyline Rd
P O Box 156
(228) 255-7584
gary@demex.us

Yeshavant Desai
Environmental Engineer
MMS
1201 Elmwood Park Blvd., MS 5231
New Orleans, LA 70123
(504) 736-2623
yeshavant.desai@mms.gov

Steven F. DiMarco
Associate Research Scientist
Texas A&M University
Dept. of Oceanography, 3146 TAMU
College Station, TX 77843-3146
(979) 862-4168
sdimarco@tamu.edu

Janet Diaz
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
janet.diaz@mms.gov

Robert Diaz
Virginia Institute of Marine Science
P.O. Box 1436
Route 1208 Greate Road
Gloucester Point, VA 23062-1346
(804) 684-7364
diaz@vims.edu

Sue Dickson
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394
(504) 736-3224
sue.dickson@mms.gov

John Diebold
Lamont-Doherty Earth Observatory
61 Rte 9W
Palisades, NY 10964
(845) 365-8367
marscico@ldeo.columbia.edu

Blaine Dinger
Mariner Energy Inc
580 Westlake Park Blvd
Houston, TX 77079-2638
(281) 584-5588
bdinger@mariner-energy.com

David Dismukes
LSU, Center for Energy Studies
Baton Rouge, LA 70803-0301
(225) 578-4343
dismukes@lsu.edu

C.J. Doiron
McMoRan Oil & Gas
New Orleans, LA 70112
(504) 852-1873
CJ_Doiron@fmi.com

Doughty Dominique
207 Bellaire Dr.
Houma, LA 70360
(985) 876-0551

Marilyn Dominique
207 Bellaire Dr.
Houma, LA 70360
(985) 876-0551

Kathleen A. Donohue
University of Rhode Island
Graduate School of Oceanography
215 South Ferry Road
Narragansett, RI 02882
(401) 874-6625
kdonohue@gso.uri.edu

David A. Dougall
Eni Petroleum Company, Inc.
1201 Louisiana
Suite 3500
Houston, TX 77002
(713) 393-6122
david.dougall@enipetroleum.com

Sharon Douglas
Systems Applications International
Fairfax, VA 220311207

David B. Driver
Metocean Specialist
British Petroleum
501 Westlake Park Blvd
Houston, TX 77079
(281) 366-2699
driverdb@bp.com

Bart Dupre
T. Baker Smith & Sons
P.O. Box 2266
Houma, LA 70361
(985) 223-9274
bartd@tbsmith.com

Mark Eckl
MMS
381 Elden Street. MS 2100
Herndon, VA 20170
(703) 787-1070
mark.eckl@mms.gov

Randy E. Edwards
University of South Florida
600 4th St. S.
Saint Petersburg, FL 33701
(727) 803-8747x 3069
redwards@usgs.gov

William Engelhardt
Biologist
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394
(504) 736-2474
bill.engelhardt@mms.gov

Dan Engelhaupt
University of Durham, England
P.O. Box 197
Picton, New Zealand
NEW ZEALAND
(03) 573-8802
danengelhaupt@xtra.co.nz

Holli Ensz
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394
(504) 736-2536
holli.ensz@mms.gov

Deborah Epperson
MMS
1201 Elmwood Blvd.
New Orleans, LA 70123

Elva Escobar-Briones
Universidad Nacional Autonoma Mexico
Instituto Oceanografico y Limnologia
Cuidad Universitaria
Mexico, DF 04510
(525) 550-5865
escobri@mar.icmy1.unam.mx

Donald P. Evans
Murphy Exploration & Production Company
131 South Robertson St.
New Orleans, LA 70112
(504) 561-2497
don_evans@murphyoilcorp.com

Caryl Fagot
Staff Assistant
MMS
1201 Elmwood Park Blvd., MS 5000
(504) 736-2590
caryl.fagot@mms.gov

James T. Fahey
RD Instruments
9855 Businesspark Ave.
San Diego, CA 92131-1101
(858) 693-1178
jfahey@rdinstruments.com

Graham Feld
Fugro GEOS Inc.
6100 Hillcroft
Houston, TX 77081
(713) 346-3606
g.feld@geos.com

Dagmar Fertl
Biologist
Geo-Marine, Inc.
550 East 15th Street
Plano, TX 75074
(972) 423-5480
dfertl@geo-marine.com

James Fields
University of Arizona
306 Park Drive
70301
Tucson, AZ 85712
(720) 839-6561
jlf722@msn.com

Charles R. Fisher
Pennsylvania State University
Department of Biology
Office 219 Muller
State College, PA 16804
(814) 865-3365
cfisher@psu.edu

John W. Fleeger
LSU Dept. of Biological Sciences
146 Thomas Boyd Hall
Baton Rouge, LA 70803
(225) 578-1738
zoflee@lsu.edu

James G. Flocks
USGS
600 4th Street South
Saint Petersburg, FL 33701
(727) 803-8747
jflocks@usgs.gov

Philip Fontana
Geophysical Manager, Marine Data Acquisition
Veritas, DGC
10300 Town Park Drive
Houston, TX 77072
(832) 573-3732
pmf52@earthlink.net

Larry D. Forster
Shell Exploration & Production Co.
P O Box 61933
New Orleans, LA 70161
(504) 728-4505

Craig Forsyth
University of Louisiana at Lafayette
P.O. Box 41652
Lafayette, LA 70504
(337) 482-5372
gf5719@louisiana.edu

Adam S. Frankel
Marine Acoustics, Inc.
706 Giddings Ave.
Suite 2A
Annapolis, MD 20764
(410) 626-1662
adam.frankel@marineacoustics.com

James K. Frederick
Offshore Operator’s Committee/Unocal
14141 Southwest Freeway
Sugar Land, TX 77478
(281) 287-6044
jfred@unocal.com

Paul E. Frederick
The Obrien's Group
645 Codifer Street
Slidell, LA 70458
(985) 781-0804
paul.frederick@theobriensgroup.com

Stacey L. Frickey
Shell E&P Company
701 Poydras St., Room 2944
New Orleans, LA 70160
(504) 728-4989
stacey.frickey@Shell.com

Sandi Fury
Chevron USA Production Co.
935 Gravier St., Room 1364
New Orleans, LA 70112
(504) 592-6095
sfur@chevrontexaco.com

Patrick C. Gallacher
Naval Research Laboratory
Code 7330, NRL/SSC
Stennis Space Center, MS 39529-5004
(228) 688-5315
gallacher@nrlssc.navy.mil

Benny Gallaway
Ecological Research Assoc.
1410 Cavitt St
Bryan, TX 77801
(409) 775-2000
bgallaway@lgl.com

Wayne Garitty
Bay-Tech Companies
1253 First Avenue
Harvey, LA 70058
(504) 328-6456
wgaritty@baytechrentals.com

James A. Garrison
SAIC
1140 Eglin Parkway
Shalimar, FL 32579
(850) 609-3417
james.garrison@saic.com

Roger Gentry
NMFS Acoustics Team
NOAA Fisheries
1315 East-West Hwy., SSMC3, Room 13602
Silver Spring, MD 20910
(301) 713-2327
roger.gentry@noaa.gov

Robert A. George
Manager, Geophysical Interpretation
C & C Technologies, Inc.
730 East Kaliste Saloom Road
Lafayette, LA 70508
(337) 261-0660
dd@cctechnol.com

Chip Gill
President
IAGC
2550 North Loop West, Suite 104
(713) 957-8080
chipgill@iagc.org

Bob Gisiner
Office of Naval Research
800 North Quincy St.
BCT-1, ONR Code 341
Arlington, VA 22217-5660
(703) 696-2085
gisiner@onr.navy.mil

Gregg Gitschlag
NOAA Fisheries
4700 Avenue U
Galveston, TX 77551
(409) 766-3513
gregg.gitschlag@noaa.gov

Angie D. Gobert
Petro Engineer
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2876
angie.gobert@mms.gov

Gary D. Goeke
MMS
1201 Elmwood Park blvd
New Orleans, LA 70123
(504) 731-3233
gary.goeke@mms.gov

Jonathan C.D. Gordon
Ecologic UK
7 Beechwood Terrace West
Newport on Tay, Fife
Fife, DD6 8JH
UNITED KINGDOM
(441) 382-5401x54
jg20@st-and.ac.uk

Gerald A. Grau
USGS, National Wetlands Research Center
700 Cajundome Blvd.
Lafayette, LA 70506
(337) 266-8501
jerry_grau@usgs.gov

Mike P. Gravois
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-5768
mike.gravois@mms.gov

Christopher S. Gregg
LSU Department of Biological Sciences
Life Sciences Bldg.
Baton Rouge, LA 70803
(225) 578-7651
cgregg2@lsu.edu

Norman L. Guinasso, Jr.
Texas A&M University
GERG
833 Graham
College Station, TX 77845
(979) 862-2323
guinasso@tamu.edu

Sarah C. Hagedorn
NOAA Fisheries
1315 East-West Highway
Silver Spring, MD 20910
(305) 361-4487
sarah.hagedorn@noaa.gov

John Hall
Halliburton/Baroid
3000 N Sam Houston Pkwy E
Humble, TX 77345
(281) 871-6046
john.hall@halliburton.com

Peter Hamilton
SAIC
615 Oberlin Road, #100
Raleigh, NC 27605
(919) 832-7242
peter.hamilton@saic.com

Robert P. Hamilton
Woods Hole Group
81 Technology Drive
East Falmouth, MA 02536
(508) 495-6229
bhamilton@whgrp.com

Jay Haney
Systems Applications International
ICF Consuting
9300 Lee Highway
Fairfax, VA 22031-1207
(703) 934-3603
jhaney@icfconsulting.com

Sandra M. Harris
Shell Oil Company
701 Poydras Street
New Orleans, LA 70139
(504) 728-4625
sandra.harris@shell.com

Alan D. Hart
Continental Shelf Associates, Inc.
759 Parkway Street
Jupiter, FL 33477
(561) 746-7946
ahart@conshelf.com

Sharon M. Hartdegen
Shell E&P Company
701 Poydras
New Orleans, LA 70139
(504) 728-3310
sharon.hartdegen@shell.com

Charles Hays
Retired, Exxon
213 Dahlia St
New Iberia, LA 70563

David Hedgeland
PGS Court
Walton-on-Thames
Surrey, KT12 1RS
UNITED KINGDOM
(019) 322-6643x4
david.hedgeland@pgs.com

A.J. Heikamp
MSRC
980 W. Lincoln Road
P O Box 4870
Lake Charles, LA 70606
(337) 475-6410
heikamp@msrc.org

Scott A. Hemmerling
LSU Dept. of Geography & Anthropology
539 Park Blvd., #3
Baton Rouge, LA 70806
(225) 343-8613
shemme1@lsu.edu

Dirk C. Herkhof
MMS
381 Elden Street
Herndon, VA 20171
(703) 787-1735
dirk.herkhof@mms.gov

Kathryn Herzog
Louisiana Department of Wildlife & Fisheries
2000 Quail Drive
Baton Rouge, LA 70808
(225) 765-2396
kherzog@wlf.louisiana.gov

Emma Hickerson
Research Coordinator
Flower Garden Banks National Marine Sanctuary
National Marine Sanctuary
1200 Briarcrest Dr., Suite 4000
Bryan, TX 77802
(979) 846-5942
emma.hickerson@noaa.gov

Brad C. Hoffman
Chevron Texaco North America Upstream
1500 Louisiana St.
Houston, TX 77002
(832) 854-3613

Robert J. Hoffman
DOC / NOAA / NMFS
9721 Executive Center Drive North
Suite 102
Saint Petersburg, FL 33702
(727) 570-5312
robert.hoffman@noaa.gov

Robert Hofman
Marine Mammal Commission
7102 Brennon Lane
Chevy Chase, MD 20815
(301) 652-8236
rjhofman@erols.com

George Hofmeister
MADCON Corporation
131-A Industrial Drive
Slidell, LA 70460
(985) 690-9993
ghofmeister@madconcorp.com

Kenneth R. Hollingshead
NOAA Fisheries
F/PR2-Room 13600
1315 East-West Highway
Silver Spring, MD 20640
(301) 713-2289x 128
ken.hollingshead@noaa.gov

Matthew K. Howard
Assistant Research Scientist
Texas A&M University
Department of Oceanography
3146 TAMU
College Station, TX 77843-3146
(979) 862-4169
mkhoward@tamu.edu

S.A. Hsu
Professor
LSU Coastal Studies Institute
Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
(225) 388-2962
sahsu@lsu.edu

Chester Huang
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-3248
chester.huang@mms.gov

Fain Hubbard
Oceanography Department
Texas A&M University
College Station, TX 77843
(979) 845-1327
fhubbard@ocean.tamu.edu

Jesse L. Hunt, Jr.
Geologist
MMS
1201 Elmwood Park Blvd., MS 5121
(504) 736-2440
jesse.hunt@mms.gov

Betty Hutcherson
Louisiana Department of Wildlife & Fisheries
2000 Quail Drive
Baton Rouge, LA 70808
(225) 765-2396
bhutcherson@wlf.louisiana.gov

Deborah R. Hutchinson
U.S. Geological Survey
384 Woods Hole Road
Woods Hole, MA 02543
(508) 457-2263
dhutchinson@usgs.gov

Omowunmi Iledare
Center for Energy Studies
Louisiana State University
Energy, Coast and Environment Building
Nicholson Drive Extension
Baton Rouge, Louisiana 70803
(225) 578-4552
wumi@lsu.edu

Masamichi Inoue
Assoc. Professor
LSU Coastal Studies Institute
331 Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
(225) 388-2521
coiino@lsu.edu

George Ioup
Professor
University of New Orleans
Dept. of Physics
New Orleans, LA 70148
(504) 280-6715
geioup@uno.edu

Juliette Ioup
Professor
University of New Orleans
Dept. of Physics
New Orleans, LA 70148
(504) 280-6715
jioup@uno.edu

Erin W. Janes
Geoscience Earth & Marine Services, Inc.
10615 Shadow Wood Drive, Suite 200
Houston, TX 77043
(713) 468-1410
emwilliams@gemsinc.com

Nathalie Jaquet
Texas A&M University
5007 Ave U
Galveston, TX 77551
(409) 741-4329
jaquetn@tamug.edu

Ewa Jarosz
Naval Research Laboratory
Code 7332
Bay Saint Louis, MS 39529-5004
(228) 688-4292
ewa.jarosz@nrlssc.navy.mil

Michael R. Jenkerson
Data Acquisition Researcher
ExxonMobil Upstream Research Co.
P.O. Box 2189
Houston, TX 77252-2189
(713) 431-6907
mike_jenkerson@exxonmobile.com

Grant Jennings
RD Instruments
9855 Businesspark Avenue
San Diego, CA 92131
(858) 693-1178
gjennings@rdinstruments.com

Ann E. Jochens
Texas A&M, Dept. of Oceanography
3146 TAMU
College Station, TX 77843-3146
(979) 845-6714
ajochens@tamu.edu

Bonnie L. Johnson
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2855
bonnie.johnson@mms.gov

James B. Johnston
Supervisory General Biologist
USGS, National Wetlands Research Center
700 Cajundome Blvd
Lafayette, LA 70506
(337) 266-8556
jimmy_johnston@usgs.gov

Alvin Jones
Sr. Environmental Scientist
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-1713
alvin.jones@mms.gov

Michael J. Kaluza
Geoscience Earth & Marine Services, Inc.
10615 Shadow Wood Drive, Suite 200
Houston, TX 77043
(713) 468-1445
mjkaluza@gemsinc.com

Jeffery A. Keay
U.S. Geological Survey
7920 NW 71st Street
Gainesville, FL 32653
(352) 264-3515
jeff_keay@usgs.gov

Sean F. Keenan
Grad Assist
LSU Coastal Fisheries Institute
218 Wetlands Resource Bldg
Baton Rouge, LA 70803
(225) 388-8306
skeenan@lsu.edu

Matt Keith
Tesla Offshore
36499 Perkins Road
Prairieville, LA 70769
(225) 673-2163
keithm@teslaoffshore.com

Christina Kellogg
U. S. Geological Survey
600 Fourth St. S.
Saint Petersburg, FL 33701
(727) 803-8747
ckellogg@usgs.gov

James J. Kendall
Chief, Environmental Sciences Section
MMS
381 Elden St MS 4023
Herndon, VA 20170
(703) 787-1591
james.kendall@mms.gov

Jan L. Kenny
DEMEX International, Inc.
16222 Halpern Falls Lane
Cypress, TX 77429
(281) 246-4738
jan@demex.us

John Kenny
Boh Bros. Construction LLC
1207 North Freeway, Suite 592
Houston, TX 77060
(281) 872-7860

Terry E. Ketler
Interactive Educational Network
3245 Clay Street, #4
San Francisco, CA 94115
(415) 922-6189
tketler@interactivenetwork.org

Mi Ae Kim
NOAA
1315 East-West Hwy
F/PR3
Silver Spring, MD 20910
(301) 713-1401x 159
mi.ae.kim@noaa.gov

Jack L. Kindinger
USGS
600 4th Street South
Saint Petersburg, FL 33701
(727) 803-8747x 3018
jkindinger@usgs.gov

Shana Kinsey
Florida Dept. of Environmental Protection
3900 Commonwealth Blvd., MS 47
Tallahassee, FL 32399
(850) 245-2163
shana.kinsey@dep.state.fl.us

Paul L. Klerks
University of Louisiana at Lafayette
P O Box 42451
Lafayette, LA 70504
(337) 482-6356
klerks@louisiana.edu

Elizabeth Komiskey
MMS
1201 Elmwood Blvd.
New Orleans, LA 70123

Gregory J. Kozlowski
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70115
(504) 736-2512
greg.kozlowski@mms.gov

Paul LaRock
Louisiana State University

Ronald J. Lai
MMS
381 Elden Street
MS 4041
Herndon, VA 20170
(703) 787-1714
ronald.lai@mms.gov

Manuel Lam
LA Department of Natural Resources
P.O. Box 44156
Baton Rouge, LA 70804-4156
(225) 342-8919
manuell@dnr.state.la.us

Dietrich K. Landis
ECL/Geocet
9801 Westheimer, Suite 1060
Houston, TX 77042
(713) 784-5800
d.landis@ecqc.com

Connie Landry
Environmental Studies Program Specialist
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394
(504) 736-2864
connie.landry@mms.gov

Randy C. Landry
T. Baker Smith & Sons
P O Box 2266
Houma, LA 70361
(985) 223-9222

randyl@tbsmith.com
William H. Lang
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
(504) 736-2866
bill.lang@mms.gov

Jennifer N. Latusek
SAIC
1140 Eglin Parkway
Shalimar, FL 32579
(850) 609-3479
jennifer.n.latusek@saic.com

Jill E. Leale
MMS
1201 Elmwood Park Blvd., MS 5413
New Orleans, LA 70123
(504) 736-5705
jill.leale@mms.gov

Kevin Leaman
Professor
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149
(305) 361-4058
kleaman@rsmas.miami.edu

Steve Leathery
NOAA National Marine Fisheries Service
Office of Protected Resources, F/PR1
1315 East-West Hwy.
Jefferson, MD 21755
(301) 713-2289
steve.leathery@noaa.gov

Griff C. Lee
Griff C. Lee, Inc.
6353 Carlson Dr.
New Orleans, LA 70122
(504) 288-5824
griff_c_lee@yahoo.com

Herb Leedy
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2776
daniel.leedy@mms.gov

Christina Leza
University of Arizona
Tucson, AZ 85712
leza@u.arizona.edu

Qianxin Lin
LSU Wetland Biogeochemistry Institute
School of the Coast and Environment
Baton Rouge, LA 70803
(225) 578-8889
comlin@lsu.edu

Christopher Lindsey-Curran
British Petroleum
lindc7@bp.com

Greg Linscombe
USFWS
(337) 373-0032
Linscombe@apwireless.com

Brian C. Lombard
MMS
381 Elden Street
Herndon, VA 20170
(703) 787-1773
brian.lombard@mms.gov

Isis Longo
Biologist II (Marine)
Louisiana Department of Wildlife & Fisheries
2000 Quail Dr.
Baton Rouge, LA 70808
(225) 765-2381
kherzog@wlf.louisiana.gov

Alexis Lugo-Fernandez
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
(504) 736-2593
alexis.lugo.fernandez@mms.gov

Jay N. Lustig
Scientific Solutions, Inc.
99 Perimeter Road
Nashua, NH 03063
(603) 880-3784
jlustig@scisol.com

Asha D. Luthra
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 731-7850
asha.luthra@mms.gov

Harry Luton
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2784
harry.luton@mms.gov

James Lynch
Woods Hole Oceanographic Institution
98 Water Street, MS 11
Woods Hole, MA 02543
(508) 289-3292
jlynch@whoi.edu

Michael Lyons
LAMOGA
801 N. Blvd., Suite 201
Baton Rouge, LA 70802
(225) 387-3205
lyons@lmoga.com

Ian R. MacDonald
Texas A&M University
727 Graham Rd
College Station, TX 77845
(409) 862-2323x-119
ian@gerg.tamu.edu

Peter T. Madsen
Woods Hole Oceanographic Institution
Woods Hole Rd. 266
Caryn House #44
Woods Hole, MA 02543
(508) 289-3292
pmadsen@whoi.edu

Leslie A. March
Sierra Club
67017 Dolan Street
Mandeville, LA 70471
(985) 871-6695
lesliemarch@hotmail.com

Bruce Mate
Oregon State University Marine Science Center
2030 SE Marine Science Drive
Newport, OR 97367
(541) 867-0202
bruce.mate@oregonstate.edu

Jason Mathews
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2886
jason.mathews@mms.gov

Haru Matsumoto
Oregon State University & NOAA/PMEL
2115 SE OSU Drive
Newport, OR 97365
(541) 867-0272
haru.matsumoto@noaa.gov

Megan Cope Mattson
NOAA, National Marine Fisheries Services
3209 Frederic Street
Pascagoula, MS 39567
(228) 762-4591x X235
megan.mattson@noaa.gov

Tom McDonald
Senior Project Manager
TDI - Brooks International
1902 Pinon Drive
College Station, TX 77845
(979) 693-3446
tommcdonald@tdi-bi.com

Jamie McKee
Biologist
SAIC
1140 Eglin Parkway
Shalimar, FL 32579
(850) 609-3418
mckeew@saic.com

James P. McKinley
Pacific Northwest National Laboratory
MS K8-96
P.O. Box 999
Richland, WA 99352
(509) 376-6573
james.mckinley@pnl.gov

Kevin McKone
LSU
P.O. Box 649
Wesson, MS 39191
(601) 643-8450
kevin.mckone@colin.edu

Robert McMillan
Oceans Technology, Inc.
3836 Spencer Street
Harvey, LA 70058-5090
(504) 340-4601
linden@oceanstechnology.com

Richard T. McNider
University of Alabama in Huntsville
Atmospheric Sciences Dept.
320 Sparkman Dr. NSSTC 3051
Huntsville, AL 35899
(256) 961-7756
mcnider@nsstc.uah.edu

David Mellinger
Oregon State University & NOAA/PMEL
2030 SE Marine Science Drive
Newport, OR 97365
(541) 867-0372
david.mellinger@oregonstate.edu

David Meloy
Louisiana Department of Natural Resources
P.O. Box 2827
Baton Rouge, LA 70821-2827
(225) 342-6119
davidm@dnr.state.la.us

Roger Melton
ExxonMobil
P.O. Box 2189
Houston, TX 77252
(713) 431-4485
rogermelton@exxonmobil.com

Carson Mencken
Baylor University
Box 97326 One Bear Place
Waco, TX 76798
(254) 710-4863
carson_mencken@baylor.edu

Robert J. Menzie
Eni Petroleum Company, Inc.
1201 Louisiana, Suite 3500
Houston, TX 77002
(713) 393-6312
robert.menzie@enipetroleum.com

Stacie Merritt-Hendon
Physical Scientist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-3276

Margaret C. Metcalf
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394
(504) 731-7801
margaret.metcalf@mms.gov

Thomas Meyer
Physical Scientist
MMS
1201 Elmwood Park Blvd., MS 5232
DOI/MMS
(504) 736-3247
tom.meyer@mms.gov

Jacqueline Michel
RPI Louisiana, Inc.
CERM Bldg. University of New Orleans
2045 Lakeshore Drive
New Orleans, LA 70122
(504) 280-4085
jmichel@researchplanning.com

Lillian Miller
Mind's Eye Productions
200 Ziegler Avenue
Houma, LA 70360
(985) 876-1810
llillian@sw.rr.com

Mark W. Miller
Research Specialist
LSU Coastal Fisheries Institute
2137 Energy, Coast & Environment Bldg.
Baton Rouge, LA 70803
(225) 578-9411
mmill16@lsu.edu

Patrick Miller
University of Saint Andrews, Gatty Marine Lab
Saint Andrews, Fife KY16 8LB
UNITED KINGDOM

Lauren K. Mione
LSU Coastal Fisheries Institute
10720 Linkwood Court, Apt. 514
Baton Rouge, LA 70810
(225) 578-7920
lmionel@lsu.edu

Douglas A. Mitchell
Naval Research Laboratory
Stennis Space Center, MS 39529
(228) 688-4865
dmitchell@nrlssc.navy.mil

Heather R. Monroe
Louisiana DNR, Technology Assessment Division
P.O. Box 44156
Baton Rouge, LA 70804-4156
(225) 342-8232
heather.monroe@la.gov

Dave Moran
Environmental Scientist
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2896
dave.moran@mms.gov

Michelle V. Morin
Environmental Scientist
MMS
1201 Elmwood Park Blvd
MS 5412
(504) 736-2797
michelle.morin@mms.gov

Thanos Moros
British Petroleum

Cheryl L. Morrison
USGS Leetown Science Center
Aquatic Ecology Branch
11649 Leetown Road
Kearneysville, WV 25430
(304) 724-4464
cheryl_morrison@usgs.gov

John L. Morse
RPS Hydrosearch
16800 Greenspoint Park Drive, Suite 165-S
Houston, TX 77060
(281) 646-0120
morsej@rpsplc.com

John Morse
Texas A&M University
Dept. of Oceanography
College Station, TX 77843-3146
(979) 845-9630
jmorse@ocean.tamu.edu

Toni Mosleh
University of New Orleans Conference Services
New Orleans, LA 70148

George Mullen
Devon Energy Corporation
1200 Smith Street, Suite 3300
Houston, TX 77002
(713) 286-5836
george.mullen@dvn.com

Keith Mullin
NOAA Fisheries
3209 Frederic Street
Pascagoula, MS 39567
(228) 762-5491x 275
keith.d.mullin@noaa.gov

Thomas W. Neurauter
Marine Geologist
Geoscience Earth & Marine Services, Inc.
10615 Shadow Wood Drive, Suite 200
(713) 468-1410
twneurauter@gemsinc.net

Joal J. Newcomb
Naval Research Laboratory
NRL Code 7185
Stennis Space Center, MS 39529
(228) 688-5234
newcomb@nrlssc.navy.mil

Alan H. Nguyen
University of Houston
Dept. Civil & Environ. Engineering
Bldg. 1-Rm N107
4800 Calhoun
Houston, TX 77204-4003
(713) 743-4267
youhaa@yahoo.com

David L. Nieland
Research Associate V
LSU Coastal Fisheries Institute
CCEER Wetlands Bldg
Baton Rouge, LA 70803
(225) 388-6373
dniela@lsu.edu

Thomas Norris
Senior Scientist/Marine Vertebrate Biologist
SAIC
10260 Campus Pt. Dr., MS D-4
San Diego, CA 92121-1578
(760) 632-6344
thomas.f.norris@saic.com

Arlette C. Nunez
Shell E & P
701 Poydras St.
New Orleans, LA 70139
(504) 728-6188
arlette.nunez@shell.com

Clifton Nunnally
Texas A & M at Galveston
5007 Avenue U, Room 354
Galveston, TX 77551
(409) 740-5001

David Ohara
GeoCet
One Sugar Land Center Blvd., Suite 355
Sugar Land, TX 77478
(281) 325-1080
davidohara@geocet.com

Roger Olien
Impact Assessment Inc.
2166 Avenida de la Playa
La Jolla, CA 92037
(858) 459-0142
iai@san.rr.com

Joel Ortega
Oregon State University
Hatfield Marine Science Center
2030 SE Marine Science Drive
Newport, OR 97365
(541) 867-0354
joel.ortega@oregonstate.edu

Bernard Padovani
Int'l Association of Geophysical Contractors
2550 North Loop West
Suite 104
Houston, TX 77092
(713) 957-8080
bpadovani@iagc.org

David R. Palmer
NOAA/AMOL/Ocean Chemistry Dept.
4301 Rickenbacker Cswy.
Miami, FL 33149
(305) 361-4416
david.r.palmer@noaa.gov

Michael E. Parker
Environmental Advisor
Exxon Mobil Production Company
P.O. Box 2180
RM 4289 EMB
Houston, TX 77541
(713) 656-3563
michael.e.parker@exxonmobil.com

Roy E. Parr
Retired, Exxon
P.O. Box 273
Baldwin, LA 70514

Robert Paulsell
LSU
LA Geological Survey
Baton Rouge, LA 70803
(225) 578-8655
rpaulsell@lsu.edu

Megan B. Peabody Westmeyer
Louisiana State University
225 Muirfield Parkway
Charleston, SC 29414
(843) 579-8502
mpeabo1@lsu.edu

Kathleen Peneguy
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123

Brian Perez
USGS, National Wetlands Research Center
700 Cajundome Blvd.
Lafayette, LA 70506
(337) 266-8556

John S. Petterson
President
Impact Assessment, Inc.
2166 Avenida de la Playa, Suite F
(858) 459-0142
iai@san.rr.com

Elizabeth A. Peuler
Supervisor, Physical Science Unit
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2581
elizabeth.peuler@mms.gov

Neal W. Phillips
Senior Scientist
Continental Shelf Associates, Inc.
308 Southway
Baltimore, MD 21218
(410) 889-7811
nwphillips@att.net

Jonathan T. Phinney
NOAA-Ocean Exploration
1315 East West Hwy.
10th Floor (R/OE)
Silver Spring, MD 20910
(301) 713-9444 x 117
jonathan.phinney@noaa.gov

Ric Pincomb
Research Associate
LSU Center for Energy Studies
1 East Fraternity Circle
Baton Rouge, LA 70803
(225) 578-4545
rpincom@lsu.edu

Tim I. Pinnington
Seamap, Inc.
10801 Hammerly Blvd., Suite 206
Houston, TX 77043
(713) 690-2228
tim.pinnington@seamap.com

Monica Powers
University of North Carolina - Chapel Hill
Institute of Marine Science
3431 Arendell- Moorehead City
Chapel Hill, NC 27514
mjanepowers@hotmail.com

Sean Powers
University of South Alabama
101 Bienville Blvd.
Dauphin Island, AL 36528
(251) 861-7591
spowers@disl.org

William F. Precht
Ecological Sciences Program Manager
PBS&J
2001 NW 107th Avenue
Miami, FL 33172
(305) 514-3488
bprecht@pbsj.com

Tyler Priest
History International, LLC
1817 Oxford St.
Houston, TX 77008
(713) 868-4039
tpriest@houston.rr.com

Kimberly A. Puglise
NOAA's Undersea Research Program
1315 East-West Highway
R/NURP
Silver Spring, MD 20910
(301) 713-2427x 199
kimberly.puglise@noaa.gov

Allan G. Pulsipher
LSU Center for Energy Studies
1 East Fraternity Circle
Baton Rouge, LA 70803
(225) 388-4550
agpul@lsu.edu

Christina Quijano
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2702
chris.quijano@mms.gov

Jeff Ramos
Lt. Commander
U.S. Coast Guard
500 Poydras
New Orleans, LA 70130
(504) 589-2455
jmramos@d8.uscg.mil

James Randolph
DOC/NOAA/NMFS
4700 Avenue U
Galveston, TX 77551
(409) 766-3505
james.randolph@noaa.gov

Robert N. Ranney
DOI/MMS
201 Energy Parkway, Suite 410
Broussard, LA 70518
(337) 289-5108
robert.ranney@mms.gov

James P. Ray
Oceanic Environmental Solutions, LLC
16606 Aldenham Place
Spring, TX 77379
(713) 992-1523
jray@houston.rr.com

Grayson Rayborn
Professor
University of Southern Mississippi
Signal Research Center
6971 Lincoln Road Extension
Hattiesburg, MS 39402
(601) 268-2681x-34
grayson.rayborn@usm.edu

Michael Rex
University of Massachusetts Boston
100 Morrissey Blvd.
Boston, MA 02125
(617) 287-6678
michael.rex@umb.edu

Julie A. Reynolds
DOI/MMS
381 Elden Street, MS 4001
Herndon, VA 20170
(703) 787-1208
julie.reynolds@mms.gov

Harry I. Rich
Clean Gulf Associates
P.O. Box 51239
New Orleans, LA 70151
(504) 593-7597
harry_i_rich@dom.com

Blake A. Richard
University of Louisiana at Lafayette
301 Manchester Circle
Lafayette, LA 70506
(337) 983-2361
bar7737@ull.edu

G. Ed Richardson
MMS
139 Deerlake Drive
Asheville, NC 28803
(828) 277-5887
ed.richardson@mms.gov

W. John Richardson
LGL Ltd., Environmental Research Associates
22 Fisher St.
P.O. Box 280
King City, ON L7B 1A6
CANADA
(905) 833-1244
wjr@lgl.com

Rian S. Riche
Shell Offshore, Inc.
P.O. Box 61933
New Orleans, LA 70161-1933
(504) 728-6012
rian.riche@shell.com

Thomas Riches
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-5790
thomas.riches@mms.gov

Deborah J. Roberts
Associate Professor
University of Houston
Engineering Building 1
Houston, TX 77204-2162
(713) 743-4281
djroberts@uh.edu

Harry Roberts
LSU Coastal Studies Institute
335 Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
(225) 578-2964
hrober3@lsu.edu

Prince Robinson, Jr.
Louisiana Department of Wildlife & Fisheries
2000 Quail Drive
Baton Rouge, LA 70808
(225) 765-2381
probinson@wlf.louisiana.gov

Carol L. Roden
MMS
1201 Elmwood Park Blvd., MS 5432
New Orleans, LA 70123
(504) 736-2377
carol.roden@mms.gov

Robert Rogers
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2898
Robert.Rogers@mms.gov

Terry Rooney
Coordinator
BP Deepwater Development
501 WestLake Park Blvd., Room 20.180
Houston, TX 77079
(281) 366-5703
rooneyt@bp.com

Pasquale F. Roscigno
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2752
pasquale.roscigno@mms.gov

Zeta Rosenberg
Vice President
ICF Consulting, Inc.
9300 Lee Highway
Fairfax, VA 22031
(703) 934-3949
zrosenberg@icfconsulting.com

Lawrence J. Rouse
Director
LSU Coastal Marine Institute
Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
(225) 578-6308
lrouse@lsu.edu

Mark Rouse
Sr. Staff Assistant
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2594
mark.rouse@mms.gov

Gil Rowe
Professor
Department of Oceanography
Texas A&M University, MS 3146 TAMU
College Station, TX 77845
(409) 845-4092
growe@ocean.tamu.edu

M. J. Samaha
117 Mcallen Drive
Houma, LA 70360
(985) 872-3768

Mary Samaha
117 Mcallen Drive
Houma, LA 70360
(985) 872-3768

Paul W. Sammarco
Professor
LUMCON
8124 Hwy. 56
Chauvin, LA 70344
(985) 851-2876
psammarco@lumcon.edu

Timothy R. Sampson
API
1220 L Street NW
Washington, DC 20005
(202) 682-8153
sampson@api.org

Scott Sanders
BHP Billiton
1360 Post Oak Blvd, Suite 150
Houston, TX 77056-3020
(713) 961-8420
scott.s.sanders@bhpbilliton.com

Bob J. Sandilos
ChevronTexaco Upstream
1111 Bagby Street
Houston, TX 77002
(713) 752-6356
rjsa@chevrontexaco.com

Kathryn M. Scanlon
U.S. Geological Survey
384 Woods Hole Rd
Woods Hole, MA 02543
(508) 457-2323
kscanlon@usgs.gov

William B. Schill
USGS-Leetown Science Center
11649 Leetown Road
Kearneysville, WV 25430
(304) 724-4438
bane_schill@usgs.gov

William Schroeder
Professor
University of Alabama
Dauphin Island Sea Lab
101 Bienville Blvd
(251) 861-7528
wschroeder@disl.org

Joseph S. Scire
Earth Tech, Inc.
196 Baker Avenue
Concord, MA 01742
(978) 371-4270
jss@src.com

Paul D. Scott
Marathon Oil Company
5555 San Felipe Drive
Houston, TX 77056
(713) 296-2217
pscott@marathonoil.com

John Seip
Environmental Specialist
Crescent Technology, Inc.
1615 Poydras Street
New Orleans, LA 70112
(504) 582-4314
john_seip@fmi.com

James Sell
University of Arizona
P.O. Box 310030
Tucson, AZ 85721-0030
(520) 626-3898

Barun K. Sen Gupta
Louisiana State University
Dept. of Geology & Geophysics
Howe-Russell Geoscience Complex
Baton Rouge, LA 70803-4101
(225) 578-5984
barun@geol.lsu.edu

Cheryl Sephus
University of New Orleans
P.O. Box 1014
New Orleans, LA 70148
(504) 283-5370
midsea20@hotmail.com

Jack L. Shanks
MMS
1201 Elmwood Park Boulevard
New Orleans, LA 70123-2394
(504) 736-2951
jack.shanks@mms.gov

Brian Shannon
Principal Environmental Scientist
B.E. Shannon/Environment Consultant
2915 Sunset Ridge
McKinney, TX 75070-4217
(972) 542-9622
b.e.shannon@comcast.net

Richard F. Shaw
Director
LSU Coastal Fisheries Institute
CCEER Wetlands Bldg
Baton Rouge, LA 70803
(225) 578-6734
rshaw@lsu.edu

William W. Shedd
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2497
william.shedd@mms.gov

Andrew N. Shepard
NOAA Undersea Research Center
UNCW/CMS
5600 Marvin Moss Lane
Wilmington, NC 28409
(910) 962-2446
sheparda@uncw.edu

Frank S. Shipley
Center Director
USGS Bio. Resources
909 First Avenue, Suite 800
Seattle, WA 98104-1055
(206) 220-4608
frank_shipley@usgs.gov

Natalia A. Sidorovskaia
University of Louisiana at Lafayette
Physics Department
UL Box 44210
Lafayette, LA 70504-4210
(337) 482-6274
nsidorovskaia@louisiana.edu

Earl R. Sims
IAGC
5912 Davenhill Court
Plano, TX 75093
(972) 781-0690
earlrsims@aol.com

James E. Sinclair
MMS
1201 Elmwood Park Blvd., MS 5432
New Orleans, LA 70123
(504) 736-2789
james.sinclair@mms.gov

Joachim Singleman
LSU Dept. of Sociology
126 Stubbs Hall
Baton Rouge, LA 70803
(225) 578-1635
joachim@lsu.edu

Kimberly A. Skrupky
Marine Acoustics, Inc.
4100 Farifax Dr., Suite 730
Arlington, VA 22203
(703) 465-8404
kimberly.a.skrupky@marineacoustics.com

Scott E. Slaughter
The Center for Regulatory Effectiveness
11 DuPont Circle, NW, Suite 700
Washington, DC 20036
(202) 265-2383
slaughter@mbsdc.com

Gregory J. Smith
USGS, National Wetlands Research Center
700 Cajundome Boulevard
Lafayette, LA 70506
(337) 266-8501
gregory_smith@usgs.gov

Lorene E. Smith
Research Associate
LSU Museum of Natural Science
119 Foster Hall
Baton Rouge, LA 70803
(225) 578-2296
lsmit18@lsu.edu

Tim D. Smith
NOAA Fisheries
166 Water Street
Woods Hole, MA 02543
(508) 495-2251
tim.smith@noaa.gov

Mark Snyder
Naval Oceanographic Office
1002 Balch Blvd.
Stennis Space Center, MS 39522
(228) 689-8019
snyderm@navo.navy.mil

Tom Soniat
Professor
Nicholls State University, Dept. of Biology
Thibodaux, LA 70310
(504) 448-4865
tom.sonait@nicholls.edu

Shashidhar Sorakayala
University of New Orleans Conference Services
New Orleans, LA 70148

Randy Soulier
Arthur J. Gallagher of Louisiana
235 Highlandia Dr., Suite 200
Baton Rouge, LA 70810
(800) 605-6102
randy.soulier@ajg.com

Jesse H. Spence
Noise Control Engineering
799 Middlesex Turnpike
Billerica, MA 01821
(978) 670-5339
jesse@noise-control.com

Tony R. St. Clair
Ecology and Environment, Inc.
220 W. Garden Street, Suite 404
Pensacola, FL 32501
(850) 435-8925
tstclair@ene.com

David R. Stauffer
Pennsylvania State University
503 Walker Building
University Park, PA 16802
(814) 863-3932
stauffer@meteo.psu.edu

Peter J. Stein
Scientific Solutions, Inc.
99 Perimeter Road
Nashua, NH 03063
(603) 880-3784
pstein@scisol.com

James Stephens
University of Southern Mississippi
6971 Lincoln Road
Hattiesburg, MS 39402
(601) 268-2681
james.stephens@usm.edu

Gregory Stone
Louisiana State University
Dept. of Oceanography/Coastal Science
CSI - E111 Howe-Russell Geoscience Complex
Baton Rouge, LA 70805
(225) 578-6188
gagreg@lsu.edu

Joanna Stone
University of Arizona
Tucson, AZ 85721
(520) 621-6282
jostone@arizona.edu

Bill Streever
British Petroleum
P.O. Box 196612
900 E. Benson Blvd.
Anchorage, AK 99519-6612
(907) 564-4383
streevbj@bp.com

Kristen L. Strellec
MMS
1201 Elmwood Park Blvd., MS 5411
New Orleans, LA 70123
(504) 736-2465
Kristen.Strellec@mms.gov

Michael G. Strikmiller
Marketing Manage
Environmental Enterprises USA, Inc.
58485 Pearl Acres Road, Suite D
(985) 646-2787
mstrikmiller@eeusa.com

Glenn M. Suir
USGS / LSU AgCenter
P.O. Box 25098
Baton Rouge, LA 70894
(225) 578-7203
gsuir@usgs.gov

Ken Sulak
Research Fish Biologist
USGS
Florida Caribbean Science Center
7920 NW 71st St.
Gainesville, Florida 32653
(352) 378-8181
ken_sulak@usgs.gov

Kavita Swaminathan
University of Houston
9900 Broadway Street, #1933
Pearland, TX 77584
(713) 743-4267
kavita.swaminathan@mail.uh.edu

David Szabo
Fugro GEOS, Inc.
6100 Hillcroft
Houston, TX 77081
(713) 346-3609
d.szabo@geos.com

Bruce A. Tackett
ExxonMobil
3225 Gallows Road
Room 07D0427
Fairfax, VA 22037
(703) 846-3764
bruce.a.tackett@exxonmobil.com

Arslan M. Tashmukhambetov
University of Louisiana at Lafayette
2509 Johnston Street, Apt. 2-1
Lafayette, LA 70503
(337) 232-3502
arsupisemnet@yahoo.com

William J. Teague
Oceanographer
Naval Research Laboratory
Stennis Space Center, MS 39529
(228) 688-4734
teague@nrlssc.navy.mil

Bill Terrebonne
Regulatory Specialist
Shell E&P Company
701 Poydras St., Office 3410
P O Box 61933
New Orleans, LA 70130
(504) 728-7281
william.terrebonne@shell.com

Aaron M. Thode
University of California, San Diego
Scripps Institute of Oceanography
9500 Gilman Drive - 0238
La Jolla, CA 92093-0238
(858) 822-4864
thode@mpl.ucsd.edu

Ian M. Threadgold
BP
502 Westlake Park Blvd.
Houston, TX 77079
(281) 366-3647
threadim1@bp.com

Wilfred W. Times
MAU-Visual Information Specialist
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2762
wilfred.times@mms.gov

Maya Tolstoy
Lamont-Doherty Earth Observatory
61 Route 9W
Palisades, NY 10964-8000
(845) 365-8791
tolstoy@ldeo.columbia.edu

Cy Toups
T. Baker Smith & Sons
P.O. Box 2266
Houma, LA 70360
(985) 223-9224
cyt@tbsmith.com

John H. Trefry
Florida Institute of Technology
Dept. of Marine & Environmental Sys.
150 W. University Blvd.
Melbourne, FL 32901
(321) 674-7305
jtrefry@fit.edu

Debby Tucker
Program Consultant
Florida Dept. of Environmental Protection
3900 Commonwealth Blvd., MS 47
Tallahassee, FL 32301
(850) 245-2163
debby.tucker@dep.state.fl.us

Kim Turner
ChevronTexaco
935 Gravier Street
New Orleans, LA 70112
(504) 592-6894
kturner@chevrontexaco.com

David C. Twichell
U. S. Geological Survey
384 Woods Hole Road
Woods Hole, MA 02543-1598
(508) 457-2266
dtwichell@usgs.gov

Peter L. Tyack
Woods Hole Oceanographic Institution
9 Maury Lane, MS 44
Woods Hole, MA 02543
(508) 289-2818
ptyack@whoi.edu

Sunil Kumar Vallur
University of New Orleans Conference Services
New Orleans, LA 70148

Allen J. Verret
Exec. Director
Offshore Operators Committee
P.O. Box 50751
New Orleans, LA 70150-0751
(504) 561-2427
allen_verret@murphyoilcorp.com

Stephen Viada
Sr. Staff Scientist
Continental Shelf Associates, Inc.
328 Aris Ave
Metairie, LA 70005
(504) 837-6253
sviada@gs.net

Debra Vigil
MMS
1201 Elmwood Park Blvd., MS 5431
New Orleans, LA 70123
(504) 736-2406
debra.vigil@mms.gov

Jenneke Visser
LSU Coastal Ecology Institute
Baton Rouge, LA 70803
(225) 578-6377
comvss@lsu.edu

Barry Vittor
Barry A. Vittor & Associates, Inc.
8060 Cottage Hill Rd
Mobile, AL 36695
(334) 633-6100
bvittor@bvaenviro.org

Latonia Viverette
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2433
latonia.viverette@mms.gov

Michael Vogel
Sr. Research Engineer
Shell E&P Company
3737 Bellaire Blvd
Houston, TX 77025
(713) 245-7454
michael.vogel@shell.com

Jon H. Volstad
Versar, Inc.
9200 Rumsey Road
Columbia, MD 21045
(410) 740-6085
jvolstad@versar.com

Fred M. Vukovich
Science Applications International Corporation
615 Oberlin Road, Suite 100
Raleigh, NC 27605
(919) 836-7563
fvukovich@raleigh.saic.com

Terry Wade
Texas A&M University
GERG -TAMU Mail Stop 3149
833 Graham Rd
College Station, TX 77845
(979) 862-2323x-134
terry@gerg.tamu.edu

Jack B. Waide
U.S. Geol. Survey-Biological Resources Discipline
12201 Sunrise Valley Drive, MS 301
Reston, VA 20192
(703) 648-4053
jwaide@usgs.gov

Christopher D. Walker
University of Southern Mississippi
Hattiesburg, MS 39406
(601) 268-2681x 39
christopher.walker@usm.edu

Nan Walker
LSU Coastal Studies Institute
Dept of Oceanography
Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
(225) 578-5331
nwalker@lsu.edu

Michael B. Wallace
MMS
1201 Elmwood Park Blvd.
New Orleans, LA 70123
(504) 736-2423
michael.wallace@mms.gov

Ellen N. Walz
MMS
381 Elden Street, MS 4010
Herndon, VA 20170
(504) 787-1275
ellen.walz@mms.gov

Dr. E.G. Ward
Texas A&M University
Offshore Technology Research Center
1200 Mariner Dr
College Station, TX 77845
(409) 862-2288
egward@tamu.edu

Douglas Wartzok
Florida International University
University Park, PC 230
Miami, FL 33199
(305) 348-2455
wartzok@fiu.edu

Stephanie L. Watwood
Woods Hole Oceanographic Institution
266 Woods Hole Road
Caryn House MS 44
Woods Hole, MA 02543
(508) 289-3643
swatwood@whoi.edu

Douglas C. Weaver
Marine Biologist/GIS Specialist
Flower Garden Banks National Marine Sanctuary
1200 Briarcrest Drive, Suite 4000
Bryan, TX 77802
(979) 846-5942
doug.weaver@noaa.gov

Chih-Lin Wei
Texas A&M University at Galveston
5007 Avenue
Galveston, TX 77551
(409) 741-7124
weic@tamug.edu

Susan E. Welsh
LSU Coastal Studies Institute
331 Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
(225) 578-0439
swelsh@lsu.edu

Karen A. Westphal
LSU/SL&E Special Programs
921 Magnolia Wood Ave
Baton Rouge, LA 70809
(225) 766-5046
kwestph@lsu.edu

Dana Wetzel
Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236
(941) 388-4441
dana@mote.org

Nick Wetzel
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70448
(504) 739-2419
nick.wetzel@mms.gov

Neil J.M. Wheeler
Sonoma Technology, Inc.
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169
(707) 665-9900
neil@sonomatech.com

Mary Wicksten
Texas A & M Dept. of Biology
3258 TAMU Butler Hall, Room 202
College Station, TX 77843
(979) 845-3388
wicksten@mail.bio.tamu.edu

Andrew T. Wigton
ExxonMobil
P.O. Box 2189
URC-GW3-866B
Houston, TX 77252-2189
(713) 431-7025
andrew.t.wigton@exxonmobil.com

Charles A. Wilson
LSU
Louisiana Sea Grant
Baton Rouge, LA 70803
(225) 578-6283
cwilson@lsu.edu

Darcy Wilson
Program Manager
Eastern Research Group, Inc.
1600 Perimeter Park Drive
Morrisville, NC 27560
(919) 468-7860
darcy.wilson@erg.com

Judith M. Wilson
Marine Biologist
MMS
381 Elden Street
Herndon, VA 20170
(703) 787-1075
judy.wilson@mms.gov

Susan Wilson
British Petroleum
200 Westlake Park Blvd.
Houston, TX 77079
(281) 366-0969
wilson4@bp.com

Debra Winbush
Public Affairs Specialist
MMS
1201 Elmwood Park Blvd., MS 5000
New Orleans, LA 70123
(504) 736-2597
debra.winbush@mms.gov

Martha Winsor
Research Assistant
Oregon State University
Hatfield Marine Science
Corvallis, OR 97331
(541) 867-0288
martha.winsor@oregonstate.edu

Mark Witten
Sr. Advisor - HSE
ChevronTexaco
935 Gravier St.
New Orleans, LA 70112
(504) 592-6336
mswi@chevrontexaco.com

Jeff F. Wolfe
U.S. Coast Guard
Coast Guard District Eight, Room 1341
500 Poydras
New Orleans, LA 70130-3396
(504) 589-6260
jwolfe@d8.uscg.mil

George Wooddell
University of Louisiana at Lafayette, Dept. of Sociology
Mouton 219
Lafayette, LA 70504
(337) 482-5373
wooddell@louisiana.edu

John H. Wormuth
Texas A&M University, Dept. of Oceanography
College Station, TX 77843
(979) 845-7132
jwormuth@ocean.tamu.edu

Andrew Wright
LADC
(202) 271-0293
marinebrit@netscape.net

Rusty Wright
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
(504) 736-2529

Greg Yarwood
ENVIRON International Corporation
101 Rowland Way, Suite 220
Novato, CA 94945
(415) 899-0700
gyarwood@environcorp.com

Craig M. Young
University of Oregon
Oregon Institute of Marine Biology
P O Box 5389
Charleston, OR 97420
(541) 888-2581x 299
cmyoung@uoregon.edu

John V. Young
ExxonMobil Exploration Company
222 Benmar
Corp. GP8-734
Houston, TX 77060
(281) 654-4298
john.v.young@exxonmobil.com

Gary S. Zeigler
Vaisala Inc.
P.O. Box 3659
Boulder, CO 80307-3659
(303) 402-4700
gary.zeigler@vaisala.com

Steve D. Ziman
ChevronTexaco Energy Technology Company
100 Chevron Way
Richmond, CA 94802
(510) 242-1530
sdzi@chevrontexaco.com

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.

MMS Securing Ocean Energy & Economic Value for America