OCS Study
MMS 2008-012

Proceedings: Twenty-Fourth Gulf of Mexico Information Transfer Meeting

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

OCS Study
MMS 2008-012

Proceedings: Twenty-Fourth Gulf of Mexico Information Transfer Meeting

January 2007

Editors

Melanie McKay
Copy Editor

Judith Nides
Production Editor

Prepared under MMS Contract
1435-00-01-CA-39526 (M05AC12281)
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
May 2008

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. 2008. Proceedings: Twenty-fourth Gulf of Mexico information transfer meeting, January 2007. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2008-012. 494 pp.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

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 and excellent service. In particular, we thank Patricia Arteaga of UNO for making the planning process appear effortless. We also thank Melanie McKay and Judy Nides for the production of the final product. Finally, we thank 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

In meeting its mission to manage energy and minerals resources on the Outer Continental Shelf (OCS), the Minerals Management Service (MMS) administers an Environmental Studies Program (ESP) to gather and synthesize environmental and social and economic science information to support decisionmaking concerning the offshore oil and gas program. The Outer Continental Shelf Lands Act established policy for the management of the OCS natural gas and oil leasing program and for the protection of marine and coastal environments. Section 20 of the Act authorizes the ESP and establishes three general goals for the program:

- to establish the information needed for assessment and management of environmental impacts on the human, marine, and coastal environments of the OCS and the potentially affected coastal areas;

- to predict marine biota impacts that may result from chronic, low-level pollution or large spills associated with OCS production, from drilling fluids and cuttings discharges, pipeline emplacement, or onshore facilities; and

- to monitor human, marine, and coastal environments to provide time series and data trend information for the identification of significant changes in the quality and productivity of these environments, and to identify the causes of these changes.

Toward this effort, MMS sponsors the biannual Information Transfer Meeting (ITM), bringing together researchers from throughout the United States and internationally to discuss research topics funded by the ESP and related areas of interest to MMS. 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 ESP 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 decisionmakers from MMS, other federal or state governmental agencies, regional industries, and academia.

The 24th ITM had diverse topics of interest ranging from coastal ecology to deepwater. Highlights this year included presentations of sperm whale seismic research, deepwater *Lophelia* coral, and deepwater technology. The Minerals Management Service has been tasked by Congress to oversee the Coastal Impact Assistance Program, a session was devoted to the program which authorizes funds to be distributed to Outer Continental Shelf (OCS) oil and gas producing states to mitigate the impacts of OCS oil and gas activities. Two sessions were devoted to socioeconomics and impacts of the oil and gas industry. One session focused solely on the socioeconomic effects of hurricanes on the Gulf region. The dynamics of deepwater currents is of particular interest since the industry is moving into waters further offshore. Other sessions focused on the air quality, deepwater habitats, platform ecology, hydrates, coastal wetland and offshore ecology, and chemosynthetic research. The meeting reflected the broad areas of interest to MMS and the excellent scientists studying these topics.

Following are the presentation summaries.

SESSION 1A

COASTAL IMPACT ASSISTANCE

Chair: **Stephanie Gambino, Minerals Management Service**

Co-Chair: **Karen Osborne, Minerals Management Service**

COASTAL IMPACT ASSISTANCE PROGRAM ALLOCATION FORMULA DEVELOPMENT DETAILS

Thomas W. Farndon and Karen L. Osborne, Minerals Management Service

Click here to view the slide show that accompanied this presentation.

Section 384 of the Energy Policy Act of 2005 (Public Law 109-58) establishes the Coastal Impact Assistance Program (CIAP) which authorizes funds to be distributed to Outer Continental Shelf (OCS) oil and gas producing states to mitigate the impacts of OCS oil and gas activities. Under the CIAP, $250 million for each of fiscal years 2007 through 2010 will be disbursed to eligible producing states and coastal political subdivisions based upon allocation formulas prescribed by the Act. The development details of the allocation formulas were presented at the 24th Information Transfer Meeting on 9 January 2007.

Six states (Alabama, Alaska, California, Louisiana, Mississippi, and Texas) and their eligible coastal political subdivisions (CPS) are eligible to participate in the program. States were eligible if a point on their coastline was within 200 nautical miles of any leased tract, and if the majority of the coastline was not subject to a moratoria, unless the specified exception in the statutory language applied. CPS eligibility was determined by calculating the distance from the nearest point on the perimeter of the CPS to the geographic center of each leased tract. Any CPS within its state's coastal zone that was also within 200 nautical miles of any active leased tract became eligible for the program. There are sixty-seven eligible CPS within the six eligible states.

Each state's allocation was based on the amount of qualified OCS revenues (QOCSR) associated with that state, determined using the allocation rules set forth in the statutory language. Minerals Revenue Management, the Minerals Management Service program that is responsible for management of federal offshore revenues, provided the Fiscal Year 2006 QOCSR data to use in the Fiscal Year 2007 and 2008 allocations. Using a combination of Microsoft Excel, Microsoft Access, ArcGIS, Visual Basic, and MMS's Technical Information Management System (TIMS), a proprietary database of the MMS, software was developed to determine the amount of QOCSR generated within 200 nautical miles of the coastline of each producing state. In the Gulf of Mexico region where many of the leased tracts are within 200 nautical miles of more than one state, the amount that is allocated to each state that is within 200 nautical miles of a specific leased tract is inversely-proportional to the distance between the nearest point on the coastline of the producing state and the geographic center of the specific leased tract. Additionally, the minimum amount allocated to each producing state is mandated to be one percent of the total amount allocated in any fiscal year.

Public Law 109-58 defines distance as the minimum Great Circle Distance between two points. The Great Circle Distance (GCD) is mathematically defined as the shortest distance between any two points on the surface of a sphere measured along a path on the surface of that sphere. To find the GCD between two points, spherical trigonometry is employed, with a correction applied to account for the flattening of the earth at the poles, which alters the spherical shape into an oblate spheroid. We used the WGS84 reference ellipse to reflect the North American Datum (NAD 27 datum). We selected this datum because the MMS Submerged Lands Act (SLA) baseline and the leased tract points in the Gulf of Mexico region, which represent the majority of the points needed for the analysis, are based on the NAD27. The SLA baseline represents the official coastline for the purpose of CIAP calculations, and all distance calculations utilize these baseline points.

Thirty-five percent of each state's allocation was set aside for the eligible coastal political subdivisions within the state. Of that amount, 25% was allocated to a CPS based on the proportion of the individual CPS population to the total population of all eligible CPS within the state, 25% was allocated based on the proportion of the individual CPS coastline length to the total coastline length of all the CPS within the state, and 50% was allocated inversely-proportional to the distance between the nearest point on the perimeter of the CPS and the geographic center of the specific leased tract for each leased tract within 200 nautical miles. Additional exceptions set forth in the statutory language provide special rules for the states of Louisiana and Alaska.

The U.S. Census Bureau 2000 Census was referenced to determine the official population of each CPS. The Submerged Lands Act baseline was used to define the coastal points for each CPS. The start and end points for the coastline of each CPS within each state were determined by merging the SLA baseline with the Topologically Integrated Geographic Encoding and Referencing System (TIGER) files developed at the U.S. Census Bureau. The length of each CPS coastline was calculated using Hawth's Analysis Tools within ArcGIS software.

The Fiscal Year 2007 and Fiscal Year 2008 allocations were published on the MMS website in April 2007. Technical documentation for the allocation formula details is anticipated to be published on the MMS website before the end of 2007.

Tom Farndon has worked as a petroleum engineer for MMS Offshore Minerals Management Headquarters since 1985. Most of that time he has spent in the Economics Division solving complex multidisciplinary analytical problems such as the implementation of this Coastal Impact Assistance Program and various royalty relief policies. He has 28 years of experience in the oil and gas industry since receiving his B.S. in petroleum engineering from Marietta College in 1978.

Karen Osborne has worked as a statistician in the Economics Division of MMS Offshore Minerals Management Headquarters since 2004. Prior to joining MMS, Karen had 15 years of experience as an analytical consultant in several industries. She received a B.S. in mathematics (1982), and an M.S. in statistics (1996), both from Montclair State University.

STATE OF ALABAMA COASTAL IMPACT ASSISTANCE PROGRAM

Will Brantley, Alabama Department of Conservation and Natural Resources

Click here to view the slide show that accompanied this presentation.

In November of 2005, the Governor of Alabama (Bob Riley) designated Alabama Department of Conservation and Natural Resources (ADCNR) as the lead entity to implement the State of Alabama Coastal Impact Assistance Program (CIAP). Soon after, the Commissioner of the ADCNR (M. Barnett Lawley) designated the State Lands Division as the lead entity for managing the CIAP. There are two Coastal Political Subdivisions (CPSs) in Alabama: Baldwin County and Mobile County. These three entities implemented the 2001 CIAP administered by NOAA. The State Lands Division is currently engaged in a dual planning process. The overall State of Alabama CIAP is being coordinated with the coastal counties and project ideas are being solicited and developed for inclusion in the State of Alabama's portion of the CIAP. The State of Alabama would like to focus on successful 2001 CIAP projects and identify projects that do not duplicate existing programs. Example projects could include land acquisition, artificial reef development, wetland restoration, and restoration of freshwater flows to coastal estuarine systems. There will be two public meetings during CIAP plan development; a meeting to announce the overall CIAP Plan Development process and a meeting to release the Draft CIAP Plan for public comment. For further information on the State of Alabama CIAP, please contact Will Brantley (334) 242-5502 or Cara Stallman (251) 625-0814.

William H. Brantley, Jr., has been involved in natural resource management for twelve years and is currently employed as a State Lands Manager for the Alabama State Lands Division (Division), a subdivision of the Department of Conservation and Natural Resources. He supervises the Administration and Planning Section of the Division and is responsible for asset management and revenue generation programs within the Division. Additionally, Mr. Brantley oversees several significant programs for the State of Alabama including the Coastal Impact Assistance Program. He received a Bachelor of Arts degree from Furman University in Greenville, South Carolina, and also holds a Master of Science degree in forest resources from Clemson University in Clemson, South Carolina.

UPDATE ON LOUISIANA'S COASTAL IMPACT ASSISTANCE PLAN

David Frugé, Louisiana Department of Natural Resources,
Office of Coastal Restoration and Management

Click here to view the slide show that accompanied this presentation.

Congress authorized the Coastal Impact Assistance Program (CIAP) as part of the Energy Policy Act of 2005. Louisiana is projected to receive up to $523 million in CIAP funds over four years, beginning in 2007. Sixty-five percent ($340 million) of those funds will go to the state, and 35% ($183 million) will go to the 19 coastal parishes. Louisiana must submit a CIAP Plan (Plan) to the U.S. Minerals Management Service (MMS), and MMS must approve it before disbursing CIAP funds. The Louisiana Department of Natural Resources (LDNR) has the lead for preparing that Plan and has worked closely with the coastal parishes and various state entities to complete a draft Plan for public review. The state will send the final Plan to MMS, after its approval by the state's Coastal Protection and Restoration Authority. That document will identify projects to be supported by the state's share of the CIAP funds, the parishes' share of those funds, and projects jointly funded by the State and parishes. The plan will include coastal conservation and restoration projects and onshore infrastructure projects to mitigate the impact of OCS activities. Initial CIAP funding will be available in the late spring of 2007. LDNR plans to begin implementing projects contained in LA's CIAP Plan before then, using money from the State's Coastal Protection and Restoration Trust Fund.

LDNR solicited input and project proposals from the coastal parishes, state and federal agencies, non-governmental organizations, landowners, and the public. A description of the program, guidelines for submitting project proposals, and project selection criteria were disseminated via meetings and mailings and were posted for download from the LDNR CIAP website. LDNR consistently said that the Plan would draw heavily from previous collaborative coastal planning efforts that have occurred in recent years (e.g., the Coast 2050 Plan, the LCA Plan, and the Governor's Advisory Panel and Science Working Group on Coastal Wetland Forest Conservation and Use).

The evaluation criteria for coastal conservation and restoration project proposals included the following questions:

1. Is the proposed project free of issues that may impact timely implementation?
2. Is the proposed project linked to a regional strategy that maintains established landscape features critical to a sustainable ecosystem structure and function?
3. Does the proposed project protect health, safety, or infrastructure of national, state, regional or local significance?
4. How cost effective is the project?
5. What is the certainty of the project's benefits?

6. Does the project address an area of critical need or high land loss?
7. How sustainable are the project's benefits?

LDNR staff provided technical assistance to parishes and other entities in the development of their proposals. The deadline for project proposals was 22 May 2006, an extension of two earlier deadlines. Three hundred and twenty-six (326) proposals were received by LDNR from the 19 coastal parishes, municipalities, state agencies, federal agencies, universities, corporations, non-governmental organizations, landowners, and the general public.

Following the 22 May proposal deadline, LDNR staff visited sites of proposed projects when more information was needed to assess site conditions and the proposed projects' features and potential benefits. LDNR staff assembled regional maps showing each proposed restoration project, and generated reports on each project proposed for state CIAP funding. Those reports identified up to 67 key features found within a 500-foot radius of proposed projects (e.g., existing restoration projects, permitted coastal use activities, pipeline rights of way, etc.). The LDNR Land Section reviewed projects proposed for State CIAP funding to evaluate landowner status and the existence of infrastructure, leases, and any other land-rights issue that might impact implementation. Proposals were also evaluated for potential conflicts with coastal protection projects, using GIS data provided by the Coastal Protection and Restoration Authority (CPRA) Integrated Planning Team.

LDNR solicited public input on the proposed projects at regional open house events in Baton Rouge and Lafayette (20 and 22 June 2006). All proposals were also available for review on the LDNR CIAP website, and comments from the public were solicited via the web site for consideration during the selection process.

Project proposals were initially screened by LDNR to determine whether state CIAP funds were being requested, whether the projects complied with the authorized uses of CIAP funds, and whether the proposals were focused on conservation/restoration or infrastructure. Each conservation and restoration proposal involving state CIAP funding for one or more of the authorized uses was then reviewed to determine whether it had clear links to a regional strategy for maintaining established landscape features deemed critical to a sustainable ecosystem structure and function. A key related question asked by LDNR staff in making that determination was whether the proposal would produce regional benefits. Another key question was whether the cost of the proposal would exceed a level reasonably supportable by CIAP. Those conservation/restoration projects which met the above criteria, had a high degree of certainty of benefits, and were generally of a cost range deemed to be supportable with CIAP funds were then selected for detailed technical analysis. An exception to that procedure involved projects that were currently being engineered and designed with CWPPRA funds; those projects were generally excluded from further consideration for CIAP evaluation and funding purposes.

A group of natural resource researchers from Louisiana conducted an external technical review of CIAP conservation and restoration projects proposed for state funding. That interactive review identified the strengths and weaknesses of individual proposals and assessed their competitiveness as candidates for CIAP funding.

Using information compiled for the projects selected for detailed analysis (including the external technical review findings), an LDNR technical review panel assigned a score (0 to 10) to each proposal. That panel then generated a preliminary list of projects for inclusion in the Draft CIAP Plan. That preliminary list formed the primary basis of the recommended list of state-funded projects presented by LDNR's CIAP Team to the CIAP selection committee. That selection committee was comprised of CPRA agency representatives from the Louisiana Departments of Transportation and Development, Wildlife and Fisheries, Environmental Quality, Natural Resources, and Agriculture and Forestry, and the Governor's Office of Coastal Activities. An external science advisor also participated at that meeting, as did members of the CPRA's Integrated Planning Team. The list adopted by that selection committee is the primary component of the Draft CIAP Plan (projects involving state CIAP funding).

The anticipated Plan components involving the state's share of CIAP funds include:

1. Enhanced management of Mississippi River water and sediment;
2. Protection and Restoration of critical land bridges;
3. Barrier shoreline restoration and protection;
4. Interior shoreline protection (lakes and critical reaches of navigation channels);
5. Beneficial use of dredged material/marsh creation;
6. A coastal forest conservation initiative; and
7. Infrastructure projects to mitigate onshore OCS impacts.

David Frugé is Acting Deputy Assistant Secretary of the Louisiana Department of Natural Resources' Office of Coastal Restoration and Management. He coordinates Louisiana's involvement in the Coastal Impact Assistance Program, authorized by Congress in 2005. He was also Administrator of DNR's Coastal Management Division from September 2003 to August 2005, overseeing the state's Coastal Use Permit Program and efforts to ensure that federal activities are consistent with Louisiana's Coastal Resources Program. Mr. Frugé administered the U.S. Fish and Wildlife Service's Ecological Services Program in Louisiana from 1982 until his retirement in 2003. He also represented the U.S. Department of the Interior on the Louisiana Coastal Wetlands Task Force from June 1995 through August 2003.

MISSISSIPPI COASTAL IMPACT ASSISTANCE PROGRAM

Tina Shumate, Mississippi Department of Marine Resources

Click here to view the slide show that accompanied this presentation.

TEXAS COASTAL IMPACT ASSISTANCE PROGRAM

Kathy Smartt, Texas General Land Office

The Office of the Governor of the State of Texas will oversee the Texas Coastal Impact Assistance Program and will submit the Texas CIAP Plan to Minerals Management Service for approval. The Texas Plan will consist of one-year plans, with amendments each year to reflect new fiscal year awards.

To develop the state portion of the CIAP program, Governor Perry established a three-member Coastal Land Advisory Board (Board) in January 2006. The Board is comprised of Texas Land Commissioner Jerry Patterson (Chairman), Railroad Commissioner Elizabeth Jones, and Transportation Commissioner John Johnson. Governor Perry designated the Texas General Land Office (GLO) as the administrative agency for the CIAP.

In May 2006, the Board approved the goals and objectives for the state portion of the CIAP program. Specifically, the goals of the program are: to conserve, restore, enhance, and protect the diversity, quality, quantity, functions, and values of the state's coastal natural resources including, but not limited to, any effects of oil and gas development of the Outer Continental Shelf. The objectives of the program are to: restore, protect, and enhance coastal natural resources; improve water quality; enhance public access; improve onshore infrastructure and environmental management; mitigate erosion and stabilize shorelines; and educate the public on the importance of coastal natural resources. Protecting coastal natural resources, while facilitating economic development and multiple human uses of coastal resources, will be a primary focus of this effort. Priority will be given to projects that meet regional and/or coast-wide goals and objectives.

For each fiscal year award, informative public meetings will be held and project nominations will be solicited for state and county funding. Informative public CIAP meetings for 2007 state funding began in May 2006. Since then, numerous public meetings have been held along the Texas Coast with representatives from state and federal agencies, county and local representatives, non-profit organizations, county task forces, and the general public. A general workshop was held in August 2006 in Austin with coastal county representatives to discuss proposed county projects and documentation needed for the state plan. The GLO staff held individual follow-up meetings with all 18 counties.

Project nominations for state projects were solicited in July 2006. Three hundred forty-nine nominations were submitted, totaling over $777 million in funding requests. One hundred eighteen nominees were asked to submit grant applications. Proposed state projects are under review. A public Board meeting will be held to finalize the selection process. The draft state plan will be posted in the Texas Register for 30 days for public comment. It is anticipated there will be 35–40 state projects and 100–110 county projects for the first year of funding.

The GLO created the 2005 CIAP Web site in March 2006 to provide continuous updates on the CIAP. This Web site has been a reliable and up-to-date source of information in the development and implementation of the Texas program, as well as a means to participate in the state project submission process.

Kathy Smartt has been an employee with the Texas General Land Office for eight years. She currently works as the Team Leader for the Texas CIAP. Previously, Kathy was the state CIAP coordinator for the 2001 program administered by NOAA. She has extensive experience in administering federal grants and managing coastal projects as a program specialist in the Coastal Resources Division of the Land Office for the last five years, Before transferring to her current position, Kathy worked three years in contract administration for the Legal Division of the Land Office.

SESSION 1B

AIR QUALITY I

Chair: **Chester Huang, Minerals Management Service**

Co-Chair: **Margaret Metcalf, Minerals Management Service**

AIR QUALITY I SESSION, INTRODUCTION

C. H. (Chester) Huang, Minerals Management Service

Click here to view the slide show that accompanied this presentation.

This session describes a project is to conduct meteorological and air quality modeling and to assess the impact of air quality on Breton National Wilderness Area (BNWA), a Class I area. This five-year project will integrate meteorological data, air quality data, and emissions inventory, using MM5 mesoscale model and CALPUFF and CMAQ air quality models.

From October 2000 through September 2001, the Minerals Management Service (MMS) conducted a number of data quality control, data validation, and data analysis studies to collect meteorological and air quality data. The studies include: Observation of the Atmospheric Boundary Layer, Development of Gridded Source Emission Inventories, Data Quality Control and Assurance for the Breton Area Activity Data System and Emission Inventory, Breton Offshore Activity Data System (BOADS), Gulfwide Offshore Activity Data System (GOADS), and Atmospheric Boundary Layer Study in the Western and Central Gulf of Mexico.

Other papers presented in this section discuss hurricane damage to the oil and gas infrastructure, the Gulf Coast mesoscale modeling study, the visibility study, and the study of reactive volatile organic compounds at the air-sea interface in the Gulf of Mexico.

Dr. C. H. (Chester) Huang is a Certified Consulting Meteorologist in the Physical Sciences Group, Environmental Sciences Section at MMS. He is responsible for the review of air quality permit application, environmental impact assessment, and air quality and meteorological study programs. His expertise is in the areas of atmospheric boundary layer meteorology, turbulence and diffusion, air-sea interaction, wind energy, and air quality and meteorological modeling. His works have appeared in several textbooks on air pollution meteorology and have been widely cited in the scientific literature. He has numerous publications in journals, conference proceedings, and technical reports. Previously, he worked on the Federal Wind Energy program and the Department of Energy's nuclear facilities. His other experience includes work at Battelle National Laboratory, Navy Fleet Numerical Meteorology and Oceanography Center, and teaching at the University of Toledo, Ohio.

ON THE RELATIONSHIP BETWEEN METEOROLOGICAL FACTORS AND HURRICANE

C. H. (Chester) Huang, Minerals Management Service

Click here to view the slide show that accompanied this presentation.

Introduction

The impacts of hurricanes on human activities in coastal areas can be dramatic, as shown by devastation Hurricane Katrina caused to human life and property, including the offshore oil and gas infrastructure. Accurate predictions about hurricanes could reduce loss of life and property as well as oil and gas production; however, in spite of the advances in hurricane studies, hurricane movement and strength often remain unpredictable.

In this study, we investigate the relationships between meteorological factors and hurricane damage to oil and gas platforms. We describe ways of determining the meteorological factors, and we develop a quick and easy-to-use method of assessing the impact of hurricane damage to the oil infrastructure in the Gulf of Mexico. We also show that a hurricane's central pressure may be a good indicator for establishing design criteria for offshore structures.

Synoptic of Hurricane Katrina

Figure 1B.1 shows the best tract and positions for Hurricane Katrina from 26 to 29 August 2005. Also shown are the stages of Katrina's development and the hurricane categories of those stages (see www.nhc.noaa.gov; Knabb et al. 2005). The hurricane tracks predicted by National Hurricane Center (NHC) and MM5 mesoscale model are also plotted in this figure. It is evident from this figure that forecasting a hurricane's track is still very difficult.

Hurricane Katrina formed north of Puerto Rico on 19 August 2005 from a combination of a tropical wave and the remnants of tropical depression. It became a tropical storm on 24 August and moved through the Bahamas and toward South Florida. It continuously strengthened and became a Category 1 hurricane near the south of Florida during the evening of 25 August.

On 26 August (at 0000 UTC), Katrina moved onshore in South Florida as Category 1 hurricane and weakened to become a tropical storm over land. After entering the eastern Gulf of Mexico it again became a Category 1 hurricane and continued its southwest movement. Due to the warmer water of Gulf of Mexico, Katrina intensified to a Category 2 hurricane by 11:30 a.m. Eastern Daylight Time (EDT) on 26 August.

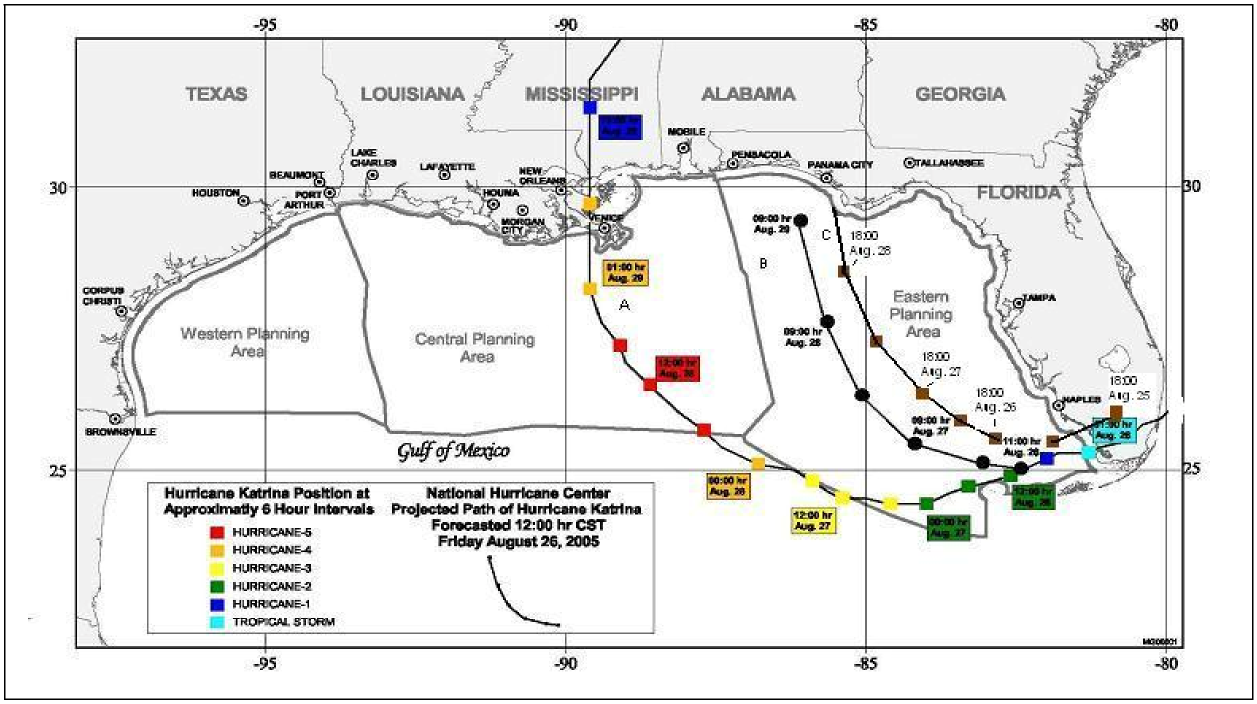


Figure 1B.1. Hurricane Katrina's track and intensity. Curve A: Best track, Curve B: National Hurricane Center predicted track, and Curve C: MM5 model predicted track.

Katrina's center pressure dropped rapidly from 968 mb to its lowest pressure of 902 mb within two days from 1 p.m. CDT 26 August to 1 p.m. CDT 28 August. Katrina's maximum sustained wind speed increased from 95 mph to 175 mph during this same period. It became a Category 5 hurricane about 170 miles southeast of the mouth of the Mississippi River, directly threatening New Orleans, Louisiana.

On 28 August, Katrina turned toward north-northwest toward the central Gulf of Mexico coast. During this period, the hurricane wind field expanded with a radius of 125 miles from the center and with tropical storm-force winds in a radius of 230 miles from the center (Figure 1B.2). Katrina made initial landfall as a Category 4 hurricane (at the southeastern tip of Louisiana near Buras) and moved toward New Orleans around 9:45 a.m. on 29 August

Hurricane's Impact

Hurricane Katrina had devastating effects on human life, property, and the oil and gas industries in the Gulf of Mexico, especially in the New Orleans area and along the Gulf Coast. It is estimated that 2000 lives were lost and $80 billion of damage to property occurred (en.wikipedia.org). Louisiana lost about 200 square miles of wetlands as a result of Hurricanes Katrina and Rita (www.nwrc.usgs.gov, 2006). Offshore oil and gas productions were disrupted when a total of 118 oil and gas platforms were destroyed. Of those, Katrina took 47 oil platforms. More than 25,000 offshore workers must be evacuated whenever a hurricane enters the Gulf of Mexico (www.mms.gov).

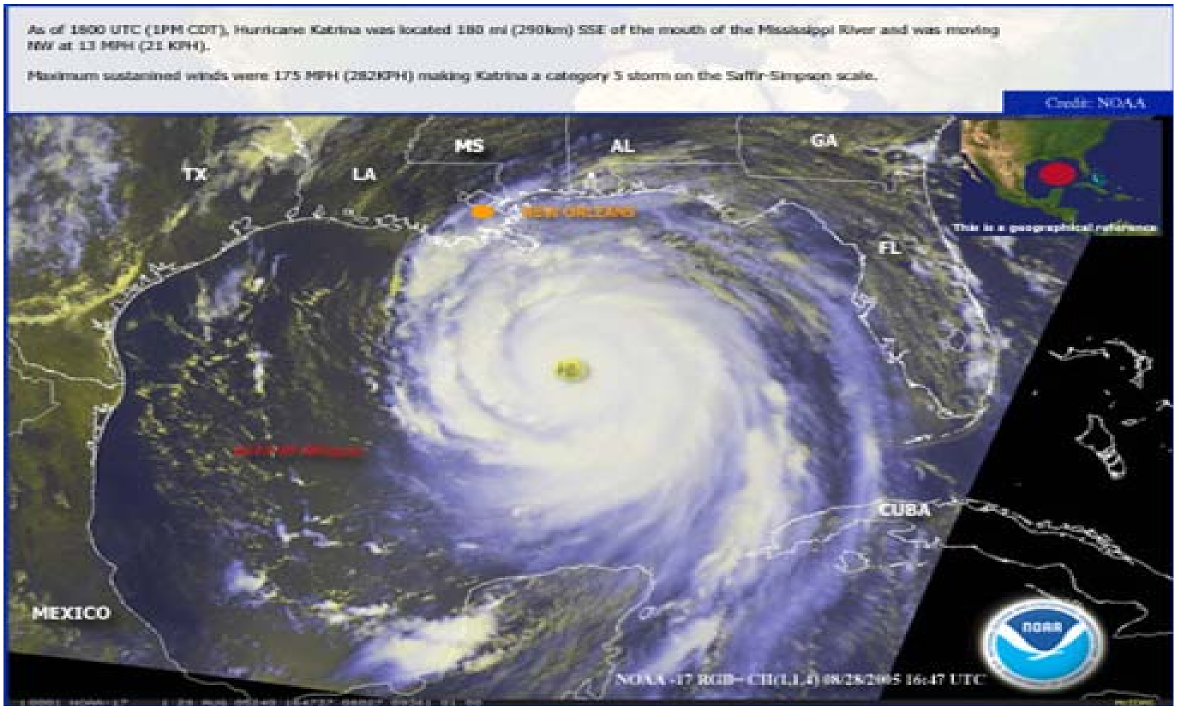


Figure 1B.2. Hurricane Katrina at 15:00 UTC was 180 miles south-southeast of the mouth of Mississippi River and moving northwest at 13 mph. The maximum sustained wind speed was 175 mph.

Model Simulations

Several numerical models have been used to predict a hurricane's track and intensity. Despite the considerable progress in recent years, predictions of a hurricane's track and intensity are still quite crude. For example, as hurricane Katrina entered the Gulf of Mexico from the South Florida, these numerical models all predicted that Katrina would veer toward northwest and make landfall somewhere in Florida. These numerical models, like the NHC's predictions, did not correctly predict the storm's path.

Model Domain and Initial Conditions

In this study, MM5 mesoscale model (www.mmm.ucar.edu) was used to simulate Hurricane Katrina's movement. The domain D2 is nested within the domain D1 and the domain D2 covers the Gulf of Mexico region. The horizontal grid resolutions are 63x41 and 55x52 for D1 and D2, respectively; there are 23 vertical layers. The D1 and D2 have horizontal grid spacing of 90 km and 30 km, respectively. NCEP data were used for the initial and boundary conditions. The MM5 model's simulated track is also shown in Figure 1B.1.

Results: Katrina's Impact on Offshore Infrastructure

Katrina's predicted tracks are shown in Figure 1B.1. Neither other numerical models nor the NHC's prediction correctly predicted Katrina's movement at this stage of development.

Four approaches can be used to obtain hurricane maximum wind speed and central pressure, i.e., meteorological measurement, dropsonde, satellite images or numerical models, which in turn can be used to estimate the number of the oil and gas platforms being destroyed. Table 1B.1 shows the maximum sustained wind speed, central pressure, and number of destroyed platforms for hurricane Ivan, Katrina, and Rita as well as damaged platforms for hurricane Lili. Katrina is a Category 5 hurricane and its maximum wind speed is 175 mph.

Table 1B.1

Maximum Sustained Surface Wind Speed, Central Pressure, and the Number of the Destroyed Platforms for Hurricanes Ivan, Katrina, and Rita, and Lili

Hurricane	Date	Wind Speed (mph)	Pressure	Platforms (destroyed)*
Rita	2005	179	897	65 (destroyed)
Katrina	2005	173	902	46 (destroyed)
Ivan	2004	138	982	7 (destroyed)
Lili	2002	144	938	6 (damaged)

*(Oynes 2006)

The data given in Table 1B.1 are used to correlate the number of destroyed oil and gas platforms with the maximum sustained surface wind speed or the hurricane's central pressure. Figure 1B.3 shows the effect of wind speed on the platforms. These wind speed data are plotted against the number of destroyed platforms in Figure 1B.3; the data can be fitted by using a linear regression. As shown in Figure 1B.3, when wind speed exceeds 135 mph, the number of platforms destroyed by the hurricane increase with increasing wind speed. On the other hand, when the maximum wind speed is less than 135 mph, it only causes damage to the platform. The maximum wind speed for hurricane Lili, which damaged six platforms, was 144 mph. The relationship between the hurricane central pressure and the number of the destroyed oil platforms in the Gulf of Mexico during the passage of hurricanes are plotted in Figure 1B.4. As seen from this figure, a linear regression fit to these pressure data and the number of the destroyed platforms is very good. When the hurricane central pressure exceeds 930 mb, the hurricane only causes damage to the platform. However, when the central pressure of a hurricane is below 930 mb, it will destroy the oil and gas platforms. It is more difficult to measure the wind speed than the pressure. This analysis shows that the hurricane central pressure is a good indicator of the number of platforms that will be destroyed by a hurricane.

A hurricane's central pressure is a variable that can be measured easily. Therefore, a hurricane's central pressure may also be used to establish the design criteria for offshore structures.

The dropsonde is usually used to measure a hurricane's central pressure. Satellite images can also be used to estimate the intensity of a hurricane. A widely used satellite measurement, the Dvorak technique developed in 1974 by Vernon Dvorak, estimates tropical cyclone intensity based solely on visible and infrared satellite images. Several agencies routinely issue Dvorak numbers for cyclones of sufficient intensity. In the case of Katrina, the Dvorak number is T7.2.

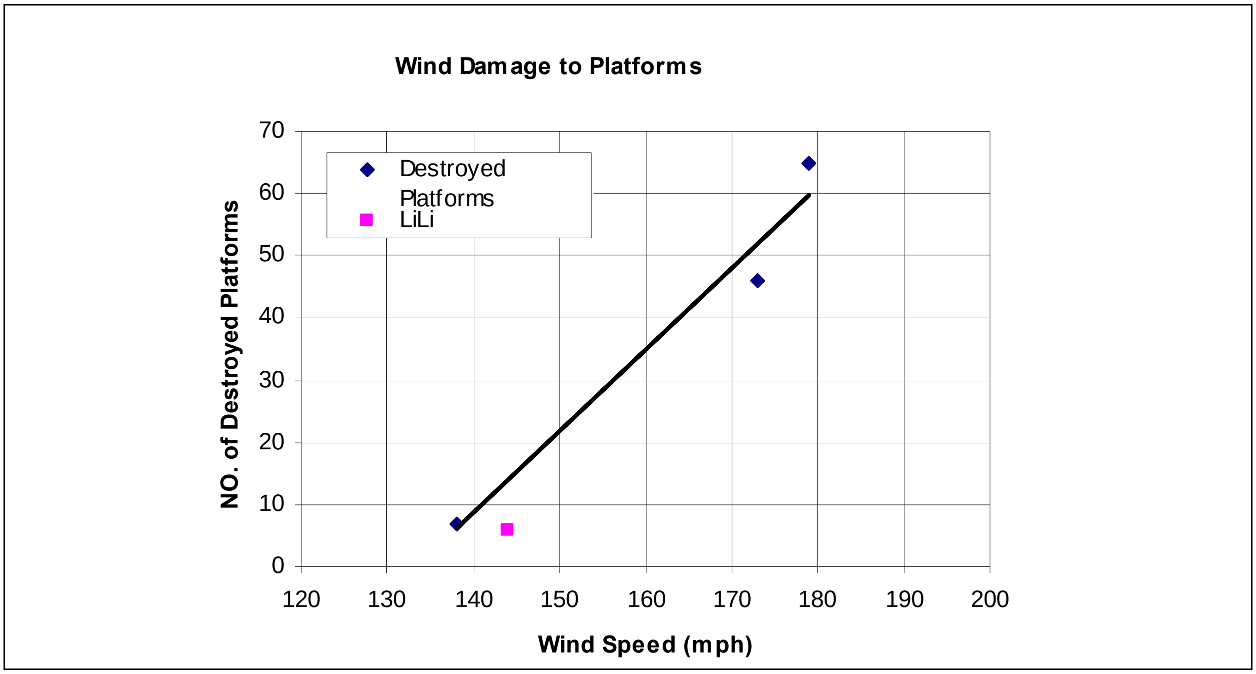


Figure 1B.3. Relationship between the hurricane maximum wind speed and the number of the destroyed oil and gas platforms.

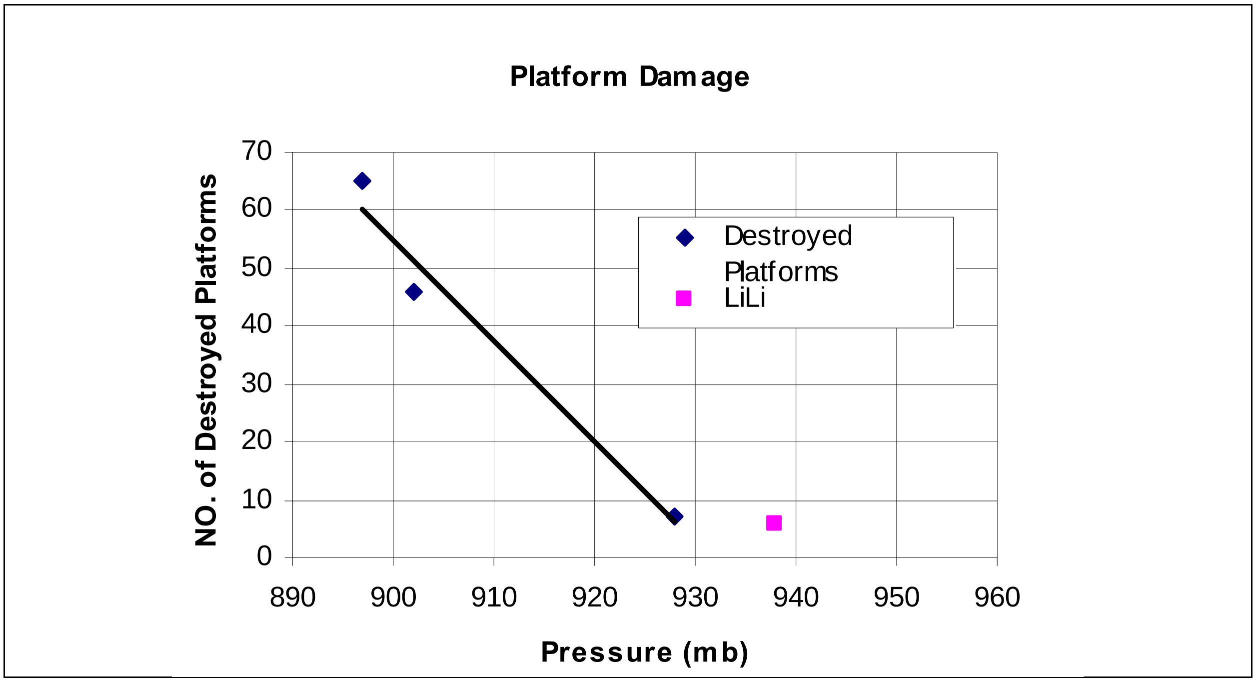


Figure 1B.4. Relationship between the hurricane minimum pressure and the number of the destroyed oil and gas platforms.

Conclusion

The accurate prediction of hurricane's track and intensity is important for saving lives and reducing the loss of property or oil and gas production. In this study, we have shown that techniques for forecasting hurricane's track and intensity are still very crude. The Katrina experience has further shown that numerical models, for both track forecasting and intensity forecasting, need improvement. Four methods used to obtain the meteorological variables are described, and a quick and easy-to-use method is developed to assess the impact of hurricane damage to the oil infrastructure in the Gulf of Mexico. This study shows that the relationships between the meteorological factors and the number of the destroyed oil and gas platforms in the Gulf of Mexico are strong. Therefore, the hurricane central pressure or wind speed can be used to estimate the number of the oil and gas platforms being destroyed offshore in the Gulf of Mexico. Hurricane central pressure, wind speed or satellite images may also be used to establish the design criteria for the oil and gas platforms. If the wind speed and pressure measurements are not available, the Dvorak technique (satellite images) may be used to determine the number of destroyed platforms. Currently, hurricane Ivan, Katrina, and Rita all exceed the 100-year design criteria for the oil and gas platforms.

References

Knabb, R.D., J.R. Rhome, and D.P. Brown. 2005. Tropical cyclone report: Hurricane Katrina 23–30 August 2005. National Hurricane Center. 20 December 2005

Oynes, C. 2006. Oil, Gas, and Society: Hurricane preparations after Katrina. Presented at Baker Institute, Rice University, 22 August 2006. Minerals Management Service.

National Hurricane Center: www.nhc.noaa.gov. Dvorak.

Dr. C. H. (Chester) Huang is a Certified Consulting Meteorologist in the Physical Sciences Group, Environmental Sciences Section at MMS. He is responsible for the review of air quality permit application, environmental impact assessment, and air quality and meteorological study programs. His expertise is in the areas of atmospheric boundary layer meteorology, turbulence and diffusion, air-sea interaction, wind energy, and air quality and meteorological modeling. His works have appeared in several textbooks on air pollution meteorology and have been widely cited in the scientific literature. He has numerous publications in journals, conference proceedings, and technical reports. Previously, he worked on the Federal Wind Energy program and the Department of Energy's nuclear facilities. His other experience includes work at Battelle National Laboratory, Navy Fleet Numerical Meteorology and Oceanography Center, and teaching at the University of Toledo, Ohio.

THE SO_2 AND NO_2 INCREMENT ANALYSIS FOR THE BRETON NATIONAL WILDERNESS AREA

Neil J. M. Wheeler, Stephen B. Reid, Kenneth J. Craig,
Sonoma Technology, Inc.

Click here to view the slide show that accompanied this presentation.

Introduction

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 were used to perform air quality modeling for past and present years. The model results were used to determine the amount of increment consumed in the BNWA.

Technical Approach

Meteorological Modeling

Meteorological modeling for these periods was performed by the Pennsylvania State University (PSU) with the PSU/National Center for Atmospheric Research Mesoscale Meteorological Model, Version 5, MM5 (Dudhia 1993; Grell et al. 1994). The modeling strategy included 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. Annual simulations for year 2000–2001 were modeled on national (36-km) and regional (12-km) domains. In addition, episodic simulations were performed on a 4-km nested grid to investigate the importance of horizontal grid spacing on model performance.

Emission Inventory Preparation

Three emission inventories were 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 1999 National Emission Inventory (NEI) were used. Projection to base line years was performed using state-specific growth factors generated with the EPA's Economic Growth Analysis System (EGAS), version 5.0. For source categories in the 1999 NEI not addressed by EGAS, including on-road mobile sources, growth factors were derived from EPA national emission trends. STI consolidated the databases and performed checks for completeness, duplication, and reasonableness. Emissions were speciated and temporally allocated, non-point sources were spatially allocated, and model-ready emissions files were prepared for the 2000–2001 year.

Episodic Air Quality Simulations

Six multi-day periods were initially selected for evaluating candidate modeling systems. Two air quality models, the California Puff (CALPUFF) model and the Community Multiscale Air Quality (CMAQ) model were applied for the six periods. The results of those applications were evaluated statistically and graphically, and the evaluations were compared to select the model that best replicated the SO_2 and NO_2 observed during those periods. Based on the analysis of model performance, the CALPUFF model was selected for performing the annual simulations needed for the increment analysis.

Annual Air Quality Simulations

Three annual CALPUFF simulations were performed 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 were performed and the results of these simulations were evaluated for model performance both statistically and graphically. Annual simulations of SO_2 with year 1977 OCS-related emissions and of NO_2 with year 1988 emissions were performed to establish the baseline concentrations.

Air Quality Assessment

An air quality assessment was performed to determine the amount of increment consumed in the BNWA. Receptors in the BNWA were identified and the annual average NO_2 concentrations at each receptor in the BNWA were 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 were calculated from the current (2000–2001) year and the 1977 baseline year simulations. Increments were calculated by subtracting the baseline year concentrations from the year 2000–2001 concentrations.

Results

The modeled annual SO_2 increment was not exceeded at any receptor within or around the BNWA. A decrease in annual SO_2 concentration was predicted almost everywhere within the CALPUFF receptor grid. The maximum allowable 24-hour SO_2 increment (5.0 $\mu g/m^3$) was not exceeded at any receptor within the BNWA; however, a maximum of 1.18 $\mu g/m^3$ of the increment was consumed. The maximum allowable three-hour SO_2 increment (25.0 $\mu g/m^3$) was not exceeded at any receptor within the BNWA. The maximum three-hour SO_2 increment consumed within the BNWA was 1.70 $\mu g/m^3$. The maximum allowable annual NO_2 increment (2.5 $\mu g/m^3$) was not exceeded at any receptor within the BNWA but a portion of the increment was consumed. The maximum annual NO_2 increment consumed within the BNWA was 0.10

μg/m^3. Because of the modeling system's tendency to underestimate concentrations, the actual increments may be larger than predicted.

References

Billings, R. and D. 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. Mon. Wea. Rev. 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.

Stauffer, D.R. and N.L. Seaman. 1994. On multi-scale four-dimensional data assimilation. J.Appl. Meteor. 33:416–434.

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.

Neil J. M. Wheeler is Vice President for Atmospheric Modeling and Information Systems at Sonoma Technology, Inc., where he is responsible for planning and leading air quality modeling studies and the application of meteorological and air quality models for use in regulatory and research studies. He has more than 32 years' practical experience in the atmospheric sciences and 25 years' experience with the development, application, and evaluation of meteorological and air quality models. 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.

A YEAR-LONG GULF COAST MESOSCALE MODELING STUDY FOR IMPROVING METEOROLOGICAL INPUTS FOR AIR-QUALITY MODELS

Jeffrey R. Zielonka and David R. Stauffer,
The Pennsylvania State University

Click here to view the slide show that accompanied this presentation.

Introduction

Accurate meteorological data is an essential aspect of air quality modeling. Standard meteorological observations are not available in spatial and temporal resolutions sufficient to resolve the processes driving the mesoscale circulations important for air chemistry and atmospheric transport and dispersion (AT&D). There is a need, therefore, for fine-resolution mesoscale modeling to fill in the spatial and temporal gaps in the observational data and create a four-dimensional gridded data set of the atmosphere for a particular area of interest. To create model simulations that best reflect the available observations throughout the model simulation periods, it is also necessary to optimally utilize any observational data sources available via a four-dimensional data assimilation (FDDA) approach. This paper summarizes the results of a year-long mesoscale modeling project funded by Minerals Management Service, in cooperation with Sonoma Technologies Inc., in which a high quality, high resolution (12-km), FDDA-assisted data set is created with the Penn State University/NCAR Fifth Generation Mesoscale Model (MM5) as described in detail by Grell et al. (1995) and Dudhia (1993). In addition to the one year of FDDA-assisted model simulations, three case studies are chosen to perform model investigations at higher horizontal resolution (4-km), for comparison to 12-km simulations, and investigate the use of a convective parameterization on a 4-km domain, and the use of a high-resolution (4-km) sea surface temperature (SST) product.

Methodology

To determine the best model configuration for the year-long study, a series of experiments were performed on a development case. These experiments included the implementation of an FDDA strategy that examined the effects of upper air and surface analysis nudging (Stauffer and Seaman 1990, Stauffer et al. 1991) and observational nudging of standard and special observational data sources (Stauffer and Seaman 1994) using the data shown in Figure 1B.5. In addition to the FDDA strategy, the sensitivity to different SST products was examined. From this set of experiments, a model configuration using upper-air analysis nudging, surface analysis nudging through the planetary boundary layer, observational nudging of standard and special observations, and the use of a MODIS SST product was chosen to run the year of model simulations.

One year of model simulations were then produced at 12-km resolution, broken into 5.5-day segments, with one half day of overlap allotted for model spin-up. This technique allowed for one year of seamless and continuous model data to be used as input to air chemistry models. For each 5.5-day model segment, mean absolute error (MAE) statistics were produced for the surface and all model layers, for vector wind difference (VWD), temperature (TEMP), mixing ratio (MIXR), wind speed (WSPD) and wind direction (WDIR). From these individual cases, a series of statistics was created over various timescales, including monthly, seasonal, and annual mean statistics to determine if there were any trends in model performance over these periods.

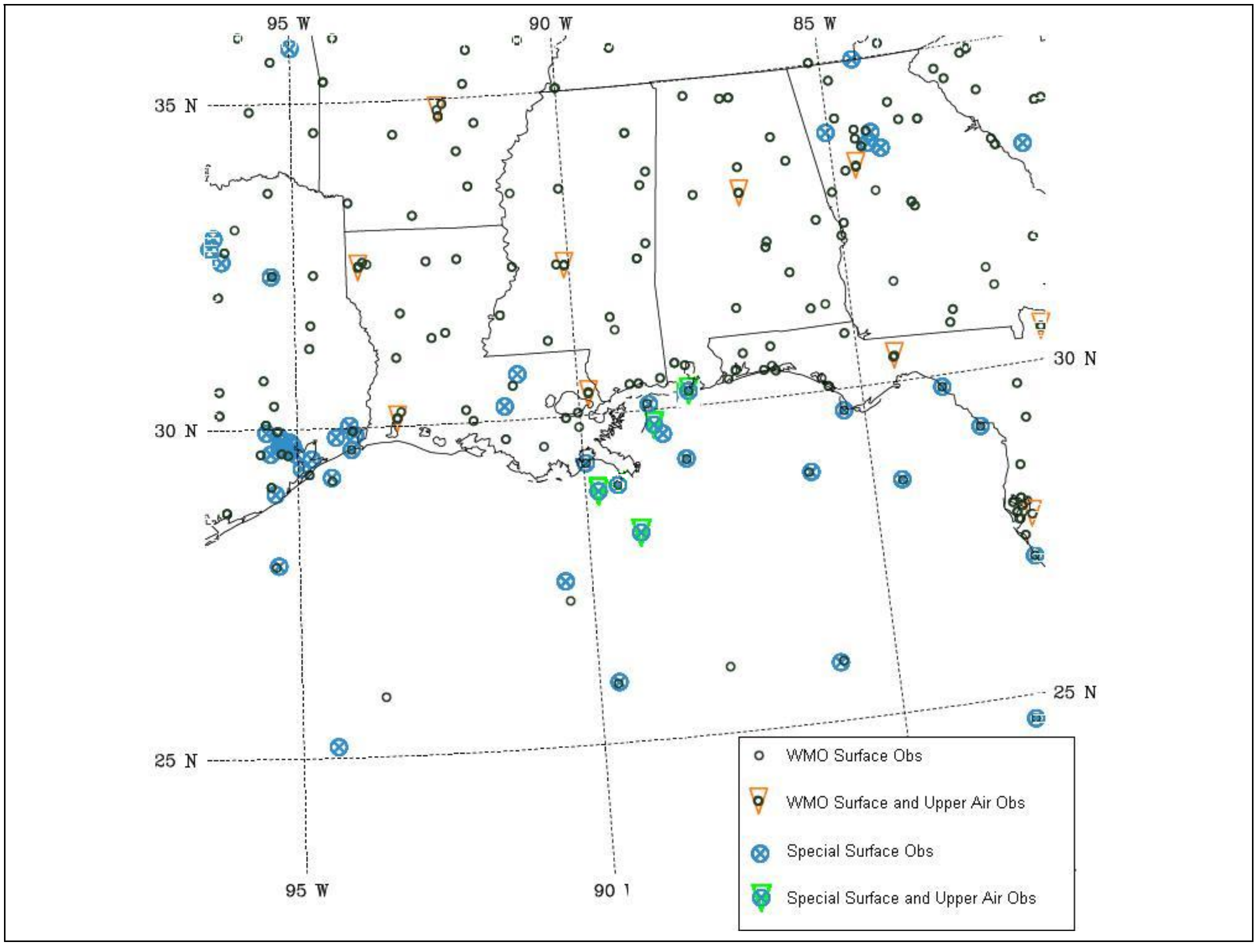


Figure 1B.5. Standard and special observation locations within the 12-km resolution domain. Observations symbols are broken into four separate categories, as denoted in the figure key.

Three cases were then chosen to perform experiments with a 4-km resolution model domain in such a way that the cases were representative of the many types of weather regimes for the region. Case 1 was defined as 12 UTC, 1 December 2000, to 00 UTC 7 December 2000, and was characterized by a cold frontal passage through the model domain, and strong, synoptically-driven flow. Case 2 was defined as 12 UTC, 1 March 2001 to 00 UTC, 7 March 2001, and included a stationary front residing within the model domain for approximately half of the case period, followed by conditions with weak synoptic forcing. Case 3 was defined as 12 UTC, 8 July 2001 to 00, UTC 14 July 2001. This case had weak synoptic forcing throughout the period, and included model-simulated sea breeze circulations during several days of the simulation. These three cases also represented three of the six pollutant episodes that were chosen by the project sponsor.

For each of these three cases, three experiments were performed. First was the control 4-km simulation allowing statistical and subjective comparison between it and the 12-km resolution simulation used in the year-long study. The second experiment used a convective parameterization on the 4-km resolution domain due to potential problems with explicit precipitation at this resolution (Deng and Stauffer 2006). Finally, the substitution of a high-resolution (4-km) MODIS SST product for a coarser-resolution (36-km) MODIS SST was investigated in the third experiment.

Results

The statistical results produced during the year-long study largely demonstrated patterns in model performance errors that were expected from a meteorological forecasting perspective. Figure 1B.6 is a histogram of the monthly average MAE for wind direction and temperature at the surface, in the boundary layer, and for all layers above the surface. As expected, the lowest direction errors at the surface occurred during the cool season, when the winds are stronger, and synoptic forcing predominated. Conversely, during the warm season when wind speeds are smaller, the wind direction errors were larger. For the temperature field, the errors showed the opposite pattern. During the cool season, when frontal passages occur more frequently and stronger horizontal gradients exist, the MAE values were larger than the warm season when there is much less horizontal variability in the temperature. Averaged over the entire year, the model accuracy for all fields in Figure 1B.7 was quite good and acceptable for air quality studies with respect to the model error criteria largely obtained for single case studies and discussed by Seaman (2000).

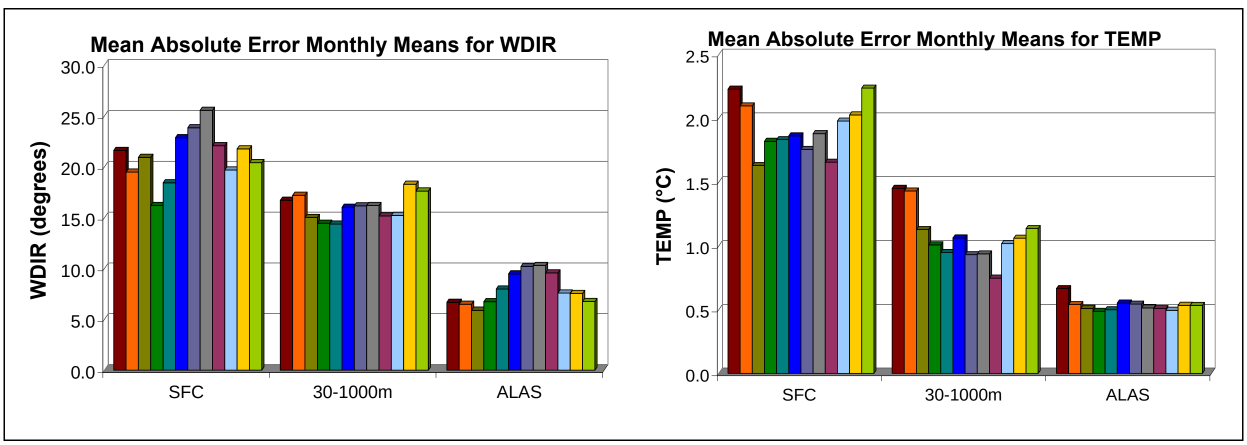
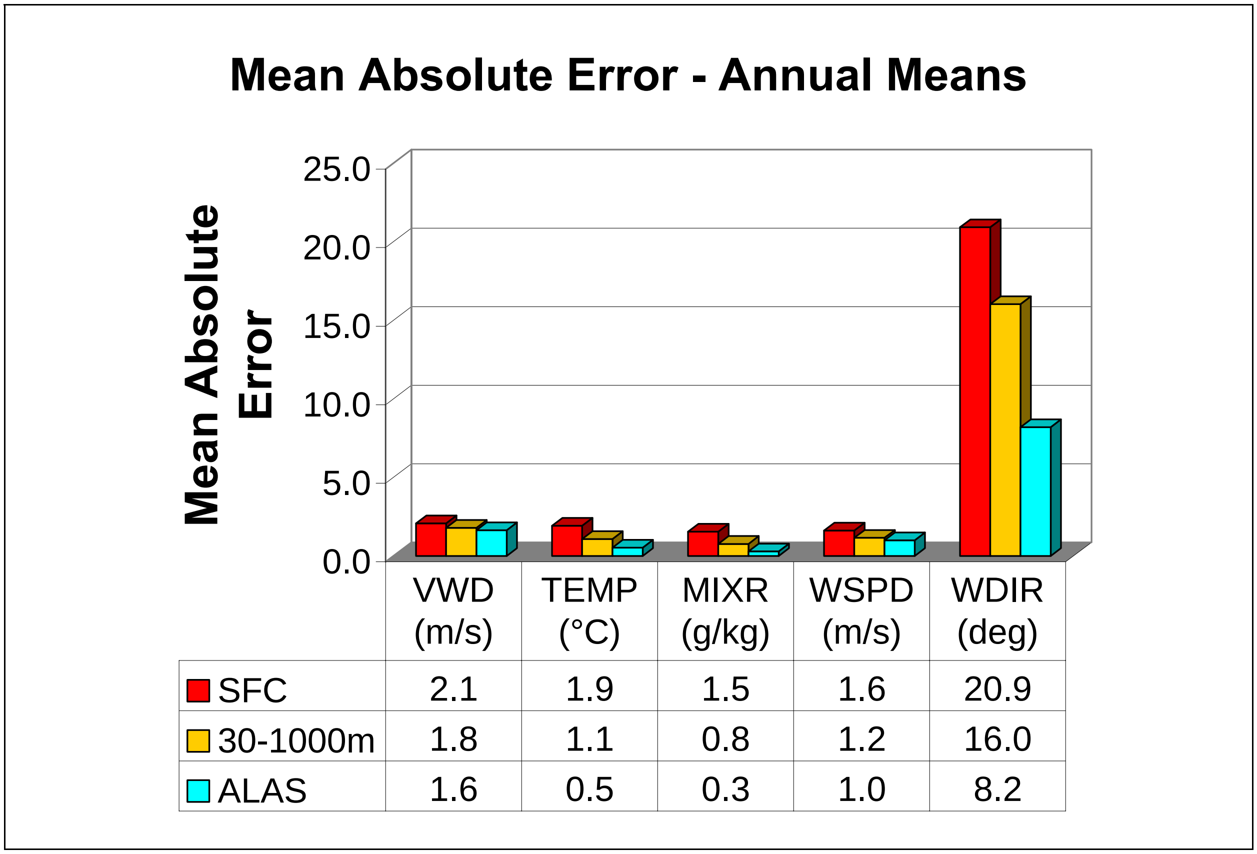


Figure 1B.6. Monthly mean values for MAE for WDIR (left) and TEMP (right) for the surface (SFC), 30–1000m above ground level, and all layers above surface (ALAS).



	VWD (m/s)	TEMP (°C)	MIXR (g/kg)	WSPD (m/s)	WDIR (deg)
SFC	2.1	1.9	1.5	1.6	20.9
30-1000m	1.8	1.1	0.8	1.2	16.0
ALAS	1.6	0.5	0.3	1.0	8.2

Figure 1B.7. Annual averages of model-simulated MAE fields for Gulf-Coast region for VWD, TEMP, MIXR, WSPD and WDIR.

The statistical comparison of the 12-km and 4-km resolution model simulations of the three selected cases shows very little difference in the model performance, with a slight advantage for the 12-km resolution simulations for most variables. This result is not unexpected, however, because similar results were obtained in Schroeder et al. (2006) in an area without complex terrain. In an area with more complex terrain features, greater statistical benefit is expected when using a higher-resolution model (Stauffer et al. 2007). Differences in the model outputs can be more readily seen, however, in the subjective analysis of the low-level model-predicted wind fields, especially during Case 3. During this case, there was daily unorganized convective activity, which was unresolved by the 12-km resolution simulation, but it was noticeable in the 4-km low-level winds (Figure 1B.8). In addition to the daytime convection, Figure 1B.8 also shows some differences in the model-predicted sea breeze fronts. Unfortunately, limited observational data prevented an adequate assessment of the sea breeze accuracy for either resolution, but the patterns and inland penetration appear to be reasonable at both resolutions. The 4-km domain had slightly further inland penetration, and stronger wind speed gradients compared to the 12-km domain. In addition, the 4-km simulation shows a much larger area of sea breeze influence across southeast Louisiana, as the sea breeze had penetrated past Lake Pontchartrain from the south and east by 21 UTC (1500 LST).

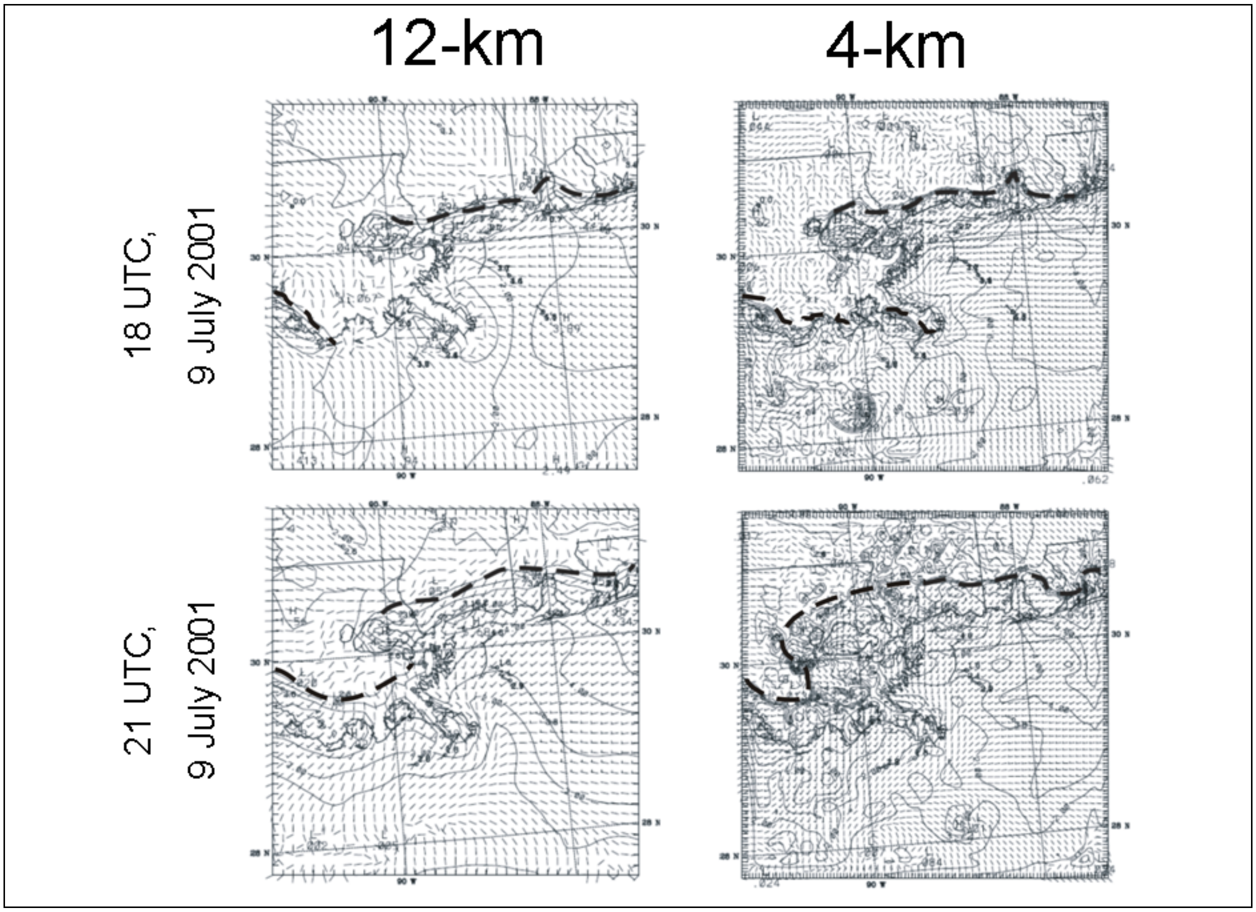


Figure 1B.8. Surface-layer wind simulations at 6 h (18 UTC, 9 July 2001) and 9 h (21 UTC, 9 July 2001) showing afternoon sea-breeze inland penetration denoted by dashed lines for 12-km vs. 4-km model simulations.

Convective parameterization on the 4-km resolution grid again showed very little evidence of statistical improvement, but there were substantial differences in the model-predicted precipitation fields during Case 3 (not shown). Without a convective parameterization, the model tends to predict localized and more intense precipitation, with large 24-hour amounts that may be anomalous based on observed 24-hour precipitation amounts (e.g. 11.2 cm in southern Louisiana). With parameterized convection, the precipitation pattern is much broader, but the precipitation amounts are much more reasonable when compared to observations. With explicit-only convection there is a risk that anomalous precipitation patterns can also adversely affect the low-level wind fields. As a meteorological input for an air quality model, this could cause more serious problems with the AT&D. The parameterized convection may also have some influence on the low-level wind fields since the sea breeze circulations in this case tended to start later in the day by ~3 hours, and were also not as strong as those in the simulation with explicit convection. This result could be caused by the more widespread precipitation across the domain.

The substitution of a 4-km resolution SST product for the 36-km resolution SST product used for the entire year of model simulations again showed very little benefit in the statistics, except for the low-level temperatures. Low-level temperatures tended to improve slightly with the higher-resolution SST, but other model levels and fields were generally unaffected, or produced slightly worse statistics with the higher-resolution product. Subjectively, the differences in the model outputs were nearly indistinguishable.

Summary and Conclusions

This modeling project produced one full year of high-quality, high resolution FDDA-assisted meteorological data inputs for air chemistry models, and these were verified using standard and special observational data sources. Statistically it was found that these modeled data performed well within the guidelines set by previous air-quality studies. The statistical evaluation also showed some monthly and seasonal trends in model performance that were expected and reasonable in both the wind and temperature fields.

A comparison between the 12-km and 4-km resolution experiments for the three cases showed no clear overall statistical advantage of a 4-km resolution simulation for this particular study. While there may be advantages in the finer mesoscale details of a 4-km resolution model output, it may only be truly beneficial for this study area on a case-by-case basis, and not for an entire year of simulations.

Changing the configuration of the 4-km resolution model showed noticeable improvements, especially when comparing the model outputs with and without convective parameterization, as anomalous precipitation fields were replaced with more widespread rainfall with more reasonable precipitation amounts. Even though there may be tradeoffs in the model output fields, it is recommended that a convective parameterization should be considered for a 4-km resolution domain if run automatically for an extended period of time such as this year-long study to protect against the atypical wind patterns that could exist as a result of anomalously heavy, localized precipitation. High resolution SST data showed slight statistical benefits in the low-level temperature fields, but no obvious benefits in any other statistics or subjectively analyzed fields for the case analyzed. If such a high-resolution data set is available, however, it is recommended that it be used, especially if low-level temperature is important for the chemistry.

References

Deng, A. and D.R. Stauffer. 2006. On improving 4-km mesoscale model simulations. Journal of Applied Meteorology 45:361–381.

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. 1995. A description of the fifth generation Penn State mesoscale model (MM5). NCAR Tech. Note NCAR/TN-398 + STR. 122 pp. [Available from NCAR Information Support Services, P.O. Box 3000, Boulder, CO 80397.]

Seaman, N.L. 2000. Meteorological modeling for air quality assessments. Atmospheric Environment 34:2231–2259.

Schroeder, A.J., D.R. Stauffer, N.L. Seaman, A. Deng, A.M. Gibbs, G.K. Hunter, and G.S. Young. 2006. An automated high resolution, rapidly relocatable meteorological nowcasting and prediction system. Monthly Weather Review 134:1237–1265.

Stauffer, D.R. and N.L. Seaman, 1990. Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic data. Monthly Weather Review 118:1250-1277.

Stauffer, D.R. and N.L. Seaman. 1994. On multi-scale four-dimensional data assimilation. Journal of Applied Meteorology 33:416–434.

Stauffer D.R., N.L. Seaman, and F.S. Binkowski. 1991. Use of four-dimensional data assimilation in a limited-area mesoscale model. Part II: Effects of data assimilation within the planetary boundary layer. Monthly Weather Review 119:734–754.

Stauffer, D.R, G. Hunter, A. Deng, J. Zielonka, P. Hayes, C. Kiley, and J. McQueen. 2007. On the role of atmospheric data assimilation and model resolution on meteorological accuracy and atmospheric transport and dispersion. Preprints, Chemical and Biological Information Systems Conference, Austin, TX, 8 – 11 January. 6 pp.

Mr. Jeffrey Zielonka is a research assistant at The Pennsylvania State University in Professor David R. Stauffer's numerical weather prediction (NWP) group. He recently finished his M.S. degree at Penn State working with Professor Stauffer on an MMS-funded project for the Gulf Coast region. The title of his thesis is "A Year-Long Gulf Coast Mesoscale Modeling Study for Improving Meteorological Inputs for Air-Quality Models." He received his B.S. in meteorology at the State University of New York at Oswego. Mr. Zielonka's research interests include mesoscale modeling, the added value of high-resolution satellite-derived sea-surface temperature products and use of convective parameterization at fine-grid resolutions, and mesoscale analysis and statistical verification of meteorological models (MM5, WRF) and atmospheric transport and dispersion models (HPAC/SCIPUFF).

Dr. David R. Stauffer is Associate Professor of Meteorology at The Pennsylvania State University. He holds B.S., M.S. and Ph.D. degrees from Penn State. He directs graduate-level research and teaches undergraduate and graduate-level courses in the Department of Meteorology. He leads his numerical weather prediction (NWP) group, consisting currently of four M.S.-level and two Ph.D. research faculty, and his graduate students, in basic and applied research projects spanning areas from military / defense to air quality / transport and dispersion. The scope of these projects ranges from fundamental scientific research to building operational NWP systems. Dr. Stauffer has more than 25 years of experience in meteorology, mesoscale numerical modeling, data assimilation and software development and management, and more than 23 years experience in air quality-related research. Dr. Stauffer is a principal developer of the Penn State University/National Center for Atmospheric Research MM5 Modeling System. He is a contributing developer of the Weather Research and Forecast (WRF) model and is widely recognized for his expertise in mesoscale NWP and data assimilation. Professor Stauffer's research interests include mesoscale modeling, probabilistic weather and model ensembles for atmospheric transport and dispersion, four-dimensional data assimilation (e.g., nudging, adjoint methods, objective analysis, variational methods and Kalman filters), physical parameterizations and coupled models (e.g., boundary layer, land-surface, parameterized versus explicit convection), and process studies (e.g., boundary layer and land-surface processes, meteorological modeling for air-quality and transport and dispersion applications, shallow and deep convection, terrain-forced circulations, coastal-zone meteorology, cold-air damming, tropical cyclones).

SIMULTANEOUS MEASUREMENTS OF ATMOSPHERIC VISIBILITY, PARTICULATE MATTER, AND MIXING HEIGHTS IN THE BRETON AREA IMPROVE SITE

S. A. Hsu and Brian W. Blanchard,
Louisiana State University

Click here to view the slide show that accompanied this presentation.

Introduction

In April 2004, a surface meteorology and visibility station was installed within the Delta National Wildlife Area at Pass-A-Loutre (PAL). The station record extended until August 2005 when it was completely destroyed by Hurricane Katrina. After months of negotiation, replacements were finally approved and the station re-deployed in September and October 2006 at PAL, where it currently continues in operation. This report presents preliminary results from data acquired at this station, along with several others along and offshore the central Gulf coast. Aspects of visibility, atmospheric stability, and boundary-layer structure are discussed.

Obstructions to Visibility

Hourly records with restricted visibility were classified by applying a modified version of the ASOS Obstuction to Visibility algorithm (NOAA 1998) to the air and dewpoint temperature values. The dewpoint temperature was derived from measured relative humidity using standard meteorological formulations (see, e.g., Hsu 1988). If the air minus dewpoint temperature was greater than or equal to 4°F, then haze was observed, if less then 4°F, fog. It was found that haze can occur in any month, but only infrequently (less than 2% of the time on average). Haze episodes are typically of short duration and do not impact visibility severely. Haze is often associated with high pressure and light winds; thus, the contribution of sea salts from wave breaking is negligible. This is also true of $PM_{2.5}$, concentrations of which are declining along the northern Gulf coast (see Figure 1B.9).

Fog displays a very seasonal pattern, with distinct peaks of occurrence during the winter months. During these peaks, fog is observed as much as 1/3 of the time, and often restricts visibility to near zero.

Atmospheric Stability

Average monthly conditions observed by National Data Buoy Center buoys 42007 and 42040 are employed to determine stability characteristics over the coastal waters. Values of stability length L were computed according to Hsu and Blanchard (2004a). Near-neutral (Class D) prevails throughout the year over almost all the area (42040, near the shelf break, becomes slightly unstable in December).

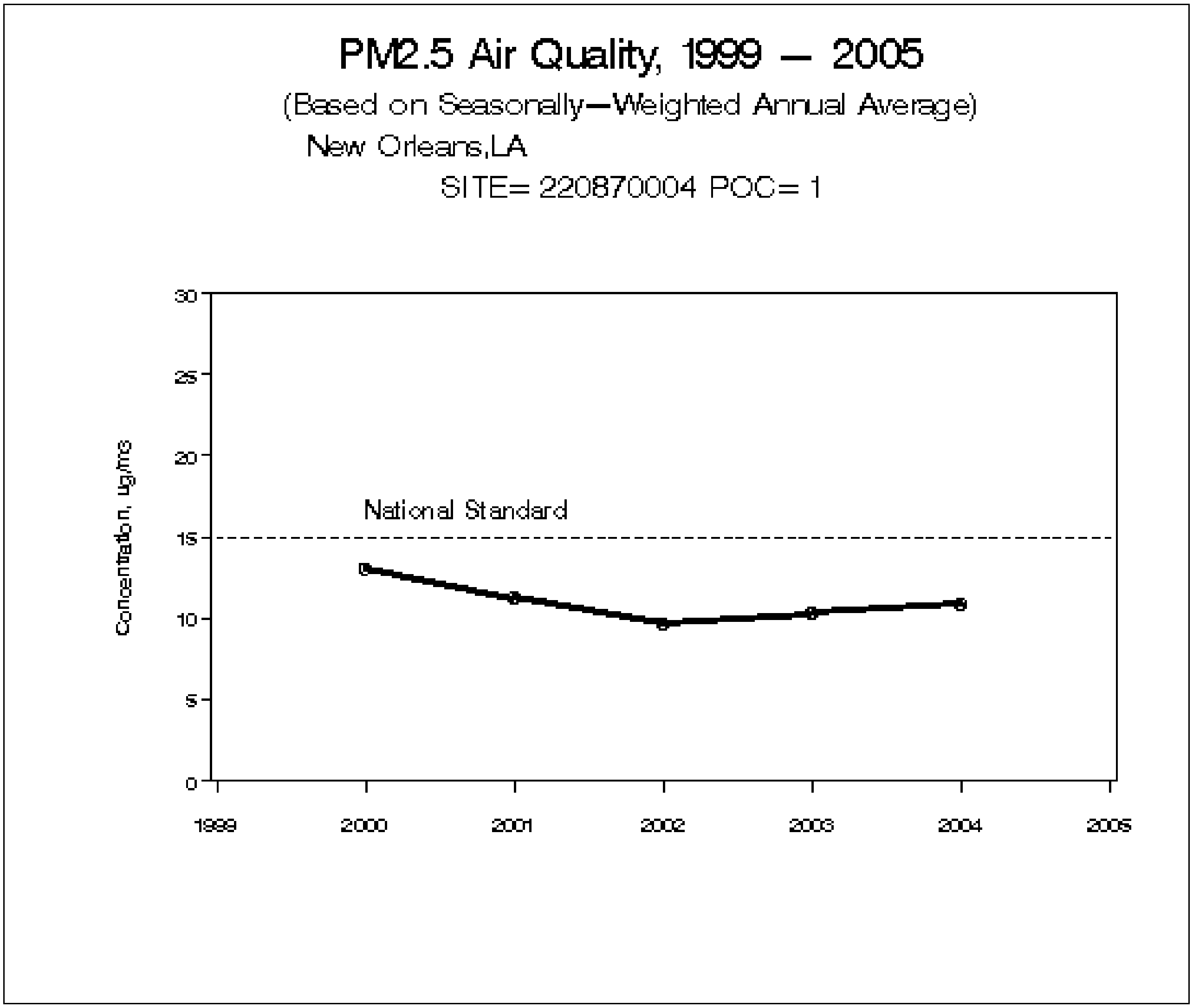


Figure 1B.9. Annual average $PM_{2.5}$ concentrations from New Orleans, Louisiana.

Stability in the coastal zone was studied using observations from station TAML1 (Tambour Bay) and the LUMCON Marine Center (LMC). For LMC, the θ_A method was used to assign P-G Categories (EPA 2000). Near-neutral stability also prevails in this area; TAML1 experiences more unstable conditions than LMC, likely due to differences in diurnal heating (i.e., 'cooler' land surfaces vs. 'warmer' SST).

Estimating Overwater Mixing Heights

The following experimental formulas are provided for estimating overwater mixing heights.

Application and verification of these equations is ongoing.

Under near-neutral conditions, from Arya (1999)

$$Z_i = 0.3 \frac{u_*}{f} \quad \textbf{(1)}$$

where f is the Coriolis parameter and from Hsu and Blanchard (2004a)

$$u_* = 0.2\left(U_{gust} - U_z\right) \quad \textbf{(2)}$$

From atmospheric thermodynamics (Hsu 1998),

$$Z_i = 125\left(T_{air} - T_{dew}\right) \quad \textbf{(3)}$$

the lower value of Equation (1) or (3) should be used.

Under unstable conditions (Hsu 2007)

$$\frac{Z_i}{|L|} = \left[2.9 + \frac{288}{|L|}\right]^{3/2} \quad \textbf{(4)}$$

where L is derived from the gust factor G (= U_{gust} / U_z) (see Hsu and Blanchard 2004b)

$$G = 0.825 + 0.371\left(1 + 3\left|\frac{z}{L}\right|\right)^{1/3} \quad \textbf{(5)}$$

In stable conditions from Venkatram (1980)

$$Z_i = 2.4 * 10^3 \, u_*^{3/2} \quad \textbf{(6)}$$

where u_* is obtained from Equation (2).

As discussed previously, atmospheric stability over the northern Gulf is predominantly near-neutral. Thus, the ventilation factor (the product of mixing height and mean mixed layer wind speed) is computed by applying Equation (3). As shown in Figure 1B.10, the ventilation factor is fair to excellent over the region, indicating good pollution dispersion potential.

LMC Profiler Verification

A separate task being conducted under this measurement program is devoted to verification of the LUMCON RASS / Profiler system by comparison with standard rawinsonde. Figure 1B.11 illustrates one example acquired in this effort. Very good agreement is seen between the profiler winds, RASS temperatures, and the sonde profile. Note that the mixed layer top is depicted by the virtual temperature profile on this occasion.

Conclusions

Surface meteorology and visibility observations along the north-central Gulf coast along with upper-air data from profiler and rawinsonde are used to study the atmospheric boundary layer structure and characteristics of restricted visibility. It is shown that fog has a much greater impact on coastal visibility than haze, both in frequency and intensity. Stability along the coastal zone and nearshore waters is predominantly near-neutral, and pollution dispersion potential good. Annual averages of particulate matter are below the national average and declining. Initial comparisons of the MMS-sponsored RASS and profiler data to standard rawinsonde yield very good agreement in wind and temperature values.

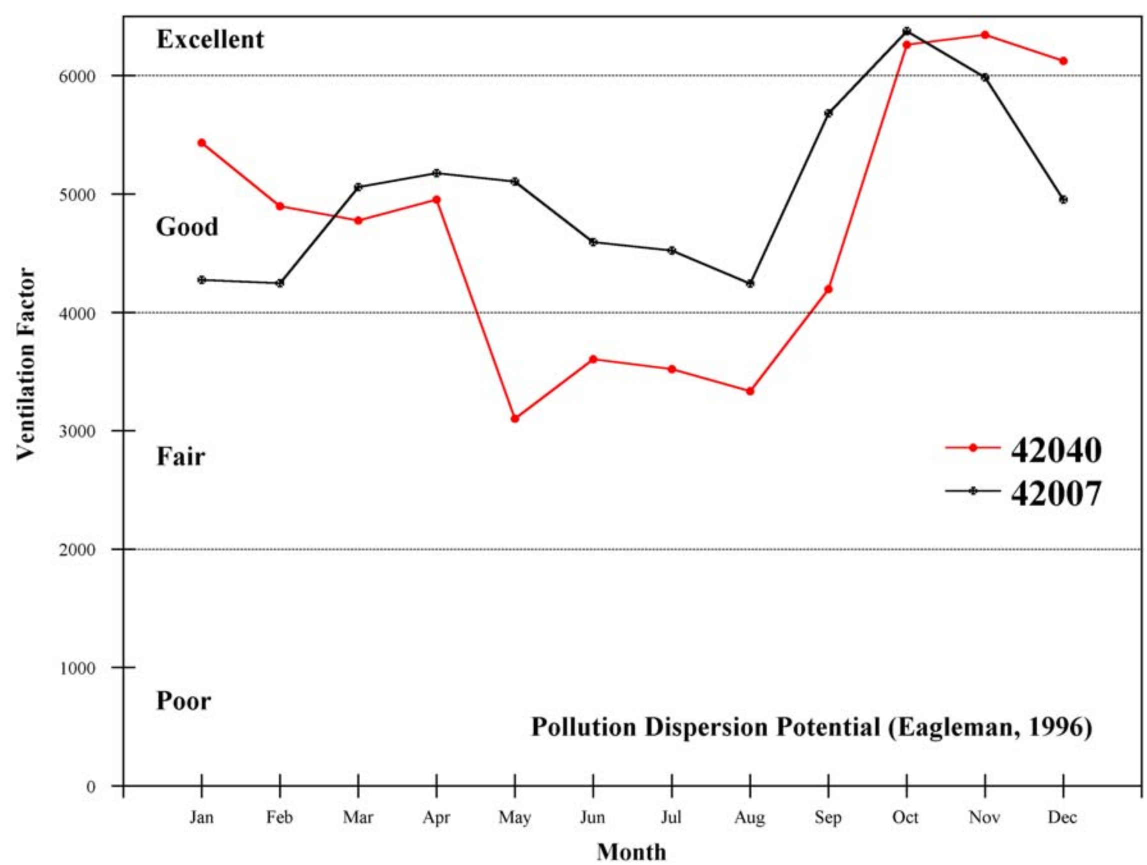


Figure 1B.10. Computed ventilation factor at NDBC buoys 42007 and 42040 east of the Mississippi River Delta.

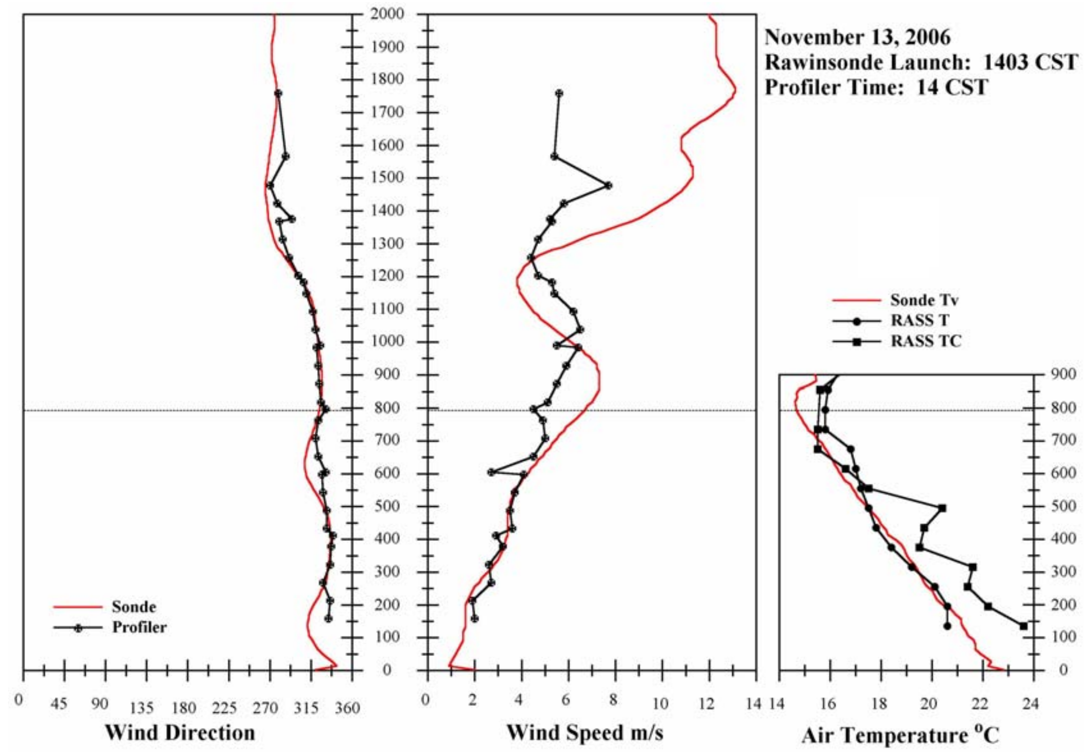


Figure 1B.11. Comparison of LUMCON RASS and Profiler data to rawinsonde.

References

Arya, S. P. 1999. Air pollution meteorology and dispersion. Oxford: Oxford University Press.

Eagleman, J.R. 1996. Air pollution meteorology. Kansas: Trimedia Publishing Co.

EPA. 2000. Meteorological monitoring guidance for regulatory modeling applications. EPA-454/R-99-005. February 2000.

Hsu, S.A. 1988. Coastal meteorology. San Diego: Academic Press.

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. 2007. Mixing height in unstable conditions: Measurements and parameterizations. 14th Symposium on Meteorological Observation and Instrumentation, JP2.4, American Meteorological Society.

Hsu, S.A. and B.W. Blanchard. 2004a. On the estimation of overwater buoyancy length from routine measurements. Environmental Fluid Mechanics 4:443–449.

Hsu, S.A. and B.W. Blanchard. 2004b. Estimating overwater turbulence intensity from routine gust-factor measurements. Journal of Applied Meteorology 43:1911–1916.

NOAA. 1998. Automated Surface Observing Network (ASOS) user's guide. March 1998.

Venkatram, A. 1980. Estimating the Monin-Obukhov length in the stable boundary layer for dispersion calculations. Boundary Layer Meteorology 19:481–485.

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, and currently holds the title of Texaco Distinguished Professor in Oceanography at the Coastal Studies Institute. His research interests are coastal and marine meteorology, air-sea interaction, boundary-layer meteorology, and pollution transport physics. Dr. Hsu has published extensively, including a textbook entitled *Coastal Meteorology*.

DETERMINATION OF NET FLUX OF REACTIVE VOLATILE ORGANIC COMPOUNDS AT THE AIR-WATER INTERFACE IN THE GULF OF MEXICO

Edward B. Overton, M. Scott Miles, and Buffy Ashton,
Department of Environmental Studies, Louisiana State University

Click here to view the slide show that accompanied this presentation.

The transfer of reactive volatile organic compounds from the sea surface to the atmosphere in the northern Gulf of Mexico (GOM) region may represent an environmentally significant source with respect to air quality problems in urbanized areas on the Gulf Coast. Ongoing programs, such as the MMS sponsored Gulfwide Emissions Inventory (Wilson, et al. 2004), will provide information on direct emissions resulting from OCS production activities. The impact on the environment of these production-related emissions, especially in comparison with natural emissions, remains an open question.

Globally, natural non-methane hydrocarbon emissions from the sea surface have been estimated at 2-50 x 10^{15}g/year (Shaw et al. 2003). This global total, however, obscures variations between locations. Clearly, some areas will have higher emission levels than others, and the GOM, with a high concentration of natural hydrocarbon seeps and high biological productivity, seems likely to be on the upper end of the curve. The emission from the sea surface of biogenic reactive volatile compound such as isoprene and acetone has been demonstrated (Fall et al. 2001). Reasonable extrapolation of the literature results suggests that isoprene emissions alone could be as high as 100kg/hour during daylight hours over the GOM region. Further, isoprene emissions may be only a small fraction of the total reactive hydrocarbons introduced to the atmosphere by natural processes. Ethene and propene have been identified as principle HRVOC (highly reactive volatile organic hydrocarbons) species in seawater both at the surface and at depth (Bonsang 2000). Interestingly, no alkenes are found in crude oils. As much as 40% of total NMHC (non-methane hydrocarbons, C2-C5) may be comprised of ethene (Plass-Duelmer et al. 1995). Studies of alkene and alkane emissions from the sea surface have not been convincingly correlated with insolation or chlorophyll content, suggesting photosynthetic or photochemical processes are not primary factors determining the concentration of alkanes and alkenes in seawater. Recent work on light hydrocarbons in near surface soil gas (Carney et al. 1996; Molecke et al. 1996) also showed the predominance of ethane and ethene in microseeps above oil and gas reservoirs. Given these results and the uncertainty with respect to the source of ethane and ethene at the sea-air interface, it is plausible that a significant fraction of ethene/ethane transported from the sea to the atmosphere may ultimately derive from deep-sea hydrocarbon seeps. Estimates of HRVOC emissions from GOM waters based on currently available HRVOC flux data would be suspect because of uncertainties in the ultimate sources of a large fraction of the total HRVOC load and the absence of GOM specific flux information. A number of factors—for example, insolation, algae/plankton density, biological productivity, sea state, organic input (oil and gas seeps)—may contribute to sea-air HRVOC emission rate. HRVOC emission rates specific to the Gulf of

Mexico would greatly improve the accuracy and reliability of air impact estimates for natural reactive volatile organics.

Accurate characterization of phenomena covering a large water body such as the Gulf of Mexico is a task ideally suited to remote sensing techniques such as satellite based photography. Available remote sensing techniques perform well in identifying the nature and extent of geographic features, but are less appropriate for quantifying a process like the net sea-air exchange of numerous reactive volatile organic compounds. The goal of this project is to associate quantitative HRVOC flux rates with easily observed geographic/oceanographic features with remote sensing techniques, namely, slicks from oil seeps, phytoplankton blooms, and "background" areas. By obtaining specific HRVOC flux information for these "typical" areas, one will be able to use remote imagery areal estimates to provide a much more accurate estimate of total HRVOC emissions from the sea surface. It will also provide the necessary information for making future estimates based on remote observations alone. A further benefit of this project will be to establish the relationship, if any, between "background" emissions of compounds such as ethane and ethene with natural oil and gas seeps. The source of these compounds is currently not well established, and it is possible that their widespread presence at low levels may be a manifestation of organic input by natural seeps.

Generally, HRVOCs have short atmospheric lifetimes and are classified as having atmospheric reactivities in categories IV and V, with Category I being the least reactive and V the most reactive. These high atmospheric reactivities have significant implications in efforts to determine accurate concentrations. Atmospheric concentrations are continually changing, and this implies a heterogeneous pattern in concentrations of the most reactive of the HRVOC compounds (like ethene). Additionally, because ethene is an important component of the HRVOCs, and has a very high vapor pressure, analytical trapping of ethene on adsorbents can be problematic. The net affect is that accurate analytical determination of atmospheric HRVOC concentration, including ethene, is difficult.

Efforts have been made to develop analytical methods for detection of HRVOC compounds using two distinctly different analytical strategies. The first strategy relies on the traditional method of trapping the HRVOC compounds on an adsorbent and transferring the sample to the laboratory for thermal desorption GCMS analysis. This method involves relatively long sample times and fewer samples collected per sample location. The second method involves use of newly developed instrumentation for the detection of HRVOC compounds at the site of sample collection. Analytical cycle times for the instrumentation are on the order of five minutes so that a significantly larger number of samples can be analyzed per sample location than is possible using the trap adsorption method. Year One of this project has been focused on working out the details of these two analytical procedures and field testing the instrumentation. Progress on these efforts will be reported. Additionally, the pros and cons of both methods will be discussed.

References

Bonsang, B. 2000. Air-sea exchanges of non-methane hydrocarbons. In: Transport and Chemical Transformation of Pollutants in the Troposphere, 9 (Exchange and Transport of Air Pollutants over Complex Terrain and the Sea). Berlin: Springer. Pp. 168–180

Carney, K.R., G. Hunt, N.J. Roques, and E.B. Overton. 1996. Simultaneous one-minute field analysis of hydrogen, helium, methane, ethane and carbon dioxide in soil gas samples. PittCon, Chicago, IL. March 1996.

Fall, R. T.G. Custer, S. Kato, and V.M. Bierbaum. 2001. New directions: The biogenic acetone-HCN connection. Atmospheric Environment 35:1713–1714.

Molecke, M.A, K.R. Carney, and W.J. Autin. 1996. Near surface gas mapping studies of salt geologic features at Weeks Island and other sites. Sandia Technical Report, SAND96-2502, Sandia National Laboratories, Albuquerque, NM.

Plass-Duelmer, C., R. Koppmann, M. Ratte, and J. Rudolph. 1995. Light nonmethane hydrocarbons in seawater. Global Biogeochemical Cycles 9(1):79–100.

Shaw, S.L. S.W. Chisholm, and R.G. Prinn. 2003. Isoprene production by *Prochlorococcus*, a marine bacterium, and other phytoplankton. Marine Chemistry 80:227–245.

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.

Edward B. Overton, Ph.D., is a professor in the Department of Environmental Studies at Louisiana State University. Research interests include development of field deployable analytical instrumentation; development of ultra fast and small GC instruments and instrument applications; technology transfer and commercialization; evaluation and interpretation of analytical, chemical, physical and toxicological data; and evaluation of data from oil and chemical spills for NOAA-HMRD.

SESSION 1C

HYDRATES

Chair: **Jesse Hunt, Minerals Management Service**

Co-Chair: **Bill Shedd, Minerals Management Service**

HISTORY OF MMS SEAFLOOR MAPPING PROJECT

Jesse Hunt, Jr., and W. W. Shedd,
Office for Resource Evaluations, Minerals Management Service

Personnel at the Minerals Management Service (MMS) in 1999 were mapping the seafloor reflector on 3-D seismic data to use in the tract evaluation process to determine fair market value of bids. It was noted that where large, deep-seated faults cut the seafloor, high positive and negative amplitude anomalies on the seafloor reflector were associated with the faults. Further research showed that large faults that cut the seafloor and had amplitude anomalies formed traps for discovered fields. It was hypothesized that the anomalies are associated with the effects of hydrocarbon seeps at the seafloor. A special project was initiated to map the seafloor reflector on all deep water 3-D seismic surveys on the slope. To date, approximately 186 surveys covering the shelf edge, the upper and lower slope, and the abyssal plain beyond the Sigsbee Escarpment have been mapped. The area of seafloor mapped is around 76,000 square miles (Figure1C.1). Some 2,600 such anomalies were mapped in the Central and Western Gulf of Mexico. It was noted that beneath the seafloor amplitude anomalies, such hydrocarbon indicators as bright reflectors or acoustic wipe out zones were associated with the faulting.

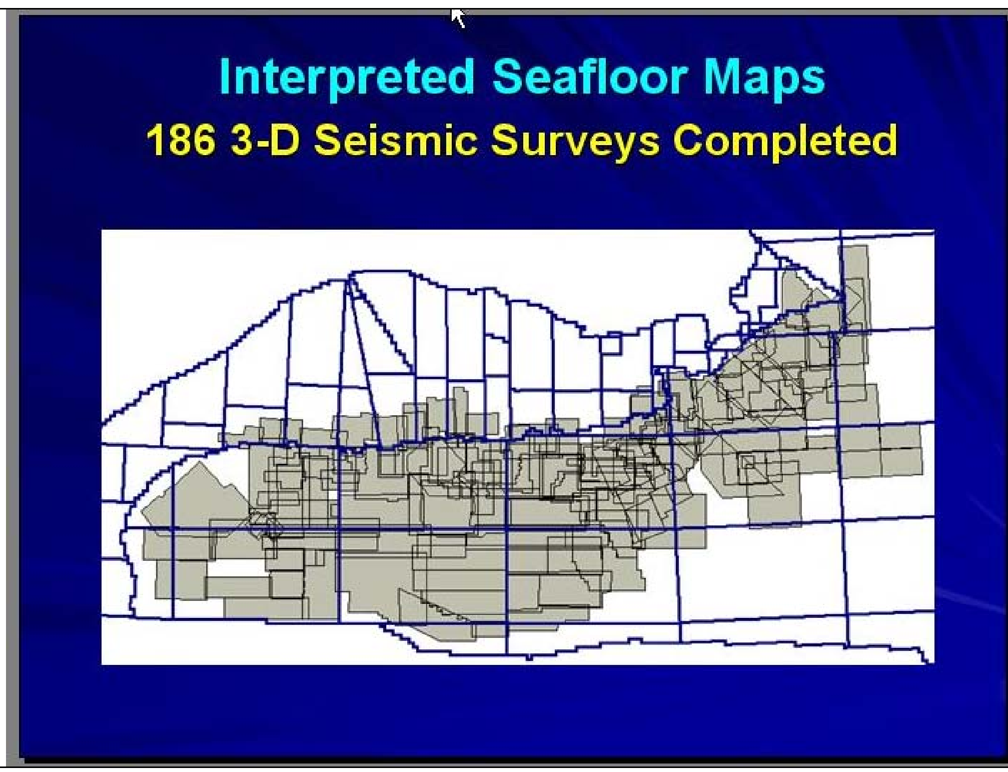


Figure 1C.1. Area of coverage of seismic seafloor maps in the Central and Western Gulf of Mexico.

In an effort to determine what the amplitude anomalies actually represent at the seafloor, a contract was let to Coastal Studies Institute at Louisiana State University to perform direct observations using Remote Operated Vehicles (ROVs) and submersibles. Two cruises were made using the *Johnson Sea Link* submersible to sites in less than 3,000 feet (914 m), which is the operational limit of the submersible. A total of 19 sites were visited, where video and still photography, as well as sampling, were performed (Figure 1C.2).

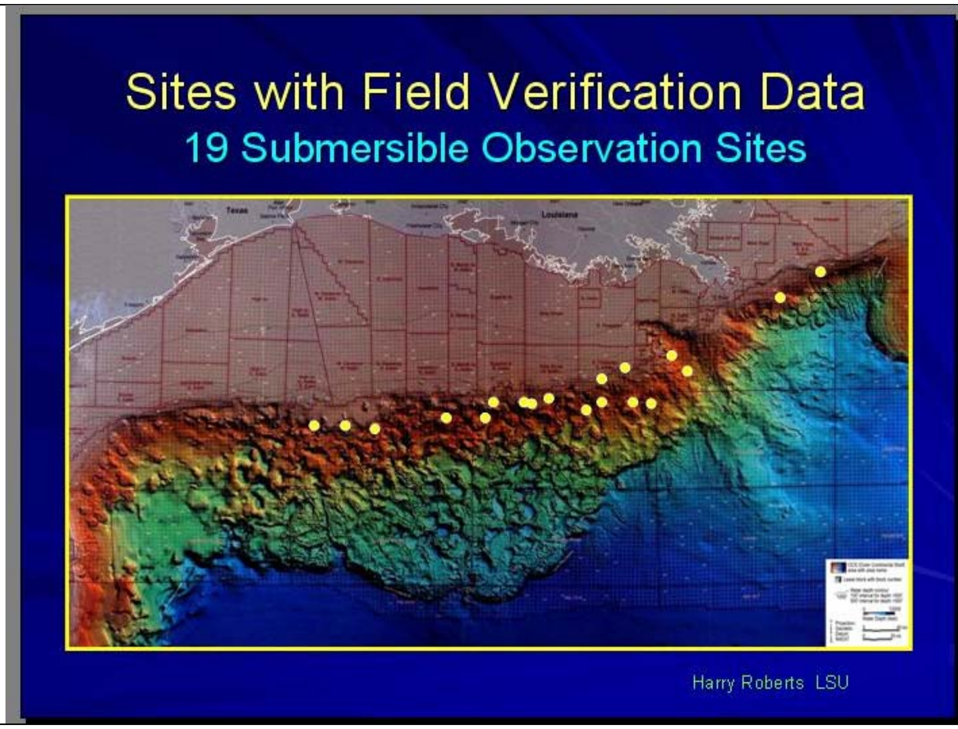


Figure 1C.2. Submersible dive sites to observe seafloor conditions at mapped anomalies.

It was found that the positive amplitude anomalies represent areas of hard seafloor caused by authigenic carbonates, clam and mussel shell beds, and gas hydrates exposed at the seafloor. The positive amplitude anomalies often had communities of chemosynthetic organisms associated with them. The small negative anomalies represent areas where the seismic velocity is less than seawater and active seep sites where gas saturation in the bottom sediments is prevalent.

One particularly interesting site that was studied with the submersible was a seep feature located in Mississippi Canyon Block 118 (Figure 1C.3). It is the easternmost occurrence of exposed gas hydrates in the Gulf of Mexico and has the largest exposed gas hydrate surface ever observed. Gas chemistry of the seeping gas and the hydrates indicates it is from a thermogenic source. The gas in the seeps and hydrates is anomalously high in propane (up to 14%). This site was selected by the Gulf of Mexico Hydrates Research Consortium as the location for a hydrates seafloor observatory that will observe the long term changes in the gas hydrates and the environmental conditions that affect them (Figure 1C.4). The observatory is being jointly funded by MMS, the National Oceanic and Atmospheric Administration's National Underwater Research Program, and the Department of Energy.

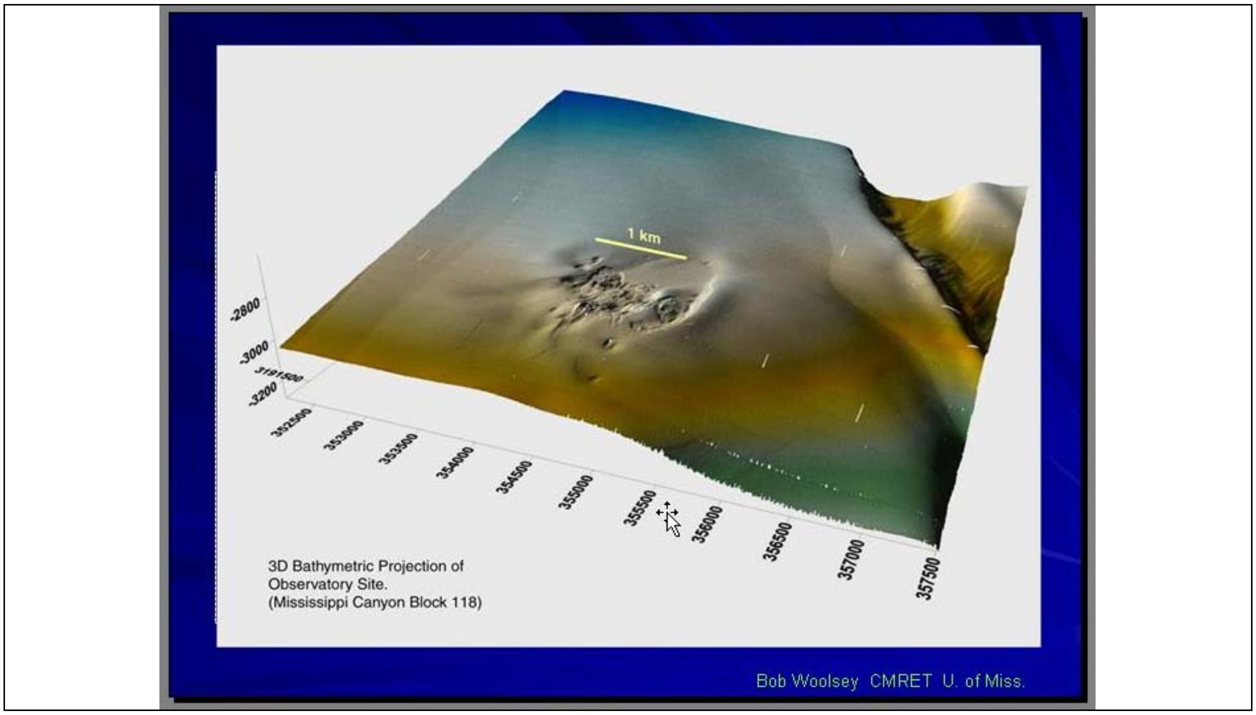


Figure 1C.3. 3-D bathymetric projection from side-scan sonar and multibeam fathometer data of the Mississippi Canyon seep feature.

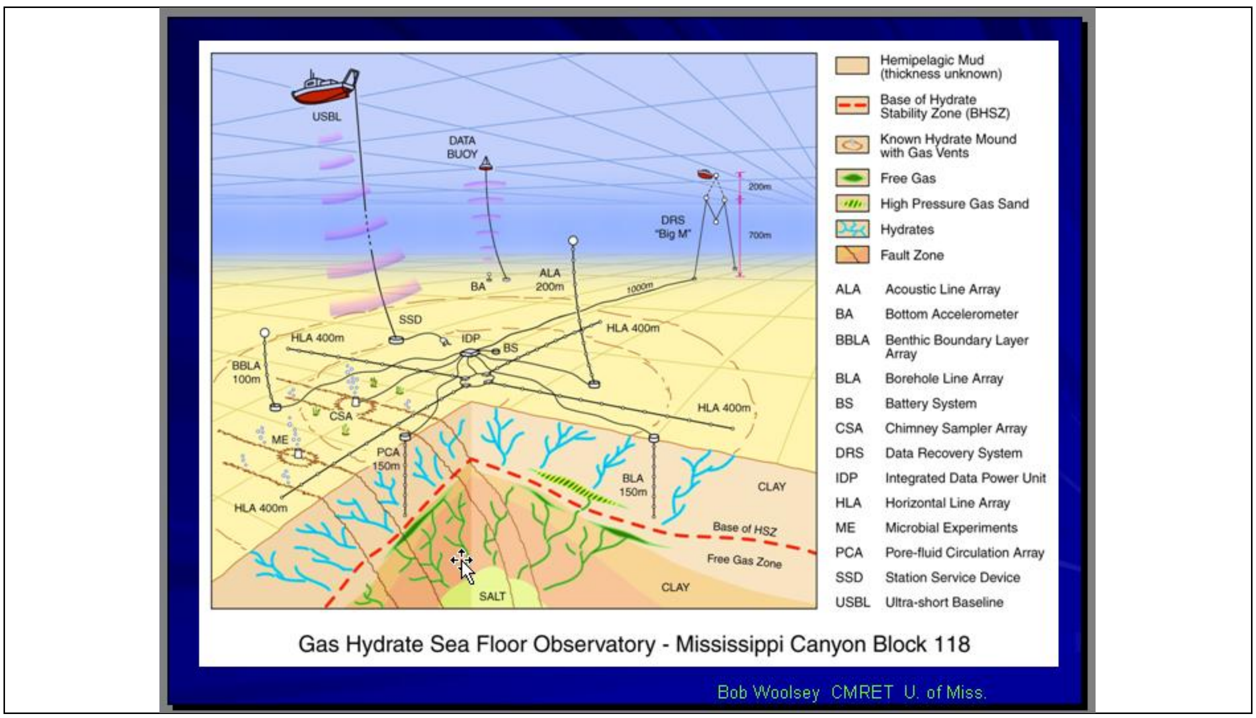


Figure 1C.4. Schematic diagram of the proposed seafloor hydrates observatory proposed for the MC 118 site.

SEAFLOOR REFLECTIVITY: AN IMPORTANT SEISMIC PROPERTY FOR INTERPRETING FLUID/GAS EXPULSION GEOLOGY AND THE PRESENCE OF SHALLOW GAS HYDRATE

H. H. Roberts, Coastal Studies Institute,
Louisiana State University

W. W. Shedd and Jesse Hunt, Jr., Office for Resource Evaluations,
Minerals Management Service

Research conducted over the last decade has focused on calibrating seafloor seismic reflectivity across the northern Gulf of Mexico (GOM) continental slope surface to seafloor geology indicates that the presence and character of seafloor bright spots can indicate gas hydrates in surface and near-surface sediments as well as locations of chemosynthetic communities (Figure 1C.5). It has become apparent that areas of seafloor reflectivity on the continental slope generally are responses to fluid and gas expulsion processes. Gas hydrate formation is related to these processes.

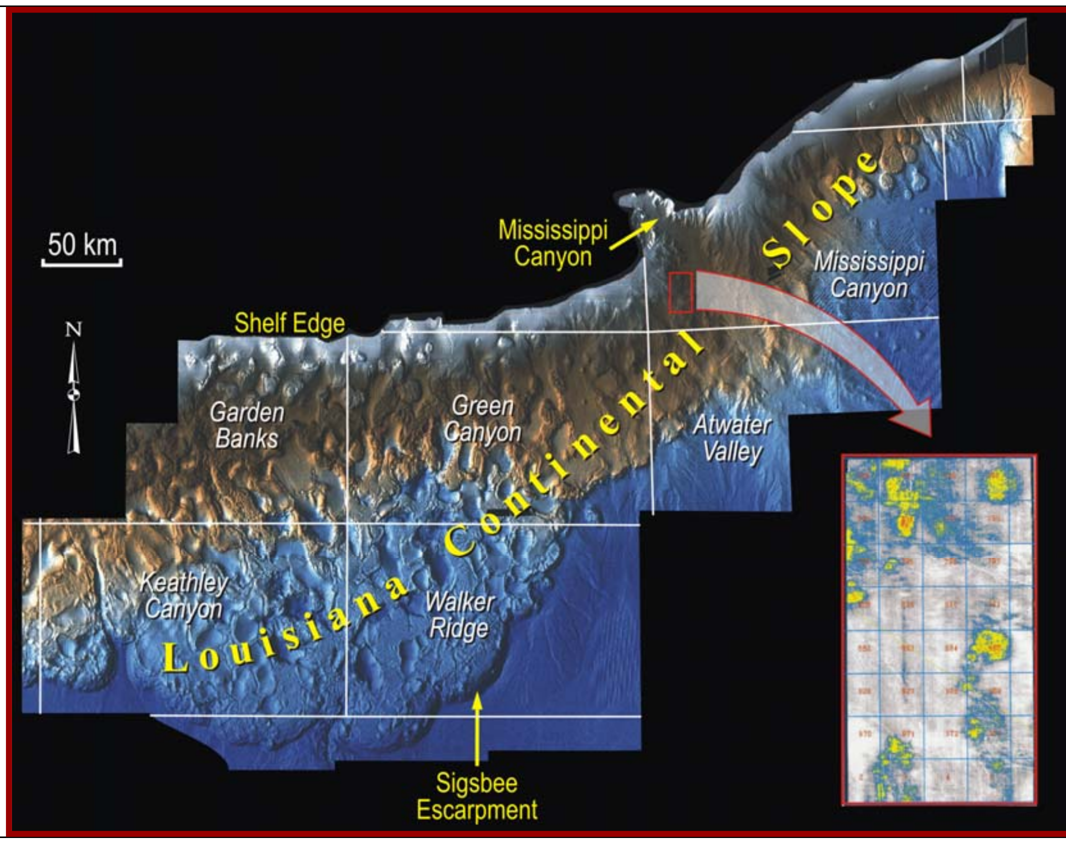


Figure 1C.5. A computer enhanced multibeam bathymetry image of the northern Gulf of Mexico continental slope showing a small sector of the Mississippi Canyon lease area and its seafloor bright spots or local areas of high seismic seafloor reflectivity on the continental slope surface. These areas represents sites of fluid-gas expulsion at the modern seafloor.

Seafloor investigations funded by the Minerals Management Service (MMS), through a cooperative agreement with the Coastal Marine Institute at Louisiana State University, has resulted in a study of seafloor reflectivity using the MMS Gulf-wide 3D seismic data base. Seismic surface amplitude anomalies across the northern Gulf's continental slope have been mapped, and numerous areas of both very high and very low reflectivity have been identified. Through research projects funded primarily by MMS and NOAA, manned submersible dives on many reflective sites have provided direct observations and samplings to calibrate actual geologic character of the seafloor to seismic reflectivity character. These investigations have led to a better understanding of the causes of surface reflectivity variations in both reflection strength and pattern. In nearly all cases where surface amplitude anomalies, identified from 3-D seismic data, have been calibrated to "ground truth" observations, these areas turn out to be sites where fluids and gases from the subsurface are reaching the modern seafloor. The fluids include formation water, brines, crude oil, and sometimes fluidized sediment. Biogenic methane and a variety of thermogenic gases are usually involved in the fluid-gas expulsion process.

Regional topography of the slope consists of basins, knolls, ridges, and mounds derived from the dynamic adjustments of salt to the introduction of large volumes of sediment over long time scales. Superimposed on this topography is a smaller class of mounds, flows, and hardgrounds that are the products of the transport of fluidized sediment, mineral-rich formation fluids, and hydrocarbons to the present sediment-water interface. Geologic response to the expulsion process is related both to the products being transported and the rate at which they arrive at the seafloor. Mud volcanoes and mudflows are typical of rapid flux settings where fluidized sediment is involved. Slow flux settings are mineral-prone. Authigenic carbonate mounds, hardgrounds, crusts, and nodules are common to settings where hydrocarbons are involved. Barite in the form of small cones, chimneys, and crusts may also be found where expulsion of barium-rich water occurs. In settings between mud-prone rapid flux and mineral-prone slow flux environments, unique conditions occur to support and sustain densely populated communities of chemosynthetic communities. These are the same areas where surficial exposures of gas hydrate have been observed and studied. Direct observation and sampling of these unusual geologic and biologic environments started in the mid-1980s using manned submersibles. To date, most submersible-supported research has been concentrated on the upper slope (<1000 m). However, fluid and gas expulsion features, chemosynthetic communities, brine seeps, and slope instabilities occur over the slope's full depth range as imaged on geophysical data and confirmed by both limited number of deep submersible dives and remotely operated vehicle (ROV) bottom imaging transects and samples.

Rapid-delivery expulsion systems generally build seafloor topography such as mud volcanoes and associated mud flows that transport down slope from an expulsion site or vent. They are commonly associated with deep-cutting faults, or migration is focused by subsurface salt bodies. Seafloor reflectivity patterns clearly distinguish rapid flux features. Precipitation of authigenic carbonates in the hydrocarbon-laced sediment flows and clam shells (lucinid-vesycomyid clams) left after exploiting the limited supply of hydrogen sulfide microbially generated in these deposits cause high seafloor reflectivity. Gas in the vent area causes low reflectivity and sometimes a phase reversal. Heat and perhaps high-salinity fluids transported during expulsion events change the boundary conditions for gas hydrate stability and force the boundary toward the seafloor. Therefore, if gas hydrate occurs in the migration pathway of a recently inactive system, it is likely to be a very thin, shallow deposit. In active venting situations, it is probable that no gas hydrate will occur in association with the vent.

In contrast to rapid delivery systems, short migration routes are common to slow-flux, or seepage, of hydrocarbon to the continental slope surface, and cementation of surficial sediments is wide spread across these systems. The process of cementation is associated with microbial communities that utilize the hydrocarbons and then produce authigenic carbonates as by-products. The most common carbonate mineral is Mg-calcite even though aragonite and dolomite also occur. These carbonate minerals share a common characteristic. They all are ^{13}C-depleted, indicating that ^{12}C, microbially separated from the hydrocarbons, is incorporated into the Ca-Mg carbonate molecules.

Moderate delivery rates of hydrocarbons to the modern seafloor provide the optimal set of conditions for gas hydrate formation at or near the seafloor. Under these conditions gas in continually supplied from the subsurface and the sulfate reducing zone is very thin or essentially at the seabed. Shallow-to-exposed gas hydrate deposits may be expected under these conditions. Seafloor reflectivity, as determined from 3-D seismic data, is highly variable for most moderate-delivery settings. That is, these sites support diverse and densely populated communities of chemosynthetic organisms and display scattered areas of seafloor lithification and may even display small areas of fluidized mud venting.

Table 1C.1 summarizes the relationships between seafloor reflectivity, as determined from 3-D seismic data, and geologic-biologic response.

Table 1C.1

Seafloor Reflectivity and Gas-Hydrate Domain

Gas-Hydrate Domain	Seafloor Reflectivity	Reflectivity Pattern	Seafloor Features	Gas-Hydrate Occurrence
Rapid fluid-gas delivery	Expulsion centers have low, positive reflectivity with common phase reversals Linear flows can be highly reflective	Circular expulsion center Linear flows radiating from expulsion centers	Gas-charged and/or gas-emitting expulsion centers Clam beds and nodular carbonates on flow deposits	None in active expulsion centers Subsurface flanks of expulsion centers
Moderate fluid-gas delivery	High spatial variability Phase reversals	Highly variable, frequently fault-aligned	Dense chemosynthetic communities, localized authigenic carbonates	Surface exposures, shallow subsurface
Slow fluid-gas delivery	Highly reflective surface No phase reversals	Broad areas of high reflectivity	Authigenic carbonate mounds and hardgrounds	Subsurface

For ten years, Harry H. Roberts was 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.

SITE SELECTION AND GEOLOGY OF KEY CHEMO III SAMPLE SITES

**H. H. Roberts, Coastal Studies Institute,
Louisiana State University**

**W. W. Shedd and Jesse Hunt, Jr., Office for Resource Evaluations,
Minerals Management Service**

The northern Gulf of Mexico continental slope is well known for hydrocarbon seeps and fluid-gas expulsion geology. Early studies of the northern Gulf of Mexico continental slope demonstrated widespread seepage with associated chemosynthetic communities as well as gas-charged sediments, authigenic carbonates, and mud volcanoes. Since the 1984 discovery of chemosynthetic communities in the Gulf, studies have been concentrated mostly on the upper continental slope in water depths < 1000 m, the maximum depth of most available manned submersibles. The Gulf's chemosynthetic communities are the most intensively studied and best understood of any cold seep communities in today's ocean. Community structure, basic biology, and life histories of the dominant animals and biogeographic variations are now known. However, prior to the summer of 2006, only a few hydrocarbon seep sites had been visited and sampled on the middle and lower continental slope. Differences in geologic setting and species composition below water depths of 1000 m pose important scientific questions concerning cross-slope and along-slope biologic variability and possible controlling factors. Advancing our understanding of middle-to-deep slope hydrocarbon seep-vent environments and their biologic communities is the overall goal of the project reported here.

During the period 7 May–2 June, an international team of researchers (biologists, geochemists, and marine geologists) studies 10 seep sites on the middle-to-lower continental slope using ALVIN. The dive sites ranged in water depth from 1070 m to 2775 m and were located from the eastern Gulf (N 27°38.8'; W 88°21.7') to the far western Gulf (N26°11.0'; W 94°37.4'), Figure 1C.6.

Success in finding chemosynthetic communities and deep coral sites can be attributed to a two stage data collection program initiated prior to the ALVIN dives. In October 2005 project personnel in conjunction with MMS geoscientists reviewed extensive volumes of 3D-seismic data using surface reflectivity, both strength, phase, and pattern of the surface reflector. In addition, fluid-gas migration pathways from the deep surface were identified in seismic profiles. The entire continental slope of the northern Gulf from DeSoto Canyon on the east to the Texas shelf to the west is covered with 3D-seismic data, some areas with multiple generations of overlapping data. These data sets are housed at MMS and used for source evaluation critical to the leasing process for oil and gas exploration and production. Because MMS is a sponsor of this project, these proprietary data were made available for site selection. By January 2006, eighty sites of potential chemosynthetic community occurrence were selected to address both potential depth dependant and geographic-dependant variations in the fauna. These sites were further prioritized to twenty candidates by March 2006. Nineteen of the sites were imaged during 11–25

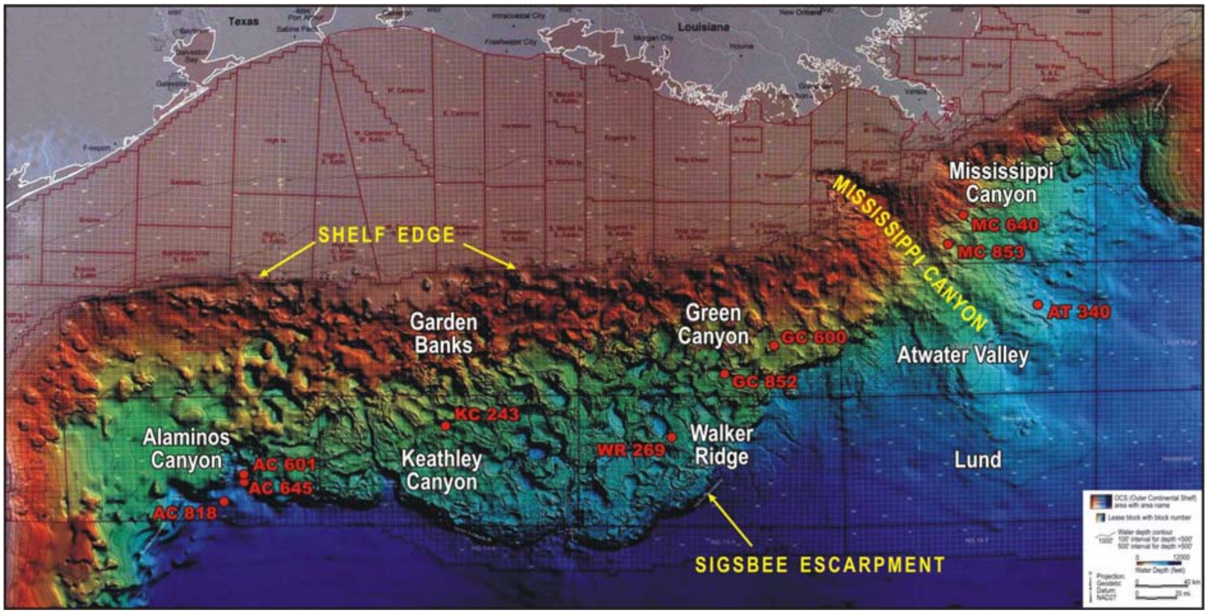


Figure 1C.6. This multibeam bathymetry image of the continental has been computer enhanced to apply 3D relief shading. The 10 hydrocarbon seepage sites visited by ALVIN in 2006 are superimposed on the slope map which also shows major oil and gas leasing areas.

March 2006 with a drift camera system comprising a digital camera, CTD, and USBL navigation pinger. Based on both characteristics of the geophysical data and bottom photography, ten locations were selected as ALVIN dive sites for the May-June cruise. Consistent with project objectives, the final dive plan represented sites from a wide range of water depth and geographic locations.

The RV Atlantis II with ALVIN and a full complement of researchers, left Key West, Florida on the morning of May 1st for a 26-day cruise across the Gulf arriving in Galveston on 2 June. At each of the ten dive sites, surface reflectivity maps and photographs taken during the drift camera cruise were used for dive planning. As a product of our dive site prioritization process, all sites had chemosynthetic communities. A minimum of dive time was spend traveling over featureless mud bottom.

This year's ALVIN cruise was the initial installment of a four-year study funded by NOAA's Ocean Exploration Program and Minerals Management Services (MMS). Twenty four ALVIN dives were made at the ten different sites. Chemosynthetic communities were found at all sites. However, Atwater Valley Lease Area, Block 340 [(AT 340) N 27° 38.8'; W 88° 21.9'], Green Canyon Lease Area, Block 852 [(GC 852) N 27° 06.3'; W 91° 09.9'], Alaminos Canyon Lease Area, Block 601 [(AC 601) N 26° 23.5'; W 94° 30.9'], and Alaminos Canyon Lease Area, Block 818 [(AC 818) N 26° 10.7'; W 94° 37.3'] were the key sampling sites. These sites generally had the most flourishing and diverse communities as well as the most interesting sea floor geology. Multiple dives focused intense biological and geological/geochemical sampling at these sites.

Sampling opportunities for building a better understanding of the biology, geochemistry, and geology of deep slope hydrocarbon seep habitats were provided by our four key sampling locations (AT 340, GC 852, AC 601, and AC 818). The At 340 and GC 852 sites were well-defined bathymetric highs supported by salt in the shallow subsurface. Both these sites were characterized by abundant authigenic carbonate blocks and pavements. Interspersed with these carbonates were well-developed and diverse chemosynthetic communities. In addition, the GC 852 site had both hard and soft corals seated on hard substrates composed of large blocks of authigenic carbonate. Characteristic of most thriving coral environments, currents were strong. Estimates of current speed made by ALVIN were in excess of 1 knot (> 50 cm/s).

Unlike the mound and ridge-like topography associated with the AT 340 and GC 852, the AC 601 site is geologically different and represents a breached anticlinal structure in the compressional regime of the lower slope. There is variable relief associated with AC 601 site. In the northwest part of the lease block a bathymetric low was found that was filled with brine (~90‰ salinity). This brine lake was ~4 m deep and ~180 m in diameter. A white precipitation floating in the brine and on the lake floor was found to be composed of barite. Dead organisms, including fish, were observed in the lake. Mussels, urchins, and holothurians were present on the "shore" around the lake. In contrast, the AC 818 site represents local leakage along a well-defined regional fault. Reducing sediment, clam beds, mussel beds, tube worms, and authigenic carbonates are localized along the fault. However, these communities, even though moderately complex, are rather limited in a real extent.

For ten years, Harry H. Roberts was 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.

A SEA FLOOR OBSERVATORY FOR REAL-TIME INVESTIGATION OF GAS HYDRATES

J. Robert Woolsey and Carol B. Lutken,
MMRI, School of Engineering, University of Mississippi

Click here to view the slide show that accompanied this presentation.

The Gulf of Mexico Gas Hydrates Research Consortium, managed by the Center for Marine Resources and Environmental Technology, University of Mississippi, is in the final stages of establishing a multi-sensor Gas Hydrate Sea Floor Observatory for long-term monitoring and investigation of hydrates and related hydrocarbon systems in the northern Gulf of Mexico, Salt Basin province. Gas hydrates are ice-like crystalline compounds composed of gaseous hydrocarbons (mainly methane) and water, formed under high pressure (>750 psi) and cold bottom temperatures (4–7° C) typically found at depths greater than 500m in the Gulf of Mexico.

The consortium, consisting of researchers from academia, industry and government, has been involved in design and development of a variety of tools and sensors and the management geophysical and geochemical surveys for site investigation/location of an appropriate observatory site. Principal citing criteria included permissive geology, outcropping hydrates, and venting hydrocarbon fluids to the water column, with water depths less than 1000m. Final selection was a hydrate mound site in Mississippi Canyon, Block 118, 850m water depth, located approximately 100 miles south of the Mississippi Coast.

The observatory project, currently in the installation phase, will on completion employ a variety of multi-sensor arrays providing more-or-less continuous monitoring of hydrographic, geophysical, geological and biogeochemical processes in the general proximity of the mound site. The complement of seismic/acoustic arrays consist of; 1) a 200m hydrophone Vertical Line Array, lower water column; 2) an 800m, 4-Component Horizontal Cross Array (pressure and shear wave sensing), bottom deployed; 3) and, a 150m borehole Vertical Line, 4-C Array. They are designed for autonomous operation on acoustic energy derived from surface noise, from passing ships and storm waves (pressure), and sea floor, low level seismicity (shear) common to the Salt Basin. Thermal gradient data will be monitored via a borehole thermistor array, and pore fluid chemistry via osmotic-pumping from horizons of interest within the sedimentary section. A number of successfully tested lower water column/boundary layer, hydrocarbon sensor arrays will be employed in a similar autonomous fashion.

The principal purpose of the observatory is to develop a better understanding of the near-seabed hydrocarbon system within the hydrate stability zone. The objective is to model phenomena related to the transit of hydrocarbon fluids through the host sedimentary section via structural conduits and the formation/dissociation of gas hydrates within the stability zone. Areas of primary interest include hydrates as: 1) a hazard to bottom founded, oil industry installations (pipelines, rig foundations, templates, etc.); 2) a potential future abundant energy resource and, 3) a source of greenhouse gases (CH4 and CO2) with potential impact on regional and global climate. A secondary function of the 4-C Horizontal Cross Array installation will be to serve in the detection and monitoring of major surface disturbances such as storm wave centers (hurricanes), their movement and intensity, and earthquakes, epicenters and intensity.

The observatory will be battery-powered, the data initially accessed via a submerged, pop-up buoy system, with fiber optic connection to sea floor installations. Full potential of the station will be realized once commercial cable access becomes available in the eastern Gulf. This will enable; 1) continuous, remote, real-time monitoring/access to critical data; 2) ability to match cause and effect observations in real-time, enabling linking of geological/environmental events; and 3) operational efficiency, eliminating the need for frequent surface vessel scientific/service related transits to and from the observatory site.

James Robert Woolsey, Jr., is a graduate of Mississippi State University and received his Ph.D. in geology at the University of Georgia. He served as a naval officer and aviator, working primarily with anti-submarine warfare, and attended the Naval Post Graduate School, where he studied ocean engineering. Prior to joining the School of Engineering at the University of Mississippi in 1980, Dr. Woolsey served for six years as a private contractor for industry and the United Nations, working with marine mineral resource and related environmental engineering projects. Since 1982, Dr. Woolsey has served as Director of the Mississippi Mineral Resources Institute (MMRI), devoted to the responsible development of the state's mineral resources. In 1988, his responsibilities were expanded, on appointment as Director of the Center for Marine Resources and Environmental Technology (CMRET), a program established through the U.S. Department of Interior, Minerals Management Service. The program was developed primarily to conduct projects of research and investigation of offshore energy/mineral resources and related environmental studies. More recently, Dr. Woolsey has assumed the additional responsibility of Division Director for the Seabed Technology Research Center within the new NOAA National Institute for Undersea Science and Technology based at the University of Mississippi. This endeavor is currently focused on the research and development of new ocean observing and survey systems technology, in keeping with the NOAA mandated mission.

SESSION 1D

AIR QUALITY II

Chair: **Holli Ensz, Minerals Management Service**

Co-Chair: **Robert Cameron, Minerals Management Service**

THE YEAR 2005 GULFWIDE EMISSION INVENTORY STUDY

Richard Billings and Darcy Wilson,
Eastern Research Group, Inc.

Click here to view the slide show that accompanied this presentation.

Introduction

This study builds upon several previous MMS air quality emissions inventory efforts for the Gulf of Mexico 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*. The Gulfwide Inventory is a base year 2005 air pollution emission inventory for all OCS oil and gas production-related sources in the Gulf of Mexico, including non-platform sources. Pollutants covered in this inventory are the criteria pollutants—carbon monoxide, nitrogen oxides, sulfur dioxide, particulate matter-10 (PM_{10}), $PM_{2.5}$, and volatile organic compounds; as well as greenhouse gases—carbon dioxide, methane, and nitrous oxide.

Development of the 2005 Offshore Platform Emission Inventory. The 2005 Gulfwide Offshore Activities Data System (GOADS-2005) Visual Basic program was provided to lessees and operators of federal oil, gas, and sulfur leases in the Gulf of Mexico OCS Region to collect monthly activity data for offshore platforms. A workshop was held in New Orleans, Louisiana, 13 October 2004, to discuss and explain the information collection and reporting procedures. Details on the data collection effort can be found at www.gomr.mms.gov/homepg/regulate/environ/airquality/goad.html.

The original activity data submittal deadline was extended from 22 April 2006, to 21 May 2006, for companies that requested an extension. Files continued to be provided up until 20 December 2006. All told, activity data were submitted for 1,579 active platforms by 114 companies. For the 2000 inventory, 90 companies submitted activity data for 2,873 active platforms. Table 1D.1 summarizes the number of active equipment records provided for 2005, compared to the number provided for 2000. The first round of quality assurance/quality control is complete on the majority of the data records, and initial emission estimates have been generated using emission factors published by the U.S. Environmental Protection Agency (U.S. EPA) and Emission Inventory Improvement Program (EIIP) emission estimation methods.

Development of the 2005 Non-Platform Emission Inventory

The non-platform sources fall into three engine categories: marine diesel engines, residual-fueled steam ships, and aviation engines. For the 2005 inventory, emission factors for marine diesel

Table 1D.1

Comparison of Platform Equipment Records for 2005 and 2000

Equipment Type	Number of Units in 2005	Number of Units in 2000
Boilers	700	637
Diesel Engines	2,860	2,982
Flares	111	90
Glycol Dehydrators	368	416
Natural Gas Engines	2,265	2,314
Natural Gas Turbines	443	379
Vents	1,004	783

engines were obtained from the Swedish Environmental Agency; emission factors for residual oil-fueled vessels were obtained from the U.S. EPA; and emission factors for helicopters were obtained from the California Air Resources Board, helicopter manufacturers, and the Federal Aviation Administration's (FAA's) Emission and Dispersion Modeling System. The following discussion summarizes some of our data gathering and emission estimation efforts for the non-platform source categories.

Development of the 2005 Non-Platform Emission Inventory

The non-platform sources fall into three engine categories: marine diesel engines, residual-fueled steam ships, and aviation engines. For the 2005 inventory, emission factors for marine diesel engines were obtained from the Swedish Environmental Agency; emission factors for residual oil-fueled vessels were obtained from the U.S. EPA; and emission factors for helicopters were obtained from the California Air Resources Board, helicopter manufacturers, and the Federal Aviation Administration's (FAA's) Emission and Dispersion Modeling System. The following discussion summarizes some of our data gathering and emission estimation efforts for the non-platform source categories.

Survey Vessels

For 2005, it is assumed that 14 identified survey vessels operated in federal waters throughout the year, and that each vessel is in port one week every two months for refueling and re-supplying. These assumptions yield an estimate of the total annual hours of operation of 94,416, which would be an increase of a factor of seven compared with 2000 activity data.

Drilling Rigs

ERG received drilling rig data from MMS for 2005. As expected, drilling rig activity declined in 2005 by 24%. For the 2005 inventory effort, horsepower data are used for individual rigs as provided by RigZone if they can be mapped to the MMS dataset. This approach allows use of actual horsepower rather than a typical horse power value. We were able to match 181 of 321 drilling rigs in the MMS dataset, or 56%. For other vessels, we developed an average horsepower value based on the reported drill ship data in the RigZone database.

Support Vessels

Offshore Marine Service Association (OMSA) data are used to estimate the support vessel population and activity levels. The 2005 activity data are roughly twice those reported by the Offshore Operators Committee, which were used in the previous MMS inventories.

Support Helicopters

Based on the FAA helicopter traffic data for the Gulf of Mexico, helicopter activity are 64% higher for 2005 than the activity levels reports for 2000.

Pipelaying Operations

MMS provided pipelaying data for 2005. These data indicate that 105 pipeline segments were installed in 2005, compared to 222 installed in 2000.

Military Vessel Operations

The Coast Guard has provided details about their fleet; specifically, they have provided a detailed list of their vessels, including estimates of the period of time individual vessels spend in port and at sea. The 2005 Coast Guard vessel list is similar to that used for the 2000 inventory. In the 2005 inventory, vessel-specific activity data will be linked to individual ports.

Commercial Marine Vessels

We obtained entrance and clearance data from the U.S. Maritime Administration (MARAD) for 2005. The entrance and clearance data concern vessels that carry international cargo and go through U.S. customs procedures. We are soliciting data from the Army Corps of Engineers to account for smaller vessels that only carry cargo between domestic ports.

Richard Billings has a master's degree in environmental science and engineering from Virginia Tech and has worked with Eastern Research Group (ERG) for 13 years. The focus of most of his work has been the quantification of air emissions from nonroad emissions sources such as marine vessels and helicopters. These nonroad projects have been developed for the U.S. EPA, Texas Commission for Environmental Quality, the Houston Advance Research Center, as well as MMS. In addition to his mobile source activities, he has also developed emission estimates for platform emission sources and marine biogenic and geogenic sources.

Darcy Wilson is a Senior Program Manager with ERG with 20 years of air quality experience. Her expertise includes air pollutant emission factor and emission inventory development, database development, and quality assurance/quality control. She has served as the program manager on several MMS air quality emissions inventory studies since 1999.

SYNTHESIS, INTEGRATION, AND ANALYSIS OF METEOROLOGICAL AND AIR QUALITY DATA

Jay L. Haney and Sharon G. Douglas, ICF International

Click here to view the slide show that accompanied this presentation.

Introduction and Background

This paper summarizes an ongoing study of Gulf of Mexico region involving the synthesis, integration, and analysis of meteorological and air quality data to better understand the air quality of the region. The study was initiated in September 2006 and will continue through July 2008. Air Resource Specialists, Inc. (ARS) of Fort Collins, Colorado, is assisting ICF and participating in the integrated database design and analysis portions of the study.

MMS, together with the oil and gas industry, has collected a variety of meteorological, air quality, and emission inventory data for the Gulf of Mexico region. These data span the years 1988 to present and have been used to support various air quality related data analysis and modeling activities. However, the amount and type of data varies throughout the period, and a fully integrated assessment of the data and the information contained in the data have not been conducted. MMS is now interested in assembling these data, as well as other data available from federal, state, and oil and gas industry studies and databases, into a coherent dataset, so that the data can be more fully "mined" to 1) provide an improved understanding of the relationships between meteorology, emissions, and air quality in the Gulf of Mexico region and 2) support future regulatory data and modeling analyses related to ozone, fine particulate matter ($PM_{2.5}$), and regional haze. Evaluation and quality assurance of all data (and flagging of questionable or erroneous data) will be a key element of the database compilation project. In addition, the project will include some basic analysis of the data which will 1) ensure the integrity and usability of the dataset and 2) provide new information about meteorological and air quality conditions in the Gulf of Mexico region, including the relationships between meteorology, emissions, and air quality revealed by the data.

A key objective of the study is to develop a comprehensive, coherent, and usable dataset of meteorological, air quality, and emissions data from MMS and oil and gas industry sponsored studies. To support the conduct of air quality related analysis, data from EPA, the National Weather Service (NWS), and other sources will also be included. The MMS-sponsored studies include the 1993 Gulf of Mexico Air Quality Study (GMAQS), the Atmospheric Boundary Layer (ABL) study (spanning 1998–2001), several monitoring studies conducted by the Louisiana State University (LSU) focusing on air quality and dispersion meteorology over the Gulf of Mexico (1995–2000), and the recent offshore activities and emissions data for the Breton area and the entire Gulf of Mexico (2000 and 2005 Gulfwide Emission Inventories). MMS and offshore oil and gas industry co-sponsored studies include the Breton Aerometric Monitoring Program (BAMP) October 2000–September 2001) and several related emission inventory studies.

The dataset will be designed to support the type and range of data analysis studies that will enhance current understanding of the relationships between emissions, meteorology, and air quality along the Gulf Coast. Input from the Science Review Group (SRG) will ensure the usefulness of the dataset for future scientific studies. It will also be designed for compatibility with the MMS Technical Information Management System (TIMS) Environmental Coastal and Offshore Resource Information System (CORIS).

The basic analyses conducted as part of this study will serve two purposes. First, they will allow the testing and refinement of the dataset and ensure its usability for similar data analysis studies. Second, and most importantly, the analyses will allow MMS, for the first time, to draw on the integrated dataset to 1) examine the relationships between meteorology, emissions, and air quality in the Gulf of Mexico region, 2) confirm and/or advance prior conceptual descriptions related to ozone, particulate, and regional-haze air quality issues along the Gulf Coast and in the Breton National Wilderness Area (NWA), 3) identify gaps in the data/knowledge bases, and 4) recommend future data analyses.

Another key objective of the study is to provide data and analyses to support the preparation of State Implementation Plans (SIPs) or maintenance plans for 8-hour ozone and $PM_{2.5}$, which, for some of the coastal areas, may include air quality modeling.

Data Assembly, Integration and Evaluation

The Gulf of Mexico Air Quality Database (GMAQDB) will be a relational database. Assembly of the database will consist of several subtasks:

- creating and secure the database
- populating the database
- making the database user friendly
- documenting the database.

The database will be Oracle-based with a user-friendly MS-Access-based front-end. The integrated database will include meteorological, air quality, and emissions data from the relevant MMS and oil and gas industry related studies. Emissions, meteorological, and air quality data available from EPA, NWS, and state and local agencies will also be incorporated, as needed to make the dataset able to support the type and range of basic data analysis studies to be performed as part of this project.

All data included in the database will undergo some evaluation. A computer-assisted validation process developed by ARS will apply both automated routines and manual interactive procedures to evaluate collected data against defined acceptance criteria. The data evaluation will identify and flag obvious outlier data points and erroneous data, and identify periods of missing data.

Data Analyses

As part of this study, we will conduct five basic data analysis activities that are designed to "mine" the integrated dataset in a variety of ways. We will use these analyses to obtain information about 1) the relationships between emissions, meteorology and air quality for Breton and selected onshore coastal non-attainment areas, 2) the potential for offshore emissions to influence onshore air quality, 3) the characteristics and frequency of occurrence of different types of meteorological conditions and their influence on air quality during selected monitoring periods, and 4) specific air quality events represented in the MMS and oil and gas industry special studies datasets. The analyses will consider ozone, NO_x, SO_2, $PM_{2.5}$ and regional haze. A variety of metrics will be calculated as part of the analysis, including 8-hour ozone design values, annual and maximum 24-hour average $PM_{2.5}$ values, $PM_{2.5}$ design values, extinction coefficients and visual range for the 20 percent best and worst visibility days, annual average NO_x concentration, maximum 1-hour and 8-hour average CO concentrations, and annual, and maximum 24-hour average SO_2 concentrations.

Wind roses showing the distribution of wind speeds and directions will be prepared. The gulf breeze index (a function of the daily change in wind direction) will be examined in conjunction with the air quality data to determine the extent to which the gulf breeze is correlated with ozone, $PM_{2.5}$ and other pollutant concentration levels along the Gulf Coast. The meteorological and air quality data summaries will be used to compare and contrast the meteorological and air quality conditions for the different areas along the Gulf Coast and among the special study periods. This information will in turn be used to guide the remaining data analysis tasks, and to aid in the interpretation of the CART analysis results.

The data analyses will also include the application of the Classification and Regression Tree (CART) statistical analysis software. CART will be used to probe the relationships between meteorology and various air quality metrics, for example, visibility (regional haze) at the Breton NWA. CART will be used to probe the relationships between meteorology and SO2, $PM_{2.5}$, and visibility (regional haze) at the Breton NWA. The CART results will be used to refine the conceptual description for these pollutants in the Breton area and to define the role of meteorology in determining pollutant concentration levels and distinguishing between hazy and clear days. The CART results will also provide qualitative information on the potential for offshore emissions to contribute to visibility degradation at the Breton Class I area. An overview of the data analysis design and components for Breton is provided in Figures 1D.1 and 1D.2.

To examine air quality trends in the coastal areas, we will also apply CART for 1996–2004 for ozone and 2000–2004 for $PM_{2.5}$. The shorter period for $PM_{2.5}$ reflects the availability of data. CART will be applied separately for ozone and $PM_{2.5}$. The CART results will be used to examine and distinguish between the effects of meteorology and the effects of emissions changes on 8-hour ozone and $PM_{2.5}$ air quality. Specifically, we will use the CART results to calculate meteorologically adjusted trends for ozone and $PM_{2.5}$. There are two primary considerations here: 1) to account for meteorology in the interpretation and use of the observed air quality data—through the preparation of meteorologically adjusted data and 2) to apply reliable statistical techniques to the estimation of air quality trends and to assess (also using statistical methods) the significance of the trends. A key benefit of this approach is that it takes into account meteorological variability so that the effects of emissions changes can be revealed.

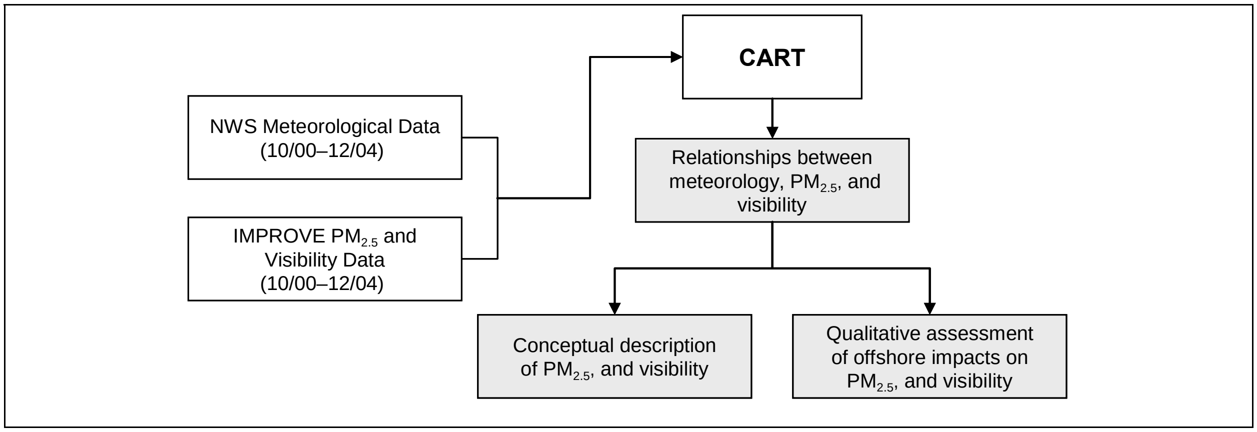


Figure 1D.1. Conceptual design of the Breton NWA CART-based meteorological and air quality data analysis: 2000 2004 regional haze baseline period.

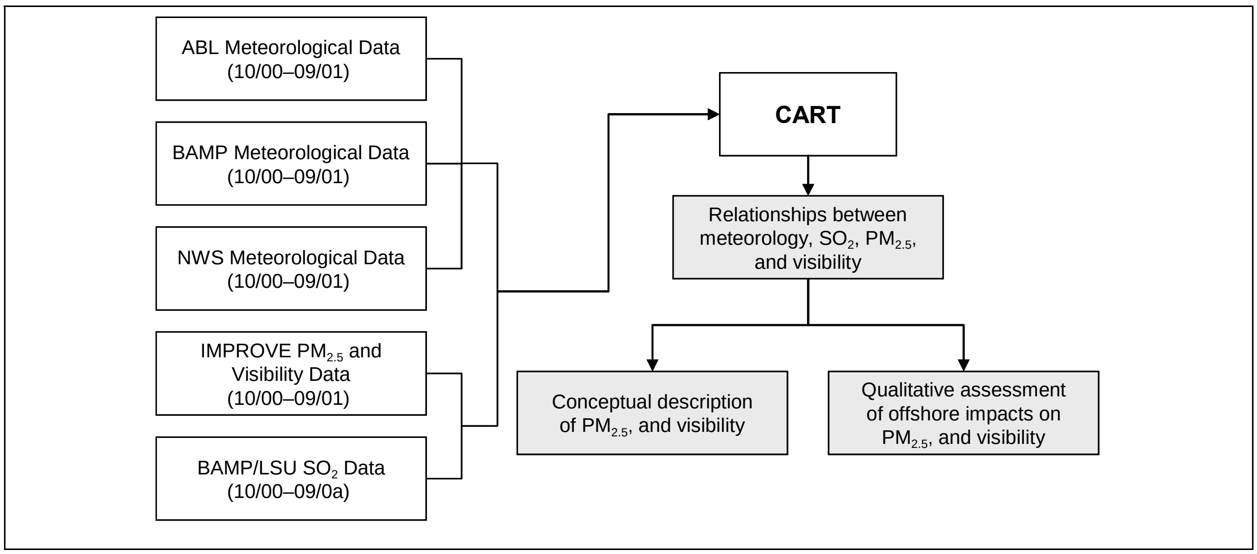


Figure 1D.2. Conceptual design of the Breton Area CART-based meteorological and air quality data analysis: ABL/BAMP period.

Jay L. Haney is Group Vice President and Director of the Air Quality Modeling Group at ICF International. He is a Certified Consulting Meteorologist and has an M.S. in meteorology from Saint Louis University. He has 27 years of experience in the refinement of data analysis and modeling techniques applied to the study of tropospheric ozone, carbon monoxide, and particulate matter.

Sharon G. Douglas is a Project Manager in the Air Quality Modeling Group of ICF International. She has an M.S. in meteorology from Pennsylvania State University. Ms. Douglas has 20 years of experience at ICF and has been principally involved in the development and application of innovative data analysis techniques and meteorological and air quality modeling tools.

FIVE-YEAR METEOROLOGICAL DATABASE FOR THE OCD AND CALPUFF MODELS

Sharon G. Douglas, ICF International

Click here to view the slide show that accompanied this presentation.

Introduction and Background

The MMS is the designated federal agency with the authority to regulate oil and gas exploration and development activities in the central and western Gulf of Mexico (GOM) Outer Continental Shelf (OCS) region. In addition to managing oil and gas resources in the region, the MMS is also charged with environmental management responsibilities, including those related to air quality. The National Environmental Policy Act (NEPA) mandates the type of environmental reviews or assessments that need to be conducted in the area to assess potential on-shore air quality impacts of exploration, development, production and pipeline right of way activities. Some assessments require the application of air quality dispersion models to evaluate potential impacts. Such analyses in the past have used a two-year meteorological data set (1991–1993) as input to air quality models. This dataset is now somewhat outdated, and in recent years, more comprehensive datasets have become available. These include those prepared using a combination of output from prognostic meteorological models, offshore buoy data, and onshore data collected by the National Weather Service (NWS), as archived by the National Climatic Data Center (NCDC).

The objective of this study is to prepare a five-year meteorological dataset for the GOM OCS region that will 1) represent more recent baseline periods, 2) include data from current onshore and offshore data sources, and 3) support air quality modeling applications for a variety of environmental assessments. Given the disruption (to environmental monitors and activities) in the GOM caused by Hurricanes Katrina and Rita in late August 2005, the dataset will include data for the period 2000–2004. The dataset will include model output from the Rapid Update Cycle (RUC) model, onshore surface and meteorological upper-air data, offshore meteorological buoy data and ozone air quality data for the GOM region. The dataset is intended for use by MMS and others to assess potential impacts with either the CALMET/CALPUFF modeling system or the updated Offshore Coastal Dispersion (OCD) model.

Dataset Components

Specific elements of the dataset include:

- Model output from the Rapid Update Cycle (RUC) prognostic model—formatted as 50 tiles covering the GOM and onshore areas
- National Weather Service (NWS) surface meteorological data (230 stations in the GOM region)
- NWS upper-air meteorological data (21 stations in the GOM region)

- National Data Buoy Center (NDBC) buoy data (~13 stations)
- NWS precipitation data (~270 stations in the GOM region)
- EPA Air Quality System (AQS) ozone data (~200 monitoring sites)

A similar dataset has already been prepared for 2003, as part of another MMS-sponsored study. Thus, this dataset will include data for 2000–2002 and 2004. The study area is shown in Figure 1D.3 This figure also depicts the RUC tiles and the location of the onshore surface meteorological stations.

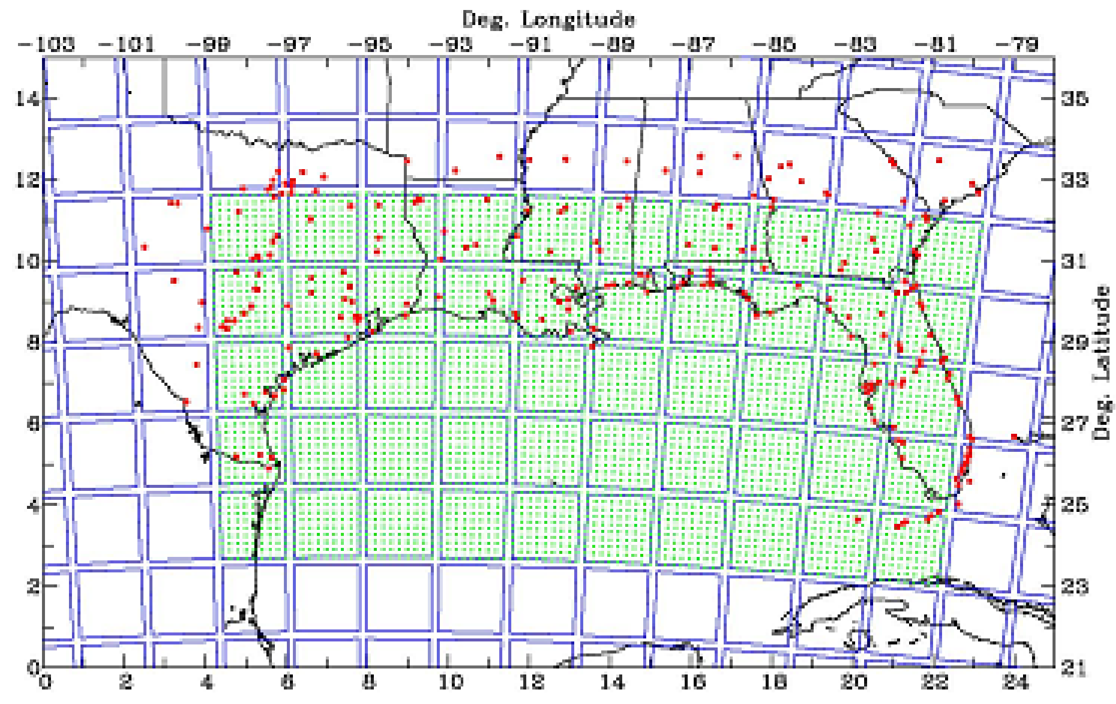


Figure 1D.3. GOM study region for the 5-year meteorological database.

Characteristics of the Dataset

To date, we have performed a limited review of the meteorological and ozone air quality characteristics of the five-year period. As an example, monthly average temperatures for Boothville, Louisiana are similar for each of the five years. The month-to-month variations in average wind speed are also similar for the five years. There are greater variations in monthly average wind direction, relative humidity and monthly precipitation totals among the years. For example, southeasterly winds were more prevalent in 2002 compared to other years, and precipitation totals were significantly higher during the autumn months of 2002 and the summer months of 2003 compared to other months within the five-year period.

Uses of the Dataset and Schedule

Separate data files will be prepared for use with the CALMET/CALPUFF modeling system and the latest version Offshore Coastal Dispersion Model (OCD5).

It is expected that the dataset will be used to support dispersion modeling of existing and new OCS sources as well as the analysis of 8-hour ozone data and evaluation of 8-hour ozone modeling results.

The schedule for the completion and quality assurance of the dataset is August 2007.

Sharon G. Douglas is a Project Manager in the Air Quality Modeling Group of ICF International. She has an M.S. in meteorology from Pennsylvania State University. Ms. Douglas has 20 years of experience at ICF and has been principally involved in the development and application of innovative data analysis techniques and meteorological and air quality modeling tools.

MODELING THE INFLUENCE OF SEA-SURFACE MICROLAYER (SSM) PROCESSES ON THE ATMOSPHERIC OZONE BUDGET IN THE GULF COAST MARINE BOUNDARY LAYER

Daewon W. Byun, In-Bo Oh, Hyun-Cheol Kim, and Soontae Kim,
Institute for Multi-dimensional Air Quality Studies, University of Houston

Click here to view the slide show that accompanied this presentation.

Introduction

Coupling of chemical reactions of the iodine-containing emissions from marine algae in the sea-surface microlayer (SSM) with ozone deposition processes is increasingly recognized as an important research area for understanding atmospheric ozone concentrations in the marine boundary layer. This study is built upon the recent research on the environmental assessment of the impact of ozone to the neuston of the sea surface microlayer of the Gulf of Mexico, on the chemical enhancement of the ozone deposition to the sea surface due to iodine-containing emissions, and on the subsequent iodine chemistry responsible for the halogen activation and ozone loss. The science questions addressed are; (a) how can we quantify the iodine emissions from the marine algae, (b) how important is the SSM process in the ozone deposition budget, and (c) what are the effects iodine chemistry in the in the Gulf Coast marine boundary layer.

Modification of Ozone Deposition Modules in CMAQ

Ozone deposition to the ocean surface is an important removal pathway (Galbally and Roy 1980; Gallagher et al. 2001) and since this can play a major role in the ozone budget in the marine boundary layer and influence onshore/inland distribution of ozone, it must be accounted for to improve onshore air quality estimates in regional air-quality models. Ozone deposition into seawater is complicated physical and chemical processes that transpire as ozone diffuses through the SSM. Considerable uncertainty surrounds these processes, particularly, the chemical loss by uptake of organic substances reacting with ozone, which is not well understood.

Deposition is commonly described, quantitatively, by the deposition velocity which depends on: aerodynamic resistance (R_a), quasi-laminar boundary resistance (R_b) and surface resistance (R_c) (Wesely and Hicks 2000). The dry deposition velocity is then defined as the reciprocal of the total resistance. For seawater surface, R_c is aqueous-phase film resistance reflecting the surface uptake efficiency that can be controlled by physical and chemical processes, which is the dominant resistance in ozone deposition (Lenschow et al. 1982). Chemical processes with dissolved iodine (mainly iodide ions) are particularly important as an ozone deposition mechanism for ozone in the SSM (Garland et al. 1980; Chang et al. 2004).

In order to consider ozone loss by iodide reaction in SSM, the original surface resistance (R_c) parameterization in the dry deposition module (M3DDEP) in Meteorological-Chemistry

Interface Processor (MCIP) of the CMAQ system is replaced with the one proposed by Chang et al. (2004), which accounts for the ozone deposition to the sea surface due to the iodide reaction, combining Garland et al.'s (1980) and Liss and Merlivat's (1986) formulations.

$$r_{gw} = \frac{H}{ak_w + \sqrt{\lambda D}} = \frac{1}{pk_w + q}, \; \lambda = \sum_i k_i C_i \tag{1}$$

where H is the dimensionless Henry's law constant, and k_w is gas-transfer velocity as a function of wind speed which can be derived from the formula of Liss and Merlivat (1986) or Wanninkhof (1992). The a term is the chemical enhancement factor, λ and D denote the integrated chemical loss of ozone by the species i (e.g., iodide, DMS, and alkenes) and the molecular diffusivity of ozone in water, respectively. $p\ (= a/H)$ denotes interactions between wind-induced turbulent transport and chemical enhancement and $q\ (= \sqrt{\lambda D}/H)$ is the deposition velocity due to only to molecular gas-transfer, including molecular diffusion and chemical reactions when wind speed is low.

Model Configurations

The model configurations used in this study is as follows:

Modeling Period

A 30 day period in August 2005 was selected for the air quality simulation. MM5 and CMAQ are used to quantitatively assess the dry deposition and fluxes of ozone. In addition, several episodic cases of the high ozone events with different meteorological regimes during August will be modeled with finer resolution (spatiotemporally) to analyze the SSM processes and their effects on offshore/onshore ozone distributions.

Horizontal Nested Grid Structure

The horizontal modeling domain structure consists of nested grids of varying resolution: a coarse grid domain (36-km cell size, 133 × 91 array) that covers the continental United States, and a regional domain (12-km cell size, 167 × 128 array) over the southern States neighboring the Gulf of Mexico. For MM5, the regional 12-km domain is a domain set by Texas A&M University for TCEQ regulatory modeling. Both MM5 and CMAQ modeling domains are defined on a Lambert Conformal mapping projection, following the perfect sphere definition used in MM5 (projection origin: 100°W, 40°N). The horizontal grids employed for CMAQ modeling are subsets of the grids used in MM5.

Vertical Grid Structure

There are 43 and 23 vertical sigma layers for MM5 and CMAQ, respectively (details are in last quarterly report), with higher resolution near the ground to better understand both the atmospheric structure and the SSM processes in the lower boundary layer. The altitudes above sea level are estimated according to the atmosphere assumptions used in MM5 (surface pressure of 1013 mb, model top at 100 mb, surface temperature of 304 K, and log-pressure lapse rate of 45 K/ln[p]). CMAQ uses 23 layers by collapsing two to three layers in the upper part of the MM5 43 layers. The MM5 and CMAQ vertical layer structures are same for the various nested domains.

Results

We compared the CMAQ results with the original dry deposition inputs with those from the new dry deposition module for water surface accounting for the iodide chemical reactions in SSM.

Model Verification

For verifying the modified deposition code and identifying the influence of iodide concentrations on ozone deposition velocities, we compared the results from three different modeling cases (Case 1: original M3DDEP in MCIP3.0, Case 2: modified M3DDEP without iodide reaction, and Case 3: modified M3DDEP with iodide reaction). Figure 1D.4 shows the relationship between modeled ozone dry deposition velocities and 10-m wind speeds for different modeling cases. For Case 3, two curves indicate dry deposition velocities for different iodide values (100 nM and 400 nM); most of the iodide concentrations measured in the surface sea water was roughly in the range of these two values (Campos et al. 1999; Campos et al. 1996; Wong and Zhang 1992). All the data used here (except the observations) are obtained from one-month hourly model output only for the seawater. Observed values from Kawa and Pearson (1989) and Lenschow et al. (1982) are also presented in order to compare with the model results. Direct comparison with observations for ozone dry deposition velocities and their dependence on iodide concentrations over the Gulf of Mexico is not yet available.

CMAQ Results

In order to assess iodide effects on dry deposition velocity for ozone over the Gulf of Mexico, averaged deposition velocities for different modeling cases over a period of one month were compared. In addition, the relationship among deposition velocity, wind speed and iodide concentrations were analyzed based on horizontal distributions of them (see Figures 1D.5 and 1D.6).

Conclusions

In order to identify the influence of iodide dissolved in surface seawater on dry deposition fluxes and ambient concentrations for ozone, we implemented new dry deposition algorithm, which accounts for the ozone deposition to the sea surface due to the iodide reaction. Differences between the simulated ozone dry deposition fluxes for Case 2 and 3 show that significant ozone loss can take place by the ozone-iodide reaction. Furthermore, the differences are pronounced at the condition of low wind speed. CMAQ run utilizing the modified dry deposition model including iodide reactions can predicted significant ozone loss at low wind speed. Relatively large differences occurred under weak wind conditions.

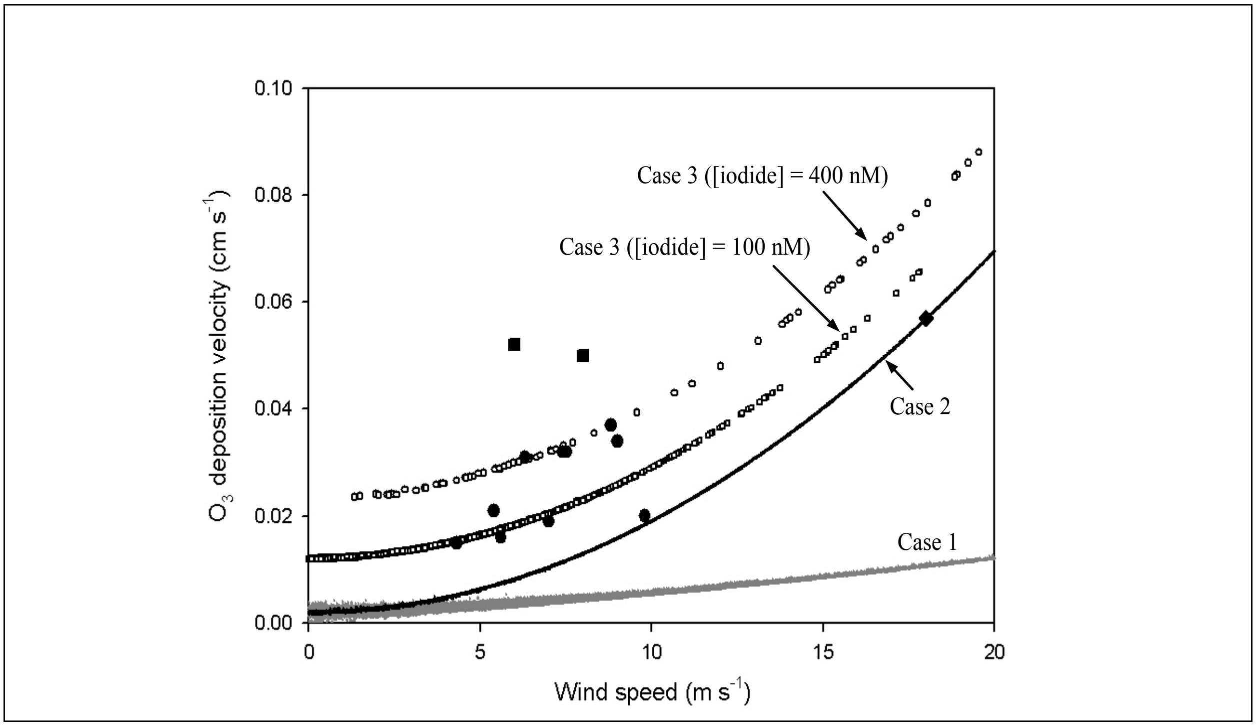


Figure 1D.4. Dry deposition velocity for ozone as a function of wind speed. The individual curves are for different modules: M3DDEP (Case 1); modified M3DDEP without iodide reaction (Case 2); modified M3DDEP with iodide reaction (Case 3). Two curves for Case 3 indicates deposition velocities corresponding to different iodide concentrations (100 and 400 nM) extracted from model results during August 2005. The filled circles indicate observations of Kawa and Pearson (1989). Solid squares and a solid diamond indicate observations of Lenschow et al. (1982) over the Gulf of Mexico and the North Pacific, respectively

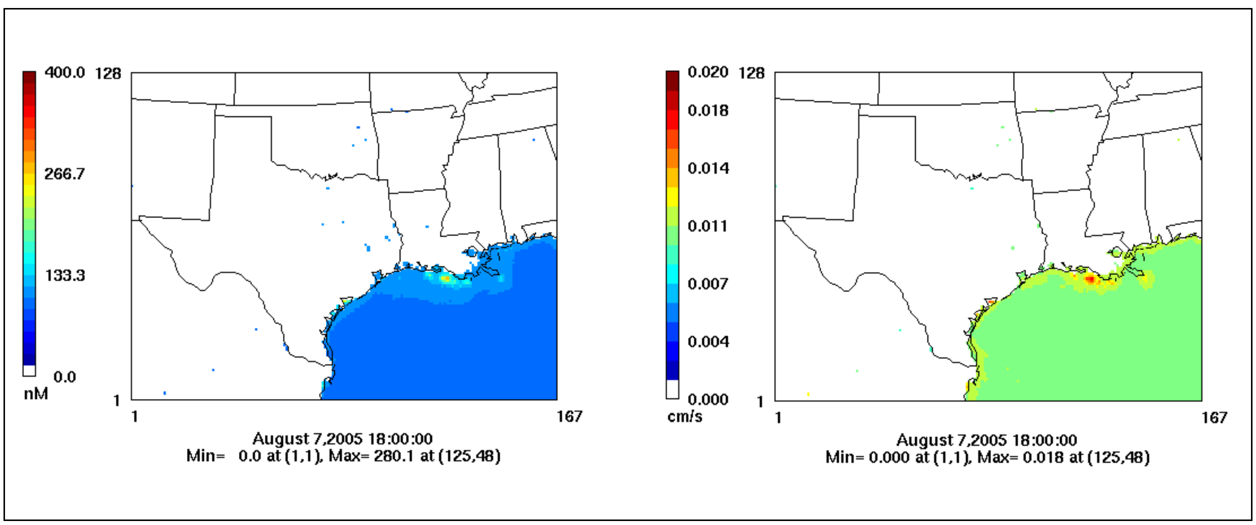


Figure 1D.5. Iodide concentrations from satellite-derived estimates of near-surface chlorophyll concentrations (left) and difference (Case 3 minus Case 2) in ozone dry deposition velocities (right) at noon, 7 August.

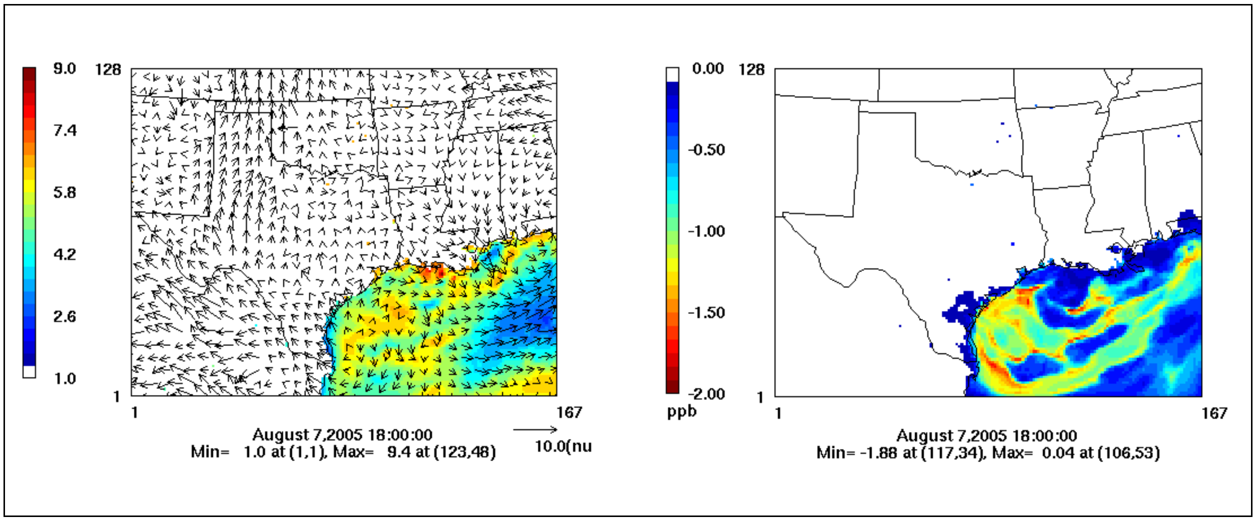


Figure 1D.6. Ratio of dry deposition velocity for Case 3 to Case 2 (left) and difference (Case 3 minus Case 2) in ozone concentration on 7 August.

References

Campos, M.L.A.M., A.M. Farrenkopf, T.D. Jickells, and G.W. Luther, III. 1996. A comparison of dissolved iodine cycling at the Bermuda Atlantic Time-series Station and Hawaii Ocean Time-series Station. Deep Sea Research Part II: Topical Studies in Oceanography 43(2):455–466.

Campos, M.L.A.M., R. Sanders, and T. Jickells. 1999. The dissolved iodate and iodide distribution in the South Atlantic from the Weddell Sea to Brazil. Marine Chemistry 65:167–175.

Chang, W., B.G. Heikes, and M. Lee. 2004. Ozone deposition to the sea surface: chemical enhancement and wind speed dependence. Atmospheric Environment 38:1053–1059.

Galbally, I.E. and C.R. Roy. 1980. Destruction of ozone at the earth's surface. Quarterly Journal of the Royal Meteorological Society 106:599–620.

Gallagher, M.W., K.M. Beswick, and H. Coe. 2001. Ozone deposition to coastal water. Quarterly Journal of the Royal Meteorological Society 127:539–558.

Garland, J.A., A.W. Elzerman, and S.A. Penkett. 1980. The mechanism for dry deposition of ozone to seawater surface. Journal of Geophysical Research 85:7488–7492.

Kawa, S.R. and R. Pearson. 1989. Ozone budgets from the dynamics and chemistry of marine stratocumulus experiment. Journal of Geophysical Research 94:9809–9817.

Lenschow, D., R. Pearson, and B. Stankov. 1982. Measurements of ozone vertical flux to ocean and forest. Journal of Geophysical Research 87:8833–8837.

Liss, P. and L. Merlivat. 1986. Air–gas exchange rate: introduction and synthesis. In: Buat-Menard, P., ed. The Role of Air–Sea Exchange in Geochemical Cycling. Hingham, MA: D. Reidel. Pp. 113–129.

Wanninkhof, R. 1992. Relationship between wind speed and gas exchange over the ocean. Journal of Geophysical Research 97:7373–7382.

Wesely, M.L. and B.B. Hicks. 2000. A review of the current knowledge on dry deposition. Atmospheric Environment 36:2261–2282.

Wong, G.T.E and L. Zhang. 1992. Changes in iodine speciation across coastal hydrographic fronts in southern United States continental shelf water. Continental Shelf Research 12 (5/6):717–733.

Dr. Daewon Byun is presently a professor in the Department of Geosciences, University of Houston (UH) and Director of the Institute for Multidimensional Air Quality Studies (IMAQS). He was the technical leader of the U.S. Environmental Protection Agency (EPA) Models-3 Community Multiscale Air Quality (CMAQ) model development project. (Thanks to this, colleagues call him "Farther of CMAQ"). Dr. Byun was awarded the EPA Silver Medal for the development of Models-3 CMAQ in 1999. He received the NOAA Air Resources Laboratory "Paper of the Year" Award in 2000. He served as the Science Board member of the NCAR and NOAA Weather Research and Forecasting (WRF) project and the External Advisory Committee for the Community Modeling and Analysis System (CMAS) until 2004. Also, he was a committee member of the American Meteorological Society (AMS) Committee for the Meteorological Aspects of Air Pollution for 2002–2005. Currently he serves as an Executive Board member of the Texas Commission for Environmental Quality (TCEQ) Science Steering Committee, the AMS Committee for the Atmospheric Chemistry, Advisory Board for Mothers for Clean Air, and the Community Advisory Panel for the Environmental Health Houston.

SATELLITE DATA ASSIMILATION INTO METEOROLOGICAL / AIR QUALITY MODELS

Arastoo Pour Biazar, Richard T. McNider, Kevin Doty, Scott Mackaroo, University of Alabama in Huntsville

William Lapenta, Gary Jedlovec, NASA Marshall Space Flight Center

Robert Cameron, Minerals Management Service

Click here to view the slide show that accompanied this presentation.

Introduction

In collaboration with MMS, the University of Alabama in Huntsville has continued in the development of satellite assimilation techniques to improve meteorological and air quality modeling along the mid-Gulf of Mexico coastline and offshore environments. These include techniques to improve the performance of surface energy budget in the physical atmospheric modeling component and photolysis information going into the photochemical modeling systems.

Sea / Land Breeze Systems

Sea and land breezes along the Gulf of Mexico are a significant part of the transport and diffusion environment for the continental shelf area where impacts of offshore operations and onshore emissions are needed for regulatory impact studies. This involves both contributions of offshore sources on non-attainment areas in Houston-Galveston, Port Arthur-Beaumont and New Orleans-Baton Rouge and the impact of PSD sources to increment consumption in the Breton Wildlife Class I area.

These sea and land breezes can re-circulate onshore emissions with alongshore movement. They can also cause local buildup in the stagnation area as the new sea breeze starts. This local stagnation can be a critical part of extreme ozone events if the sea breeze stagnation occurs over a significant source region.

Sea breezes and land breezes are controlled by the sensible heat fluxes in the coastal zone. Thus, the correct specification of the surface energy budget is critical to predicting the timing and intensity of the sea and land breezes. Previous work along the Alabama/Mississippi/Florida coast has shown that using standard land surface values in mesoscale modeling systems can understate the intensity and penetration of the sea breeze. Under this activity, UAH has been testing a satellite assimilation system which by using morning and evening skin tendencies from GOES recovers improved specification of surface moisture and heat capacity – both ill described variables. Previous applications for the Texas Gulf Coast and Florida Gulf Coast have shown that while temperatures are improved in the simulation using this technique, latent heat fluxes are degraded. The work described below discusses tests and improvements in the satellite assimilation techniques.

Cloud Specification

Prediction of clouds in mesoscale models has proved to be difficult so that timing and location of clouds represents one of the biggest errors in air quality modeling in humid areas such as the Gulf Coast. Not only are clouds important in impacting the solar radiation inputs into surface energy budget in physical models, but they also play a direct role in impacting photolysis fields in photochemical models. Additionally, they play an important role in venting pollution and precursors out of the boundary layer.

UAH has developed satellite assimilation techniques where satellite-derived solar radiation fields and satellite derived photolysis fields (based on cloud distributions) were used in place of the erroneous model fields (Biazar et al. 2007). While this improves the performance of the model, it produces an inconsistency in that model clouds which produce mixing are not consistent with the satellite clouds used for solar radiation and photolysis calculations. In order to reduce this inconsistency, UAH has begun to develop a dynamic cloud initialization scheme that allows the model clouds more closely to represent the observed cloud fields. The technique described below uses a target vertical velocity and other factors important in cloud formation to provide dynamic support needed to create model clouds where and when the satellite observations have clouds and a cloud clearing technique (also based on target vertical velocities) where the satellite shows clear sky conditions.

Surface Moisture & Heat Capacity Correction

The satellite assimilation technique to recover surface moisture and heat capacity is based on the assumption that the least known parameters in the model are surface moisture and heat capacity (McNider et al. 1994, 2005). The technique has its roots in sensitivity studies by Carlson (1986) and Wetzel et al. (1984) that showed that the surface temperature is more sensitive to variations in moisture than other terms during the morning; during the evening, it is more sensitive to heat capacity variations. Because moisture availability is not a direct observable quantity and is fraught with errors in its specification, we assume that the other terms are correctly specified and that all the error in the surface energy budget is due to the incorrect moisture availability.

Figure 1D.7 shows the results of a simulation over the southeastern United States and compares the results with two independent observations. Panel (A) illustrates a snapshot of model ground temperature predictions versus satellite observations. The spatial pattern of warm temperatures in the assimilation run is in agreement with the satellite observations while the control simulation exhibits a cold bias. In panel (B) model predictions are compared with the observations from National Weather Service stations. While the moisture availability correction improves the daytime cold bias, heat capacity adjustment is needed to overcome the night-time warm bias in the predictions. While the technique has improved substantially by refinement and by improving MM5 solvers, model dry bias still remains an issue that needs to be resolved.

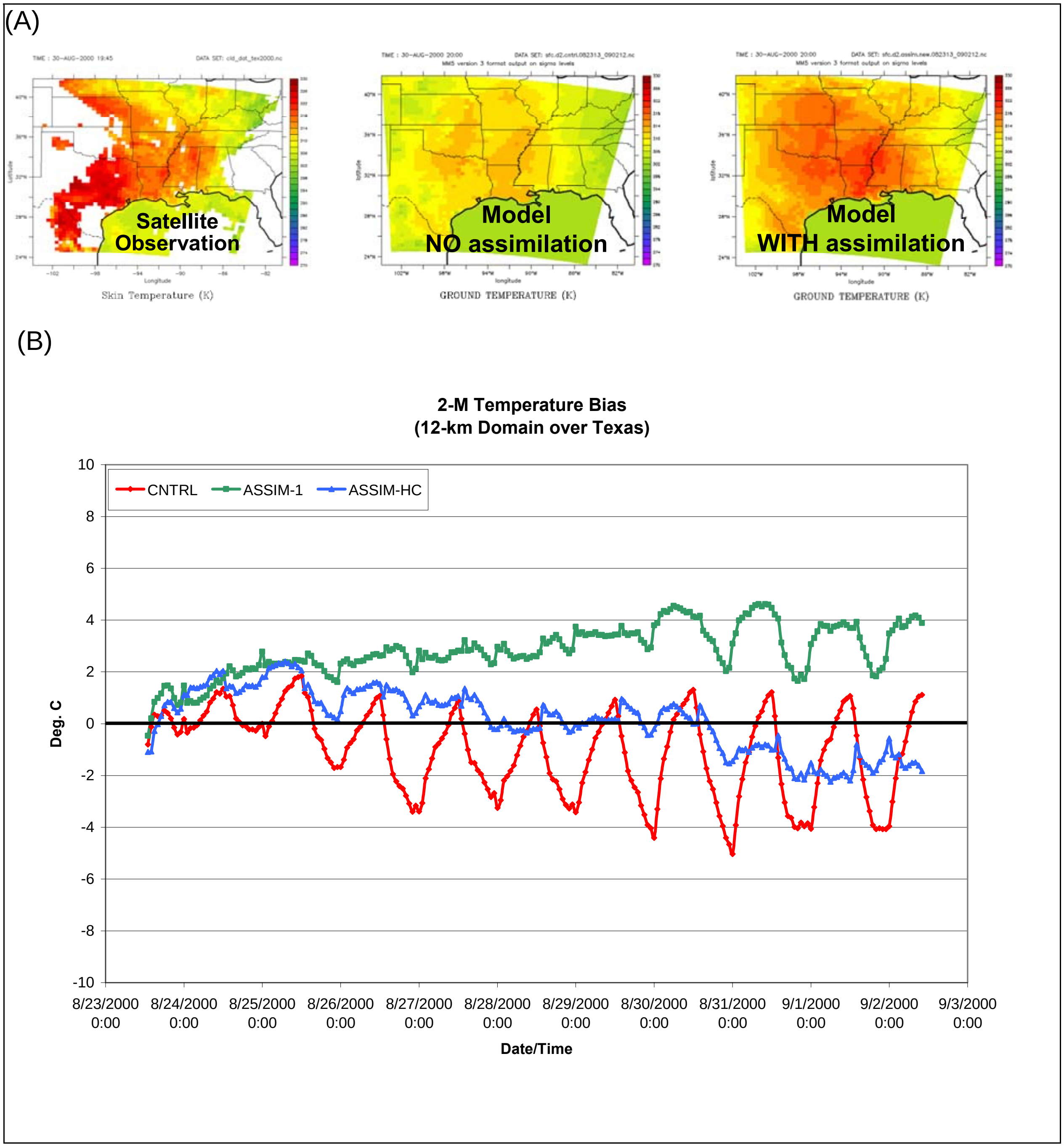


Figure 1D.7. The impact of GOES data assimilation on temperature predictions over southeast: (A) model ground temperature predictions for 30 August 2000, show a better agreement with satellite observations in the assimilation run; (B) when both moisture availability and heat capacity are adjusted (blue line) the 2-M temperature bias against observations from NWS stations is reduced (both the daytime cold bias and night-time warm bias).

Dynamic Cloud Correction in MM5

In this work in a dynamically sustainable manner observed clouds are assimilated into MM5. The basic approach is to utilize GOES observations to estimate the maximum vertical velocity in a cloudy atmospheric column. Then, horizontal components of the divergent wind are adjusted so that they are consistent with this maximum vertical velocity while moisture and diabatic heating are also modified. The procedure also removes erroneous model clouds.

The technique was tested for a ten-day simulation from 1 July through 10 July 1999, over the southeastern United States. Figure 1D.8 shows the statistical improvements in model predictions of clouds. The cloud bias is defined as the total model predicted cloud divided by the total observed cloud. The figure indicates that the control simulation greatly over-predicts the cloud cover in this case. Cloud correction technique, just by removing erroneous clouds, has substantially improved the cloud prediction. Figure 1D.9 shows model snapshots of surface insolation (indicating clouds) versus GOES observations for 2 July and 6 July 1999. In both cases dynamic cloud adjustment has improved model cloud predictions. The technique, however, seems to be excessively removing the clouds. Moreover, several known caveats in this technique are currently being addressed. For example, since the technique relies on instantaneous hourly observations to initiate the cloud formation/removal, the timing of cloud formation/removal will be ahead of the observations.

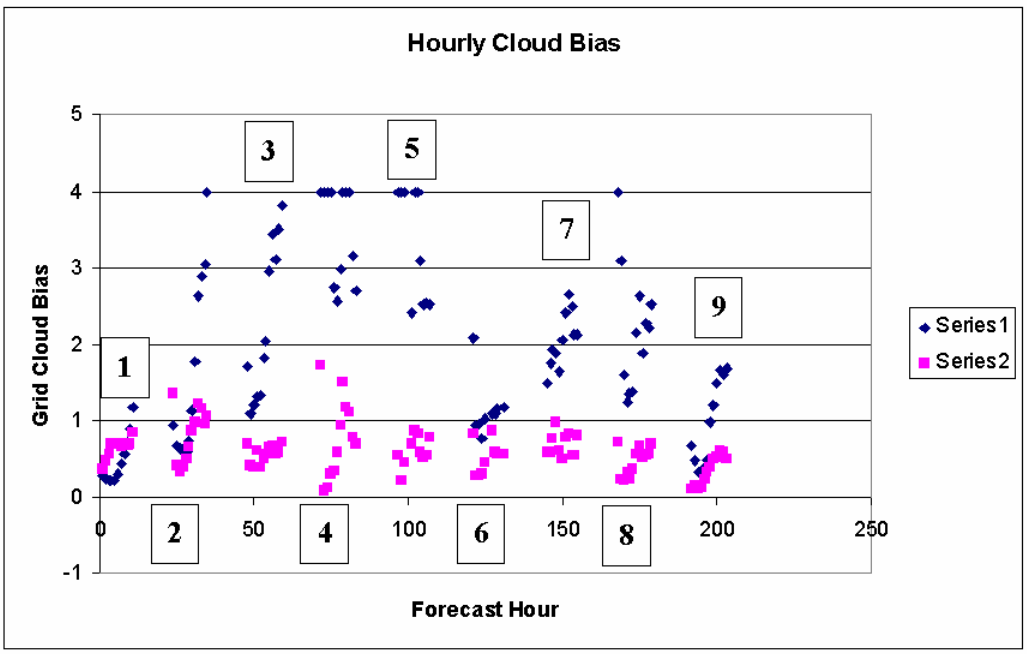


Figure 1D.8. Model cloud bias (total model predicted cloud/total observed cloud) for a MM5 simulation from 1 July through 10 July 1999. Series 1 (blue diamonds) are from the control simulation, and series 2 (purple squares) are from the simulation utilizing GOES cloud assimilation technique.

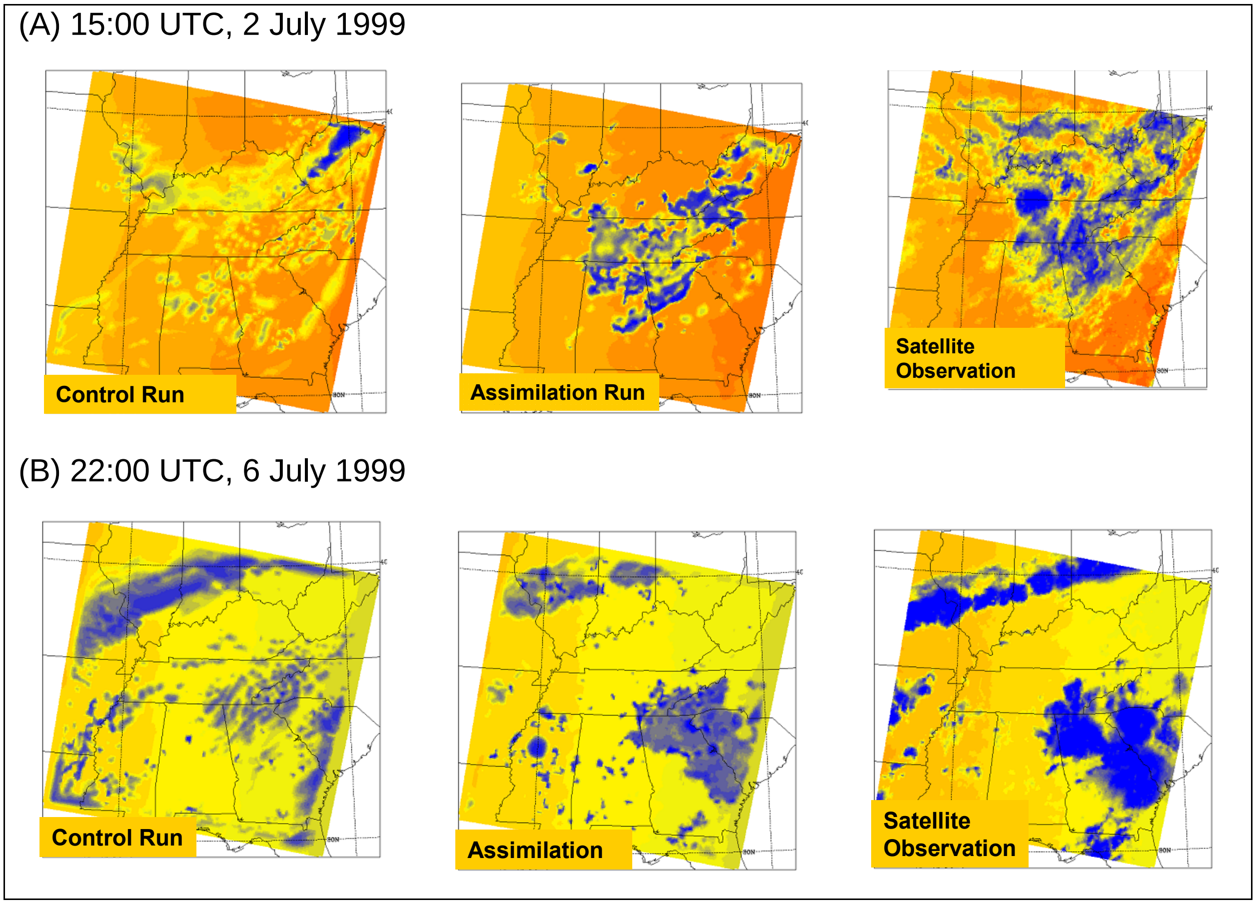


Figure 1D.9. Surface insolation from model predictions and satellite observations for 15:00 UTC 2 July (top panel) and 22:00 6 July 1999 (bottom panel). The figures are from MM5 control simulation (marked control), MM5 simulation with dynamic cloud assimilation (marked assimilation), and GOES observations. GOES observations lags the model data by 15 minutes.

Acknowledgments

This work was accomplished under partial support from Cooperative Agreement Between the University of Alabama in Huntsville and the Minerals Management Service on Gulf of Mexico Issues.

References

Biazar, A., R.T. McNider, S.J. Roselle, S. Haines, R. Suggs, G. Jedlovec, S. Kim, D.W. Byun, J.C. Lin, T.C. Ho, B. Dornblaser, and R. Cameron. 2007. Assimilation of GOES satellite data in CMAQ: Correcting photolysis rates based on observed clouds. Accepted J. Geophys. Research, manuscript # 2006JD007422.

Carlson, T.N. 1986. Regional scale estimates of surface moisture availability and thermal inertia using remote thermal measurements. Remote Sensing Rev. 1:197–246.

McNider, R.T., A.J. Song, D.M. Casey, P.J. Wetzel, W.L. Crosson, and R.M. Rabin. 1994. Toward a dynamic-t thermodynamic assimilation of satellite surface temperature in numerical atmospheric models. Mon. Wea. Rev. 122:2784–2803.

McNider, R.T., W.M. Lapenta, A.P. Biazar, G.J. Jedlovec, R.J. Suggs, and J. Pleim. 2005. Retrieval of model grid-scale heat capacity using geostationary satellite products. Part I: First case-study application. Journal of Applied Meteorology 44:1346–1360.

Wetzel, P.J., D. Atlas, and T.H. Woodward. 1984. Determining soil moisture from geosynchronous satellite infrared data: A feasibility study. J. Climate Appl. Meteor. 23:375–391.

Dr. Arastoo Pour Biazar received his Ph.D. in atmospheric sciences from the University of Alabama in Huntsville (UAH) in 1995. While involved in the Southern Oxidant Study (SOS) investigating the role of natural emissions in ozone production in the southeastern United States, he constructed a chemical transport model to help in the analysis of data from SOS field campaigns. He then joined the Earth System Science Center at UAH where he helped develop the EPA's Models-3 Community Multiscale Air Quality (CMAQ) modeling system. He also developed the Plume-in-Grid module for CMAQ. In 1998, he moved to Australia to participate in global tropospheric studies at the Cooperative Research Centre for Southern Hemisphere Meteorology at the Monash University. In recent years, Dr. Pour Biazar has performed air quality studies for the State of Texas. Currently under a cooperative agreement with the Minerals Management Service, he is addressing air quality issues along the Gulf of Mexico using geostationary satellite data.

SESSION 1E

SOCIOECONOMICS I

Chair: Kristen Strellec, Minerals Management Service

Co-Chair: Asha Luthra, Minerals Management Service

SOCIAL CAPITAL AND OFF-SHORE OIL DEVELOPMENT IN MORGAN CITY AND ST. MARY PARISH, LOUISIANA: SOME PRELIMINARY FINDINGS

William B. Bankston and Timothy C. Brown, Louisiana State University

Craig J. Forsyth, University of Louisiana at Lafayette

Click here to view the slide show that accompanied this presentation.

Conceptual Background

This paper applies the sociological concept of social capital to the analysis of an ongoing policy question, the social impact of oil and gas extraction on local communities. The industry's impact on society has long been acknowledged and studied in sociology. The oil industry is similar to other mining activities in having a cycle of expansion and contraction dependent of levels of supply and demand. Previous literature suggests that the cycle leads to boomtown communities, although recent literature has questioned the roles of the industry in creating such communities. These researchers argue that the oil industry is different from other mineral extraction industries, and because of these differences, its impact on communities does not fall into the same patterns. This research has generated a new perspective on the social impact of the oil industry, particularly in the Gulf of Mexico region, given that the boomtown model may not be isomorphic with the effects offshore oil development. The mining towns of the southwestern United States exemplify the boomtown model: mining activity causes a small rural town to expand quickly, and in some cases creates a town. When that activity ends, the area experiences a decline. But offshore oil has had a different history in Louisiana communities that predate OCS activities and have survived the industry's cyclical character. Scholars who argue for similarities may be guilty of looking to confirm the classic boomtown paradigm and its implied long-lasting disruptive consequences rather than being open to evidence that may suggest otherwise. As a result, we have no competing paradigms and nearly all social impact assessment research on offshore oil development in the Gulf of Mexico is organized in this boom/bust form. The present research is premised on the assumption that long-standing communities and the participants in them, though shaped by oil development and its related activity, are likely to have changed and continue to in a variety of ways, not all of which are deleterious to individual or community life. Indeed, different communities may experience very different consequences and adaptations. The classic boomtown paradigm may neglect or ignore these as it assumes the consequences of OCS activity.

Social Capital as a Conceptual Guide

Previous research has focused largely on economic and demographic consequences of the oil industry on affected areas. The guiding concepts that direct and inform this study, however, will be "human, cultural and social capital," and we focus on how OCS activity has influenced the development (or decline) of these capital resources in this area. Though these concepts have somewhat diverse meaning in social science research, they generally refer to social phenomena that are closely tied to the lives of human subjects. Human capital refers to the traits of individuals that facilitate production, e.g. education or job skills. Cultural capital refers to symbolic resources, e.g. language and values that promote the development of human potential to be productive. Social capital occurs in the form of valuable links to social groups, kinship, voluntary associations, and neighborhoods. We use the concept of "social capital" as inclusive of all of these. Using the concept in this way allows us to emphasize the diversity of effects that the development of the oil industry may have had on a community through time.

Methodology

The unit of analysis in this study is Morgan City, Louisiana, and the surrounding areas of St. Mary Parish. This is essentially a case study in which we attempt to develop an in-depth understanding of a single community's long-term experience with the presence and growth of the off-shore oil extraction industry. Our aim is to construct an interpretive understanding of the community effects that the oil industry has had through the eyes of those that have experienced them. Thus, we primarily utilize an ethnographic approach. The project involves face-to-face interviews using snow-ball sampling techniques to obtain this information. At present we have conducted over one hundred interviews with both current and previous residents of Morgan City and St. Mary Parish, Louisiana. The findings reported here are drawn from 38 in-depth interviews, which at this point we have analyzed in detail.

Preliminary Findings

Three inter-related themes have emerged in the cases we have analyzed thus far: the first is the effects of oil on civic participation and voluntary organizations of the community; second, the consequences for familial/inter-generational mobility; and third the introduction of weak ties into the area allowing for new bridging capital. With respect to the organizational consequences the industry brought in new residents to the area who brought with them a variety of needs and assets associated with community organization that the area lacked. Oil companies as well as their employees recognized these voids and fostered plans for facilitating their emergence within the community. The second theme highlights the industry's presence allowing for increased opportunities for residents' intergenerational mobility through such avenues as increased educational and occupational opportunities. For example, often the negative aspects of out-migration on communities has been emphasized, but our findings also suggest a positive long-term consequence on family status attainment. The third theme, bridging capital, refers to the external ties that the oil industry brought into the area, ties that have expanded not only the opportunity of the residents but of the community itself. This has allowed the community to maintain and expand the base of social capital that was established when oil companies came through the perpetuation of inter-community ties.

Appendix: Interviews

Social Capital in the Form of Participation in Civic/Community Organizations

Respondent 21: "With the influx of people it helped these organizations build. And I guess they were able to bring in new talents and educated people to new ideas. They gave them a new concept because they are from another state."

Interviewer: "How much did these people get involved in the community?"

Respondent 12: "Quite a bit. I mean they felt like however long they were going to be here they needed to put their children in school, they wanted them to get involved in church, whichever church it was. They did everything here they would have done in their home town."

Social Capital in the Form of Participation in Community Organizations

Interviewer: "What effect did changing from a mainly shrimping economy to oil economy have on the populace?"

Respondent 9: "You had people that came in from the oil industry that had ideas, that had seen things in other communities that they tried to develop. They probably were a big factor in furthering the Mardi Gras krewes and civic events."

Interviewer: "What about the community concert?"

Respondent 23: "It is put on by a group of community people. It is several times a year."

Interviewer: "Did that start with the oil industry?"

"Yes, they were trying to bring up some type of social activity."

Respondent 36: "During the boom the municipal auditorium was built. That was another good thing that happened from the oil field."

Social Capital in the Form of Community Action

Interviewer: "Did the incoming engineers offer new ideas to the people of the area?"

Respondent 34: "A lot of engineers were active. The city would call on them a lot of times for help. They were helpful to the city. Being young guys coming out of school they probably had a lot of ideas …. They got involved in the summer time sports. We always did have that program but they would get into it because they had younger kids and what not …. These guys had the hammer so to speak. Here is an engineer that works for an oil company that gives this guy all this business. So if he wants to do something with his children, as far as ballparks are concerned, like if they needed another backstop. All he has to do is pick up the phone and call one of his welding buddies and say, them days you could get away with that, he'd say 'You got any old pipe around there that you could put together for baseball?' 'Oh, yeah, whatever you want we could do it for ya.' Then they would go out and build it for him …. We saw plenty of that. Whenever we needed something for a school, talk to some guy, might not have necessarily been someone related to the oil field but it might have just been a service company."

Social Capital and Education

Respondent 2: "Nicholls State got created by oil …. More people were coming in so schools had to expand. The area always had good teachers. With the new wave of people coming in they asked for more subjects to be offered: geometry, calculus, and fine art."

Interviewer: "Do you remember oil people placing more demands on the school system?"

Respondent 33: "They had strong PTAs then. They all supported everything."

Respondent 34: "Oil really helped us by offering jobs. Before we were a shrimping community. They [oil] gave good high paying jobs. They [oil] did much to set up the infrastructure. When people make money they can afford to build schools and roads and other things. I was elected to the school board in 1973. They built the new high school in Berwick and Patterson during that time. They were able to raise a lot of money due to the jobs that were created in the area due to the oil.

Interviewer: "Did you see the school system improve as oil came in?"

Respondent 34: "I would say it was beneficial. With my background on the school board, I can tell you when you have a lot of money it is going to be beneficial. Now you have to do the right thing with the money. Money was never a problem until '82. It got tough after '82, had to make cuts. I think the oil industry had an impact allowing the people to be able to do what they wanted to do with the schools."

Interviewer: "How are they doing now?"

Respondent 34: "They are still doing well. All public systems have problems but overall they do pretty good."

Status Attainment

Respondent 11: "I think that the engineers and all brought in experiences that the people of Morgan City didn't have. I think that the resistance to getting a job outside was the lack of a college education. I graduated first in my class; three of us went to college. The rest of them, and this is not degrading, were going to work on their father's shrimp boats or the welding shops. There wasn't even a thought of going to college. So in order to go work outside you need a college education. Now, more from Morgan City attend [Nicholls State University] because Nicholls at that time was just a day college and they ran the buses from Morgan City. More from that area went but again the thought was never to get an education and go somewhere else. It was always to get an education and come back, to teach school doing education. And I think when those engineers came in they brought life experiences into the mix that were not there."

Consequences for Familial/Inter-Generational Mobility

Respondent 35: (Respondent was a registered nurse, husband M.D., came to Morgan City when hospital expanded in the early 1960s): "I have three grown sons. One lives in Berwick, one in Morgan City and the other in Hattiesburg, Mississippi. The child in Hattiesburg is a physician. The other two own their own oil related businesses … I also have three granddaughters. Two are attending Nicholls State while the other already received a degree from there."

Introduction of Weak Ties into the Area Allowing for New Bridging Capital

Respondent 34: "I remember a couple of distinct times, probably two or three. One of them [newcomers from oil] would come in to the office and say, 'I need a favor.' I would say ' what's the matter?' Says 'I'm bringing my wife to Morgan City and I need you to convince her to move here. She says she is not coming. She doesn't want to live down here, we are coming from Houston or from New Orleans. She doesn't want to live in Morgan City, Louisiana.' So I say 'Ok, let me talk to her.' Boy, one time the lady was sitting out in the car and she would not get out the car. So I asked for her to please give me ten minutes of her time and she agreed. She said 'I am not moving to Morgan City.' She said 'This is the end of the earth.' I am going to promise you one thing if you move to Morgan City, when you leave Morgan City you will hate to leave Morgan City, you will not want to go.' She answers with 'I don't believe that.' I said 'This is a close knit town, the oil folks are all close to each other and the local people are all very friendly people and you are going to love this area once you get settled here.' Her eyes kind of lit up a little bit and she said 'Well I will give it a shot.' Eventually they bought a house and stayed here and then got transferred after six years to Houston and hated to go."

Interviewer: "Did they keep in contact after they left?"

Respondent 34: "Oh yeah."

Respondent 12: "My own saying that I created: 'They cried when they came and cried when they left.'"

Respondent 36: "I cried the first year I moved here, one solid year."

Respondent 35: "My husband had to bring me home [where they moved from] every three months."

Interviewer: "Do you remember after being here for a while and the culture change, do you remember feeling more at ease?"

Respondent 35: "Oh yeah."

Respondent 36: "It only took me a year."

Negative Outcomes

- Negative effect of dense homogeneous networks

- Initial rejection of newcomers brought in by the oil industry

  Respondent 35: "When I came here on weekends with my old roommate from New Orleans nursing school, she took me one day to Berwick where Golden Farms was just being built. She said 'I am going to take you over to where the oil people live.' I said 'they look like good homes to me.' She said, 'Oh you don't want to fool around with those people.'"

- Political conflict

- Strains related to the cyclical nature of the industry

William B. Bankston received his Ph.D. in sociology from The University of Tennessee, Knoxville and currently is Professor of Sociology at Louisiana State University, Baton Rouge. His primary area of research interest has been in the sociology of deviance and crime, particularly the social and cultural influences on violent crime and homicide. Most recently his research has focused on the effects of socio-economic change on community crime patterns and social disruption.

IDLE IRON, REUSE AND SCRAP IN THE GULF OF MEXICO

Mark J. Kaiser, Center for Energy Studies, Louisiana State University

Click here to view the slide show that accompanied this presentation.

Offshore structures are installed to produce hydrocarbons, but at some point in time during the life cycle of the field, when the cost to operate a structure exceeds the income from production, the structure will exist as a liability instead of an asset. Federal regulations require that an offshore oil and gas lease be cleared of all structures within one year after production on the lease ceases. In recent years, the Minerals Management Service has begun to encourage operators to remove structures on producing leases that are no longer "economically viable." The purpose of this paper is to quantify the amount of idle iron that exists in the Gulf of Mexico and to describe its geographic distribution and ownership patterns. The basic question of what idle iron is and why it exists is addressed, followed by a discussion of the policy implications involved in the interpretation of federal regulations. Summary statistics that quantify and define the idle iron inventory is then presented.

Mark J. Kaiser is an associate professor at the Center for Energy Studies, Louisiana State University. His primary research interests are related to policy and modeling issues that arise in the energy industry. Dr. Kaiser conducts research and policy analysis on energy consumption and conservation issues, environmental effects of energy production, tariff analysis, and broad policy issues in electricity, natural gas, and oil markets. He has made significant contributions to the policy debate on the federal energy assistance LIHEAP and WAP allocation mechanisms, the economics and regulatory structure of offshore decommissioning, and fiscal system analysis and design. Dr. Kaiser is known for his fundamental and applied energy research activities. His work appears across a broad spectrum of energy, engineering, mathematics and scientific journals. He has consulted and served as technical advisor to corporations and government agencies, and is a member of the United States Association for Energy Economics (USAEE), International Association for Energy Economics (IAEE), and The Institute of Management Science and Operations Research (INFORMS). Dr. Kaiser received his Ph.D. in industrial engineering from Purdue University.

COMPETITION AND PERFORMANCE IN LEASE SALES AND DEVELOPMENT IN THE U.S. GULF OF MEXICO OCS REGION, 1983–1999

Omowumi Iledare, Center for Energy Studies, Louisiana State University

Click here to view the slide show that accompanied this presentation.

This paper characterizes and analyzes petroleum lease sales and development in the U.S. Gulf of Mexico OCS using estimated physical and economic measures of performance in offshore petroleum lease development. The physical performance measures we estimated include lease prospectivity index, lease expeditious index and lease development productivity. In addition, we estimated two economic performance measures, profitability index and internal rate of return.

The framework adopted in this paper is such that each annual portfolio of leases is treated as a unique but interdependent investment decision by firms at different points in time. Thus, in an aggregate sense, the estimated rates of return earned from investment by important lease category in the Gulf of Mexico OCS region are estimated.

Lease categories considered to be central in the determination of the expected value of or realized value from purchased leases by firms of different sizes are incorporated in the paper. Such categories include the following:

- Water depth—the shelf (0-200m), the slope (201-800) and the deep (801m and above)
- Lease type—wildcat, drainage and development
- Bid structure and size—single bid or at least two bids
- Product type—oil or gas
- Firm size—integrated or independent, top 4, top 8 or big 20 firms.
- Bidding conduct—solo or joint ventures

Empirical analysis of lease specific data suggests the Gulf OCS is just as attractive to the big four oil and gas integrated firms as it was two decades ago. However, there is evidence of influx of more new active players in petroleum lease development in the region than two decades ago. There is also strong evidence from lease prospectivity results, which suggests that the risk of lease development failure rises with firm size and water depth leases.

Regarding prospectivity of OCS in terms of lease development index, we found that of the 13,641 leases issued from 1983–1999, 26% reported some drilling activity as of year end 2004. Of those 3,581 leases reporting drilling activity from 1983–1994, MMS qualified 43% as producible leases. The drilling failure rate in the aggregate was about 57% as of 2004

The overall aggregate lease development index (the product of the proportion of drilled leases and the proportion of successful drilled leases) for leases issued from 1983–1999 was 11.4% as of 2004. In other words, approximately one out of nine leases produced hydrocarbons in the Gulf of Mexico OCS. Variations in lease prospectivity within group are evident in the report.

The time interval from lease sale to first drilling activity (spud) and from sales to first production by lease category is called expeditious development index in the report. Our study shows evidence of declining trends over time in the average lag from sales to production on leases issued from 1983–1999. On average, it took about 78.9 months prior to first production on leases sold from 1983–1987. In comparison, it took approximately 50.3 months on average from sales to production for leases sold from 1995–1999.

Regarding productivity as a measure of physical performance of lease development in the Gulf of Mexico, we found evidence that the overall aggregate productivity per drilled lease declined significantly from a high of 4,536 MBOE for leases issued from 1983–1987 to 2,864 MBOE for leases issued in the early 1990s. Further, for all categories of leases, the productivity ratios in the early 1980s were significantly higher than productivity ratios in the early 1990s, notwithstanding the fact that more leases were issued and drilled in the 1980s than in the early 1990s.

For comparative purposes, we used two representative discount rates in this report for all categories of leases. Thus, our results do not reflect any cross sectional or time variations in the cost of borrowed capital by firms for projects. The key finding in the profitability index analysis is that the estimated indices were significantly low for all categories of leases. This finding notwithstanding, we found that the impact of bonus payment, which has been suggested to be regressive in nature, is significant on the economic performance of lease development.

In general, our estimated measures of aggregate economic performance, the profitability index and internal rates of return are relatively low in comparison to returns in the manufacturing sector during the period. The reported low profitability measures, notwithstanding, we find that aggregate annual average rate of return on all leases issued from 1983–1994 increases with water depth and across time. The same pattern, however, is not evident in the late 1990s, probably because of data limitations. Also, the aggregate average rate of return increases with firm size in the 1980s, but no definitive trend is apparent across firm size in the 1990s.

Omowumi Iledare is a professor at the Center for Energy Studies, Louisiana State University. He received his Ph.D. in mineral economics from West Virginia University and his M.S. in energy resources from the University of Pittsburgh. His bachelor's degree is in petroleum engineering with honors from the University of Ibadan, Nigeria. Dr. Iledare's research interests are focused primarily on exploration and production economics and policy issues. He conducts research and economic analysis on oil and gas upstream industry structures and the global oil markets; environmental effects of oil and gas exploration and production; and taxation and regulation of the oil and gas industry. Prior to joining the LSU faculty, he worked briefly as an associate energy specialist with the California Energy Commission in Sacramento, California, and as a research associate with West Virginia Public Energy Authority. He has also worked for Shell as a petroleum/reservoir engineer and as a reservoir and production engineer trainee with Mobil Producing, both in Nigeria. Dr. Iledare is a member of the Society of Petroleum Engineers (SPE), a member of the International Association for Energy Economics (IAEE), the immediate past secretary-treasurer of the United State Association for Energy Economics (USAEE), an affiliate of IAEE. He is also the editor of USAEE Dialogue, a newsletter published quarterly by USAEE. Dr. Iledare presents and discusses technical papers regularly at conferences sponsored by these associations. He has published several articles on petroleum economics and policy analysis in trade and academic journals.

HISTORY OF OFFSHORE OIL DEVELOPMENT IN THE GULF OF MEXICO: DESIGNING AND MANAGING A PROJECT TO BENEFIT MULTIPLE STAKEHOLDERS

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

Click here to view the slide show that accompanied this presentation.

The development of the offshore petroleum industry is a remarkable story of inventiveness, entrepreneurship, hard work, and risk-taking that turned Louisiana's relatively isolated coastal communities into significant contributors to the United States and global economies. To explore the history and evolution of this industry and the people and communities where it was born, in 2001 the U.S. Minerals Management Service (MMS) sponsored a study to examine the historical evolution of the offshore oil and gas industry and its effects on Louisiana's coastal culture, economy, landscape, and society. The study represented the convergence of the ideas of several people who recognized that an important piece of history—the origins of the offshore petroleum industry – was being lost and that capturing it would require the use of published works, periodicals and other documents, and oral histories. The idea for the study was supported by the Social Science Subcommittee of the MMS Scientific Committee, staff from MMS Headquarters and the Gulf of Mexico Region office in New Orleans, members of the business and academic communities, and Louisiana civic leaders and educators. As a result, researchers from the Center for Energy Studies at Louisiana State University (LSU), the Departments of History and Business at the University of Houston (UH), the Program in Public History Studies at the University of Louisiana at Lafayette (ULL), and the Bureau of Applied Research in Anthropology at the University of Arizona (UA) came together to trace the development of the industry from land and marsh to state waters and then out across the Outer Continental Shelf.

The approach selected for this study was to combine oral history, documentary research, interviews, and historical economic analysis to establish the basis for understanding the history and evolution of the offshore oil and gas industry in southern Louisiana, the birthplace of the industry. The study was designed to gather information from the industry's pioneering engineers, managers, and entrepreneurs who created the organizations and technology required to produce oil and gas, sometimes hundreds of miles from land in thousands of feet of water. In addition, oral histories were collected from workers, family members of workers, community leaders, and others whose lives were shaped by the offshore industry. Finally, the researchers sought the perspectives of government and political leaders who developed the strategies and laws that were used by MMS to regulate and manage the development of offshore resources.

As the study progressed, the focus on oral histories grew. Beyond the stories of the "winners" and of the technological "firsts," little of this rich history had been written. Due to the size of the onshore area associated with offshore petroleum development and the continuing change and innovation required for the steady march farther and farther offshore, the story developed in many places and involved thousands of entrepreneurs. The researchers recognized and capitalized on the complexity of the industry and its history by reaching into communities across southern Louisiana, as well as into Houston and other locations where pioneers could be found. They worked to encourage the participation of individuals from throughout the region, of both genders, and of diverse socioeconomic backgrounds and racial and ethnic groups. Due to the advanced age of the earliest pioneers and the need to reach as many people as possible in a limited period of time, the researchers worked in teams and utilized various strategies to identify and locate the pioneers. To ensure that information about the earliest days in the development of the offshore petroleum industry was collected, the researchers focused on the years leading up to and including the 1970s, saving the study of the development of the deepwater industry for another time.

Many pioneers had received little recognition for their efforts, so researchers went to their homes and communities to seek them out. To find and gain access to these individuals, the researchers established relationships with community and business leaders and developed mechanisms through which they and the pioneers could develop mutual trust and open channels of communication. In the close-knit communities of southern Louisiana, this presented a special challenge. In addition, the years of the 1930s, 1940s, and 1950s were marked by fierce loyalty to political leaders and companies, even when those were not acting in the best interest of the communities. Consequently, researchers and community members exerted considerable effort to assure pioneers that their stories were important and that they could determine what they wanted to share. Throughout the effort, community partners were crucial to project success.

In one effort to gain trust and increase local participation, researchers identified and trained local schoolteachers in New Iberia and Houma to serve as teacher-researchers and to share information about the study in their communities. In Morgan City, researchers worked with the editor of the local paper, *The Daily Review,* to write and publish articles about the pioneers who had been interviewed for the study. They also worked through local groups such as company retirees clubs, the Barataria-Terrebonne National Estuary Program's Management Conference, the Offshore Energy Center's Pioneer Hall of Fame, the local Desk and Derrick Clubs,[1] the United Houma Nation Tribal Council, and local branches of the Louisiana Technical College to inform people about the study and identify people who should be included. They attended meetings and gatherings such as the annual Divers' Reunion in Bush, Louisiana. The researchers also used phone directories and city directories to identify companies that had been in existence for decades and met with company executives and staff to interest them in the study and elicit their support in finding early pioneers. In addition, the researchers networked with local historians, librarians, and archivists at places like the Morgan City Archives and Nicholls State University in Thibodaux, Louisiana to find potential participants. The study would not have succeeded as it did without the knowledge and support of dozens of local contacts.

[1] The first Desk and Derrick Club was organized in New Orleans in 1949 for women working in the petroleum industry. The clubs reached their height during the early 1980s with 12,750 members nationwide (1982) and 127 clubs (1983).

By the summer of 2006, researchers from the University of Arizona, University of Houston, and University of Louisiana at Lafayette had conducted 486 interviews with 517 individuals. The earliest offshore pioneers were all men, and the interviews reflect that; 441 men and 76 women participated in the interviews. The distribution of interviews, the majority of which were conducted in southern Louisiana, is shown in Figure 1E.1.

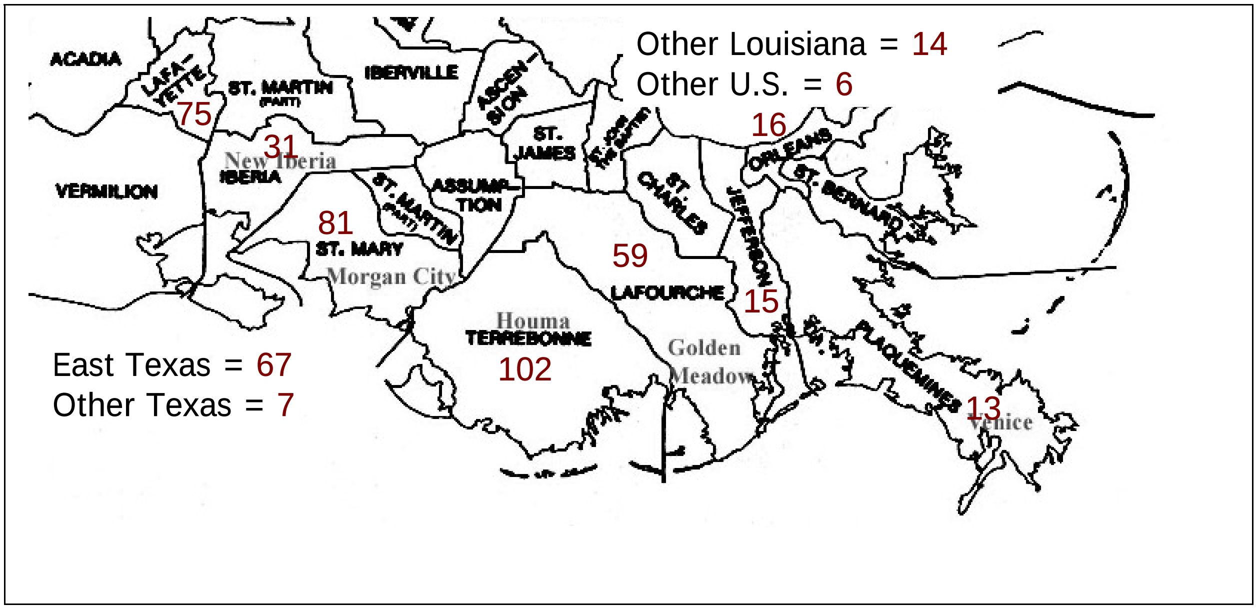


Figure 1E.1. Distribution of interviews.

Researchers identified potential interviewees through a snowball approach, beginning first with individuals and organizations where they had contacts prior to the study, and then working from those contacts to find other potential participants. The source of each interview conducted by the UA team was tracked. Of the 320 separate contacts of the UA team, the major sources of contacts were individuals within the study, other individuals, organizations, local gathering places, and self-referral. In most cases, interviewees were asked if they knew anyone else they believed should be included in the study. On a number of occasions, interviewees that were referred by someone in the study then referred the researchers to someone else. This created "chains" of contacts, two types of which are shown in Figure 1E.2.

The length of the chains ranged from 1 (the interviewee did not refer the researcher to anyone else who agreed to participate in the study) to 8. There were 234 chains for the 320 separate interviewee contacts. The majority of chains had only one interviewee, reflecting a dispersed systems through which the interviewees were identified (see Figure 1E.3). Most interviewees were referred by individuals within the study, and the average length of a chain was 2.1, as shown in Figure 1E.4.

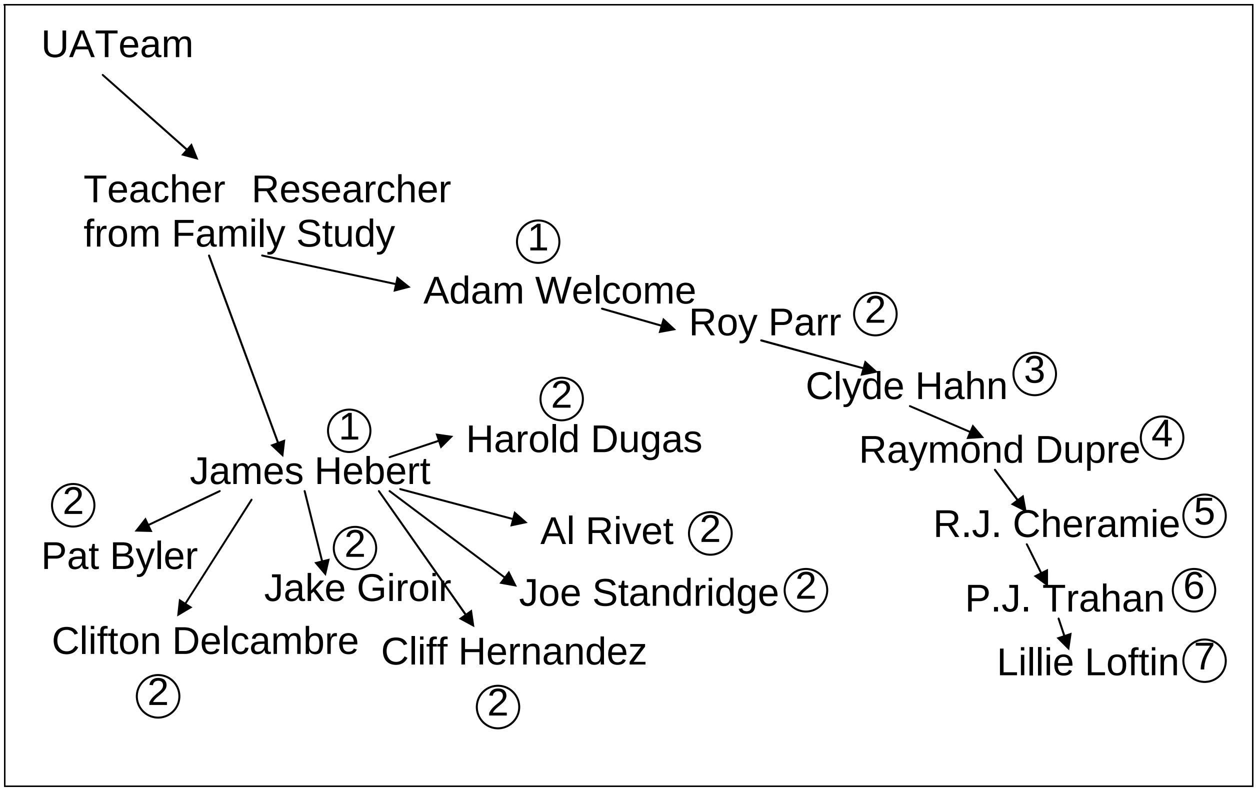


Figure 1E.2. Sample chains of contact.

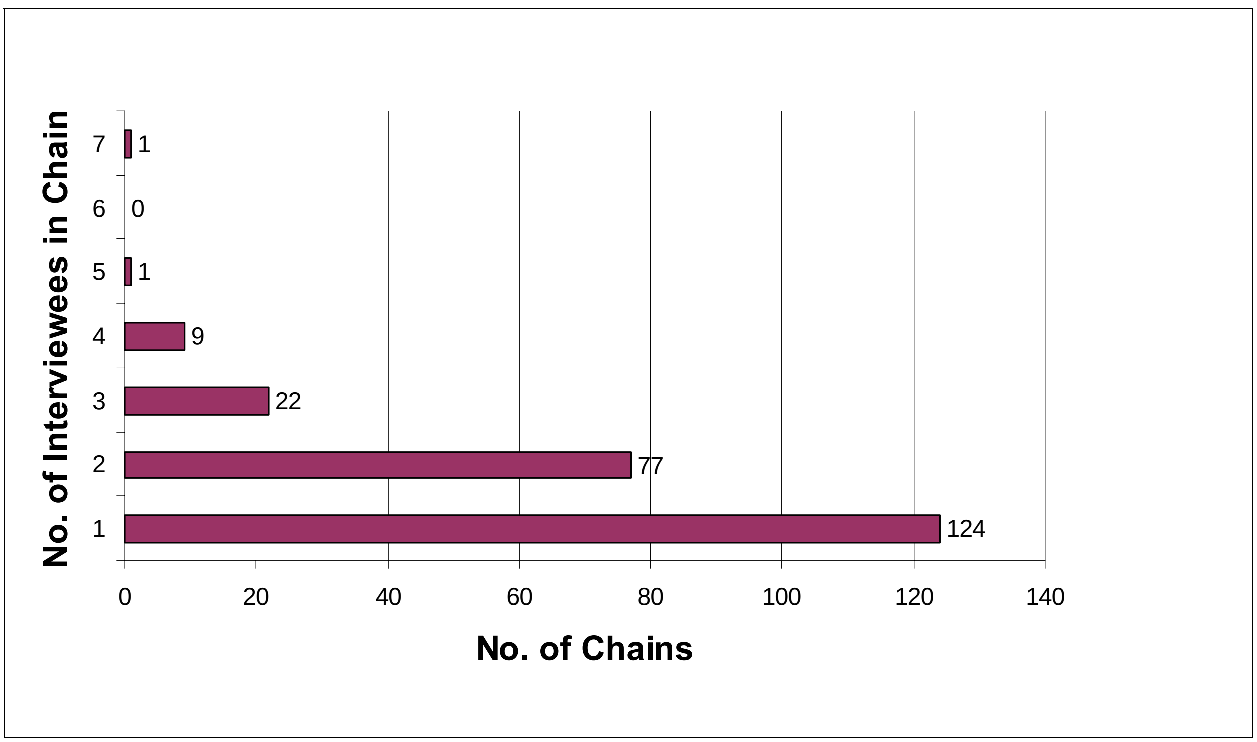


Figure 1E.3. Length of chains of contact for UA team.

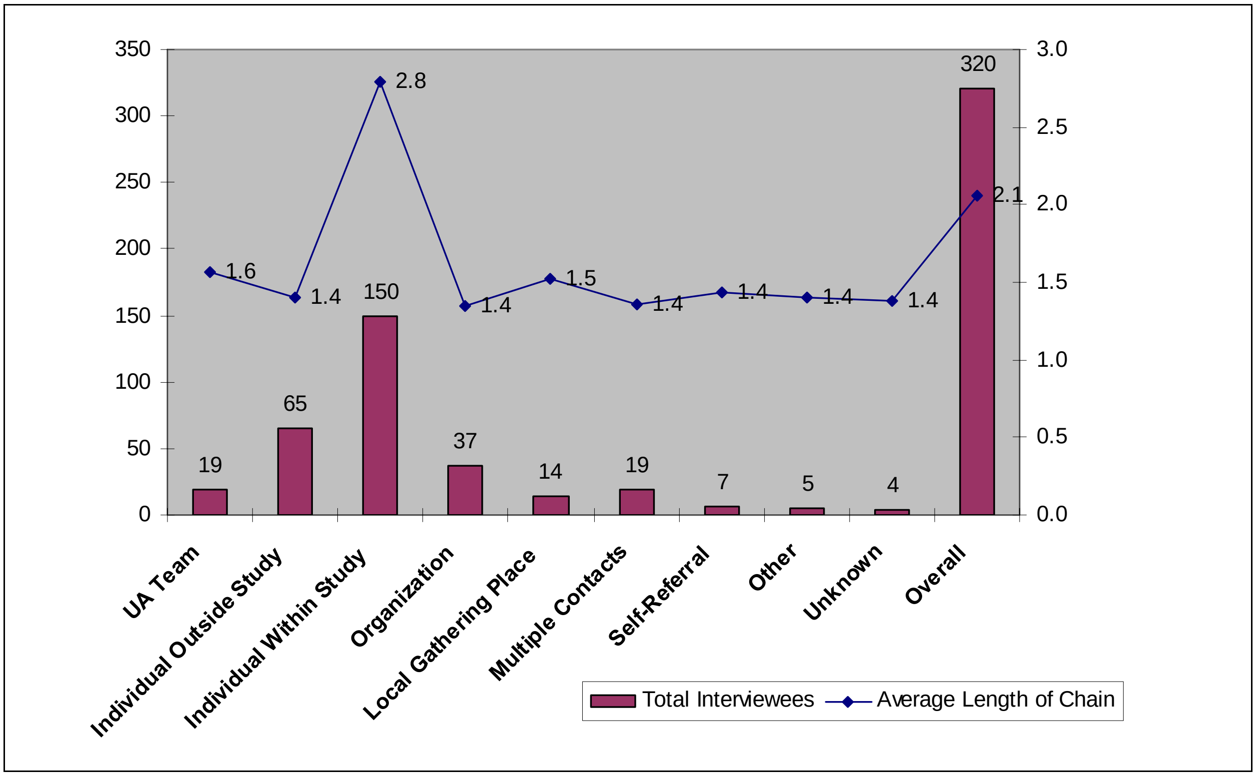


Figure 1E.4. Chains of contact by source.

The goal of the oral history study was to collect and archive as many stories of the early pioneers as possible. However, as the study progressed and researchers observed the local enthusiasm for the project, it became clear that simply archiving the materials would be inadequate. In addition, researchers realized that providing information about the study and sharing some of what had been learned within the communities would help spread the word about the study and identify more potential participants. Several outreach activities were designed to make information available within the communities, increase awareness of the project, and bring in more people. These included a project website, the series of articles in *The Daily Review*, a 15-minute video (later DVD) about the project, inclusion of industry pioneers in the 2005 MMS Information Transfer Meeting in New Orleans, and collaboration with the Morgan City Shrimp and Petroleum Festival Board. In 2004, the researchers worked with a Houma-based independent company, Minds Eye Productions, to produce a traveling exhibit, "The Offshore Oil and Gas History Project," which opened first at the Southdown Museum in Houma and has so far traveled to Raceland, Morgan City, and Lockport. Prior to the exhibit openings in Houma, Raceland, and Morgan City, researchers and local supporters hosted receptions for the study participants from the surrounding communities.

The value of the oral history collection and other data gathered during this study will only be realized if it is used. To get information out to researchers and others with potential interest in the collection, the researchers organized the collection to be easily accessible to users and participated in several events to inform others of its existence. First, a spreadsheet of all participants was created and a bibliographic database was constructed to include information about how each individual was selected for participation in the study, highlights of the individual's career and personal history, and a summary of the main topics discussed during the interview. Both the spreadsheet and database can be printed into booklets and used electronically. In electronic form, they are readily searched by participant name, occupation, and any keyword of interest to the user. A spreadsheet was also created to organize the thousands of digital photos collected during the study, and digital copies of the photos were organized in folders and stored on compact discs.

All interviews were transcribed and digital copies of the transcripts, as well as the databases and digital photos described above, will be available in the archives at the University of Houston, University of Louisiana at Lafayette, Nicholls State University, Louisiana State University Center for Energy Studies, Morgan City Archives, and Lafourche Parish Library. The study researchers collaborated with researchers from the National D-Day Museum in New Orleans to identify and conduct oral history interviews with offshore pioneers who had also served in World War II. The video tapes of those interviews will also be included in the National D-Day Museum collection. To spread the word about the collection and its potential as a research tool, the researchers organized sessions for the conferences of the American Society for Environmental History, the Southeast Historians Association, and the Society for Applied Anthropology. The information contained in the interviews will serve as the core for numerous further investigations of this important era in the history of the petroleum industry.

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.

AN EXAMINATION OF THE DEVELOPMENT OF LNG ON THE GULF OF MEXICO

Kristi A. R. Darby and David E. Dismukes,
Center for Energy Studies, Louisiana State University

Click here to view the slide show that accompanied this presentation.

This research examines the role, importance, and development of liquefied natural gas (LNG) regasification facilities along the Gulf of Mexico (GOM). The central thesis of the research is that the GOM is perhaps the best situated location for the development of LNG regasification facilities given the close proximity of a wide range of energy infrastructure that can help support and serve as a market to these new infrastructure investments.

The research starts with by providing some background on LNG development in the U.S. and the factors that are making this round of LNG development different than what occurred during the late 1970s and early 1980s. Changes in natural gas markets have been examined and the role that new environmental pressures are placing on natural gas-fired power and industrial applications discussed. The LNG value chain is discussed at length, as well as the respective costs and break-even prices estimated to import natural gas into the U.S.

Of particular interest is the interaction of these new facilities with existing GOM energy infrastructure. The research notes that GOM pipeline and storage infrastructure in the region is perhaps one of the most important sets of energy assets that will help facilitate the movement of imported gas across the region and into other regions of the U.S. Gas processing and other supporting gas infrastructure is also examined.

Perhaps the biggest area of concern for many policy makers along the GOM is the ability of imported natural gas to help dampen both the increases and volatility of prices to all end users in the region, particularly those end users in the petrochemical sector. The research examines both the challenges that high natural gas prices are having on this sector and the regional job losses that have occurred in the aftermath of the large natural gas price run up of 2000–2001.

The conclusion of the research is that the development of LNG regasification facilities along the GOM will be supplemental, and even complimentary, to the existing set of energy infrastructure in the region. These facilities will provide new sources of revenue for pipelines, storage, and gas processing facilities, which in turn can be used to service existing and ongoing domestic natural gas production. Currently anticipated expansions of existing infrastructure in certain areas are expected to be more complementary to, as opposed to competitive with, existing domestic production.

Kristi A. R. Darby is a geologist and research associate at the Center for Energy Studies, Louisiana State University. Her research interests focus on projects evaluating economic and policy issues associated with the energy industry in Louisiana, in particular the oil and gas industry both onshore and offshore the state. Prior to joining CES in January 2004, Ms. Darby worked as a petroleum geologist for five years in California and Texas. She has been active in many aspects of the Center's research efforts over the past two years, including the impact of hurricanes on energy infrastructure in the GOM and the development of liquefied natural gas (LNG) facilities along the GOM. Ms. Darby has spoken on the issue of LNG development before various Department of Energy sponsored events in Boston and Houston and at educational training seminars for the U.S. Coast Guard. She received a M.S. in geology from the University of Southern California and a B.S. in geology from California Lutheran University.

David E. Dismukes is an associate professor and the Associate Director of the Center for Energy Studies, Louisiana State University. His research interests are related to the analysis of economic, statistical, and public policy issues in energy and infrastructure industries. Over the past 19 years, he has worked in consulting, academia, and government service. Dr. Dismukes joined the LSU faculty in 1995 and since that time has led a number of the Center's research efforts in such topics as the economic impacts of offshore oil and gas exploration and production (E&P) activities; the restructuring of natural gas and electric power markets; market structure issues in various energy industries; and the economic impacts of independent power on the economies of the Gulf South region. He has published over 100 articles and conference papers in scholarly journals and trade publications. Dr. Dismukes recently completed a book on electric restructuring and competition published by CRC Press entitled *Power Systems Operations and Electricity Markets*. He received his M.S. and Ph.D. in economics from the Florida State University.

SESSION 1F

DEEPWATER HABITATS

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

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

MACROFAUNA COMMUNITY STRUCTURE AND FUNCTION: DEEP GULF OF MEXICO

Gilbert Rowe, Department of Marine Biology, Texas A&M at Galveston

Click here to view the slide show that accompanied this presentation.

Macrobenthos of the deep, northern Gulf of Mexico (GOM) have been sampled with large box cores along multiple cross-depth transects extending from depths of 200 m out to 3700 m. Four major depth zones have been identified based on the faunal similarities between geographic sites, with the two intermediate-depth zones being divided horizontally down the middle of the basin. Strong correlation between export POC flux and faunal similarities, as well as characteristic animal density, biomass and biodiversity (α diversity) in each zone and sub-zone suggested that the input of food resources may control the observed zonal pattern. Highest density and biomass occurred in two large submarine canyons, the Mississippi and De Soto canyon, reflecting the terrestrial input and canyon physiography. The α diversity displays an intermediate depth maximum with a diversity hotspot on east mid-slope, due, we suggest, to the balance between competition for resources and physical disturbance, but the α diversity is lowest at the head of Mississippi Canyon due to extreme dominance by amphipods. Small mean individual size and low densities encountered are a reflection of the meager surface water production, albeit with exceptional isolated habitats in which detrital material is concentrated, such as canyons on the upper continental slope.

Sediment community oxygen consumption (SCOC) has been measured from the continental shelf out to the Sigsbee Abyssal Plain in the NE Gulf of Mexico (GOM). SCOC rates on the continental shelf were an order of magnitude higher than those on the adjacent continental slope (450 to 2750 m depth) and two orders of magnitude higher than those on the abyssal plain at depths of 3.4 to 3.65 km. Oxygen penetration depth into the sediment was inversely correlated with SCOC measured within incubation chambers, but rates of SCOC calculated from either the gradient of the [O_2] profiles or the total oxygen penetration depth were generally lower than those derived from chamber incubations. SCOC rates seaward of the continental shelf were lower than at equivalent depths on most continental margins where similar studies have been conducted, and this is presumed to be related to the relatively low rates of pelagic production in the GOM. The SCOC, however, was considerably higher than the input of organic detritus from the surface-water plankton estimated from surface-water pigment concentrations, suggesting that a significant fraction of the organic matter nourishing the deep GOM biota is imported laterally downslope from the continental margin.

The standing stocks and biological exchanges between the living components of the benthic boundary layer in the deep, northern GOM have been assembled into a hypothetical, interactive food web based on recent cooperative investigations. Estimates of standing stocks of bacteria, Foraminifera, metazoan meiofauna, macrofauna, invertebrate megafauna, and demersal fishes allow comparison of these different stocks across a 3 km depth gradient. The carbon demand of each "size" or functional group has been estimated from allometric models of respiration rate, supplemented by direct measurements in the laboratory. Total carbon demand by the sediment-dwelling organisms has been constrained by measurements of SCOC utilizing incubation chambers on a remote benthic lander, submersible-deployed chambers or laboratory incubations of recovered cores. The rates and stocks have been incorporated into a set of coupled differential equations that represent carbon flow between the different size groups in the food web. A comparison of the upper continental slope (450 m depth) with the Sigsbee Abyssal Plain (3.4 to 3.7 km depth) illustrates a distinct decline in biomass of all groups with increasing depth. The decline however was more abrupt in the larger forms (fishes and megafauna), resulting in a relative increase in the predominance of smaller sizes (bacteria and meiofauna) at depth. Rates and stocks appear to be lower in the deep GOM than at comparable depths on other continental margins where similar comparisons have been made, reflecting the modest pelagic production characteristic of the surface waters of the GOM.

Gilbert T. Rowe received his B.S. and M.S. degrees (1964 and 1966) from Texas A&M and a Ph.D. from Duke University (1968). His professional experience has included 10 years at the Woods Hole Oceanographic Institution, 8 years at the Brookhaven National Laboratory and 19 years at Texas A&M, where he is presently a professor and head of the Department of Marine Biology, Galveston. Dr. Rowe has published over 110 papers in the peer-refereed literature, in addition to editing or co-authoring several volumes devoted to deep-sea life. Dr. Rowe can be credited with taking some of the first quantitative samples of the deep benthos in the Gulf of Mexico, which led to a series of papers describing the extreme oligotrophic (desert-like) nature of the Sigsbee Abyssal Plain. This initiative included measuring the oxygen consumption of the sediment-dwelling biota and the attraction of deep-living scavengers to bait. He served as the program manager of the MMS-supported Deep Gulf of Mexico Benthos study from 1999 through 2005. Presently he is cooperating with a NOAA-supported, interdisciplinary group attempting to understand the causes of hypoxia on the Gulf of Mexico continental shelf. Other research by Dr. Rowe includes quantifying continental shelf benthic biomass; oxygen, carbon and nitrogen cycling related to shelf-edge export and benthic-pelagic coupling; the application of numerical simulations to predict possible effects of organic enrichment on deep-sea communities in relation to production of deep-ocean fossil resources.

SPATIAL AND BATHYMETRIC VARIATION OF MEIOFAUNAL COMMUNITY STRUCTURE AND FUNCTION IN THE NORTHERN GULF OF MEXICO DEEP SEA

Jeffrey Baguley, The University of Nevada-Reno

Paul Montagna, Larry Hyde, Rick Kalke, Texas A&M University at Corpus Christi

Wonchoel Lee, Hanyang University, Korea

Joan Bernhard, Woods Hole Oceanographic Institution

Gilbert Rowe, Texas A&M University at Galveston

Click here to view the slide show that accompanied this presentation.

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. In order to more fully understand the distribution of meiofauna and how they respond to topographic, geochemical and physical forcing in the northern Gulf of Mexico, meiofaunal abundance and environmental variables were analyzed in a hypothesis-based univariate and multivariate design. Meiofaunal abundance is significantly related to water depth, but also exhibits significant longitudinal differences resulting from proximity to the Mississippi River outflow. Canyon features in proximity of Mississippi River outflow were found to greatly enhance meiofaunal 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 meiofaunal abundance.

Harpacticoida (Copepoda) are the second most abundant metazoan 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 northern Gulf of Mexico 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 northern Gulf of Mexico 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 (2700 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 1200 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.

In sum, 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 meiofaunal community function (grazing, respiration, etc.) has only been sparsely investigated. In the present study, metazoan meiofaunal 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. Metazoan meiofauna account for 10–25% of whole sediment community respiration and are therefore an important component of global biogeochemical cycles.

In addition to metazoan meiofaunal analyses, benthic foraminiferal biomass, density, and species composition were determined at ten sites in the GOM. The >63-μm fraction of box-core subcores was examined shipboard for benthic foraminifera , which were individually extracted for adenosine triphosphate (ATP) using a luciferin-luciferase assay to indicated the total ATP content per specimen; that data was converted to organic carbon using established conversions. Foraminiferal biomass and density varied substantially (~2–53 mg C m^{-2}; ~3,600–44,500 individuals m^{-2}, respectively) and inconsistently with water depth. For example, although two ~1000-m deep sites were geographically separated by only ~75 km, the foraminiferal biomass at one site was relatively low (~9 mg C m^{-2}) while the other site had the highest foraminiferal biomass (~53 mg C m^{-2}). Although most samples from Sigsbee Plain (>3000 m) had low biomass, one Sigsbee site had >20 mg foraminiferal C m^{-2}. The foraminiferal community from all sites (i.e., bathyal and abyssal locales) was dominated by agglutinated, rather than calcareous or tectinous, species. Foraminiferal abundance never exceeded that of metazoan meiofauna at any site. Foraminiferal biomass, however, exceeded metazoan meiofaunal biomass at five of the ten sites, indicating that foraminifera constitute a major component of the Gulf's deep-water meiofaunal biomass.

Jeffrey Baguley received his Ph.D. in December 2004 from the University of Texas at Austin, Marine Science Institute (Paul Montagna, Advisor). He completed post-doctoral studies at the Baruch Institute for Marine and Coastal Sciences at the University of South Carolina under the guidance of Dr. Bruce Coull. Dr. Baguley is now a lecturer in the Department of Biology at the University of Nevada-Reno. His 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 received his Ph.D. from the University of South Carolina in 1983 under the direction of Dr. Bruce Coull. He spent several years as a professor and senior research scientist at The University of Texas at Austin, Marine Science Institute, where he developed a well-respected research program. Dr. Montagna is now the Endowed Chair for Ecosystem Studies and Modeling at the Harte Research Institute for Gulf of Mexico Studies (Texas A&M University), and his research continues to focus on quantitative ecology. His research uses benthos as a data module for quantitative ecology. Quantitative ecology is comprised of experimental design, univariate and multivariate statistical analyses, deterministic and predictive modeling, and geographic information system studies.

Dr. Wonchoel Lee is an associate professor in the Department of Life Sciences, Hanyang University, Seoul, Korea.

Joan Bernhard received her Ph.D. in 1990 from Scripps Institution of Oceanography under the tutelage of Robert R. Hessler. She then did postdoctoral studies in cell biology at the Wadsworth Center, New York State Department of Health as well as at the Department of Geology at the University of Oslo in Norway as a Fulbright Scholar. After six years as a research faculty at the University of South Carolina's Department of Environmental Health Sciences, she was hired as a biogeochemical sedimentologist by Woods Hole Oceanographic Institution, where she is an associate scientist (with tenure) in the Department of Geology and Geophysics. Dr. Bernhard's main research interests are two fold: 1) deep-sea benthic foraminiferal ecology, cell biology, and paleoceanography studies; and 2) investigations of protistan-prokaryote symbioses in sulfidic environments.

Larry Hyde is a research associate at the Harte Research Institute for Gulf of Mexico Studies, Texas A&M University, Corpus Christi.

Richard Kalke is a research associate at the Harte Research Institute for Gulf of Mexico Studies, Texas A&M University, Corpus Christi.

Dr. Gilbert Rowe is head of the Department of Marine Biology, Texas A&M University.

PREDICTING AND MAPPING SPECIES RICHNESS IN THE DEEP GULF OF MEXICO: LESSONS LEARNED IN THE DGoMB PROGRAM

Richard L. Haedrich, Jennifer A. Devine, and Krista D. Baker, Memorial University, St. John's, Newfoundland

Click here to view the slide show that accompanied this presentation.

Support from MMS through the DGoMB program has been very much appreciated in Newfoundland, and a number of students from Memorial University have taken part in *R/V Gyre* cruises and in identification and analyses of the faunal data. DGoMB provided material for four student theses.

The Deep-Sea Demersal Fish Fauna of the Northern Gulf of Mexico

Shawna Powell's Master of Environmental Sciences thesis described the DGoMB fishes that were sampled with bottom trawls in May and June 2000. Forty-six stations were occupied and 1065 individuals in 119 demersal fish species were taken. Cluster analyses showed the fish fauna to be zoned with depth. Assemblages were identified on the deep shelf (188–216 m), upper slope (315–785 m), mid-slope (686–1359 m), lower slope (1533–2735 m), and the rise (2248–3075 m). The most abundant species found on the shelf was the small caproid *Antigonia capros*. Deeper, the fauna is dominated by Macrouridae: *Bathygadus macrops* and *Caelorinchus caribbaeus* on the upper slope and *Nezumia cyrano* and *N. aequalis* at mid-slope. The lower slope and rise are dominated by Ophidiidae, *Dicrolene kanazawai* and *Acanthonus armatus* respectively. Species richness is highest on the upper slope (53 species) and decreases with depth; the rise has 17 species. Abundance too, is greatest on the upper slope, especially in the Mississippi Trough and DeSoto Canyon, and declines greatly with depth. Diversity was also highest on the upper slope; however, values for the mid-slope, lower slope, and rise were all similar. Data on fishes supports DGoMB hypotheses relating to depth zonation and east-west abundance. Due to limited numbers of samples, hypotheses comparing fauna in-and-out of basins, and in-and-out of canyons could not be addressed conclusively. (This work was published in 2003 in the *Journal of Northwest Fisheries Science,* 31, 19–33)

The thesis also reported the natural and human-generated debris that occurred in the trawls, and preliminary findings concerning the distribution of bacteria and meiofauna. Natural debris from *Sargassum* and *Thallassia* was found throughout the Gulf. Human-generated trash was restricted to the canyon and eastern regions of the Gulf. Bacteria from boxcores were found throughout the Gulf, with higher abundance in the Mississippi Trough, shallow depths in the northeast, and at deep depths in the 'basin' region. The meiofauna collected from boxcores were found throughout the northern Gulf. Nematodes had the highest abundance in the Mississippi Trough. All other meiofauna, including harpacticoid copepods were more abundant at shallow depths and decreased with increasing depth.

Species Richness in Atlantic Deep-Sea Fishes Assessed in Terms of the Mid-Domain Effect And Rapoport's Rule

Val Kendall's Bachelor of Science (Honours) thesis considered deep-sea fish distribution patterns more generally. A decrease in species richness with increasing latitude had been documented for a broad range of taxonomic groups. A number of hypotheses relating to biological, environmental, and historical factors had been proposed to explain this phenomenon, and the mid-domain effect (MDE) had been proposed in the form of a null model. This model considers only the geometry of spatial gradients and species' range extents, excluding any assumptions of environmental, biological, or historical causes, and predicts that species richness will peak in the center of a domain in which species occur when their ranges are randomly distributed. The model has been applied to latitudinal, elevational, and depth gradients to quantify the extent to which non-random processes influence species richness patterns in comparison to those based on geographical boundary constraints alone. The MDE model was applied to empirical datasets for the ranges of the bottom-living fish species occurring in the Faroe-Iceland Ridge, Denmark Strait, southern New England and northern Gulf of Mexico. All the observed patterns showed a decline in richness with depth and did not match patterns from the null model. Therefore, non-random processes must have produced the observed patterns. Applied to bathymetric ranges, Rapoport's Rule predicts that richness decreases and range size increases with depth and latitude. The rule explained decreasing fish species richness with depth and between latitudes but did not appear to explain increasing range size with depth. (This work was published in 2006 in *Deep Sea Research I,* 53, 506–515)

Deep Gulf of Mexico Corals: Distribution, Faunal Associations and Biogeography

Tarah Cunningham's Bachelor of Science (Honours) thesis took a broad-scale look at the deepwater coral fauna. The corals caught in the DGoMB trawls comprised only six taxa out of a total of 100 known species from the deep Gulf of Mexico. There was no significant difference in the abundance and richness of corals in canyon vs. non-canyon and escarpment vs. non-escarpment habitats. Forty-three species of fish were caught only at stations where corals were caught, but conclusions about fish/coral associations could not be made because both individual trawls covered more than 1.5 km across the bottom. There was no statistically significant difference in the abundance of fishes in coral vs. non-coral stations. The deep-sea coral fauna of the Gulf of Mexico is more species-rich than that of Nova Scotia (100 vs. 35 species) and the two areas only have ten species in common. The majority of species of the Gulf of Mexico have a tropical or warm temperate western Atlantic or amphi-Atlantic distribution, while the majority of corals of Nova Scotia have a cold temperate amphi-Atlantic or cosmopolitan distribution.

A Comparison of the Mesopelagic Fish Fauna in the Gulf of Mexico with That of the Caribbean and Sargasso Seas

Jessica Bangma's Bachelor of Science (Honours) thesis was concerned with the relationships between the mesopelagic fish faunas of five adjacent but oceanographically distinct areas of the Western North Atlantic Ocean: the Gulf of Mexico, the Venezuelan and Colombian Basins of the Caribbean Sea, and the North and South Sargasso Seas. The South Sargasso and Colombian are the least similar in terms of their faunal composition, and the Venezuelan and Colombian Basins are the most similar. The Gulf fauna lies somewhere in between and is a composite of that in the Sargasso and Caribbean Seas. The Gulf of Mexico is also intermediate in percent endemism (7.1%), but has the most diverse fauna, with 140 species recorded. The centrally located Gulf can be considered an ecotone between the Atlantic Tropical and Subtropical faunal regions.

Predictors of Species Richness in the Deep-Benthic Fauna

The development of the DGoMB database and archive has allowed examination of some important general questions in deep-sea ecology. PhD students Jennifer Devine and Krista Baker collaborated in a study of species richness in macrofauna and megafauna from box cores and trawls from 35 standard stations over a depth range of 175–3720 m in the northern Gulf of Mexico. Two questions were of primary interest: 1) are observed patterns random, and 2) if not, what environmental factors might account for the patterns? A null model (MDE) tested whether richness vs. depth distributions were random. Groups with species that had broad vertical depth ranges fit the null model better than groups with small ranges, but for almost all phyla a non-random pattern was indicated. With randomness as a proximal explanation ruled out, further examination of the relationship between richness and environmental factors was justified. A generalized linear model (GLM) showed that a suite of 18 factors categorized as food-related, habitat-related, pollution-related and location-related were significantly related to richness patterns, but that different mixes of factors applied to different phyla. No one factor accounted for any observed patterns. Thus, each taxonomic group needs to be examined individually, and no generally applicable explanation for the causes of richness patterns may exist. Nonetheless, mapping richness itself is quite informative and indicates distinctive and valuable areas that must receive special consideration and possible protection. The Mississippi Trough is particularly important in this regard.

Coldwater Corals and Fishes of the Labrador Sea

Krista Baker is involved in studies around an exploratory drill site in the Orphan Basin, Labrador Sea. She is doing experiments on faunal settling rates there, and has been identifying the fishes recorded in ROV photographs. The pictures we show are of exceptional quality and come from 2338-m depth at the exploratory well.

Richard Haedrich is a biological oceanographer and ichthyologist with broad research experience in the systematics and biology of fish. He is well-known for his work on the biogeography and ecology of deep-sea fishes, often focusing on the relationships of fishes to their environment. This has led him, with his students, to research on the fisheries, both commercial marine and, in freshwater, the recreational salmonid fishery. He is the author of over 130 publications, with recent topics especially focused on changes in the fishery ecosystem of Newfoundland before, during, and after its major collapse in 1992. Other work has ranged from the remote satellite sensing of ocean color off Newfoundland to salmon in urban rivers and even to questioning the existence of communities in the deep sea. With Nigel Merrett, he is co-author of the book *Deep-sea Demersal Fish and Fisheries* (London: Chapman & Hall, 1997). Beyond these research interests, his administrative responsibilities—as Director of the Newfoundland Institute of Cold Ocean Science, the Marine Sciences Research laboratory, and Memorial's expanded Ocean Sciences Center—have given him a broad overview of aquatic research. He has been chief scientist on numerous scientific research cruises, beginning at Woods Hole and continuing on Canadian ships out of the Bedford Institute. Now an emeritus professor, he has taught courses at Memorial University since 1979 in his specialities—fisheries biology and oceanic biogeography—and also in introductory ecology. He was the first co-chair of COSEWIC's (Canada's Endangered Species Committee) Marine Fish Subcommittee from 1999 to 2004.

Jennifer Devine received her Ph.D. from Memorial University. She recently accepted a job with the National Institute of Water and Atmospheric Research, Wellington, New Zealand. She is particularly interested in deepwater surveys, quantitative applications of novel multivariate and times series analyses, and ecosystem level studies.

Krista Baker is a Ph.D. student at Memorial University. Her background includes a Master's thesis on criteria for the establishment of marine protected areas in the offshore and reports on endangered species. Her current research examines the distribution and associations between deepwater fishes and coldwater corals in the Labrador Sea, some of which involves community ecology at the Orphan Basin exploratory drill site.

MULTIVARIATE ANALYSIS TO SYNTHESIZE BENTHIC DATA COLLECTED DURING THE DEEP GULF OF MEXICO BENTHOS (DGoMB) PROJECT

Paul A. Montagna, Texas A&M University-Corpus Christi, Harte Research Institute

Jeffrey Baguley, University of Nevada-Reno, Department of Biology

Gilbert T. Rowe, Chihlin Wei,
Department of Marine Biology, Texas A&M-Galveston

Terry Wade, Geochemical and Environmental Research Group,
Texas A&M University

Gary Wolff, TDI-Brooks International, College Station, Texas

Click here to view the slide show that accompanied this presentation.

Introduction

The rapid expansion of offshore hydrocarbon exploration and production in the Gulf of Mexico (GOM) has created a need for increased understanding of deep-sea benthic habitats. In response to this development a program, referred to as Deep Gulf of Mexico Benthos (DGoMB) was designed to determine in greater detail the composition and structure of slope bottom biological communities, to infer relationships between biological patterns and major controlling processes, to characterize the area as to its present "health" and function, and to compare and contrast the region with similar oceanic regions.

The DGoMB program design was developed based on historical knowledge of deep-sea communities in the GOM. The interdisciplinary nature of the scientific objectives was recognized and the study design balanced the benthic survey aspects of the program with experimental (or "process oriented" studies needed to understand the deep-sea community's structure and function. Previous information was used to focus the study on the most relevant areas and those areas most likely to allow the establishment of generalities about the structure and function of deep-sea benthic communities. The results now provide a predictive capability for areas not directly sampled or observed. This predictive capability is a framework for ascertaining the potential for, and the most likely impact from, fossil fuel exploration and exploitation in the deep-sea (Rowe and Kennicutt in prep.)

The DGoMB program was conducted over a 65-month period. Three major oceanographic cruises were conducted, one in each of the first three years of the program. The biological sampling program included both trawls for fish and epibenthos and box cores for infauna and sediment characteristics. The interdisciplinary program had 16 investigators and nine different components. The purpose of the current study is to perform a statistical analysis focused on synthesizing all biotic and abiotic data from the box cores and relating it to water columns conditions and depth.

Methods

Biotic variables measured from box cores samples included representatives of meiofauna and macrofauna: Harpacticoida, Polychaeta, Crustacea (Amphipoda, Isopoda, and Cumacea), and Mollusca (Bivalvia and Aplocophora). Two main measures were used to link with abiotic varibles: total abundance and diversity. Bacteria total abundance was also used. Diversity is calculated using Hill's diversity number one (N1) (Hill 1973). It indicates the number of abundant species in a sample, and is a measure of the effective number of species (Ludwig and Reynolds 1988). It is calculated as the exponentiated form of the Shannon diversity index: N1 = $e^{H'}$. As diversity decreases, N1 will tend toward 1. The Pielou's evenness index (J') was calculated to represent the second component of diversity, which is the distribution of species in a sample. Even samples have representatives from many species with relatively even distributions; in contranst, samples with dominance of a few species lack evenness.

Abiotics variables to represent environmental conditions in the overlying water column included particulate organic carbon (POC), dissolved organic carbon (DOC), ammonium (NH_4), and nitrate (NO_3), and chlorophyll-a (Chl-a). The remaining variables were from sediments and included grain size (sand, silt, and clay content), total polycyclic aromatic hydrocarbons (PAH) excluding perylenes, the trace metals calcium (Ca), chromium (Cr), tin (Sn), and strontium (Sr), total organic nitrogen (OrgN), and total organic carbon (OrgC).

Prior to analysis, all environmental data were transformed to validate assumptions of parametric tests, and to weight the contribution of high or low measurements. The angular transformation (x = arcsin sqrt[y]) was used for the sediment grain size data, and a natural logarithm transformation (x = logn [y+1]) was used on all other biotic and abiotic data. The average value for each transformed variable was calculated for all replicate samples, and the biotic and abiotic data sets were merged by station.

Principal components analysis (PCA) was used to reduce the environmental variables. Each new principal component (PC) variable accounts for a percentage of the total variance in the original data set. The new variables are extracted in decreasing order of variance, such that the first few PC explain most of the variation in the data set. The contribution of each environmental variable to the new PC is called a load. Typically, the new PC variable loads can be interpreted to indicate structure in the data set. Each observation contributing to the PC is called a score. The PCA was performed using the SAS FACTOR procedure on the covariance matrix and using the VARIMAX rotation option (SAS Institute Inc. 1991). Details of implementations of the SAS program used are provided in (Long et al. 2003). The PCA station scores were used to correlate the environmental setting with the biological variables (i.e., abundance and diversity) with Pearson product-moment correlation coefficients (r) using the SAS procedure CORR.

One common problem with environmental data is that many variables measuring the same effects can skew the result. Thus pre-analysis was performed to determine if certain classes of variables could be dropped from the analysis. Only the total amount of PAHs was used. Perylene was dropped from the total because there are natural sources in the environment, and the goal was to include only those originating from human activities. A total of 29 metals were measured and had to be reduced for the final analysis using an initial PCA of all trace metals only. The first metals principal component (PC1) accounted for 70.1% of the variance in the metals data set and was the only PC with an eigenvalue greater than one. Thus, four metals, the two with highest positive and two with the most negative loadings, were chosen for the final PCA analysis including all environmental variables. These four metals (listed above) represent a proxy for the general trace metal pattern seen at all stations.

Community structure of macrofauna species was analyzed by multivariate methods. Ordination of samples was performed using the non-metric multidimensional scaling (MDS) procedure described by Clarke and Warwick (2001) and implemented in Primer software (Clarke and Gorley 2001). The software creates a Bray-Curtis similarity matrix among all samples and then an MDS plot of the spatial relationship among the samples. Cluster analysis on the similarity matrices was performed to determine the degree of relatedness of stations that were grouped near one another in the MDS plot. Community structure station patterns for harpacticoids, polychaetes, crustaceans, and mollusks were compared using the RELATE procedure in Primer, which tests for matching among the station patterns.

Results and Discussion

In the environmental PCA, the first three principal components accounted for 61.5% of the total variance in the data set. The sign of variable loads (negative or positive) indicates gradients in concentrations. Variables that load negatively will have highest concentrations for negative PC loads with decreasing concentrations moving in the positive direction, and vice versa. PC1 accounted for 33.5% of the total variance, had high positive loadings by clay, total PAH's, tin, chromium, and high negative loadings by sand, strontium and calcium (Figure 1F.1.A). PC1 is interpreted as the sediment properties, with high silt, clay, organic (PAH) and metal (Cr and Sn) contaminants near the Mississippi River, and higher sand and natural background metals (Ca and Sr) with increasing distance from the Mississippi River. PC2 accounted for 16.7% of the total variance and highly positive loadings by Chl-a and POC, weak positive loadings by OrgN and NH_4^+, and weak negative loadings by NO_3^- and urea (Figure 1F.1A). PC2 is interpreted as particulate organic matter (POM) flux. PC3 accounted for 11.3% of the total variance and had highly positive loadings by DOC, and highly negative loadings by urea (Table 1F.1, Figure 1F.1B).

There are many correlations and autocorrelations among biotic components. Many of these correlations are trivial, e.g., a strong correlation between total macrofauna abundance and polychaetes abundance, because polychaetes dominate macrofaunal abundance. Other trivial correlations are abundance and diversity of the same taxa. Some correlations, however, are interesting. For example, meiofauna abundance is strongly correlated with every biotic parameter

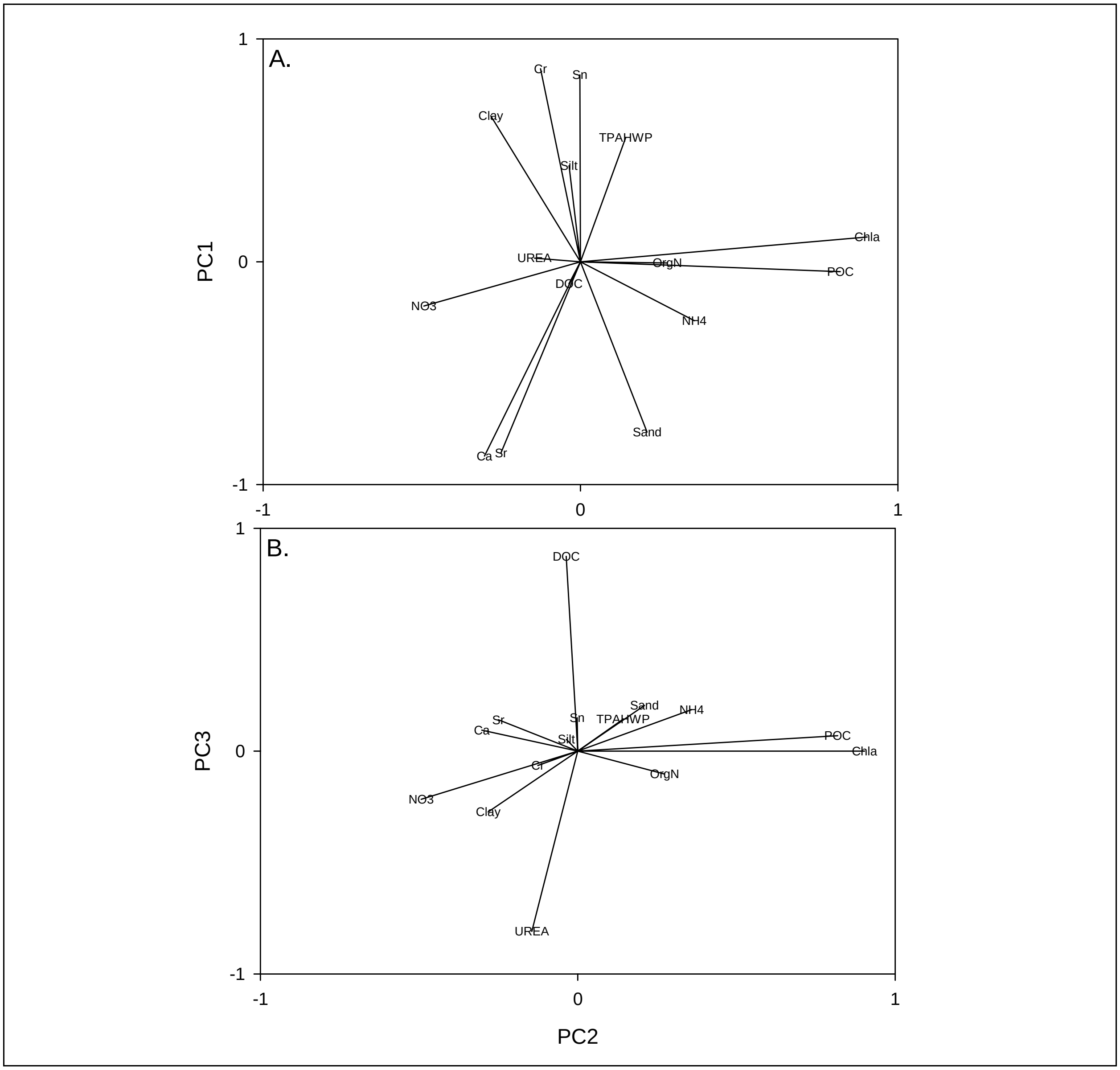


Figure 1F.1. Variable loads for the principal components (PC) analysis for abiotic variables. A) PC1 and PC2. B) PC2 and PC3.

except mollusk diversity. Yet, mollusk diversity is the only biotic variable strongly correlated with bacterial abundance, and it is also the only significant negative correlation. Some correlations are surprisingly weak, such as the harpacticoid and crustacean diversity correlation.

Community structure of harpacticoids, crustaceans, mollusks, and polychaetes was examined for spatial patterns among stations. Analysis was limited to the 43 stations where all species were analyzed to have a balanced design with no missing cells. The number of total species found in the different taxa was different. Harpacticoids had 716 species, Crustacea had 369 species (118 Amphipoda + 119 Cumacea + 132 Isopoda), Mollusca had 118 species (94 Bivalvia + 24

Aplocophora), and Polychaeta had 498 species. Comparison of average diversity index measures indicates that harpacticoids are the most diverse, followed by polychaetes, crustaceans, and mollusks (Table 1F.1). Evenness was very similar among the taxa, ranging from 0.84 to 0.95.

Table 1F.1

Mean and Standard Deviation of Diversity Measures for the Major Taxa. Richness Is Number of Species, Abundance Per Sample, J' Is the Pielou's Eveness Index, H' Is Shannon Diversity Index, and N1 Is Hill's Number of Abundant Species.

	Harpacticoida		Crustacea		Mollusca		Polychaeta	
Richness	51.7	(19.0)	31.9	(18.8)	21.2	(7.0)	59.7	(38.6)
Abundance	90.5	(50.6)	482.4	(2114.1)	147.2	(112.3)	871.0	(763.5)
J'	0.95	(0.03)	0.87	(0.11)	0.84	(0.12)	0.86	(0.07)
H'	3.70	(0.33)	2.88	(0.57)	2.52	(0.46)	3.29	(0.50)
N1	42.6	(14.4)	20.4	(10.6)	13.5	(5.0)	30.2	(14.5)

The cluster and MDS ordination plots indicate other trends. There was more similarity among stations for polychaetes and mollusks than for crustaceans and harpacticoids. Choosing 35%, an arbitrary level of similarity, harpacticoids had the most number of stations (33) that did not share at least 35% of the species with another station. Crustaceans had the second most number of stations (24) that did not share at least 35% of the species with another station. Polychaetes had only nine stations that did not share at least 35% of the species with another station and mollusks had only two stations that did not share at least 35% of the species with another station. This indicates much more cosmopolitanism with mollusks and polychaetes, and more endemism with crustaceans and harpacticoids. Another interesting characteristic is that more stations are contained within clusters for polychaetes and mollusks than for crustaceans and harpacticoids. In fact, nearly all the clusters for crustaceans and harpacticoids contain only two stations. In nearly all instances the stations are very near one another. Regardless of the high degree of endemism and uniqueness of stations, the overall patterns for each taxa match well (Table 1F.2). The crustacean and mollusk patterns match best (Rho = 0.608), and the harpacticoid and mollusk pattern match least (Rho = 0.172), but all matches are significant, none being greater than 0.003.

Linking the environment and benthos is done by correlating the PCA results with biotic metrics. The PC1 and PC2 station scores were significantly correlated with bacterial, meiofaunal, and macrofaunal total abundance (Table 1F.3). However, the association with PC2 was much stronger than with PC1. Thus, total abundance of the three main groupings generally increases with increasing fine sediment structure and particulate organic matter flux, but the relationship with flux may be stronger. The same pattern held true for abundance and diversity of specific taxa (i.e., harpacticoids, polychaetes, crustaceans, and mollusks). There were few, weaker significantly and positively correlations with PC1 than with PC2. Diversity had few correlations with the abiotic PC loads, except for a weak positive correlation with polychaetes diversity and

PC2, and a weak negative correlation with mollusk diversity. The strongest associations were with PC2 and meiofaunal abundance and polychaetes abundance. Meiofauna abundance is dominated by nematode abundance, but its diversity was not measured during the present study. The trends indicate that nematode and polychaete abundance increases with increasing flux.

Table 1F.2

Relatedness of the MDS Community Structure Patterns. Sample Statistic (Rho) on Top, Which Tests the Matching of the Two MDS Patterns and the Significance Level of Sample Statistic on Bottom.

	Crustacea	Mollusca	Polychaeta
Harpacticoida	0.214	0.172	0.349
	0.002	0.003	0.001
Crustacea		0.608	0.425
		0.001	0.001
Mollusca			0.318
			0.001

Table 1F.3

Relationship between Biological Components Abundance and Environmental Principal Components. Pearson Correlation Coefficients (r), Probability that r=0 (p), and Number of Observations (n). Taxa Abbreviations: A=Abundance, N1 = Hill's Number of Dominant Species Diversity Index. Significance Levels: 0.05 < * 0.01, 0.01 < ** <0.001, 0.001 < * < 0.0001, and <0.0001 ****.**

	PC1						PC2		
Taxa		r	p	N			r	p	n
Meiofauna A	**	0.48	0.0021	39		***	0.56	0.0002	39
Macrofauna A	*	0.33	0.0415	38		****	0.70	<.0001	38
Bacteria A	*	0.39	0.0136	39		**	0.47	0.0028	39
Harpacticoida A		0.25	0.1282	39		***	0.55	0.0003	39
Harpacticoida N1		-0.17	0.3048	39			0.25	0.1190	39
Polychaeta A		0.27	0.0924	39		****	0.73	<.0001	39
Polychaeta N1		0.20	0.2131	39		*	0.38	0.0185	39
Crustacea A	*	0.39	0.0130	39		**	0.49	0.0017	39
Crustacea N1		-0.17	0.2962	39			0.07	0.6746	39
Mollusca A	***	0.53	0.0005	39		***	0.52	0.0007	39
Mollusca N1	*	-0.32	0.0463	39			-0.18	0.2825	39

References

Clarke, K.R. and R.N. Gorley. 2001. PRIMER V5: User Manual/tutorial. Plymouth, U.K.: Primer-E.

Clarke, K.R. and R.M. Warwick. 2001. Change in marine communities: An approach to statistical analysis and interpretation, 2nd edition. Plymouth, U.K.: Primer-E.

Hill, M.O. 1973. Diversity and evenness: A unifying notation and its consequences. Ecology 54: 427–432.

Long, E.R., R.S. Carr, and P.A. Montagna. 2003. Porewater toxicity tests: Value as a component of sediment quality triad assessments. In: Carr, R.S. and M. Nipper, eds. Porewater Toxicity Testing: Biological, Chemical, and Ecological Considerations. Pensacola, FL: Society of Environmental Toxicology and Chemistry (SETAC) Press. Pp. 163–200.

Ludwig, J.A. and J.F. Reynold. 1988. Statistical ecology. New York: Wiley.

Rowe, G. and M.C. Kennicutt, eds. In preparation. Northern Gulf of Mexico continental slope habitats and benthic ecology: Final report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.

SAS Institute Inc. 1989. SAS user's guide, version 6, fourth edition, vol. 1. Cary, NC: SAS Institute Inc. 943 pp.

Dr. Paul Montagna is the Endowed Chair in Ecosystem Studies and Modeling at the Harte Research Institute for Gulf of Mexico Studies, Texas A&M University at Corpus Christi. He completed his doctoral studies at the University of South Carolina in 1983, completed a post-doc at the Lawrence Livermore National Laboratory, and spent 20 years at the University of Texas at Austin. He is a marine ecologist who focuses on benthic processes and is expert in experimental design and statistical analysis. He has worked on numerous OCS studies in Alaska, California, and the Gulf of Mexico.

ARCHAEOLOGICAL AND BIOLOGICAL ANALYSIS OF SIX WORLD WAR II DEEPWATER SHIPWRECKS IN THE GULF OF MEXICO

Robert A. Church and Daniel J. Warren, C & C Technologies, Inc.

Click here to view the slide show that accompanied this presentation.

German U-boats devastated merchant shipping along the American Coast during World War II. The Gulf of Mexico was a relatively unprotected hunting ground for the U-boats during the early years of the war. As a result, the Gulf contains one of the greatest concentrations of Allied vessels lost to German U-boats worldwide. Currently, the remains of eighteen WWII vessels, including *U-166*, the only known German U-boat sunk in the Gulf, have been identified in federal waters as a result of survey requirements by the United States Department of the Interior, Minerals Management Service (MMS). Taken together, these sites represent an underwater battlefield, and a vital historical resource documenting a little-studied area during an important period in American History. These sites also represent artificial reefs dating to a known period thereby offering biologists a unique opportunity to study the "artificial reef effect" of man-made structures in deepwater.

In 2004, a multidisciplinary team documented and assessed the biological and archaeological aspects of six World War II-era shipwrecks in the north-central portion of the Gulf of Mexico. The vessels (*Virginia*, *Halo*, *Gulfpenn*, *Robert E Lee*, and *Alcoa Puritan*) were lost to wartime activity in 1942 (Figure 1F.2). Each of the shipwrecks was discovered in recent years during oil and gas surveys and reported to the MMS as required by federal regulations. The shipwrecks were investigated to determine site boundaries, National Register eligibility, state of preservation and stability, and the potential for man-made structures or objects to function as artificial reefs in deepwater.

This paper provides a brief overview of the 2004 project with an emphasis on the archaeological component. The biological findings are provided in other papers from this session. The archaeological objectives for the study were to 1) positively identify each site and document its history; 2) determine each vessel's condition and state of preservation, assess any environmental impacts of the wreck, assess rate of deterioration, and determine the potential for future research; 3) determine the horizontal extent of the wreck debris field; 4) determine potential eligibility to the National Register of Historic Places; and 5) assess the impacts of bio-fouling communities on the stability of the sites.

The MMS and the National Oceanic and Atmospheric Administration's Office of Ocean Exploration (NOAA OE) sponsored the study under the auspices of the National Oceanographic Partnership Program (NOPP). The MMS contracted C & C Technologies, Inc. (C & C), to manage the project, provide survey support, and conduct the archaeological analysis. The

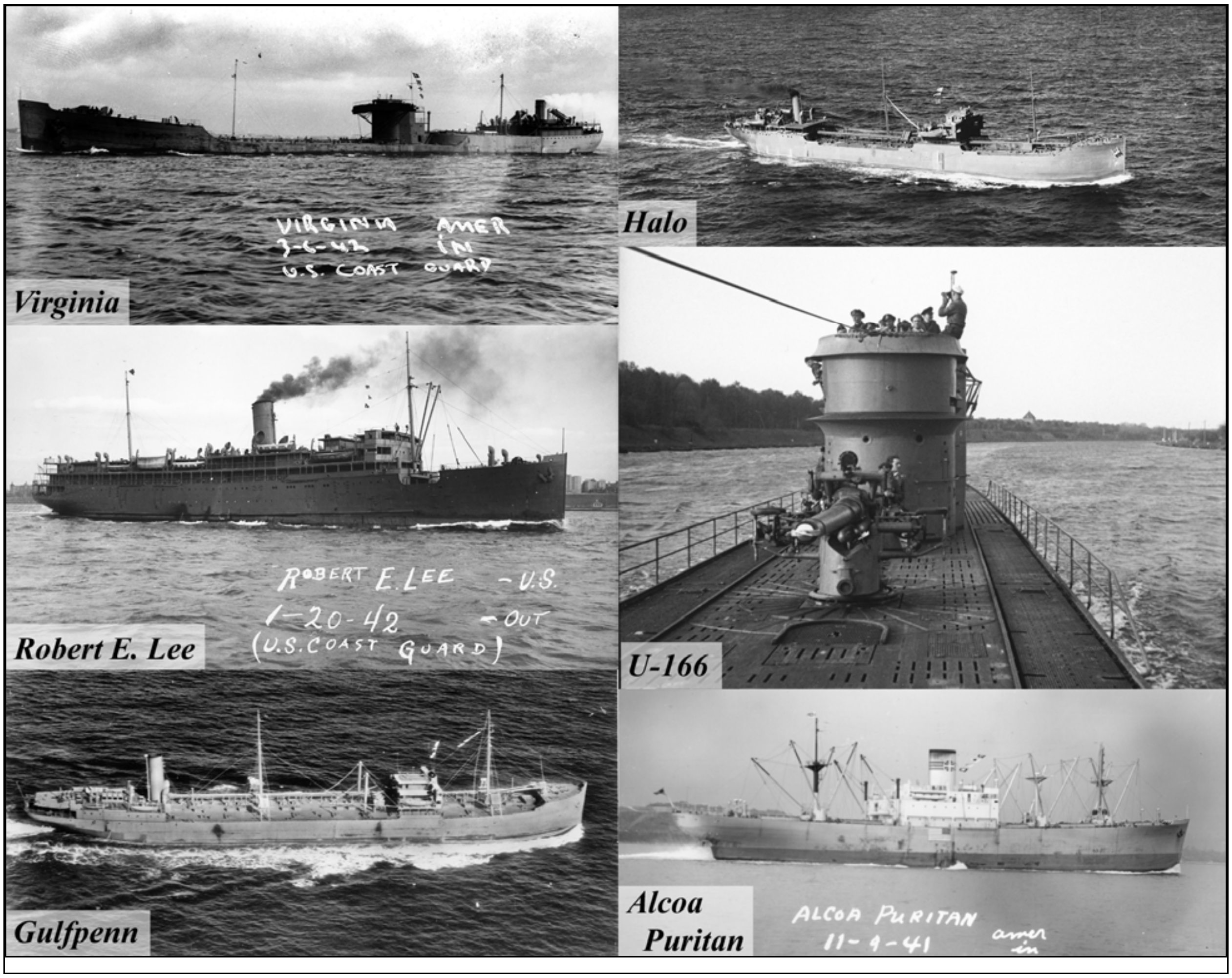


Figure 1F.2. Photographs of *Virginia, Halo, Robert E. Lee, U-166, Gulfpenn,* and *Alcoa Puritan* (Courtesy of the Mariner's Museum, Newport News, Virginia; Steamship Historical Society of America, University of Baltimore; and PAST Foundation, Columbus, Ohio (Kuhlmann Collection).

following organizations and individuals joined C & C for the biological analysis: Dr. Roy Cullimore and Lori Johnston with Droycon Bioconcepts, Inc., Dr. William Schroeder with the University of Alabama/Dauphin Island Sea Lab, Dr. William Patterson with the University of West Florida, and Dr. Thomas Shirley with the University of Alaska, Fairbanks. C & C also partnered with the PAST Foundation (directed by Dr. Annalies Corbin) along with Montana State University's film department (lead by Dr. Dennis Aig) to conduct the project's educational outreach component, which consisted, among other things, of documenting the study on film, managing a project web site, and developing secondary education curriculum. NOAA OE contracted Sonsub Inc. to provide vessel and Remote Operated Vehicle (ROV) support for the project. In addition to the principal investigators, masters and Ph.D. candidates from five universities participated in the study in the fields of archaeology, biology, and film.

Each site was systematically investigated using an acoustically positioned ROV following a pre-established survey grid. The ROV survey was designed to maximize the efforts and time for both the archaeological and biological studies. Detailed visual inspections provided needed data to document each wreck's cultural and biological characteristics. Although different specific elements were of interest to the biologists and the archaeologists, the video footage collected was used for both the biological and archaeological studies undertaken.

Water depth at the wreck sites ranges from 87 to 1,964 meters. The shallowest site on the study is the tanker *Virginia*, which was sunk by *U-507* on 12 May 1942. She now rests in 87 meters of water near the mouth of the Mississippi River. The tanker *Halo* was sunk by *U-506* on 20 May 1942, and now rests in 143 meters of water above the Mississippi Canyon's western escarpment.. The tanker *Gulfpenn* was sunk by *U-506* on 13 May 1942, and now rests in 554 meters of water along the east slope of the Mississippi Canyon. The German U-boat, *U-166* was sunk by U.S. navy *PC-566* shortly after the U-boat sank the passenger freighter *Robert E. Lee* on July 30, 1942. The U-boat and freighter now rest in approximately 1,480 meters of water along the upper Mississippi Fan. Finally, the deepest site on the study was the cargo freighter *Alcoa Puritan*, which sunk by *U-507* on 6 May 1942. She now rests in 1,965 meters of water along the upper Mississippi Fan.

Of the six wrecks designated for this study, only three (*Alcoa Puritan*, *Robert E. Lee*, and *U-166*) were positively identified before the project. The remaining vessels (*Gulfpenn, Halo,* and *Virginia*) had only tentative identifications based on previous geophysical surveys and limited video documentation. Water clarity at the *Gulfpenn* and *Halo* sites allowed relatively easy confirmation of the vessel's identity based on structural and hull characteristics. At the *Virginia* site, however, limited visibility and sedimentation made positive identification difficult. Close examination of the site's physical evidence and historical documentation confirmed that the vessel is *Virginia*.

A primary archaeological goal of the project was determining site boundaries for each wreck. An examination of the debris distribution data from the study revealed a trend that the site area increases proportionately as water depth increases (Figure 1F.3). The maximum distance from the shipwreck main hull to the site's periphery, forms a uniform curve with respect to water depth that closely follows the mean distribution average between distance and water depth.

Using the data from the study, the following formula was developed to estimate a radius slightly larger than the suspected boundary size of a steel-hulled shipwreck site in deepwater:

$$(.20wd + vl > \underline{\text{ site boundary radius)}}$$

wd=water depth
vl=vessel length

This formula uses twenty percent of the water depth at the site plus the estimated shipwreck length to calculate the boundary radius. However, this formula is based on only a small data set consisting of steel-hull shipwrecks lost under catastrophic conditions. It does not take into account wooden shipwrecks or smaller iron vessels that foundered at sea. It is intended as a working model for future research.

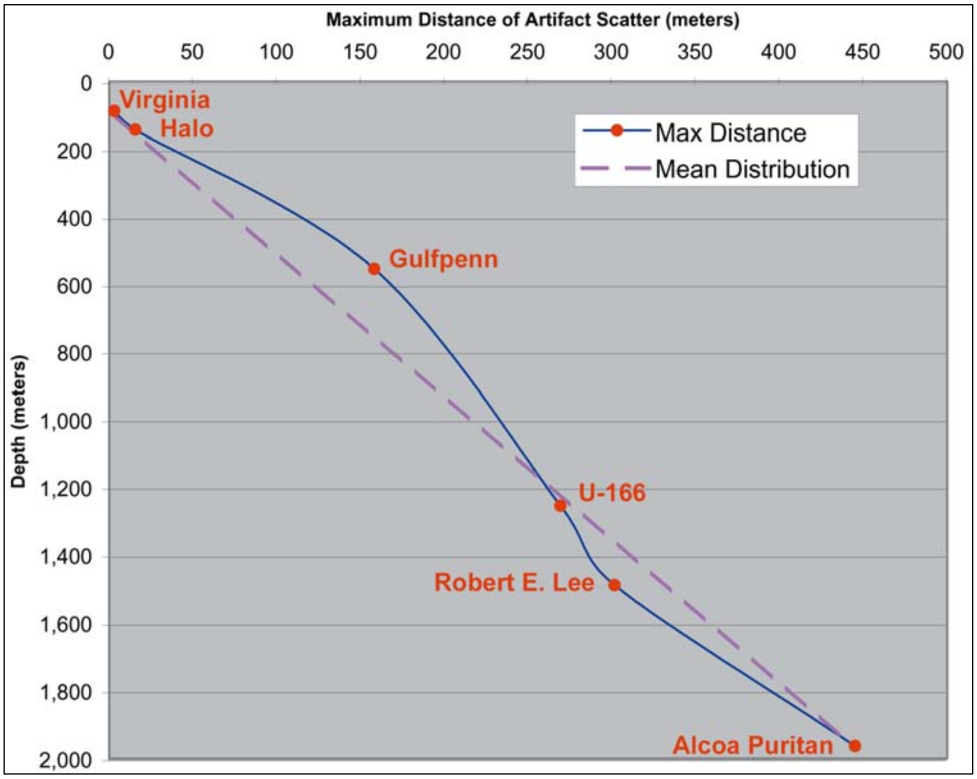


Figure 12F.3. Graph showing the maximum site debris distribution of the project wreck sites compared to the mean distribution with respect to water depth.

Each wreck site was assessed for National Register of Historic Places (NRHP) eligibility. After reviewing the archaeological and historical data, it was decided that each site is potentially eligible for the NRHP for their association with events that have made a significant contribution to the broad patterns of our history and as archaeological sites. Additionally, *U-166* is deemed potentially eligible as a representative example of a distinctive architecture.

The DeepWrecks project was one of the most comprehensive deepwater shipwreck investigations to date. The multidisciplinary approach used for the project sets a precedent for future deepwater shipwreck investigations. The biological data collected in this study has provided scientists with an unparalleled amount of information regarding the artificial reef effect of shipwrecks at varying ocean depths. The interpretation of this data will provide a base of knowledge that future studies around the world will be able to utilize and expand upon. Archaeologically the study has provided a substantial amount of information on deepwater wreck formation processes for steel-hulled vessels, positive identification of the study sites, useful analysis regarding the current state of preservation, future research potential, and the sites' cultural significance both individually and as a whole.

Acknowledgments

The information for this paper came from the following Report of Findings:

Church, R., D. Warren, R. Cullimore, L. Johnston, M. Kilgour, J. Moore, N. Morris, W. Patterson, W. Schroeder, and T. Shirley. 2007. Archaeological and biological analysis of World War II shipwrecks in the Gulf of Mexico: Artificial reef effect in deepwater. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2007-015. 373 pp.

Robert A. Church has a master's degree in maritime history and nautical archaeology from East Carolina University and a Bachelor's degree in history with a minor in biology from the University of Arkansas at Little Rock. Robert has been employed as a marine archaeologist with C & C Technologies, Inc., since 1998. He has worked on numerous marine survey projects in the Gulf of Mexico and abroad including directing over a dozen deepwater shipwreck investigations. Some of these include the discovery and identification of the WWII tanker, *Halo* (2000); the discovery of the German U-boat, *U-166* and investigation of the SS *Robert E. Lee* (2001); the *U-166* archaeological mapping project (2003); the investigation of three 19th century shipwrecks (2004 & 2006); and chief scientist for the MMS *Deepwater Shipwreck Study in the Gulf of Mexico* (2004), which included investigating six WWII shipwrecks and assessing the artificial reef potential in deepwater.

Daniel J. Warren has a bachelor's degree in anthropology with a minor in history from the University of Illinois at Champaign-Urbana and a Master's degree in maritime history and nautical archaeology from East Carolina University. He has over 20 years of experience as a professional archaeologist and has been employed as a marine archaeologist with C & C Technologies, Inc., since 1998. He has worked on numerous archaeological and hazard assessments for the oil and gas industry, government agencies, and submarine cable surveys in the Gulf of Mexico, Asia, Central, and South America. He was co-principle investigator for the discovery of the *U-166* and investigation of the SS *Robert E. Lee* (2001); principle investigator for the discovery and identification of the Steam Yacht, *Anona* (2002); project manager and chief scientist for the *U-166* archaeological mapping project (2003); and co-principle investigator for the MMS *Deepwater Shipwreck Study in the Gulf of Mexico* (2004).

FISH COMMUNITY AND TROPHIC STRUCTURE AT DEEPWATER SHIPWRECK SITES IN THE NORTHERN GULF OF MEXICO

William F. Patterson, III and Nicole M. B. Morris, University of West Florida

Click here to view the slide show that accompanied this presentation.

We examined fish community and trophic structure as part of the marine vertebrate component of the larger deep shipwrecks study described by Church and Warren (this volume). The goal of this part of the project was to document the utilization of deep-water shipwrecks as fish habitats. Specific objectives of this portion of the study were to 1) examine the community structure of fishes associated with deepwater shipwrecks in the northern Gulf of Mexico; 2) perform gut content analysis to examine trophic structure within the fish community; and, 3) analyze stable isotopes of carbon and nitrogen in fish tissue to estimate source(s) of carbon to wrecks and corroborate trophic structure inferred from gut content analysis.

Community structure of fishes associated with shipwrecks was examined to determine whether significant differences in the fish community existed among the wrecks and to test whether significant differences existed over ships versus nearby natural habitats. Community structure was estimated primarily with video from ROV transects and with fish traps. Sampling the fish community during visits to all wreck sites followed a standard methodology. Once the archaeological survey of a given wreck was completed, two chevron fish traps (dimensions = 150 centimeter width x 180 centimeter length x 60 centimeter height; opening = 44.5 centimeter x 10 centimeter; mesh = 5 centimeter plastic coated wire) and two small baitfish traps (dimensions = 75 centimeter width x 75 centimeter length x 50 centimeter height; opening = 10 centimeters x 10 centimeters; mesh = 2.5 centimeter plastic coated wire) were baited with menhaden and squid, and fished for between 5 and 15 hours. One small and one large trap were set immediately adjacent to the wreck and the second pair of traps was set approximately 300 meters away from the wreck. While traps were soaking, ROV transects (n = 3) were flown over the ship's long axis. Video was also recorded over transects immediately adjacent to the wreck (n = 3) and approximately 300 meters away from it (n = 3) to estimate the biological communities at varying distances (over, adjacent, and distant) from the ship's main structure. During biological transects, attempts were made to sample encountered fishes with the ROV's suction sampler. The size of the suction sampler opening limited sampling to fishes less than 12.5 centimeters deep or wide.

Muscle tissue was dissected from of fish (n = 79) sampled with traps or with the ROV's suction sampler and preserved in ethanol. In the laboratory, fish samples were removed from ethanol and any associated bone was dissected from samples. All samples were rinsed with distilled water for 30 seconds and then placed in glass vials to soak in distilled water for 24–48 hours. Samples were removed from vials, rinsed again with distilled water, and then placed in a drying oven where they were dried at 60° C for at least 48 hours. Dried samples were weighed and stored in glass vials. Stable isotopes of C, N, and S were analyzed with a Europa Scientific GSL/Geo 20-20 isotope ratio mass spectrometer. Analytes included $\delta^{13}C_{V\text{-}PBD}$ ($\delta^{13}C$), $\delta^{15}N_{Air}$ ($\delta^{15}N$), and $\delta^{34}S_{V\text{-}CDT}$ ($\delta^{34}S$). International Atomic Energy Agency (IAEA) standard reference materials were run periodically to assess machine performance. Analytical precision was estimated from duplicate analysis of 20 randomly selected samples. Mean difference (± SD) between replicate sample runs was 0.05 ‰ (± 0.18) for $\delta^{13}C$, 0.03 ‰ (± 0.11) for $\delta^{15}N$, and -0.03 ‰ (± 0.32) for $\delta^{34}S$.

Stable isotope analysis results were used to infer source of production and trophic position of fish and invertebrate samples. Typical oceanic phytoplankton ranges of -20 to -18 ‰ for $\delta^{13}C$, 5 to 9 ‰ for $\delta^{15}N$, and 18 to 20 for $\delta^{34}S$ were assumed (Fry 1988; MacAvoy et al. 2002) for the northern Gulf. Trophic fractionation (enrichment) from prey to consumer was assumed to average 1 ‰ for $\delta^{13}C$ and 3 ‰ for $\delta^{15}N$ (Fry 1988); fractionation was assumed not occur for $\delta^{34}S$ (Connolly et al. 2004). Thus, trophic level was inferred from apparent enrichment of $\delta^{13}C$ and $\delta^{15}N$ values. Values of $\delta^{34}S$ were used to estimate whether the source of production was pelagic or benthic, as benthic production imparts a $\delta^{34}S$ signature depleted relative to pelagic phytoplankton (Connolly et al. 2004). In the deep ocean, both $\delta^{13}C$ and $\delta^{34}S$ were used to infer the relative importance of chemosynthetic versus phytoplankton production as the base of the food web. MacAvoy et al. (2002) reported consumers associated with western Gulf seep environments where significant sulfate reduction occurred had very depleted $\delta^{13}C$ (~ -30 ‰) and $\delta^{34}S$ (~ -7 ‰) values, while an area with significant production from methanogenic bacteria imparted depleted $\delta^{13}C$ (~ -55 ‰) and $\delta^{15}N$ values (~ -12 ‰).

A total of 105 taxa were observed in video and/or collected in traps or with the ROV suction sampler among all sites. *Halo* had the greatest community richness, with 54 taxa observed, followed by *Gulfpenn* (n = 38 taxa), *Robert E. Lee* (n = 21 taxa), *Virginia* (n = 17 taxa), *U-166* (n = 14 taxa), and *Alcoa Puritan* (n = 11 taxa). One potential source of bias occurred in that *Halo* was visited twice and *Gulfpenn* visited three times to collect biological samples. Thus, there was a greater probability of documenting ichthyofauna associated with those two sites than the other four. It should be noted, however, that if species observed on subsequent visits to those sites were removed from the sum of taxa documented, *Halo* and *Gulfpenn* still would rank first and second in ichthyofaunal diversity by a wide margin.

There was a significant difference in the fish community among wreck sites [Analysis of Similarity (ANOSIM); p <0.01] and among transect locations nested within site (ANOSIM; $p <$ 0.01). The three shallowest (*Virginia*, *Halo*, and *Gulfpenn*) sites had soft or azooxanthellae hard corals (see Schroeder this volume) that fouled the ships and added structural complexity required by reef fishes. *Virginia* and *Halo* had Lutjanid, Serranid, and Carangid reef fishes typical of northern Gulf shelf reef communities. *Gulfpenn* had deepwater Trachichthyid and Sebastid reef fishes associated with it. Reef fishes on the three shallowest sites likely would have recruited to a given wreck without corals present, but the fact that corals and rich fouling communities exist at those depths is the precise reason reef fishes are found there as well. Thus, depth-specific reef fish fauna and fouling communities typical of natural reef environments in the northern Gulf were associated with each of the three shallowest wrecks.

The fish community documented at the deepest wrecks (*U-166*, *Robert E. Lee*, and *Alcoa Puritan*) was similar among transects over, adjacent to, and away from the ships. The three deepest sites (*U-166*, *Robert E. Lee*, and *Alcoa Puritan*) had very similar fish communities. As was expected *a priori*, we found no true reef fishes in the deep sea. Some fishes on the deepest wrecks were associated with a given ship's rigging or superstructure, but individuals of the same or similar taxa also were found away from wrecks. As a result, the fish community at those sites did not differ among transects flown over, adjacent to, and away from the ships, and no artificial reef effect was apparent. There were some differences in the relative dominance of taxa present, but for the most part, fishes seen at each of the deep sites were predominantly from only a few groups: orders Ophidiiformes (cuskeels) and Anguilliformes (eels), and families Halosauridae (halosaurs) and Macrouridae (grenadiers), all of which are typical of the abyssal ichthyofauna of the northern Gulf (Powell et al. 2003).

Trophic position of predominant fish taxa was difficult to infer from gut content analysis. Stomachs were extracted from 101 individuals, but only 60% of them contained food items. Clearly, depth of sampling was a significant factor as many fishes had distended anterior portions of their alimentary canals upon transfer to the surface. Therefore, stable isotope analysis proved to be a much more powerful tool to infer trophic structure in the fish community.

Planktivorous reef fishes were abundant at *Virginia* (vermilion snapper) and *Halo* (athiinae basses), thus indicating their importance in transferring carbon up the food web to larger, piscivorous reef fishes. At the tree deepest sites, most fish had $\delta^{13}C$ values that indicated phytoplankton production exported from the photic zone was the most significant source of organic C to our deepest shipwreck sites. However, several cutthroat eels and some grenadiers had $\delta^{13}C$ values that indicated some percentage of their biomass was derived from chemosynthetic primary production.

References

Connolly, R.M., M.B. Guest, A.J. Melville, and J.M. Oakes. 2004. Sulfur stable isotopes separate producers in marine food-web analysis. Oecologia 138:161–167.

Fry, B. 1988. Food web structure on Georges Bank from stable C, N, and S isotopic compositions. Limnology and Oceanography 33:1182–1190.

MacAvoy, S.E., R.S. Carney, C.R. Fisher, and S.A. Macko. 2002. Use of chemosynthetic biomass by large, mobile, benthic predators in the Gulf of Mexico. Marine Ecology Progress Series 225:65–78.

Powell, S.M., R.L. Haedrich, and J.D. McEachran. 2003. The deep-sea demersal fish fauna of the northern Gulf of Mexico. Journal of Northwest Atlantic Fishery Science 31:19–33.

Will Patterson received his Ph.D. in marine sciences from the University of South Alabama in 1999 and currently is an assistant professor in the Department of Biology at the University of West Florida. His research is focused on population dynamics, population connectivity, and habitat requirements of marine fishes. Although the types of questions he and his students and colleagues ask are quite varied, the underlying theme in all their work is understanding the rates of ecological processes that drive the ecosystems they examine. Techniques they employ include age and growth estimation from otolith thin sections; estimating population structure and connectivity with otolith shape and otolith chemistry analysis; artificial tagging to estimate site fidelity and dispersion of adult fishes; gut content and muscle stable isotope analysis to examine trophic position and source(s) of production; remotely operated vehicle-based estimation of reef fish community structure; and, various modeling approaches to examine population dynamics, population connectivity, and ecosystem function.

Nicole Morris received her B.S. in biology from Jacksonville State University in 2003 and currently is a master's candidate in the Department of Biology at the University of West Florida. Her thesis is titled "Artificial Reef Effect of Deepsea Shipwrecks in the Northern Gulf of Mexico." Ms. Morris plans to defend her thesis in February 2007 just prior to beginning a Sea Grant Knauss Fellowship during which she will work with NOAA's Ocean Explorer Program in Washington, D.C.

STRUCTURE AND ABUNDANCE OF INVERTEBRATES AT DEEPWATER SHIPWRECKS IN THE NORTHERN GOM

Tom Shirley and Morgan Kilgour, Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi

Click here to view the slide show that accompanied this presentation.

The macroinvertebrates (excluding corals) and meiofauna on, adjacent, and away from (>61 m) six World War II shipwrecks at depths from 87 to 1964 m were examined in 2004 in the northern Gulf of Mexico. The shipwrecks were used as surrogates for deep sea drilling platforms to determine if they serve as artificial reefs. An ROV was used to conduct video transects on the wrecks and through the adjacent debris fields. The hydraulic arm of the ROV was used to collect specimens, but a suction device and nine baited traps deployed by the ROV collected most voucher specimens used to aid video identifications; differences in abundance (number$\cdot$m^{-2}) were compared between three treatments. Four sediment cores were collected by the ROV adjacent to, near and away from the wrecks and sieved through 0.063 mm mesh to quantify meiofauna. A total of 79 species of macroinvertebrates were collected. Crustaceans were the most abundant macrofauna (47 species), followed by echinoderms (14 species), and mollusks (13 species), with lesser numbers of other taxa. The two most abundant crab species (*Chaceon quinquedens*, *Rochinia crassa*) were observed at four of the six shipwrecks, and two species (*Eumunida picta* , *Munida* spp.) were observed at a single wreck. All crab species except *R. crassa* had no correlation to proximity of the wreck; however, significant differences in crab abundance occurred on different substrates. Significant correlations occurred between crab abundance and bathymetric distribution; some species were stenobathyal while others were eurybathyal. Species richness of all macroinvertebrates increased with depth to a maximum at 554 m (26 species), then decreased a low of 8 species at the deepest depth. Nematodes predominated (approximately 90% numerically) in the meiofauna, followed by harpacticoid copepods; densities decreased from 1,117$\cdot$10 cm^{-2} at the shallowest depth to 81$\cdot$10 cm^{-2} at the deepest depth. Micromollusks were abundant in cores and sediments retained in the slurp collection box; 73 species were identified, mostly from the *Halo* at 146 m depth.

The shipwrecks and debris fields supported higher species richness and increased abundance of macrobenthic, epifaunal organisms than adjacent level bottom at all sites.

Dr. Thomas Shirley is a professor and Endowed Chair of Marine Biodiversity and Conservation Science, Harte Research Institute, Texas A&M University-Corpus Christi. He is a marine invertebrate ecologist with particular interest in biodiversity, ecology of high latitude crabs, systematics of priapulids, and meiofauna. A recent focus has been seamount ecology and invertebrate assemblages of deep water corals. He has described species in three phyla from the Mediterranean, Antarctica, Arctic, Philippines, Alaska, and Gulf of Mexico.

COLONIZATION OF *LOPHELIA PERTUSA* ON THE WORLD WAR II DEEPWATER SHIPWRECK *GULFPENN*

William W. Schroeder, Marine Science Program, The University of Alabama, Dauphin Island

On 13 May 1942, the 146 m tanker *Gulfpenn* was struck by a torpedo from the German submarine U-506 and sank in 544 m of water 60 km south of the Mississippi Delta. In the summer of 2004, the wreck was surveyed with an ROV as part of an MMS/NOAA-OE/NOPP sponsored archaeological and biological study. *Lophelia pertusa* was observed to have colonized 10–12% of the wreck. It appears to have developed most successfully on vertically oriented (hull, bulwarks, superstructures), upright (davits, railings, masts), raised (catwalks, deck piping), or open (booms, rigging) surfaces and structures. Overall, the most extensive growth is occurring on the starboard side and on catwalks and deck piping along the port side of the aft deck and foredeck. At numerous locations colonies are coalescing into thickets. The largest development is a 6–7 m high by 3–3.5 m wide aggregate of at least five or six colonies growing from the main deck/bulwarks level to above the top of the pilot house on the forward starboard corner of the main superstructure. This vertical assemblage of colonies has formed what amounts to an upright thicket. Generally, little or no colonization has occurred on most deck areas and other horizontal surfaces. One notable exception is mid-ships aft of the superstructure where colonies are growing on a deteriorating region of the deck beneath a coral encrusted mast and boom. Colonies were also found living on the sediment adjacent to the hull and on wreckage scattered about in the adjacent debris field.

Dr. William W. Schroeder is a professor of in the Department of Marine Science at the University of Alabama, Dauphin Island, Alabama. He has been involved in interdisciplinary oceanographic investigations for nearly 40 years and has conducted research in the Gulf of Mexico for the past 30 years. In addition, he has participated in research endeavors in the Bahamas, Caribbean, Gulf of Papua, Azov Sea, Australia and South Africa. He has authored and co-authored over 125 scientific publications dealing with geological and biological characterizations of estuarine and marine habitats to estuarine, shelf and open ocean hydrography and circulation. Currently his research activities include: 1) coupled biological-geological-physical studies of deep-water corals in the Gulf of Mexico; 2) validation of distributed marine-environment forecast systems; 3) Late Quaternary sea level and paleoceanography investigations of hardbottom sites in the northern Gulf of Mexico; 4) an integrated study of physical and biological processes along the west coast of Australia; and 5) model validation of the coupled katabatic wind, coastal ocean and ice systems in Antarctica. He received his Ph.D. in oceanography from Texas A&M University.

SESSION 2A

SOCIOECONOMIC EFFECTS OF THE HURRICANES

Chair: Asha Luthra, Minerals Management Service

Co-Chair: Kristen Strellec, Minerals Management Service

OCS-RELATED INFRASTRUCTURE IN THE GULF OF MEXICO: UPDATE AND SUMMARY OF THE IMPACTS FROM THE 2005 HURRICANE SEASON

David Dismukes, Center for Energy Studies, Louisiana State University

Click here to see the slide show that accompanied this presentation.

This research expands upon prior work conducted by the author during the 1999–2001 time period. The original research examined a wide range of Gulf of Mexico (GOM) energy infrastructure that includes pipelines, gas processing facilities, refineries, platform fabrication yards, ports, and waste disposal facilities, to name a few. The original research examined the nature of each type of infrastructure asset, its relationship with GOM production activities, and trends/issues impacting operation and future investments. The current research, in particular, expanded the existing information by considering the impacts each experienced during the 2005 tropical season.

The research explored three sequential periods: 1) pre-storm activities; 2) a consequence/ restoration analysis; and 3) post-storm assessment. The pre-storm activities analysis focused generally on the factors impacting each type of infrastructure (or sets of infrastructure) prior to the storm and noted the tightness in energy markets that were driving up energy prices generally and putting increased pressure on many infrastructure types through increased utilization.

The consequence/restoration analysis examined the destruction that occurred to each type of energy infrastructure—or sets of infrastructure—during the course of the 2005 season, particularly after the direct passage of both Hurricanes Katrina and Rita. Outages were examined as well as restoration rates, progress, and challenges. A key theme in the consequence analysis was the recognition of the overwhelmingly inter-related nature of infrastructure in the region. While this is a significant asset during times of normal production, it created a number of cyclical challenges during the restoration process (i.e., no power to run refineries but limited diesel supplies to get restoration crews to power outage locations).

The post-storm assessment examined the longer term impacts on overall energy infrastructure and its ongoing outlook for operation and well as future investment. The conclusion of the research is that most important energy infrastructure damaged by the storms is back on line. Those assets that were not restored were typically too old for cost effective restoration or may have represented excess capacity and were unneeded on forward-looking basis. The contingency plans for most industries supporting these assets proved to be on target and effective in restoring the nation's energy supplies.

David E. Dismukes is an associate professor and the Associate Director of the Center for Energy Studies, Louisiana State University. His research interests are related to the analysis of economic, statistical, and public policy issues in energy and infrastructure industries. Over the past 19 years, he has worked in consulting, academia, and government service. Dr. Dismukes joined the LSU faculty in 1995 and since that time has led a number of the Center's research efforts in such topics as the economic impacts of offshore oil and gas exploration and production (E&P) activities; the restructuring of natural gas and electric power markets; market structure issues in various energy industries; and the economic impacts of independent power on the economies of the Gulf South region. He has published over 100 articles and conference papers in scholarly journals and trade publications. Dr. Dismukes recently completed a book on electric restructuring and competition published by CRC Press entitled *Power Systems Operations and Electricity Markets*. He received his M.S. and Ph.D. in economics from the Florida State University.

SOCIAL NETWORKS AFTER KATRINA: ECONOMIC AND SOCIAL OUTCOMES

John J. Beggs, Louisiana State University,
Department of Sociology and LSU Hurricane Center

Click here to view the slide show that accompanied this presentation.

Research Foci:

- We investigated the role that social networks, and the resources they provide, play in affecting individuals' preparation for, response to, and recovery from hurricanes.

- Initial work on this topic was conducted in Hurricane Andrew. We then investigated Hurricane Georges, and now Katrina.

Genesis of Research:

- We initially did not intend to study hurricanes.

- Our initial focus was on how individuals activate social networks to obtain resources.

- We knew a great deal about what kind of ties help people get jobs, on the one hand, and on social support, on the other.

- We did not know much about networks from which those ties were drawn or about the process by which individuals activated ties from their social networks.

Social Activism and Tie Activation:

- To study that question, we looked at individuals' social networks and studied how they activated ties from those networks for resources. We needed a situation in which a large number of individuals would activate ties simultaneously.

- We were planning to study a base or plant closing, situations where large numbers of people would need to activate networks for job-finding and support, all at the same time.

Why Not Hurricane?

- Then, Hurricane Andrew struck south Louisiana in August 1992.

- We realized that we had an opportunity to address our central question in a different context.

- We had a situation in which a large number of people needed to get help at the same time.

Hurricane Andrew Study:

- With support from the National Science Foundation, we conducted a telephone survey with residents of St. Mary and Iberia parishes, two to three months after Andrew struck the area.

- We collected information on the structure of individuals' social networks, pre-Andrew—the extent to which they activated ties from their networks for help to prepare for and recover from the storm.

- We also collected a wide range of demographic information: information about prior hurricane experience; measures of loss and harm in the storm; and depression in the short-term recovery period.

- We gathered a wealth of information about how individuals relied upon both informal help from their social networks and from formal sources in preparing for and recovering from this storm.

Andrew Findings:

- One of the key findings was that individuals who received more social support from their social networks in the short-term recovery phase experienced lower levels of depression than people who received less social support.

- Stronger (closer, particularly kin) ties to people who tended to be similar served as key support conduits.

Implications from Andrew:

- The findings are consistent with general literature on social support, which emphasizes the importance of strong ties and dense network sectors in which they tend to occur.

- The findings suggest that, for Katrina's victims, having dense social networks with more strong ties will prove beneficial for recovery.

Will the Andrew Story Hold for Katrina?

- As we all know, though, Katrina was different, in many respects.

- First, Katrina was not a "standard" disaster. It was a catastrophe—the nature and scope of the effects extending far beyond what had been previously seen in the U.S. from any natural or man-made disaster.

How Katrina Was Different:

- The scope and duration of evacuation also distinguished this event, as did the level of social and economic disruption.

- For many of Katrina's victims, the disruption was long-term and involved not just the need to repair houses but also the need to find new housing, schools for children, and jobs.

What Will Be the Story for Katrina:

- The question, then, is how the recovery process will unfold for Katrina's victims, and what role social networks will play in the process.

- There are many fundamental questions regarding the effects on individuals, organizations, and the community as a whole.

- Answering those questions is critically important because of the unprecedented nature of this event.

- The focus of this presentation is on data from residents of post-Katrina Orleans and Jefferson Parishes and examines three main issues (Tables 2A.1 through 2A.6):

  — First, the structure of social networks

  — Second, how people are doing in terms of stressors, physical health, and mental health

  — Third, economic outcomes, focusing primarily on income

Table 2A.1

Mental Health: 2006 Citizen Recovery Survey and Baseline Survey Data[1]

	Andrew	Orleans	Jefferson		Orleans		Baton Rouge	
	1992	2003	Spring	Fall	Spring	Fall	Middle	Poor
Depression Indicators								
Couldn't get going	1.72	1.02	1.61**	1.75	1.50**	1.84	1.47	2.31
Felt sad	1.31	1.06	1.94**	1.83	2.25**	2.05	1.24	2.02
Had trouble sleeping	1.61	1.38	2.32**	2.44	2.67**	2.28	1.49	2.02
Felt everything an effort	1.79	1.31	2.18**	2.39	2.38**	2.48	1.46	2.57
Felt lonely	0.99	0.72	1.05*	1.45	1.23*	1.57	0.88	1.74
Couldn't shake blues	1.01	0.70	1.16**	1.49	1.27**	1.24	0.64	1.52
Had trouble keeping mind on track	1.15	1.18	1.88**	1.95	2.19**	2.03	1.29	1.67
Depression Index	1.36	1.06	1.74**	1.89	1.93**	1.92	1.20	1.95
Depression Summary	9.56	7.40	12.17	13.26	13.47	13.49	8.43	13.65
Felt Irritable			2.11	1.86	2.28	2.19		
Felt Tired			3.39	3.74	3.39	3.42		
General Health	2.98	3.01	2.89+	2.75	2.95	2.88	3.25	2.79

[1] Comparison to 2003 New Orleans baseline data.
* Orleans 2003 difference is significant at .05 alpha level.
** Orleans 2003 difference is significant at .01 alpha level.

Table 2A.2

Mental Health: 2006 Citizen Recovery Survey and Baseline Survey Data, Part 2

	Andrew	Orleans	Jefferson		Orleans		Baton Rouge	
	1992	2003	Spring	Fall	Spring	Fall	Middle	Poor
Depression Symptoms (%)								
No symptoms	35.6	27.5	16.7	22.1	14.8	18.5	1.47	2.31
1 to 6	19.6	34.6	28.3	21.2	23.8	27.0	1.24	2.02
7 to 13	17.9	17.7	21.7	20.2	21.3	15.5	1.49	2.02
14 to 20	10.3	9.4	9.7	11.6	14.8	15.5	1.46	2.57
21 to 27	5.7	5.7	8.9	6.5	9.4	4.0	0.88	1.74
28 to 34	3.9	2.5	5.0	6.9	6.4	5.0	0.64	1.52
35 or More	7.1	2.7	9.7	11.7	9.4	14.5	1.29	1.67
Depression Index	1.36	1.06	1.74**	1.89	1.93**	1.92	1.20	1.95
Depression Summary	9.56	7.40	12.17	13.26	3.47	13.49	8.43	13.65
General Health:								
Excellent	30.0	27.3	26.0	19.5	30.5	23.0	40.8	21.3
Good	45.3	50.1	44.3	48.5	38.9	51.0	46.1	43.5
Fair	18.0	18.8	22.9	22.2	25.6	16.5	10.2	27.9
Poor	6.7	4.9	6.9	9.9	4.9	9.5	2.8	7.3
Enough Help:								
All the time		52.5	18.9	18.6	6.1	13.2	61.5	37.5
Most of the time	91.7	27.0	29.9	25.6	31.2	19.8	24.7	30.5
Only some of the time	7.8	20.5	51.2	49.7	52.8	58.4	13.8	32.0
Do not need help				6.4		8.6		

Table 2A.3

Everyday Stressors: 2006 Citizen Recovery Survey

	Jefferson		Orleans	
	Spring	Fall	Spring	Fall
Have Difficulty:				
Getting groceries	1.50	1.23	1.49	1.40
Shopping for other things	1.84	1.44	1.96	1.69
Sending and receiving mail	2.18	1.34	2.54	1.55
Getting around town	2.18	1.65	1.92	1.58
Getting medical care	1.53	1.49	1.85	1.74
Making home repairs	2.15	1.78	2.29	2.22
Difficulty Index	1.91	1.49	2.01	1.69
Difficulty Summary	11.46	8.92	12.06	10.12
Index 2 or More	45.7 %	19.4 %	55.2 %	32.0 %

Table 2A.4

2006 Citizen Recovery Survey and Baseline Survey Data

	Andrew	Orleans	Jefferson	Orleans	Baton Rouge		GSS	
	1992	2003	Fall 2006	Fall 2006	Middle	Poor	1985	2004
Network Size (%)								
0	6.0	25.4	18.1	18.0	13.2	22.7	10.0	24.6
1	34.5	41.5	37.0	29.5	29.0	32.8	15.0	19.0
2	22.4	19.0	28.5	31.0	16.2	13.5	16.2	19.2
3	16.2	8.9	10.9	14.5	16.5	12.9	20.3	16.9
4	6.6	3.0	3.9	4.5	10.7	8.9	14.8	8.8
5	14.5	2.3	1.5	2.5	14.3	9.2	23.6	11.4
Means:								
Network size	2.26	1.30	1.55	1.66	2.25	1.80	2.94	2.08
Density		0.86	0.96	0.96	0.85	0.83		
Especially close (%)		71.0	78.0	77.7	73.1	70.4		
Kin (%)	83.7	45.4	60.0	52.2	37.6	34.6		
Heterophily:								
Race	3.9	7.7	9.7	12.3	6.7	4.5		
Sex	52.5	43.4	46.0	42.5				

Table 2A.5

2006 Citizen Recovery Survey

	Jefferson		Orleans		Orleans
	Spring	Fall	Spring	Fall	2003
Family Income:					
Less than $40,000	36.15	43.41	36.26	47.49	44.59
$40,000 to $80,000	31.46	33.86	28.65	22.34	32.27
$80,000 or more	32.39	22.72	35.09	30.17	23.14
Income Change Since Katrina:					
Increased	20.00	22.96	12.87	16.33	
About the same	57.31	59.76	49.50	55.10	
Decreased	22.69	17.28	37.62	28.57	
Likely to Leave New Orleans in the Next Two Years:					
Very likely		17.39		16.75	
Somewhat likely		15.54		15.23	
Not very likely		67.06		68.02	

Table 2A.6

T-Tests: Means by "Likely to Leave New Orleans in the Next Two Years"

	Jefferson			Orleans		
	No	Yes	Probability	No	Yes	Probability
Depression Indicators						
Couldn't get going	1.75	1.76		1.51	2.65	.004
Felt sad	1.56	2.29	.048	1.72	2.84	.005
Had trouble sleeping	2.18	3.01	.053	2.10	2.68	
Felt everything an effort	1.97	3.15	.006	2.06	3.40	.002
Felt lonely	1.29	1.75		1.11	2.60	.001
Couldn't shake blues	1.21	2.08	.021	0.85	2.13	.002
Had trouble keeping mind on track	1.58	2.75	.004	1.79	2.52	.065
Depression Index	1.65	2.39	.014	1.60	2.67	.001
Depression Summary	11.55	16.73	.015	11.19	18.73	.001
Felt Irritable	1.51	2.37	.021	1.78	3.14	.001
Felt Tired	3.50	4.30	.069	2.99	4.33	.002
Had Difficulty:						
Getting groceries	1.21	1.26		1.32	1.56	.014
Shopping for other things	1.41	1.47		1.55	1.94	.000
Sending and receiving mail	1.25	1.51	.009	1.50	1.65	
Getting around town	1.60	1.79	.090	1.49	1.76	.012
Getting medical care	1.41	1.66	.033	1.66	1.87	.090
Making home repairs	1.77	1.80		2.15	2.42	.033
Difficulty Index	1.44	1.58	.061	1.60	1.84	.000
Difficulty Summary	8.61	9.46	.057	9.62	11.10	.000
Index 2 or More (%)	15.45	25.86	.085	23.13	49.21	.000
Age	57.43	47.22	.000	53.06	51.15	
Race (Black) (%)	20.72	34.86	.034	51.49	33.33	.017
Over 65 in Household	0.53	0.28	.022	50.76	34.92	
Attend Church	1.81	2.33	.005	2.20	2.24	
Family Income						
Up (%)	29.61	8.07	.001	17.91	12.70	
Same (%)	59.18	56.18		58.21	46.03	
Down (%)	10.61	28.30	.002	21.64	39.68	.008
Social Networks:						
Alter age	51.06	43.37	.001	48.14	48.43	
Zero alters	14.95	19.42		23.13	6.35	.004
Especially close (%)	79.77	73.97		73.30	88.28	.012
Sex heterophily (%)	47.27	42.88		38.36	50.93	.041

John J. Beggs is an associate professor in the Department of Sociology at Louisiana State University and has an adjunct appointment with the LSU Hurricane Center. His research in stratification and inequality considers how race and gender affect economic and noneconomic outcomes, and how social contexts affect these processes. He is currently studying how network social capital, including social support and job-finding resources, affects health outcomes. The hurricane context has been an important focus for his work.

POST-HURRICANE KATRINA POLLS CONDUCTED IN BATON ROUGE, LOUISIANA

Frederick Weil, Edward Shihadeh, and Matthew Lee,
Sociology Department Louisiana State University

Click here to view the slide show that accompanied this presentation.

The investigators polled households in Baton Rouge, Louisiana, 27 September to 29 November 2005 and February to April 2006.

Preliminary findings were the following:

- Half of Baton Rouge households housed evacuees, and 60% of Baton Rougeans did volunteer relief work, most more than once, and most with faith-based organizations.

  — It is sobering to think what would have happened to evacuees if private citizens had not provided so much relief: Could government and relief agencies alone have coped? And given South Louisiana's close ties of kinship and community, it is sobering to think what would happen in a disaster of similar magnitude in a location without these close social networks.

- People in Baton Rouge mainly felt compassion toward evacuees, but there were negative feelings of fear and irritation, also.

- Rumors of crime were initially widespread, but after initially spiking, fear of crime subsided fairly quickly. Fear of crime continued its years-long decline; fear after Katrina was not as high nor as sustained as it was during the time of the Baton Rouge serial killer.

- A majority of citizens said they were willing to pay higher taxes for recovery. They preferred some other solution, but they were increasingly skeptical that a real alternative exists.

- Crowding in Baton Rouge produced substantial problems and irritants, though most of these subsided over time. However, even as the situation improved, blame of government rose, especially of federal and state government. Local government was better regarded.

- Baton Rougeans were understandably angry and depressed after the disaster, but notably, their levels of optimism were even higher. However, they felt more hopeful about improvement in the economy than about Baton Rouge as a place to live.

- Most people did not live near the FEMA trailer parks and did not know much about them, yet they would be upset if one were placed near them. They predicted that bad things would happen and that they would change their behavior. Still, a third of Baton Rougeans believed they themselves could end up in a trailer park if their own homes were destroyed in a hurricane.

Frederick Weil is an associate professor in the Department of Sociology at Louisiana State University in Baton Rouge. He specializes in community and political sociology, social theory, and research methods. His current research is on the recovery of community in New Orleans since Hurricane Katrina; earlier work was on democratization after dictatorship.

HURRICANE-RELATED TRANSPORTATION INFRASTRUCTURE DAMAGE AND RECOVERY

Kirt Clement, Louisiana Department of Transportation and Development

Click here to view the slide show that accompanied this presentation.

On 29 August 2006, Hurricane Katrina made landfall, resulting in the largest natural disaster in the history of the United States. Levees broke, causing flooding and serious damage to portions of the Interstate Highway System and to state highways including, to mention a few, the I-10 Twin Span Bridge, LA 1 at the Leeville Bridge, the Causeway bridge, the LA 23 South End Empire Bridge, the LA 1 Caminada Bay Bridge, the Almonaster Bridge, and DOTD ferries.

Then 24 September 2006, Hurricane Rita made landfall, causing further flooding and damage to the state's transportation system.

Post-hurricane challenges:

- Communications out
- ~25 % workforce directly affected
- ~10% missing
- No utilities/services/housing/food/etc.
- Mobilizing resources from around the state
- Recovering from disaster while continuing to pursue state transportation program

The Recovery Process:

- Debris
- Traffic signals, signs, ITS
- Movable bridges

- Roads & bridges
- Subsurface

Debris – DOTD:

- Has picked up over 3.6 million CY of debris
- At a cost ~$ 140 million

Debris State-wide

- Debris total estimated at 60 million CY
- 25 X World Trade Center volume
- ~50 million CY picked up to date

Traffic Signal Repair & Restoration

- 840 signals damaged statewide
- New Orleans signals
    - 300 of 415 intersections damaged
    - 170 complete rebuild
    - Total cost of repairs $25 million
    - New Orleans – $20 million

Traffic Sign Repair

- Repaired over 1,000 Interstate signs statewide
- Replaced 104 large overhead guide signs
- Fabricated 807 ground-mounted signs
- Provided 6,000 temporary stop signs for City of New Orleans

- Executed contract to inspect sign trusses
- Estimated cost of repair – $10 million

Movable Bridges

- 142 movable bridges in storm-affected areas
- 37% damaged
- 28% close
- $9 million in damages
- Louisiana has more movable bridges than any other state

DOTD Facilities Covered by

- Two federal agencies with
- Two approaches to recovery and
- Two processes and procedures and
- Two storm events

Funding Priority and Challenges

- Keep cash flow positive
- Pay contractors on time
- Speed up the recovery effort
- Keep the regular highway program on track
- Aggressively push for Congressional approval of ER funds
- Set up line of credit (but did not have to use it)
- Aggressively pursue approval of damage claims through FHWA and FEMA

Management Objectives

- Aggressively manage reimbursement processes to accelerate the flow of federal funds
- Communicate and manage information with transparency
- Implement controls to mitigate audit risk

Overview

FEMA Public Works has authorized $71 million. The Federal Highway Administration Emergency Relief Funds has authorized $1,189 million.

The forecast DOTD hurricane expenditures, total capital outlay contracts through November 12, 2006, are approximately $280 million.

LA DOTD Success Stories:

- Contraflow evacuation
- DOTD ferry rescue/recovery
- Customer Call Center
- Motorist Assistance Patrol
- LA Swift Bus Program
- I-10 Twin Span Bridge over Lake Pontchartrain

The Contraflow Plan (in place at the time of Katrina on major routes out of New Orleans)

- Operated for 25 hours
- Over 1 million (estimated) evacuated
- Longest delay: 2–3 hours

- Successes
  - Metro New Orleans evacuated
  - Motorist Assistance patrols

DOTD Ferry Rescue/Recovery

- Evacuated 6,000 stranded citizens
- Provided food/water/ supplies for recovery
- Ferried over 100 emergency vehicles for recovery operations

Customer Service Call Center

- Established 24/7 call center
  - Routed public to critical service outlets
  - Emergency rescue calls
  - Miscellaneous information requested
- Handled 7,645 calls from 8/31 to 9/26

LA Swift Bus Program

- LRA, LA DOTD and Louisiana Department of Labor initiative
- Free bus service from Baton Rouge to New Orleans
- Transit option for displaced residents to return to New Orleans
- Originally funded by FEMA
- Began October 2005
- DOTD funding thru February 2007
- Averages more than 700 riders per weekday
- Has provided 250,000 rides since inception

I-10 Twin Span Bridge

- Two lanes open to traffic in six weeks
- Phase I opened 14 October 2005
- Groundbreaking on new bridge on 13 July 2006

Other Initiatives

- LA 1 toll toad to Port Fourchon
- LA Rail
- Pavement system subsurface damage

LA-1

- This is the only evacuation route for Grand Isle and Port Fourchon.
- Many of the offshore workers will evacuate via LA 1.

Bayou Lafourche Approaches and High Level Crossing – Construction Schedule

- Started construction in May 2006
- Contract requires completion and open to traffic by 1 December 2009
- Tolls will be implemented when opened

Elevated Roadway to Port Fourchon – Construction Schedule

- Opened bids – December 2006
- Construction started in first quarter 2007
- Completion and open to traffic first quarter of 2011

LA Swift to LA Rail – The next step in moving Louisiana forward

Concept of Operations

- Challenge: Establish intercity passenger service with a trip time of approximately two hours.

- Long-term: FY 2010 and beyond. Establish permanent intercity passenger service with additional stops and a trip time of approximately 1.5 hours.

Submerged Roads – Overview

- Nearly the entire street network in Orleans (80%) and St. Bernard (87%) Parishes, and portions of the network in Plaquemines (50%) and Jefferson (30%) Parishes, were submerged in flood waters for up to five weeks.

- The area was flooded for three weeks by Katrina, then re-flooded for two weeks by Rita.

- Approximately 2,000 miles in greater New Orleans were submerged in floodwaters up to five weeks.

  - 500+ miles of federal-aid

  - 1,500 miles NFA

- Substantial testing of most state-owned roads has been completed.

  - 238 miles federal-aid

- Broken water and sewer lines under roadways demonstrated that bases have been weakened due to saturation.

Kirt A. Clement is a graduate of Louisiana State University in chemical engineering and is currently serving as is the Deputy Undersecretary for the Louisiana Department of Transportation and Development. He spent a major part of his career on various materials assignments in the Materials and Testing Section. He was appointed Associated Director of the Louisiana Transportation Research Center in 1998 before assuming his current position as Deputy Undersecretary. Kirt has most recently provided leadership in instituting the DOTD Change Management Program and has served as the DOTD point of contact for the Louisiana Recovery Authority, Transportation and Infrastructure Task Force.

SESSION 2B

DEEPWATER HABITATS: *LOPHELIA* I

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

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

CHARACTERIZATION OF NORTHERN GULF OF MEXICO DEEPWATER HARD-BOTTOM COMMUNITIES WITH EMPHASIS ON *LOPHELIA* CORAL — AN INTRODUCTION

Stephen T. Viada, CSA International, Inc.

Click here to view the slide show that accompanied this presentation.

CSA International, Inc. and its subcontractors/consultants have completed 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 areas with extensive densities of scleractinian coral Lophelia pertusa. Six study sites were selected for investigation during the first field sampling effort in 2004 (Cruise 1). The selection of these sites was based on 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, 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). The second field sampling effort (Cruise 2) was conducted during 2005. Five sites were revisited (VK 826, VK 862, MC 885, GC 234, and GC 354) and one site in Green Canyon (GC 185) was added. In addition, a National Oceanic and Atmospheric Administration Ocean Exploration Program (NOAA-OE) proposal was funded for three additional ship days (six Johnson Sea-Link [JSL] dives) as an add-on component to Cruise 2. Three sites (VK 826 NE, VK 862 S, and MC 929) were selected to meet NOAA-OE's thematic priorities to explore, map, and characterize deep-sea coral habitats (Figure 2B.1).

The program had three components: physical oceanography studies geological characterization and biological characterization and studies. The objectives of the physical oceanography studies were 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 were 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 were 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

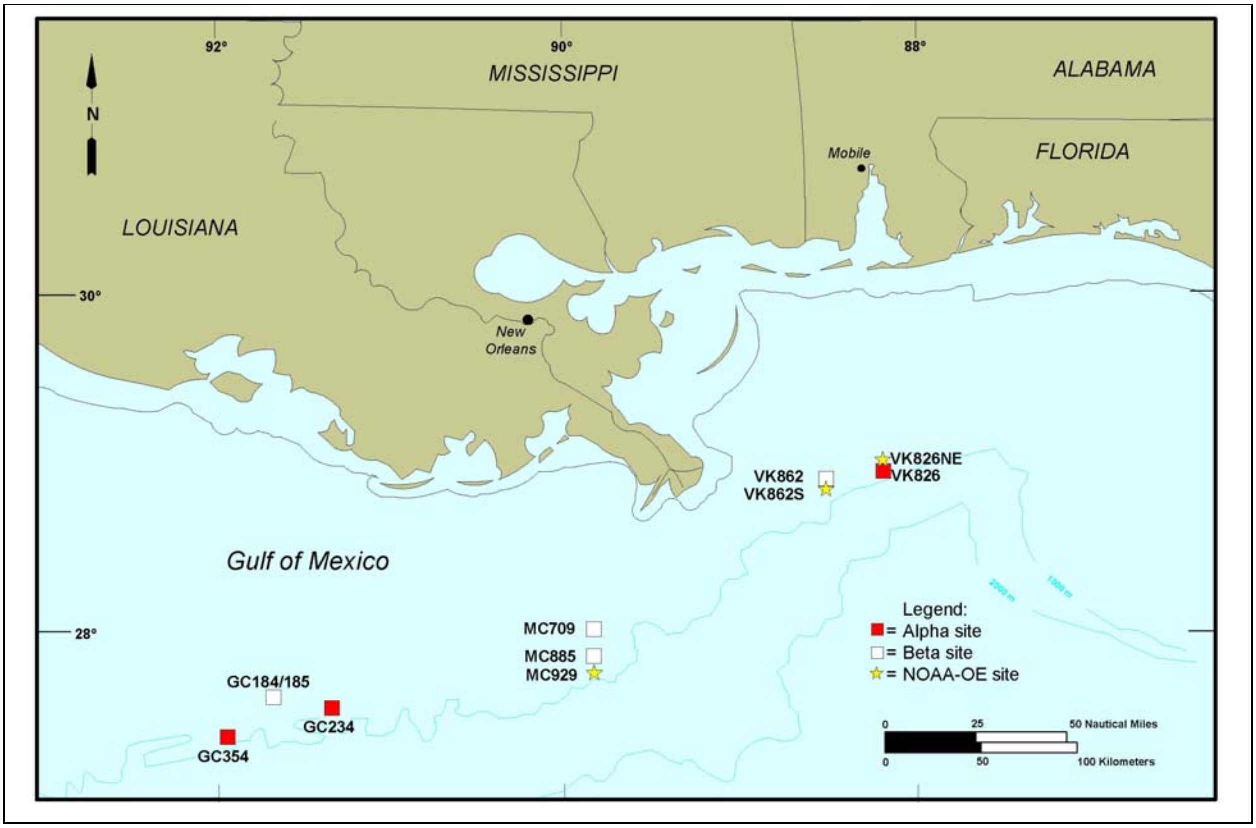


Figure 2B.1. Location of study sites.

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 the deployment of recording temperature probes, 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.

Cruise 2 was conducted between 5 and 15 September 2005. Current meter arrays, temperature probes, sediment traps, and *Lophelia* transplants and stained colonies were retrieved. Additional photomosaics, Bushmaster samples, video transects, water samples, sediment core samples, and carbonate and macroinvertebrate samples were collected.

All analyses are complete, and the draft final report has been submitted to the MMS.

Stephen Viada is a Senior Staff Scientist with CSA International, Inc., located in Jupiter, Florida. He has 28 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. degree in biological oceanography from Texas A&M University in 1980.

THE PHYSICAL OCEANOGRAPHIC ENVIRONMENT IMPACTING NORTHERN GULF OF MEXICO DEEPWATER CORAL COMMUNITIES

Steven L. Morey, Center for Ocean–Atmospheric Prediction Studies, Florida State University

Click here to view the slide show that accompanied this presentation.

Introduction

The U.S. Minerals Management Service funded a research effort in 2004–2006 to characterize northern Gulf of Mexico (GOM) deepwater hard-bottom communities with emphasis on *Lophelia* coral. To support the objectives of this research program, a study of the physical oceanography of the regions with known deepwater coral communities was performed using *in situ* observations and analyses of numerical model data. The physical oceanographic study had the goals of gaining a better understanding of the variability of currents and temperature near the coral communities, large-scale currents that could impact larvae dispersal, the structure of the bottom boundary layer that could relate to sedimentation processes, and processes that could supply organic material to the benthic food webs.

Regional Ocean Circulation

The circulation offshore of the continental shelves in the GOM is dominated by the Loop Current, which enters the Gulf through the Yucatan Channel and exits through the Straits of Florida. This current penetrates northward into the basin before turning clockwise to exit the Gulf to the east, thus forming the famous loop. The Loop Current northward extent varies. A mature Loop Current can sometimes extend northwestward toward the outer continental shelf off of the southeastern Louisiana coast, and in its immature phase will immediately turn eastward once past Cuba. When the Loop Current penetrates far into the Gulf, it aperiodically constricts forming a large anticyclonic (clockwise) eddy that separates and drifts generally westward. These energetic Loop Current eddies have current speeds of roughly 1-2 m/s, comparable to the Loop Current itself, and can exist for many months before decaying in the western Gulf. Associated with these Loop Current eddies and the Loop Current itself are a series of smaller frontal cyclonic eddies which travel around the periphery. A field of smaller cyclonic and anticyclonic features is ubiquitous in the Gulf.

Anticyclonic eddies are considered “warm-core” features, in that there is a depression of the thermocline within the center so that water at a given level is warmer within the center than outside the feature. Similarly, cyclonic eddies are cold-core features. The thermal and dynamic expressions of these features can be found several hundred to over one thousand meters deep. Due to potential vorticity conservation, these features remain offshore of the continental shelf. However, the Loop Current and mesoscale eddies in the Gulf can influence the circulation over the continental slope, where they become influenced by the topography. The relevant habitats are found on the slope offshore of the continental shelf along the northern GOM, generally between roughly 300m and 1000m depth, and thus much of the variability of temperature and currents at these sites is influenced by mesoscale circulation features.

Circulation on the shelf regions is dominantly wind-driven. Morey et al. (2003a, 2003b) showed that the seasonal wind patterns over the region result in reversing coastal circulation patterns in the northern Gulf. In the summer months, buoyant water influenced by the Mississippi River is more commonly transported eastward across the continental shelf break where it can become entrained in currents associated with offshore mesoscale features. Intermittent plumes of low salinity water flowing southeastward along the edge of the LC or its eddies occur more frequently in the summer months. This riverine-influenced water is also high in chlorophyll so this transport mechanism results in a distinct seasonal cycle in upper ocean chlorophyll concentration in the surface water above the deepwater coral communities to the east of the Mississippi River Delta (Figure 2B.2). This, combined with sinking of organic material, may provide for seasonal variability of the supply of organic material to the benthic food webs in the affected areas.

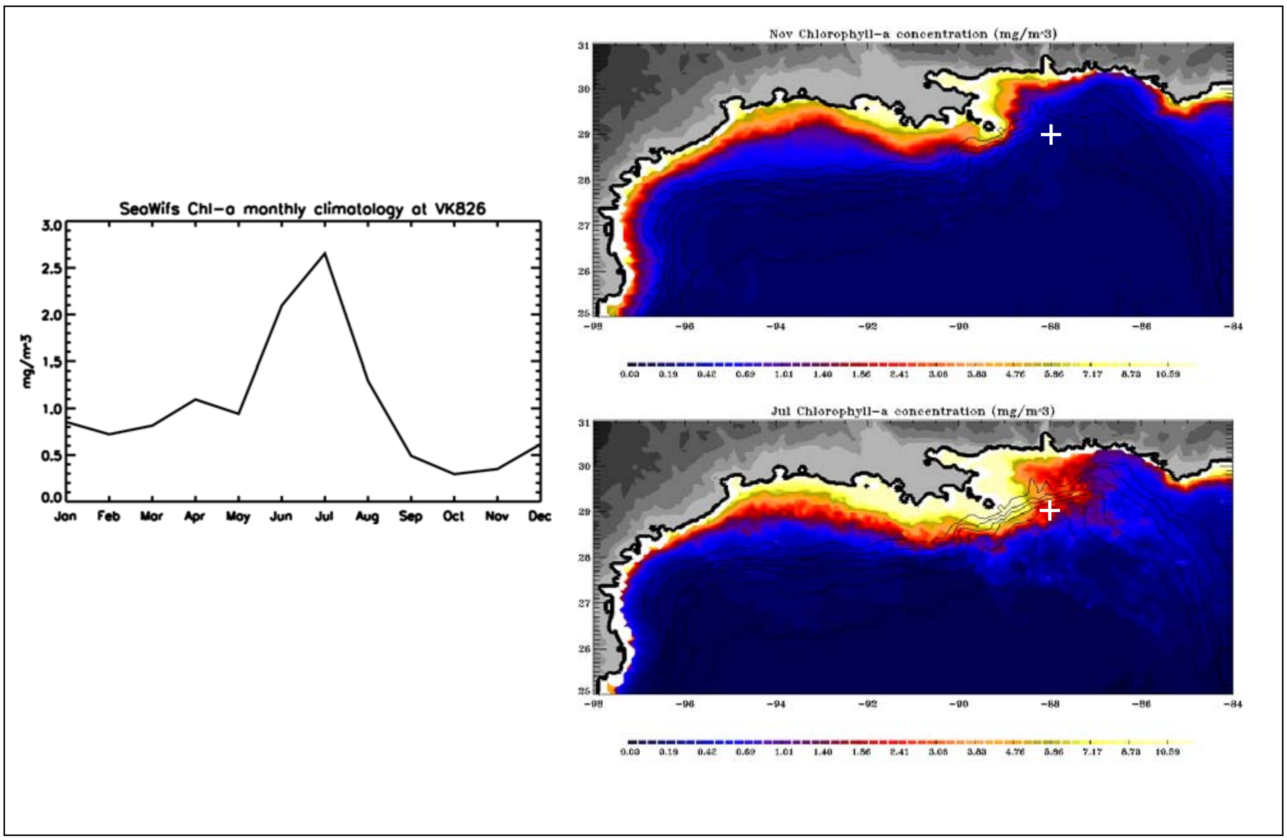


Figure 2B.2. Left: Monthly climatology chlorophyll *a* concentration derived from SeaWiFS satellite ocean color data at the VK826 location (shown with a white cross in the right panels). Right: Monthly average chlorophyll *a* concentration maps for November and July.

Circulation Variability and Dispersal of Larvae

Two sites were instrumented with current meters during the program, Viosca Knoll (VK826; 29° 09.5005'N, 88° 01.066'W) and Green Canyon (GC234; GC234 27° 44.812'N, 91° 13.483'W). Limited data were recovered from VK826 due to instrument failure, but an nine-month record was recorded at GC234 2.7m above the bottom. Deep currents have dominantly along-isobath variability with intermittent episodes of downslope current being seen when a series of cyclonic frontal cyclones along the periphery of a large LC eddy translated through the region. Tidal fluctuations are dominantly diurnal and 1-3 cm/s in magnitude. The maximum speed recorded was 44 cm/s. The mean vector velocity was 6.7 cm/s directed at 276° (westward) and the expected value of the speed was 9.6 cm/s. Analysis of eight years of model data also shows dominantly along-isobath variability but with more instances of eastward currents.

To estimate the potential dispersal patterns for larvae released at these two study sites, a number of particles are passively advected in the model horizontal flow field. One hundred particles are released randomly distributed within a 5km x 5km bin every six hours for three days, yielding a total of 1200 particles. Each particle is advected for a total of 25 days. This procedure is repeated beginning the first day of each calendar month for each of the eight years of model data yielding a total of 115,200 particles per study site. Maps of the distribution of the particles at various times following their release show that dispersion is primarily in the along-isobath direction and biased eastward (Figure 2B.3). There is no obvious seasonal pattern and interannual variability is due primarily to the configuration of the LC and mesoscale eddies.

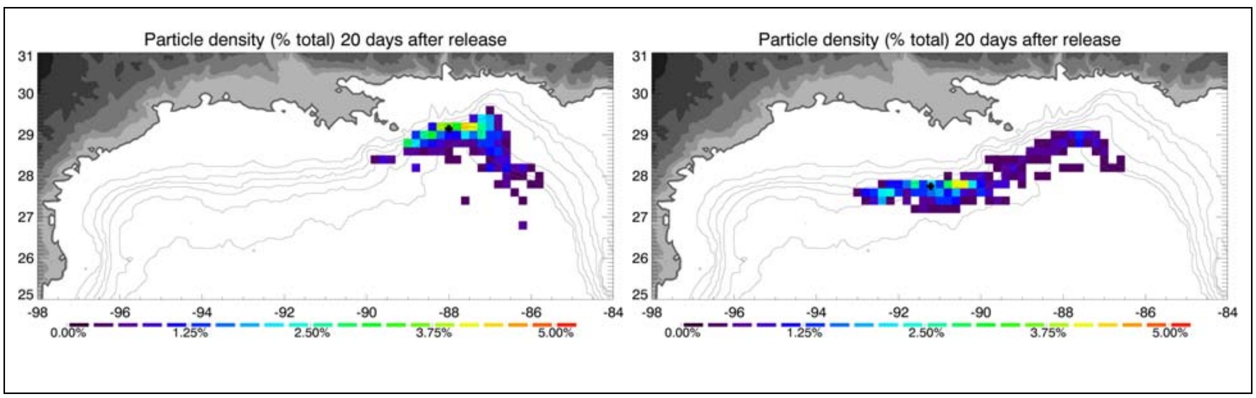


Figure 2B.3. Percentage of all 115,200 particles 20 days after release from locations at VK826 (at 400m depth) (left) and GC234 (at 487m depth) (right) in each .5°x.5° bin.

Estimation of Bottom Stress

Estimates of the bottom stresses from observations can yield information useful for determining sedimentation processes, resuspension that can expose hard substrate for attachment of sessile organisms, and the structure of the velocity profiles impacting organisms in the area. Fitting a classic logarithmic boundary layer profile $u(z) = u_* \kappa^{-1} \ln z/z_0$ to the bottom-current meter velocity data of the long-term mooring requires an estimate of the roughness height z_0 since

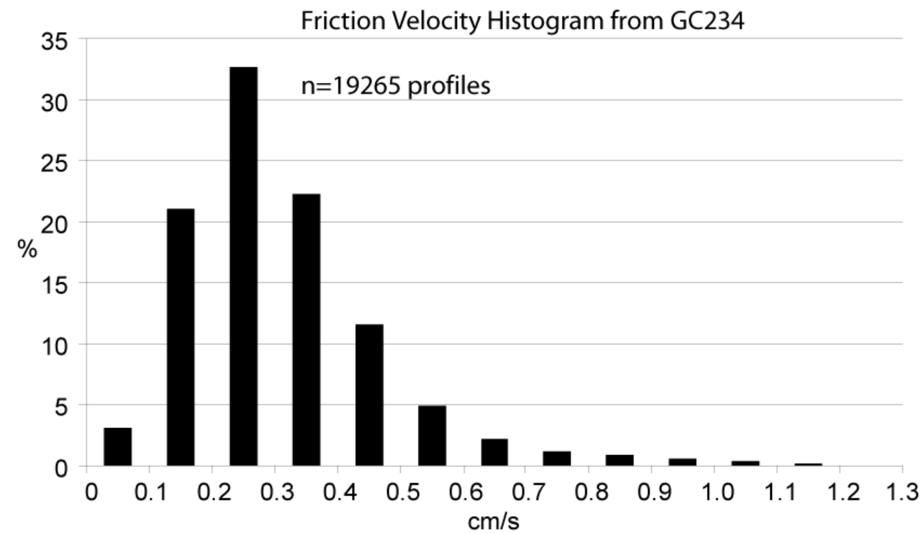


Figure 2B.4. Histogram of friction velocity (u_*) estimates from nine months of current meter data fit to a logarithmic velocity profile.

velocity data are available at only one depth within the boundary layer. From inspection of characteristics of the seafloor and estimations of the friction velocity u_* using the spectral method (Weatherly 1972) applied to high-frequency observations collected at the same location provides us with an estimated $z_0 = 10^{-5}$ m. Fitting the observations to the logarithmic profile now gives an estimate of the distribution of friction velocity values at GC234, and thus the bottom stress $\tau = \rho \ u_*^2$ (Figure 2B.4).

Summary

Variability of currents and temperature along the northern GOM continental shelf slope is dominated by mesoscale circulation features. At the study sites, currents vary dominantly in the along-isobath direction, and it is anticipated that larvae will be dispersed in a similar manner. The main source of any seasonal variability impacting the deepwater ecosystems is likely linked to the local seasonal cycle of upper ocean productivity caused by seasonally varying transport pathways for Mississippi River influenced water.

An attempt has been made to estimate the temporal distributions of bottom stresses at two study sites (although only a very limited time series was available at the VK826 site). Additional measurements of currents for estimation of the stresses, and of the characteristics of the local sediments, can lead to a better understanding of sedimentation processes and the likelihood for sediment removal to expose hard substrate. Longer velocity time series are needed to better characterize the mean and variability of the deep currents and to understand the likelihood of extreme currents. Finally, further knowledge of the behavior and life cycle of the *Lophelia* larvae can be used together with better circulation models to refine estimations of dispersal patterns.

Acknowledgments

This work has been funded by the U.S. Department of the Interior Minerals Management Service under the project "Characterization of Northern Gulf of Mexico Deepwater Hard-Bottom Communities with Emphasis on *Lophelia* Coral."

References

Morey, S.L., P.J. Martin, J.J. O'Brien, A.A. Wallcraft, and J. Zavala-Hidalgo. 2003a. Export pathways for river discharged fresh water in the northern Gulf of Mexico. J. Geophys. Res. 108(C10):3303, doi:10.1029/2002JC001674.

Morey, S.L., W.W. Schroeder, J.J. O'Brien, and J. Zavala-Hidalgo. 2003b. The annual cycle of riverine influence in the eastern Gulf of Mexico basin. Geophys. Res. Let. 30(16):1867, doi: 10.1029/2003GL017348.

Weatherly, G.L. 1972. A study of the bottom boundary layer of the Florida Current, J. Phys. Oceangr. 2:54–72.

Steven Morey is currently an assistant scholar/scientist at the Center for Ocean-Atmospheric Prediction Studies at Florida State University. His research interests combine observational and numerical model data to examine ocean processes and circulation variability. Much of his research focuses on the Gulf of Mexico.

SEABED CHARACTERISTICS AND *LOPHELIA PERTUSA* AND OTHER SESSILE MEGAFAUNA DISTRIBUTION PATTERNS: NORTHERN GULF OF MEXICO

William W. Schroeder, Marine Science Program,
The University of Alabama, Dauphin Island

Seabed characterizations at and surrounding the study sites were developed at three spatial scales:

- Continental slope regions or major physiographic features, at scales of 2,500 km2 (50 x 50 km) to 10,000 km2 (100 x 100 km)
- Local-landscape descriptions of the seabed surrounding each site, at scales of 4 km2 (2 km x 2 km) to 25 km2 (5 km x 5 km)
- Site-specific features

Study sites were located in three continental slope regions:

- Upper Central Dome and Basin Region – Texas-Louisiana Slope Subprovince
- Upper Henderson Ridge – Upper Mississippi Fan Subprovince
- Upper DeSoto Slope Subprovince

Local landscapes of the surrounding seabed for each of the eight study sites varied across a spectrum from relatively simple to moderately-complex:

- Mounds – Small to large with varying degrees of vertical relief
- Mound and ridge complex adjacent to a small submarine canyon
- Seaward edge of the plateau-like feature adjacent to a steep scarp
- Graben/half-graben complex in a shallow depression

Site-specific features include various sizes and shapes of clasts, nodules, blocks and boulders, hardgrounds and isolated slabs (often fractured and/or sediment veneered), outcrops, buildups, and carbonate capped mounds and ridges:

- The extent of areal coverage varied from scattered, generally small solitary features to more widespread accumulations of larger structures to fairly complex settings.

- Vertical relief of individual features range from none up to 5 m.

Distribution Patterns of *Lophelia pertusa* and other sessile megafauna:

- Colonization of *Lophelia pertusa* and other sessile megafauna on these hard substrates was observed to be highly variable.

- Distribution patterns range from scattered, isolated individuals to aggregations of varying densities that in some areas are in the initial phase of thicket building. One site, VK826-Knobby Knoll, is possibly at a thicket/coppice stage of development.

- Considering the percentage of un-colonized substrate at all the sites, except VK826-Knobby Knoll, space does not appear to be a limiting factor in the development of *L. pertusa* or other sessile megafauna assemblages.

Dr. William W. Schroeder is a professor of in the Department of Marine Science at the University of Alabama, Dauphin Island, Alabama. He has been involved in interdisciplinary oceanographic investigations for nearly 40 years and has conducted research in the Gulf of Mexico for the past 30 years. In addition, he has participated in research endeavors in the Bahamas, Caribbean, Gulf of Papua, Azov Sea, Australia and South Africa. He has authored and co-authored over 125 scientific publications dealing with geological and biological characterizations of estuarine and marine habitats to estuarine, shelf and open ocean hydrography and circulation. Currently his research activities include: 1) coupled biological-geological-physical studies of deep-water corals in the Gulf of Mexico; 2) validation of distributed marine-environment forecast systems; 3) Late Quaternary sea level and paleoceanography investigations of hardbottom sites in the northern Gulf of Mexico; 4) an integrated study of physical and biological processes along the west coast of Australia; and 5) model validation of the coupled katabatic wind, coastal ocean and ice systems in Antarctica. He received his Ph.D. in oceanography from Texas A&M University.

ASPECTS OF BIOLOGY AND ECOLOGY OF *LOPHELIA PERTUSA* IN THE NORTHERN GOM

Sandra D. Brooke, Craig M. Young, and M. Holmes, University of Oregon

Click here to view the slide show that accompanied this presentation.

This presentation is a subsection of a larger collaborative project entitled "Characterization of Northern Gulf of Mexico Deepwater Hard-Bottom Communities with Emphasis on *Lophelia* Coral." The overall project objectives were to 1) describe the biological communities on hard-bottom areas, particularly those with dense assemblages of *Lophelia pertusa,* using submersible survey and sampling techniques; 2) investigate environmental conditions that may correlate with the observed distribution and development of observed communities. The objectives of this subsection of the project include assessment of the distribution and abundance of *L. pertusa* (and other benthic cnidarians) at each study site, identification of biotic and non-biotic factors that may influence the distribution of *L. pertusa* and investigation into *L. pertusa* reproductive biology. These were addressed through field studies and collections, and manipulative laboratory experiments.

The JSL submersible was used to collect photographic, video, and sample data used for habitat characterization. At each study site, multiple video transects were conducted, each approximately 100 m in length along parallel bathymetric contour lines. The video footage was split into consecutive image frames for benthic community analysis. For the 'alpha' sites, which supported significant quantities of *Lophelia pertusa* (Viosca Knoll 826, Green Canyon 234, and GC354), the percentage cover of live and dead coral was measured and other fauna were counted. The highest percentage of live coral cover was recorded at VK826, but distribution was patchy with large thickets of coral interspersed with sediment, shell hash or chemosynthetic communities. Coral was found along a ridge feature at GC234 and in patches at GC354, but these were mostly dead colonies with a small amount of live coral. For the other 'beta' sites (VK862, GC184/185, and Mississippi Canyon 885), all visible components of the benthic fauna were counted and identified. The most diverse cnidarian community was found at VK862, where the dominant benthic fauna were multiple species of white anemones. The hard-bottom habitat at MC885 and GC184/185 supported many large colonies of the gorgonian *Callogorgia Americana delta.*

Standing dead coral colonies are a characteristic feature of many *Lophelia* habitats. The reasons for the coral mortality and the age of the dead coral are unknown. Suggested causes include temperature fluctuations, disease or parasites, and sediment load or burial. In the Gulf of Mexico, temperatures fluctuate over time, but in all but VK862, they most likely remain below the mortality threshold temperature. There are currently no known pathogens of deepwater corals, but since most deepwater scleractinian reefs are composed of a single keystone species, a disease outbreak could cause widespread mortality. Similarly, a benthic storm or slumping event could smother large areas of coral, leaving standing dead colonies. To measure sediment flux differences between the sites, sediment traps were deployed in 2004 and recovered in 2005; two sets of three traps were placed at each alpha site (high-coral vs. bare substrate) and one set at each beta site. Sediment traps were recovered from all of the alpha sites; but from only one (VK 862) of the beta sites. These data can be used to compare sediment characteristics from within and outside coral stands, and across a geographic range but do not provide sufficient information to permit comparison between our designated alpha and beta sites. Results indicate that sediment deposition increased significantly from GC354 (Western site) to VK826 (Eastern site), but there was no difference between high-coral vs. no-coral areas. The sediment was dominated by very fine particles <20um at all sites. Organic content ranged from ~13–21% and showed no difference between sites or between coral vs. no-coral areas. Since corals consume small plankton, the zooplankton in the sediment traps were also counted (fixative was placed in the traps prior to deployment for this purpose). The zooplankton content was very low at all sites and showed no significant difference between sites or between coral and no-coral areas in either abundance or composition.

There are large areas of VK826 that appear to be suitable coral habitat, but with no evidence of coral colonization. A transplantation experiment was used to test the hypothesis that bare substrate areas could not support survival and growth of mature *L. pertusa*. Four replicate transplant units, each with alizarin-stained coral fragments were deployed for 14 months in each of two locations: 1) exposed substrate and 2) dense coral habitat as a control for handling artifacts. Transplant survival was high in both dense coral and no-coral locations, and amount of new growth and number of new polyps showed no significant difference between sites. This experiment was designed to test the hypothesis that coral distribution on VK826 is driven by habitat suitability and that the bare substrate areas are not good habitat for adult *Lophelia*. This experiment shows, however, that adult corals can survive and grow equally well in both habitat types; therefore some other factor must be responsible for the absence of corals in habitat that appears suitable for colonization. The growth observed in these experimental fragments was extremely variable, as was the degree to which each fragment incorporated the alizarin stain.

A series of laboratory studies were conducted to determine the physiological tolerance of *L. pertusa* to environmental variables that potentially control the distribution and abundance of live coral. Fragments of *L. pertusa* were exposed under controlled conditions to a range of temperatures, sediment loads and food ration for both short (24h) and/or extended (7–30 days) duration.

The temperature tolerance experiment showed that *L. pertusa* can survive for short periods of time (up to 24h) at 15°C, but mortality occurs if the corals remain at this temperature for a week. The threshold for long-term survival was between 10°C and 15°C. An upper-temperature threshold of 12°C has been suggested for *L. pertusa* distribution elsewhere, and this seems to hold true for the Gulf of Mexico populations, implying a potential physiological constraint on distribution. The temperatures recorded at VK862 fluctuated around 11.5°C, which is close to the suggested temperature threshold and agrees with the experimental data. Sublethal stress effects can occur when organisms are living close to their environmental limits. Therefore, VK862 could provide an interesting site for further investigations into this aspect of *Lophelia* biology.

Results of the sediment load experiment showed survival of >50% after two weeks of exposure to ~100 mg/L^{-1} of Gulf of Mexico sediment, or after complete burial for two days; however, although *Lophelia* can tolerate fairly severe sediment conditions, mortality increases rapidly with longer burial or higher sediment loads. Information on duration and severity of sediment events in the Gulf of Mexico are required to put these results in context, since they are probably temporally and/or spatially variable phenomena.

Results of the feeding experiment indicated that (as expected) lipid content increased in response to increased food supply. Those polyps fed the highest ration contained an average of 25.2% (SE: 1.65) lipid over two trials, whereas the starved fragments contained only 13.1% (SE: 0.58). The latter however, survived 30 days without an external food supply, which raises interesting questions regarding metabolic rates and alternative carbon sources for *L. pertusa*. A field sample collected in September 2003 from VK826 was analyzed at the same time as the experimental fragments and contained 21.5% lipid, which fell between the experimental values obtained for corals fed every two days and four days. The feeding experiment data are preliminary and serve to demonstrate appropriate techniques for calculation of *Lophelia* energy consumption in the field. Lipid content appeared to be a reliable estimator of different energetic regimes, and calories per treatment can be calculated with reasonable accuracy if sufficient care is taken during the experiment. This experiment indicate that corals in the field might be energy limited, since fragments show higher lipid content in laboratory experiments than in the field; however, this study should be expanded to include replicate samples from different seasons and different locations before drawing firm conclusions. Seasonal fluctuations in lipid content are possible, particularly for female colonies since eggs contain lipid.

Small samples from multiple colonies of *L. pertusa* were collected during each cruise and processed according to standard histological protocols to determine the reproductive strategy and timing of gametogenesis. *Lophelia pertusa* is a gonochoristic, broadcast spawning species, which means colonies are separate sexes and each colony releases gametes into the water column to undergo external fertilization and larval development. Females collected in July contained vitellogenic oocytes with an average diameter of 73.4 µm (SE: 1.22), which increased to 88.1 µm in September as the eggs matured, then decreased substantially in November. These data, together with the absence of reproductive material in the October samples, indicates that the gametogenic cycle of *L. pertusa* begins in the spring, with vitellogenesis commencing through the summer and mature oocytes observed in September. The size frequency distributions for July and September show a wide spread, but with a definite single peak in the distribution, which indicates that spawning is probably not synchronous but occurs over a seasonal time period. More samples are required from other months to fully describe the reproductive cycle.

The benthic community at the Viosca Knoll area is very different from the other study sites: VK862 had by far the most extensive and well-developed *L. pertusa* community, with a much more heavily calcified skeletal morphology than was found at other locations. The VK862 beta site also had a unique benthic community, dominated numerically by anemones, and with the highest anthozoan diversity than any of the other sites. The western study sites were similar in their geology and benthic community, with extensive patches of a large gorgonian, *Callogorgia* *americana delta* representing the dominant cnidarian species. The reasons for these observed differences are still unclear; the measured abiotic (temperature, depth, salinity, sediment load) and biotic (plankton availability) components of the habitats did not satisfactorily explain the observed differences between sites, and the transplant experiments show that colonies can survive in areas that do not have coral cover. Either benthic community is driven by some factor that was not measured, or by extreme environmental events such as benthic storms, high currents and sediment slumps.

Laboratory experiments were useful in defining the tolerance limits of *L. pertusa* to some of the environmental influences that potentially affect the distribution and extent of the coral community. The upper thermal limit of 10–15°C from laboratory experiments, concurs with the observed upper thermal limit for *L. pertusa* distribution *in situ*. These manipulative studies also showed that *L. pertusa* has a fairly high tolerance to sediment level and to low food supply. Such studies may be useful in the future to address questions that cannot readily be answered by *in situ* observations.

Sandra Brooke earned her Bachelor's degree in biological sciences from Essex University in England and spent a few years working in mosquito control in the Cayman Islands before discovering marine biology. Her Master's degree (1996) was from the Virginia Institute of Marine Biology (VIMS), and her Ph.D. (2002) was a joint venture between the University of Southampton in England and Harbor Branch Oceanographic Institution in Florida. Her dissertation research focused on the reproductive ecology of a deepwater scleractinian Oculina varicosa, which forms large fragile reefs systems at 100m depth, along the shelf edge of Florida's Atlantic coast. These reefs support a diverse invertebrate community and are essential spawning and nursery habitat for a number of commercially important fisheries species. Between 2002 and 2006, she worked as a research associate at the Oregon Institute of Marine Biology where she was involved in several deepwater coral projects, including NMFS Alaska project to survey deepwater coral systems of the Aleutian Islands, reproduction of Lophelia pertusa in the Norwegian Fjords, a multidisciplinary study of the deepwater coral habitats off the Florida coast, as well as the MMS funded research: "Habitat Characterization of Deepwater Coral Habitats in the Gulf of Mexico." In the summer of 2006, she moved to the Florida Fish and Wildlife Research Institute as an associate research scientist for the coral research and monitoring group, where she works on several projects involving both shallow and deep water coral ecosystems.

COMMUNITIES ASSOCIATED WITH *LOPHELIA PERTUSA*, SIMILARITY TO SEEP FAUNA, AND POTENTIAL TROPHIC INTERACTIONS

Erik E. Cordes, Erin L. Becker, Stephanie Lessard-Pilon, Elizabeth L. Podowski, Michael McGinley, and Charles R. Fisher, Pennsylvania State University

Click here to view the slide show that accompanied this presentation.

Hard-grounds on the continental slope of the northern Gulf of Mexico are dominated by seep-related authigenic carbonates. Colonizing these substrata at active seeps are animals with internal methane- or sulfide-oxidizing symbionts, mussels and tubeworms. Also present on these substrata are deep-water corals (broadly encompassing species in numerous taxonomic group including scleractinian, gorgonian, antipatharian, alcyonacean, and hydrozoan cnidarians). The presence of corals on seep-related carbonates leads to the question of the nature of their association with seeps. This study investigates the role of *Lophelia pertusa* in forming habitat structure for other species on the hard-grounds of the upper slope and the potential for Lophelia-associated communities to represent an additional stage in seep community succession. We describe the communities associated with *Lophelia pertusa* using quantitative photographic and physical samples, their similarity to the communities inhabiting tubeworm aggregations at the same sites, trophic relationships within the community, and potential ties to seep productivity.

A total of 12 photomosaics were assembled from successive overlapping images taken over a haphazardly selected target. Carbonate outcrops of less than 50 m^2 containing relatively high densities of *Lophelia pertusa* were selected for analysis. Photographs were adjusted automatically and assembled into mosaics either manually or with a program written by Woods Hole Oceanographic Institution scientists. The percent coverage of colonial or encrusting fauna, the density of mobile fauna, and potential associations of mobile fauna with different substrata was examined using ArcGIS.

The most common substrata sampled were dead coral, coral rubble, live coral, and bare carbonate. The most common mobile fauna in the mosaics were *Munidopsis* spp., *Eumunida picta*, ophiuroids, crinoids, and fishes. In at least one of the mosaic samples, *Munidopsis* spp. were significantly associated with live coral or seep habitats (bacterial mats or tubeworms) and away from dead coral. *Eumunida picta* were commonly found on dead coral or other cnidarians in close proximity to live coral or bare carbonate. Ophiuroids, primarily a large species of ophionerid, *Asteroschema* sp., were most commonly found on other colonial cnidarians, usually *Callogorgia americana*. Crinoids were significantly associated with dead coral or mixed dead and live coral in close proximity to live coral polyps. Fishes were found on most substrata, but in some cases were significantly more common near live or mixed coral or bare carbonate. On the whole, the megafaunal communities sampled in the photomosaics were most similar when they were from the same sites, at the same depth, and contained similar proportions of dead coral.

Quantitative physical samples of the coral thickets were obtained using the Bushmaster collection device. The volume and surface area of coral skeleton was determined and all of the associated fauna that were retained on a 2mm sieve were separated from the collection. The fauna were sorted to morphospecies and subsampled for stable isotopes if they could be reliably identified on board the ship. Representatives of all species were sent to taxonomic experts for confirmation of identifications and identification of unknown species.

A total of 68 taxa were collected in close association with *L. pertusa* in the physical samples. The most common taxa were the polychaetes *Euratella* sp., *Glycera tesselata*, and *Eunice* sp., a small unidentified ophiuroid, sponges and hydroids. Three potentially coral-endemic species were identified in the collections. *Coralliophila* sp. is from a genus of known coralivores. *Eunice* sp. is likely to be similar to *Eunice norvegica* in habit, a species that has been shown to actively assemble coral skeleton and facilitate colony growth. *Stenopus* sp. is from a genus that includes species that are cleaner shrimp on shallow-water coral reefs.

Community similarity was most closely correlated with similarity in depth and the proportion of live coral in the collection, followed by distance between collections and habitat complexity (surface area of coral per unit coral volume). There was little overlap with tubeworm-associated communities collected from the same sites leading to separate groupings of these community types in an ordination analysis. However, there were a few species in common to both types of biogenic habitat. Most of these species were from the background Gulf communities and are likely to simply be attracted to the increased habitat heterogeneity provided by these biogenic structures. Bathymetric trends in community similarity observed here likely stem from the previously demonstrated trends in these background communities. Some of species sampled among *Lophelia pertusa* colonies were previously reported as seep endemics including the polychaetes *Branchinotogluma* sp. and *Harmothoe* sp., the gastropods *Bathynerita naticoidea* and *Provanna sculpta*, and the galatheid crabs *Munidopsis* sp. 1 and 2. The presence of these species indicates that there are some similarities in the habitat characteristics of tubeworm aggregations and coral thickets and that these biogenic habitats form different components of the same broad system. Therefore, coral structures could represent a final stage of community succession at hard-grounds on the upper slope.

This hypothesis is supported by the stable isotope values of coral associates. The range of values measured (-25 to -14 $\delta^{13}C$, 6 to 16 $\delta^{15}N$, 13 to 27 $\delta^{34}S$) only slightly overlapped those measured previously in seep communities, which are generally lighter in all 3 isotopes. The fauna sampled in the *Lophelia pertusa* collections were mainly generalists feeding within a single trophic level, with only a few potential direct trophic relationships suggested including a number of species feeding on the common sabellid polychaete *Euratella* sp. The only species appearing to feed directly on *Lophelia pertusa* tissues was the gastropod *Coralliophila* sp. In the few cases where the stable isotope values overlap the range of seep fauna, they are in a few individuals of seep species collected in this study (i.e., *Provanna sculpta*) or in background species collected in the oldest tubeworm aggregations sampled.

The range of stable isotope values of sampled *Lophelia pertusa* tissues were also outside the range found in suspension feeding species in seep communities. This indicates that little or no seep production is included in the diet of *L. pertusa*, either from direct ingestion of particulate organic matter, or indirectly through predation on small mobile fauna. In addition, a series of skeletal samples from different distances along the *Lophelia pertusa* skeleton did not show a change in the $\delta^{13}C$ signal. The carbon in skeletal calcium carbonate is derived from the seawater dissolved organic carbon pool. During periods of active seepage, the isotopic signature of the DIC would be lighter due to the influence of carbon derived from the oxidation of methane. If *Lophelia pertusa* settled at this time, the base of the skeleton should have lighter $\delta^{13}C$ values than portions of the skeleton in more recently formed skeletal structures. This was not detected in this study, suggesting that *L. pertusa* does not settle on authigenic carbonates in areas of active seepage.

These skeletal carbonate samples were also analyzed for δ18O values in a preliminary investigation of their potential for climate reconstruction. The relationship of $\delta^{13}C$ to $\delta^{18}O$ has been used previously to determine the temperature of the waters at the time of the precipitation of the skeleton. In this study, samples from VK826 and VK862 were analyzed. The temperature at VK862 (315 m depth) was calculated to be 8.04°C at the time of skeletal formation, and the temperature at VK826 (465 m depth) was calculated to be 7.32°C. Both of these values are within the range measured for these two sites and reflect the cooler temperatures at greater depths. Additional investigations are required to examine this further, but these results suggest that this may be a fruitful avenue for future studies.

This study describes the communities associated with *Lophelia pertusa* in the northern Gulf of Mexico for the first time. At the megafauna and macrofauna level, they are dominated by background species from the Gulf, although a few species of potential coral endemics and individuals of species thought to be seep endemics were recovered in the collections. Communities were most similar in samples from the same site at the same depth and with similar proportions of live coral. Most of the species appeared to be feeding generalists, and a portion of the trophic structure of the communities was reconstructed. The few species present in both coral- and tubeworm-associated communities and the continuation of the trend of increasing stable isotope values from young to old tubeworm aggregations to the coral structures sampled supports the inclusion of *L. pertusa* communities in the successional progression of hard-ground fauna in the northern Gulf of Mexico.

Erik Cordes is a post-doctoral fellow at Harvard University. As a visiting scientist at Pennsylvania State University, he is involved in the joint MMS-OE funded study of the deep-water (>1000 m) hardgrounds in the northern Gulf of Mexico, or Chemo III. His primary responsibilities are an analysis of the deepwater coral communities inhabiting the hardgrounds. He is also assisting in the oversight of the collection and processing of seep community samples, distribution of specimens to taxonomic collaborators, and data analysis. He was also involved in the MMS-funded *Lophelia* I study, and he was responsible for the analysis of communities asso-

ciated with *Lophelia pertusa* including biodiversity, biogeography, trophic relationships, and potential ties to seep productivity. Following his undergraduate degree at Southampton College, he studied soft coral and gorgonian age, growth, and reproduction at Moss Landing Marine Laboratories where he received a Master of Science degree. His doctoral research at Pennsylvania State University involved modeling the population dynamics and sulfide uptake of the tubeworms inhabiting the upper Louisiana slope seeps, and analyses of the communities associated with them. Over the course of his research, he has participated in 11 research expeditions and made 30 dives in the Johnson Sea-Link and Alvin submersibles and has published eight papers on the ecology of deep-water habitats in the Gulf of Mexico.

SESSION 2C

DEEPWATER PHYSICAL OCEANOGRAPHY I

Chair: **Alexis Lugo-Fernandez, Minerals Management Service**

Co-Chair: **Carole Current, Minerals Management Service**

INTRODUCTION TO DEEPWATER PHYSICAL OCEANOGRAPHY I

Carole L. Current, Minerals Management Service

Click here to view the slide show that accompanied this presentation.

The Deepwater Physical Oceanography I session covers numerous aspects of deepwater physical oceanography in the Gulf of Mexico. It begins with a general presentation of NASA's applied science program, followed by results of several MMS-sponsored studies in progress. Acoustic Doppler Current Profiler (ADCP) data are being collected by operators in response to MMS Notice to Lessees (NTL) 2005-G05, and early results of an analysis of these data will be described. Offshore oil production was heavily impacted in 2005 by two Category 5 hurricanes in areas of considerable activity; another highlight of this session will be some preliminary results from MMS-sponsored numerical modeling of waves and currents produced by hurricanes Katrina and Rita. Additionally, some fascinating new observations of Loop Current frontal eddies by means of remote sensing are described in this session. In recent years, MMS Environmental Studies has overseen the collection of considerable physical oceanographic data, and these data are now being used in a collection of "data mining" studies. A final highlight of this session is the Northeast Gulf of Mexico program, which has collected physical oceanographic data in regions generally offshore of the state of Alabama.

While some of the MMS studies described in this session are fully completed, others are in earlier stages. Some, such as the NTL ADCP data analysis, have been in progress for only a few months, but their results are awaited with great anticipation by many.

Carole L. Current is a Physical Oceanographer at the Minerals Management Service, Gulf of Mexico Region, New Orleans, Louisiana. Dr. Current has been with the MMS since 1999. Previously, she was an Assistant Professor, Research at the Coastal Studies Institute, Louisiana State University. Her interests are in Gulf of Mexico physical oceanography and are primarily focused on uses of Gulf of Mexico physical oceanographic data in numerical circulation modeling. Dr. Current earned a B.S. in electrical engineering and an M.S. and Ph.D. in physical oceanography, all from Texas A&M University.

NASA APPLIED SCIENCES: COASTAL MANAGEMENT

Terry McPherson, NASA Applied Sciences Program

Click here to view the slide show that accompanied this presentation.

Terry McPherson is the former Deputy Director of NASA Stennis Space Center, Mississippi and now Deputy, Program Manager for NASA's Coastal Management Program. He has a B.S. in meteorology from San Jose State University (1975) and an M.S. in meteorology and oceanography from the Naval Postgraduate School, Monterey, California (1981). Prior to joining NASA, Mr. McPherson had a distinguished naval career that included a wide variety of operational and executive positions, including Chief of Staff, Naval Meteorology and Oceanography Command (2001–2003), Commanding Officer, Naval Pacific Meteorology and Oceanography Center/Joint Typhoon Warning Center, Pearl Harbor, Hawaii (1999–2001), Executive Officer, Naval Oceanographic Office, Stennis Space Center (SSC) (1996–1999).

PRELIMINARY RESULTS OF THE OIL PLATFORM ADCP DATA ANALYSIS

Chunyan Li, Jennifer Coor, Larry Rouse,
Coastal Studies Institute, Department of Oceanography and Coastal Sciences,
Louisiana State University

Richard L. Crout, NOAA, Stennis Space Center, MS

Click here to view the slide show that accompanied this presentation.

Introduction

In the spring of 2005, the U.S. Department of the Interior's Minerals Management Service (MMS) issued a Notice to Lessees and Operators (NTL) No. 2005-G05, followed by NTL 2007-G17, to require oil companies operating on the outer continental shelf (OCS), Gulf of Mexico OCS region to measure vertical profiles of the horizontal current velocity using acoustic Doppler current profilers (ADCP) or comparable equipments mounted on fixed and or floating mobile offshore drilling units (MODU's) and floating production facilities. The data have since been published starting April–June 2005 using an internet web site maintained by the National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC). Data are recorded in waters with a total depth of greater than 400 m at 10–20 minute intervals from near the surface (~30 m) to ~2000 m. In places with depth greater than 1000 m, two ADCPs may be used. Currently, there are a few dozens of ADCPs that are collecting data continuously. These instruments are scattered mostly in the northern Gulf of Mexico over the continental slopes.

These ADCP data provide unprecedented opportunity for researchers to gain insight of the dynamics and three dimensional structures of horizontal flows and related horizontal spatial variability in the Gulf of Mexico, where wind driven flows, inertial oscillations, resonance with tidal motions, loop currents, loop current eddies (e.g. Hamilton et al. 1999; Welsh and Inoue 2000; Frolov et al. 2004b), deep water currents (e.g. Hamilton 1990; Hamilton and Lugo-Fernandez 2001; Hamilton et al. 2003; DiMarco et al. 2004; Frolov et al. 2004a,b) and hurricane induced motions (e.g. Maeda et al. 1996; Zheng et al. 2006) are of great interest.

Data Description

The ADCP data are obtained from platforms owned by numerous companies including Amerada Hess, Anadarko Petroleum, ATP Oil & Gas, BHP, BP Inc., Chevron, Conoco Phillips, Dominion Exploration, ENI Petroleum, Exxon Mobile, Kerr-McGee, Marathon, Mariner Energy, Murphy Exploration, Newfield Exploration, Nexen, Petrobras, Remington Oil & Gass, Shell, Tana Exploration Company, Total USA, Water Oil & Gas Williams, and W&T Offshore, etc. The locations of these oil platforms are shown in Figure 2C.1. These oil platforms are mostly located in water depth of 200–2000 m. There are about 50–60 such stations operating and reporting data

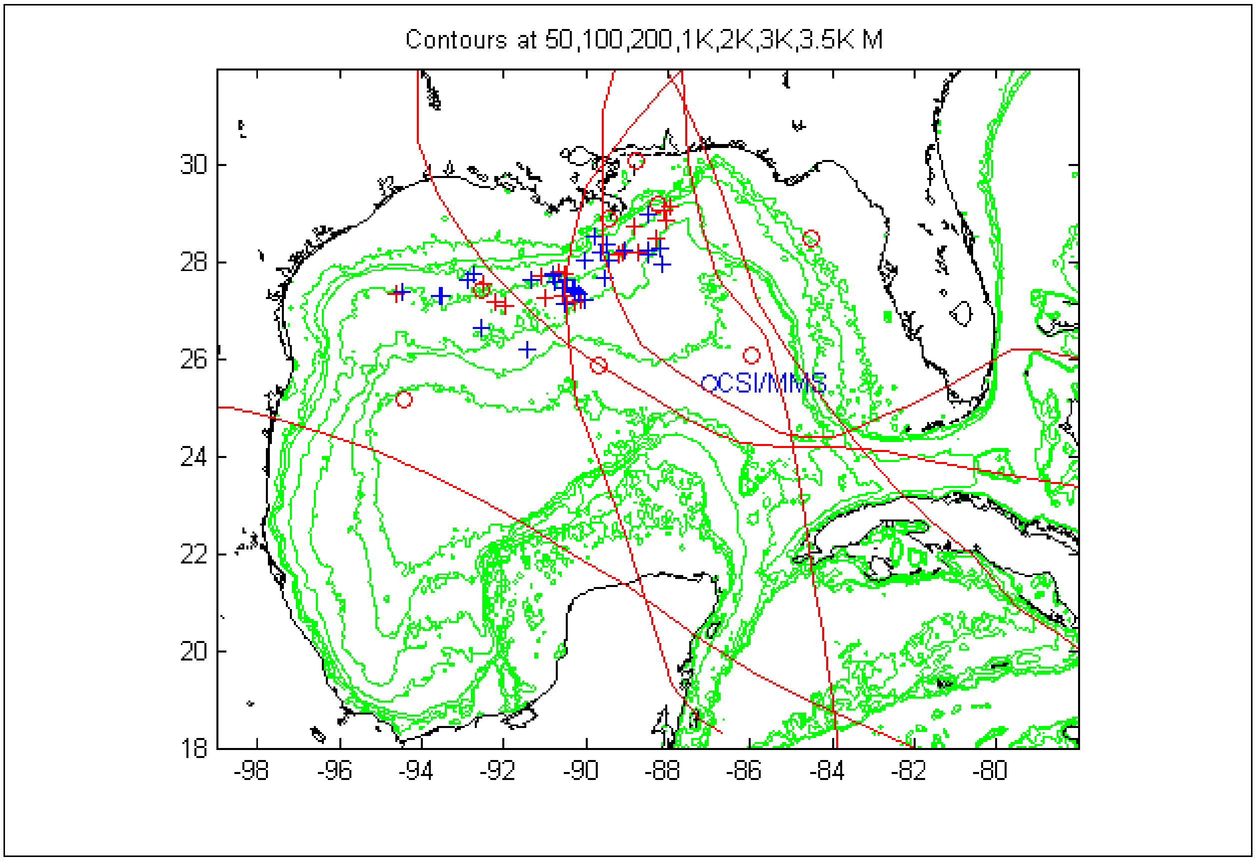


Figure 2C.1. Most of the oil platforms and ADCP stations, met stations, and recent hurricane tracks in the northern Gulf of Mexico. Red crosses show the locations of fixed platforms and blue ones are for mobile units. The circles are weather stations or the CSI mooring site.

at any time. The data usually covers part of the water column. In some instances, two ADCPs may be operating at the same time at different depths in the water column. For the stations with ADCPs installed on fixed platforms, the 5-digit station numbers start with 423; while for the stations with ADCPs installed on moving platforms, the 5-digit station numbers start with 428 or 429. The ADCP data usually only covers part of the water column (Table 2C.1). For example, station 42361 is installed on a fixed platform located in water of total depth of 872 m; with data covering 51 through 803 m at 10-minute time intervals and 16 m vertical bins with a total of 48 bins in the vertical. Table 2C.1 lists the ADCP stations on fixed oil platforms. The MODU's move from place to place at irregular intervals and are thus not listed here. Figure 2C.1 shows all the available platforms, fixed or mobile, with ADCPs. Obviously, they are all concentrated in the northern Gulf of Mexico only near the U.S. coastlines of Louisiana, Texas, and Mississippi.

Preliminary Data Analysis

We have performed data analysis using various time series techniques for data from 2005 and 2006. Most of the data from 2007 have not been analyzed yet. Specifically, we have done basic low pass and high pass filtering to separate the high frequencies (daily or shorter oscillations)

Table 2C.1

List of ADCP Stations on Fixed Oil Platforms

Stn number	Lat (N)	Lon (W)	Depth (m)	Data Range		dt (min)	Bin Size / *# Bins*
				Start Depth (m)	End Depth (m)		
42361	27.55	92.49	872	51	803	10	16 / *48*
42362	27.8	90.67	910	79	1023	10	16 / *60*
42363	28.16	89.22	894	45	989	10	16 / *60*
42364	29.06	88.09	980	51	995	10	16 / *60*
42365	28.2	89.12	1158	60	1004	10	16 / *60*
42366	27.12	91.96	1615	114	610	20	16 / *32*
42367	28.74	88.83	860	94	1024	20	30 / *32*
42368	27.2	92.2	1424	66	1122	10	32 / *34*
42369	27.19	90.27	1372	123	867	10	16 / *32*
42370	27.32	90.54	1311	61	1315	20	30, 20 / *32, 28*
42372	27.78	90.52	789	27	662	13	8 / *80*
42373	27.35	94.63	1113	596	103	20	16 / *32*
42374	28.87	88.06	1646	45	1645	10, 20	16, 32 / *32*
42375	28.52	88.29	1920	1416	1912	20	16 /*32*
42376	29.16	87.94	986	53	984	20	30 / *32*
42377	27.29	90.97	1524	68	1497	20	30 / *32, 37*
42379	27.36	90.18	1286	683	1259	20	16 / *37*
42380	28.21	88.74	1710	20	1684	20, 240	16 / *37, 50*
42381	28.22	89.62	911	80	945	10	32 / *28*
42382	27.3	93.54	960	125	1623	20	36 / *42*

and low frequencies (longer than daily variations), power spectrum analysis, harmonic analysis, rotary spectrum analysis, and some EOF and wavelet analyses. We have also examined the flow features under non-hurricane or storm and hurricane or storm conditions. We have examined the inertial oscillations caused by wind events including during hurricanes such as Hurricane Katrina and Hurricane Rita. The preliminary results highlight the fact that the data from these oil platforms are unique and can be useful for multiple purposes, either theoretical or practical. They can be valuable information for the understanding of the spatial structures of flows influenced by the deep water circulations and winds.

Examples of Results

While the analyses are continuous and underway, we present some examples of results here in this short paper. The first of which, as a common feature of the flow that covers most of the record, is the inertial oscillation. The inertial oscillation exists at almost every station and every month though the magnitude of flow fluctuates, which may be caused by the variation of wind. Figure 2C.2 is an example of the vertical structure of east velocity component (cm/s) at station 42361. It covers the water column between 70 m and 800 m. The velocity changed from -30 cm/s to 55 cm/s. The alternating maximum and minimum flow in the east direction is obviously

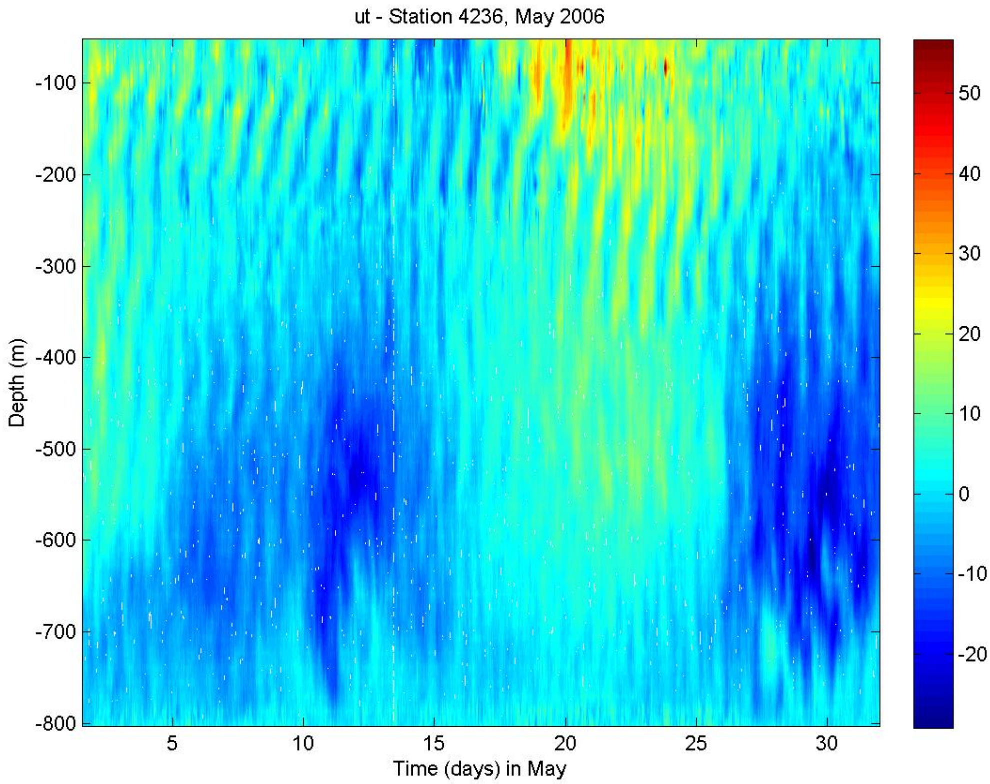


Figure 2C.2. Vertical profile of time series of the east velocity obtained from Station 42361, May 2006.

a signal of inertial oscillation. Superimposed on the inertial oscillation are the lower frequency variations that are strongly dependent on depth. For example, between 10 May and 15 May, there was a strong westward flow centered at 500–700 m. This westward flow repeated again between 26 May and 31May. Between 16 May and 26May, however, there was a strong eastward flow, particularly above 200 m. On 20 May, the eastward flow reached its maximum above 150 m.

Among all the results obtained so far in the extensive analyses, the most interesting ones are probably those with responses of deep water currents to hurricanes including Hurricane Katrina and Hurricane Rita. To illustrate this, and for brevity, we will present only some representative results. Here we choose station 42375 where the water depth is 1920 m and the ADCP covers between 1416 m and 1912 m (Table 2C.1). The ADCP samples at 20-minute intervals with a uniform 16 m vertical bin size. A vertical profile of the high-passed time series plot of the velocity at this station is shown in Figure 2C.3.

Hurricane Katrina landed on 29 August (241st day of the year), while Hurricane Rita landed on 24 September (267th day of the year). Clearly, Figure 2C.3 shows the almost immediate response of the deep water flow at 1400 to 1900 m below the surface to the hurricanes. The response is mainly in the form of periodic oscillations—the inertial oscillations (e.g. Kundu and Thomson 1985; Pedlosky and Stommel 1993; Chen et al. 1996). The response to each of the hurricanes

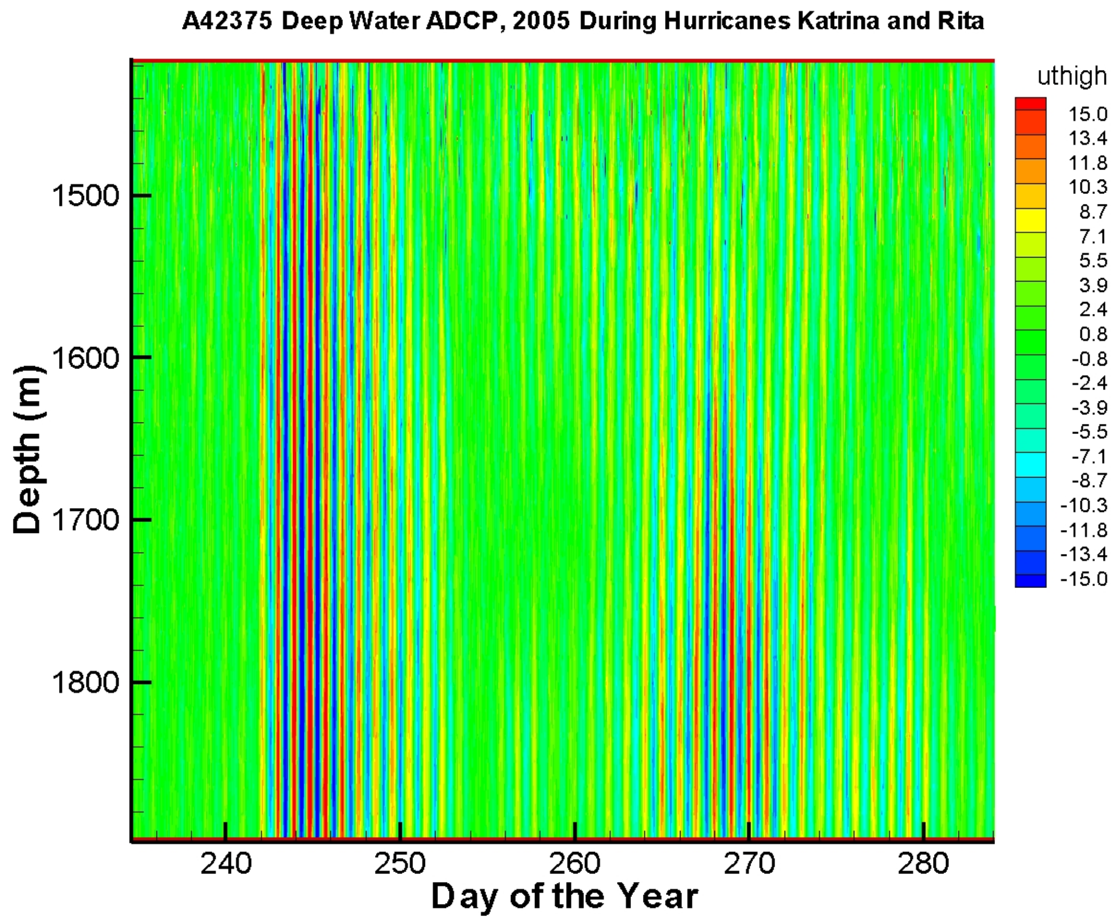


Figure 2C.3. Vertical profile of time series of the east velocity obtained in 2005 covering Hurricane Katrina and Hurricane Rita.

lasted for at least 10 days to two weeks. The oscillation after Katrina was almost vertically uniform while that of Rita showed obvious bottom intensification. To verify its inertial nature and to determine the magnitude of oscillation at different near inertial oscillations, we conducted rotary spectra analysis. The results are shown in Figure 2C.4.

The red line is the clockwise spectrum and the black line the counter-clockwise spectrum. Obviously, the black line is negligible compared to the red line, indicating that the motion is indeed consistent with inertial oscillation. The peak of the red line is at about T = 22.7 hr. The inertial oscillation period is about $T = 2\pi / f$, in which f is the Coriolis parameter, determined by $2\,\Omega \sin(\theta)$, where Ω and θ are 7.29 x 10^{-5} /s the latitude, respectively. Since the station is at the latitude of 28.5 degree north, the inertial oscillation period is calculated to be 25.07 hr. This gives a ratio between the inertial period and the peak of the spectrum to be 25.07/22.7 = 1.10. In comparison, the same analysis to the data during Hurricane Rita (Figure 2C.5) gives us a peak of

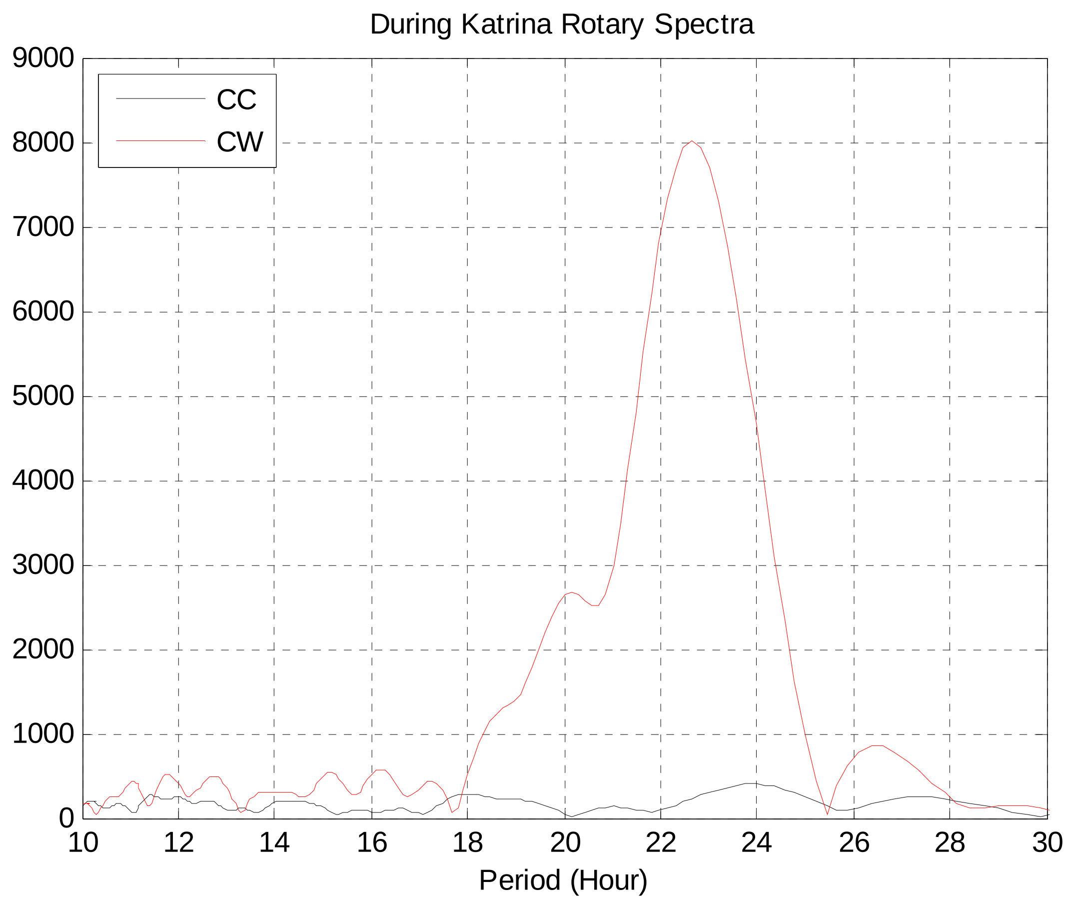


Figure 2C.4. Rotary spectra for data during Hurricane Katrina.

the rotary spectrum at 24.3 hr, which yields a ratio between the inertial period and the peak of the spectrum to be 25.07/24.3 = 1.03. This shift of oscillation of frequency (period) toward larger (smaller) values of the inertial oscillation frequency (period) is consistent with previous studies (e.g. Zheng et al. 2006).

Summary

We have presented some results of data processing and analysis of the ADCPs mounted on the oil platforms in the Gulf of Mexico. Large amount of results have been generated for various processes, the detail of which is now being organized for dissemination. The datasets provide unique information at high resolution for the northern Gulf of Mexico areas. More and more results are being produced. The challenge is not only because of the amount of information, but also because of the wide range of processes involved in influencing the dynamics. The proper analysis can only be demonstrated with proper interpretations.

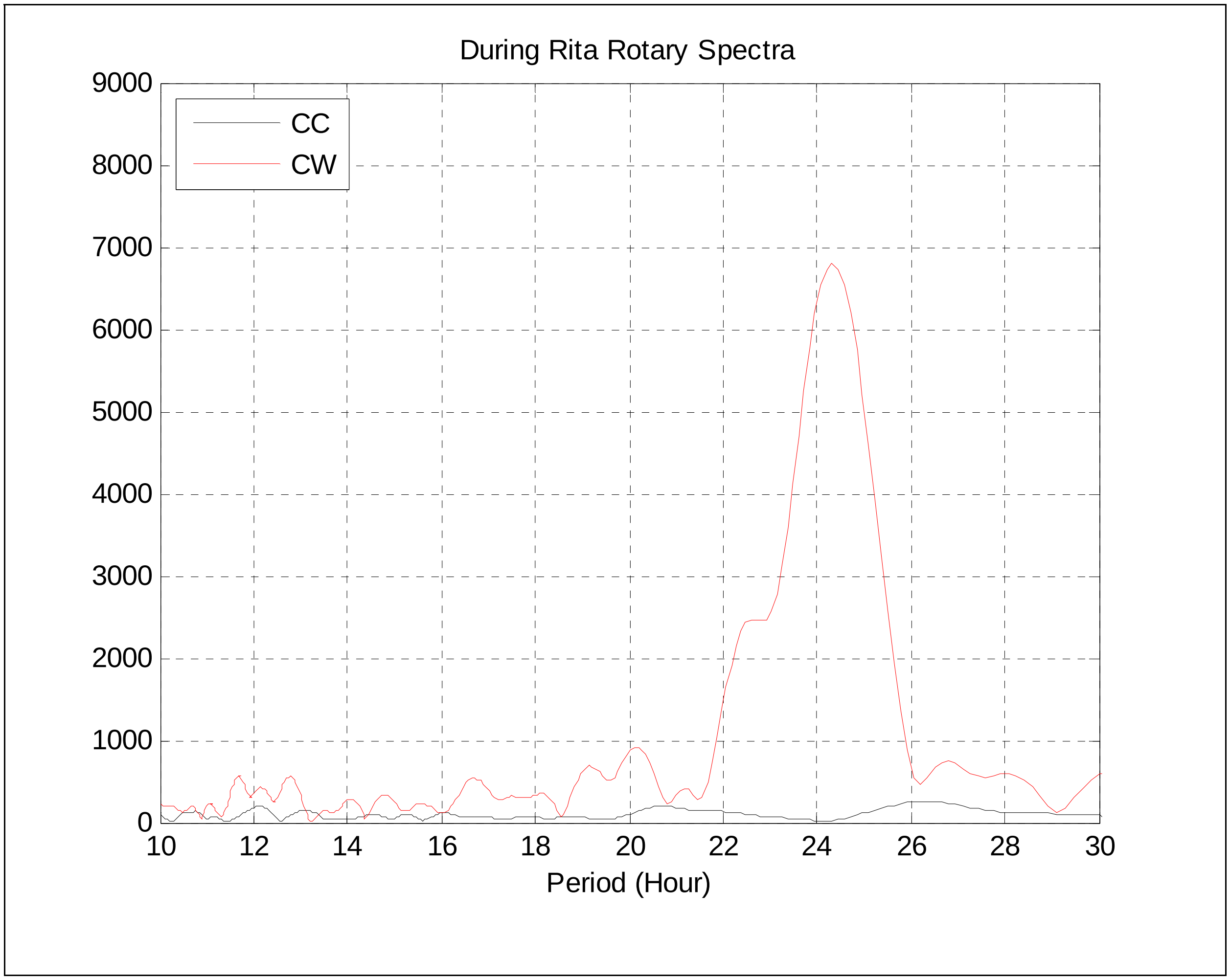


Figure 2C.5. Rotary spectra for data during Hurricane Rita.

Acknowledgment

This study was funded by the Minerals Management Service (MMS) through Cooperative Agreement 0104CA32806, Task Order 0106TO39901.

References

Chen, C., R.O. Reid, and W.D. Nowlin. 1996. Near-inertial oscillations over the Texas-Louisiana shelf. JGR-Oceans 101:3509–3524.

DiMarco, S.F., M.K. Howard, W.D. Nowlin Jr., and R.O. Reid. 2004. Subsurface, high-speed current jets in the deepwater region of the Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-022. 98 pp.

Frolov, S.A., G.D. Rowe, L.M. Rothstein, and I. Ginis. 2004a. Cross-shelf exchange processes and the deepwater circulation of the Gulf of Mexico: Dynamical effects of submarine canyons and the interactions of Loop Current eddies with topography, final report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-017. 149 pp.

Frolov, S.A., G.G. Sutyrin, G.D. Rowe, L.M. Rothstein. 2004b. Loop current eddy interaction with the western boundary in the Gulf of Mexico. JPO 34:2223–2237.

Hamilton, P. 1990. Deep currents in the Gulf of Mexico. J. Phys. Oceanogr. 20:1087–1104.

Hamilton, P., G.S. Fargion, and D.C. Biggs. 1999. Loop Current eddy paths in the western Gulf of Mexico. J. Phys. Oceanogr. 29:1180–1207.

Hamilton, P. and A. Lugo-Fernandez. 2001. Observations of high-speed deep currents in the northern Gulf of Mexico. Geophys. Res. Lett. 28:2867–2870.

Hamilton, P., J.J. Singer, E. Waddell, and K. Donohue. 2003. Deepwater observations in the northern Gulf of Mexico from in-situ current meters and PIES. Final report. Volume I: Executive summary. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-048. 14 pp.

Kundu, P. K. and R.E. Thomson. 1985. Inertial oscillations due to a moving front. Journal of Physical Oceanography 15(8):1076–1084.

Maeda, A., K. Uejima, T. Yamashiro, M. Sakurai, H. Ichikawa, M. Chaen, K. Taira and S. Mizuno. 1996. Near internal motion excited by wind change in a margin of the typhoon 9019. Journal of Oceanography 52(3):375–388.

Pedlosky, J. and H. Stommel. 1993. Self-sustained inertial oscillations. Journal of Physical Oceanography 23(8):1800–1808.

Welsh, S.E. and M. Inoue. 2000. Loop Current rings and the deep circulation in the Gulf of Mexico. J. Geophs. Res. 105(C5):16,951–16,959.

Zheng, Q., R.J. Lai., N.E. Huang, J. Pan, and W.T. Liu. 2006, Observation of ocean current response to 1998 Hurricane Georges in the Gulf of Mexico. Acta Oceanologica Sinica 25(1):1–15.

Dr. Chunyan Li is an assistant professor in the Department of Oceanography and Coastal Sciences at Louisiana State University. His research interests include physical oceanography, storm surges, modeling, mixing and transport processes, coastal and estuarine circulations, innovative observations, fronts, and fine structures.

HURRICANE CURRENTS AND WAVES

L.-Y. Oey, Princeton University

D.-P. Wang, Stony Brook University

Click here to view the slide show that accompanied this presentation.

Summary

The goal is to provide MMS with "best estimates" of currents and waves produced by hurricanes Katrina and Rita, and to understand and explain the underlying physics. We accomplish these through a combination of observational data analyses and numerical modeling. A bred-ensemble analysis technique that incorporates satellite data is used to derive estimates of the strengths and positions of Loop Current and rings, and model experiments through periods of hurricanes were then carried out free from further data assimilations.

Analysis winds from the NOAA's Hurricane Research Division were also used to force both the circulation and wave models (Figure 2C.6). Satellite and drifter data, as well as wave data from

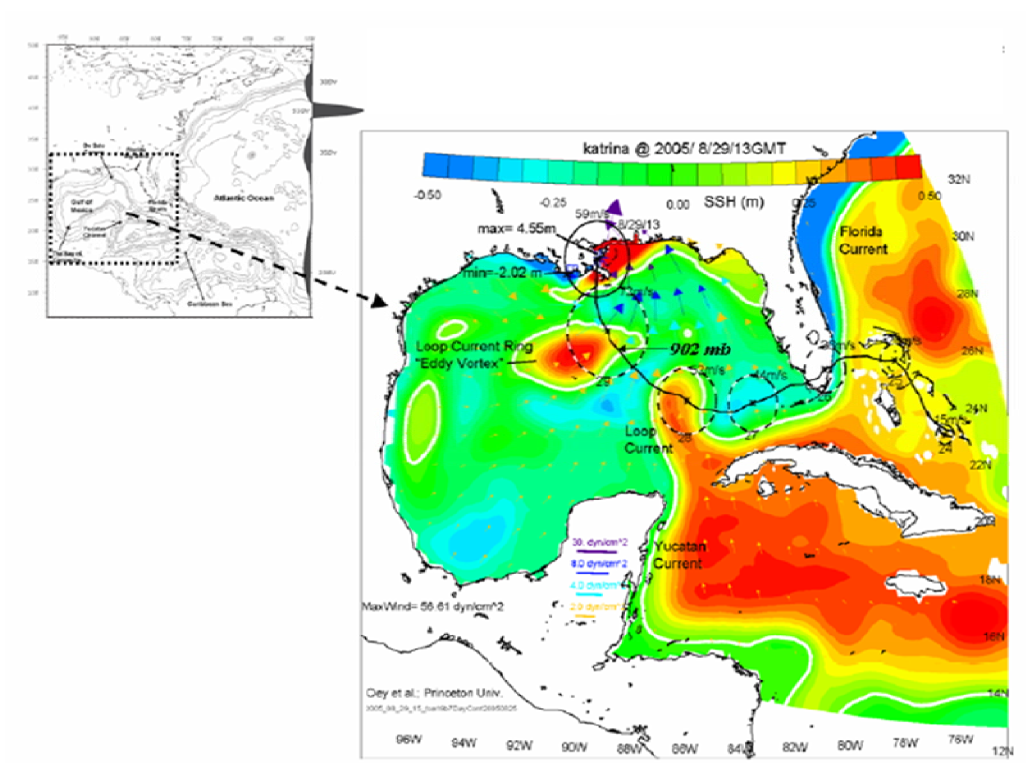


Figure 2C.6. Forecast SSH and Currents shortly after Hurricane Katrina made landfall. Note the high SHH (red; max = 4.5m) and strong flow convergence near New Orleans.

NDBC buoys data were used to skill-assess the model results. It is shown that interaction of hurricane-induced currents and currents produced by the Loop and eddies is significant. It is also shown that inertial currents are particularly strong on the right side of the hurricane Katrina but are damped by the presence of eddy vortex (Figure 2C.7).

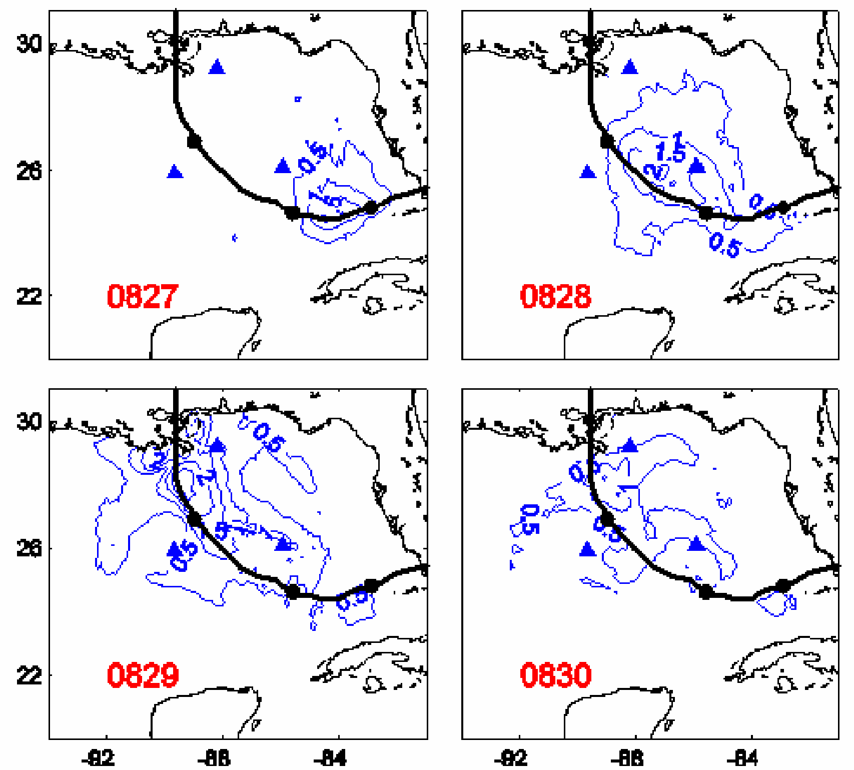


Figure 2C.7. Katrina excited intense initial currents to the right.

Hurricane Katrina caused extensive damages to offshore oil and gas production facilities in the Gulf of Mexico. In this study, an ocean circulation model and a surface wave model are used together to predict the current and wave conditions during Katrina. The model is driven by high-resolution analyzed winds from NOAA Hurricane Research Division. The model shows strong (> 2 m/s) surface wind-driven and inertial currents superposed on the Loop Current and Loop Current Eddy as well as very large (> 15 m) waves (Figure 2C.8). Moreover, as a consequence of intrinsic ocean dynamics the distributions of inertial currents and surface waves are strongly biased to the right of the storm path. The predicted wave field is successfully verified with surface buoy and satellite altimetry observations (Figures 2C.9 and 2C.10). It is suggested that the highly focused wave and current forces contribute to the enormous hurricane impact.

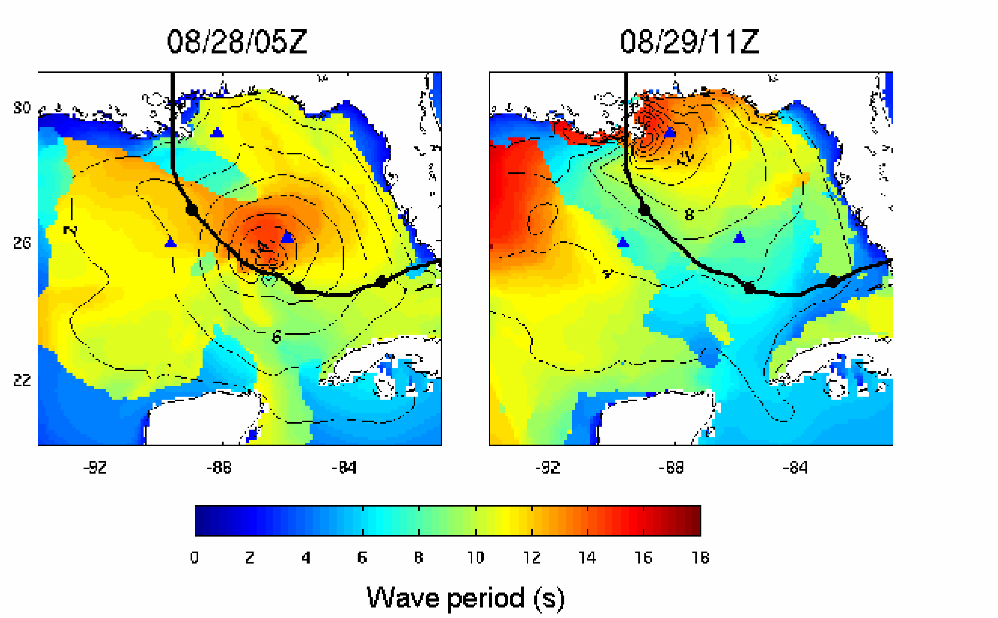


Figure 2C.8. Katrina waves are much larger on the right of the storm path.

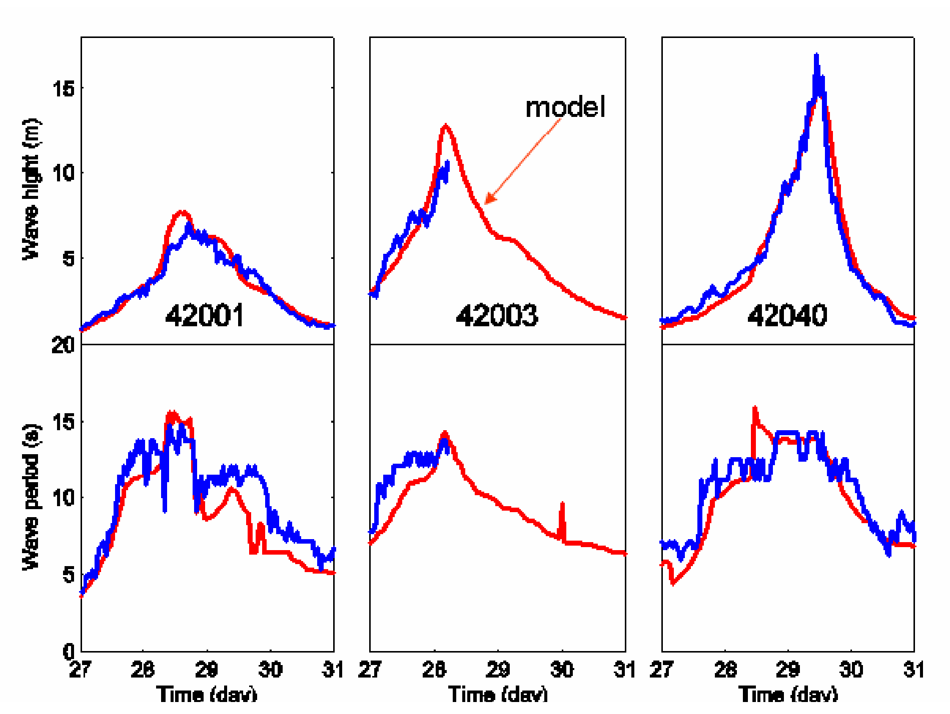


Figure 2C.9. Model reproduces wave amplitude and period at buoys.

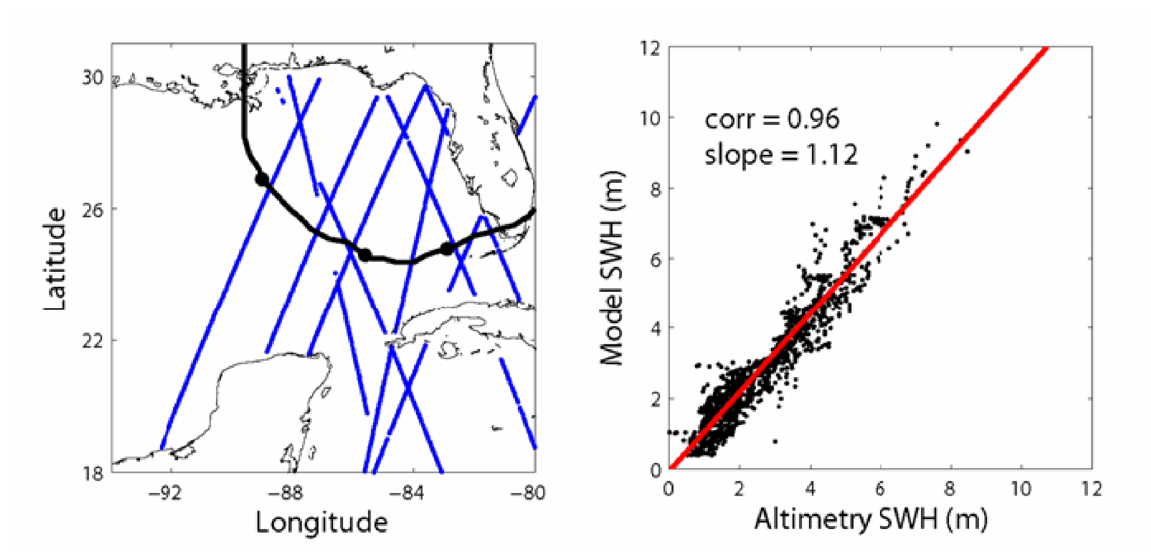


Figure 2C.10. Model wave heights are validated against satellite data.

Dr. Oey is a research scholar at Princeton University. He received his B.Sc. from the University of London (1974) and his M.S. and Ph.D. from Princeton (1976 and 1978). His interest is in ocean modeling and data analyses. Dr. Oey has served as PI and co-PI of various MMS projects dealing with the Gulf of Mexico, Santa Barbara Channel, and Cook Inlet, Alaska.

REMOTE SENSING OF LOOP CURRENT FRONTAL EDDY CYCLONES

Nan Walker and Shreekanth Balasubramanian, Louisiana State University

Robert Leben, University of Colorado

Steve Anderson, Patrice Coholan, and James Feeney, Horizon Marine, Inc.

Click here to view the slide show that accompanied this presentation.

Project Goal

The main goal of this project is to develop new and innovative methods using satellite remote sensing and in-situ data to elucidate important circulation characteristics associated with Loop Current Frontal Eddy (LCFE) cyclones and how they affect circulation throughout the water column in areas of oil and gas operations.

Data and Methods

Three main sources of data are being used in our research; satellite-derived sea surface temperatures (SSTs), satellite measurements of sea surface height (SSH), and satellite-tracked drifters. Although the main time period of interest is the Exploratory Study Period: March 2003 – June 2004, historic data outside this time period have been processed and are being analyzed for selected time periods starting January 2000. GOES GVAR radiometer infrared measurements, obtained every 15 minutes, are used to quantify SST and to provide a surveillance of the Loop Current (LC) and LCFE cyclones on a daily basis. Although relatively coarse in spatial resolution (4 km pixels), the GOES data provide a substantial advantage over NOAA AVHRR and MODIS data (1 km pixels) due to repeat frequency. We are using the methods developed by Walker et al. (2003) for eddy detection, based on the mid-infrared channel (least attenuated by atmospheric water vapor) and a warmest pixel compositing technique to erase clouds over a night-time sequence of images. This technique provides the best available SST product for daily feature detection through high humidity and cloudy conditions. Sea surface height data undergoes extensive processing as described in Leben et al. (2002). Satellite altimetry is the only remote sensing technique that directly measures a dynamical variable which reveals the variation of density throughout the water column and, by the associated geophysical fluid dynamics, the distribution and redistribution of mass and momentum in the ocean (Leben et al. 2002). This technique has the added advantage of providing an all-weather, all-season capability. Although the rapidly moving LCFEs are not always resolved in the gridded SSH data, the along-track data can provide information on the intensity of cyclones, which the SST data cannot. The availability of several altimeters simultaneously (TOPEX/POSEIDON, GFO, Envisat, Jason-1) has improved SSH accuracy and usefulness in recent years. The study also makes use of the Far Horizon Drifting buoy, satellite-tracked drifters drogued at 50m, deployed in strategic locations in and around the LC and eddies of interest.

Results and Discussion

Web-published Integration Products

The first task accomplished in this study was the merging of the near real-time SST and SSH data streams into integrated quick-look products. Contoured SSH data are superimposed on the GOES night-time SST composites each morning and updated on the Earth Scan Lab (http://www.esl.lsu.edu/research/CMI-GOES) web page. A multi-year archive of image products (January 2000 to present) has been developed showing LSU and SAIC mooring locations to facilitate analyses. The second phase of integration products were developed by Steve Anderson whereby five days of drifter tracks were superimposed on SST and SSH data. The integration of SST, SSH, and drifter data and creation of movie loops have assisted greatly in the detection and interpretation of circulation events of interest. The SST/drifter animation from April 2001 to November 2004 is accessible on the LSU web page. In addition, movie loops of the SST/SSH images can be made interactively for time periods of interest on the ESL web page.

LCFEs and High Velocity Surface Flow

SST, SSH and drifter data were combined to study near-surface circulation of LCFEs during several months in 1999, 2000 and 2001. In all events, the drifters moved most quickly in the region where SSH gradients were most intense between the LC and LCFEs. The February/March 2001 time period is particularly instructive as it demonstrated extreme high velocities of 1.75 m/s where two LCFEs abutted with the LC in the time frame 27 February – 3 March 2001 (Figure 2C.11). The drifter data revealed a small cyclone on the NW margin of the LC, a feature that was not obvious in either the SST or SSH data.

LCFEs and High Velocity Bottom Currents

Bottom currents measured at LSU moorings along the Sigsbee Escarpment near 26º N, 91º W and on the plateau near 26º N, 92º W have exhibited close relationships with LCFE activity as well as analogous FE activity along the margin of detached warm core rings. During the anomalous NW intrusion of the LC in February/March 2002 two distinct short-lived westward current pulses were measured when FE cyclones moved into regions of pre-existing deep cyclonic circulation. A similar circulation event occurred in late February 2001 when a LCFE moved into a region of cyclonic circulation along the NW margin of the LC. Current acceleration occurred from surface to bottom and bottom flow on the plateau in 2250 m water reached the deployment maximum of 30 cm/s (Figure 2C.11 exhibits feature location during event). These observations corroborate the suggestion by Hamilton and Lugo-Fernandez (2001) that LCFEs provide a trigger mechanism for accelerations in bottom flow. Bower and Rossby (1989) described in detail the vigorous upwelling and downwelling regimes associated with meanders and frontal eddies of the Gulf Stream. These processes could be even more intense along the margin of the LC as it undergoes dramatic anticyclonic curvature in the northern Gulf.

LCFE Motions as Revealed by Time/Latitude and Time/Distance Plots

We have developed two automatic LCFE tracking techniques using GOES data. In our initial attempt we created a time/latitude diagram from April 2001 to November 2004 by sampling along a line (21ºN, 86ºW to 28ºN, 90º W) roughly parallel to the western LC margin at a distance of ~50 km (Figure 2C.12–top). LCFE motion was best observed from February 2004 to May

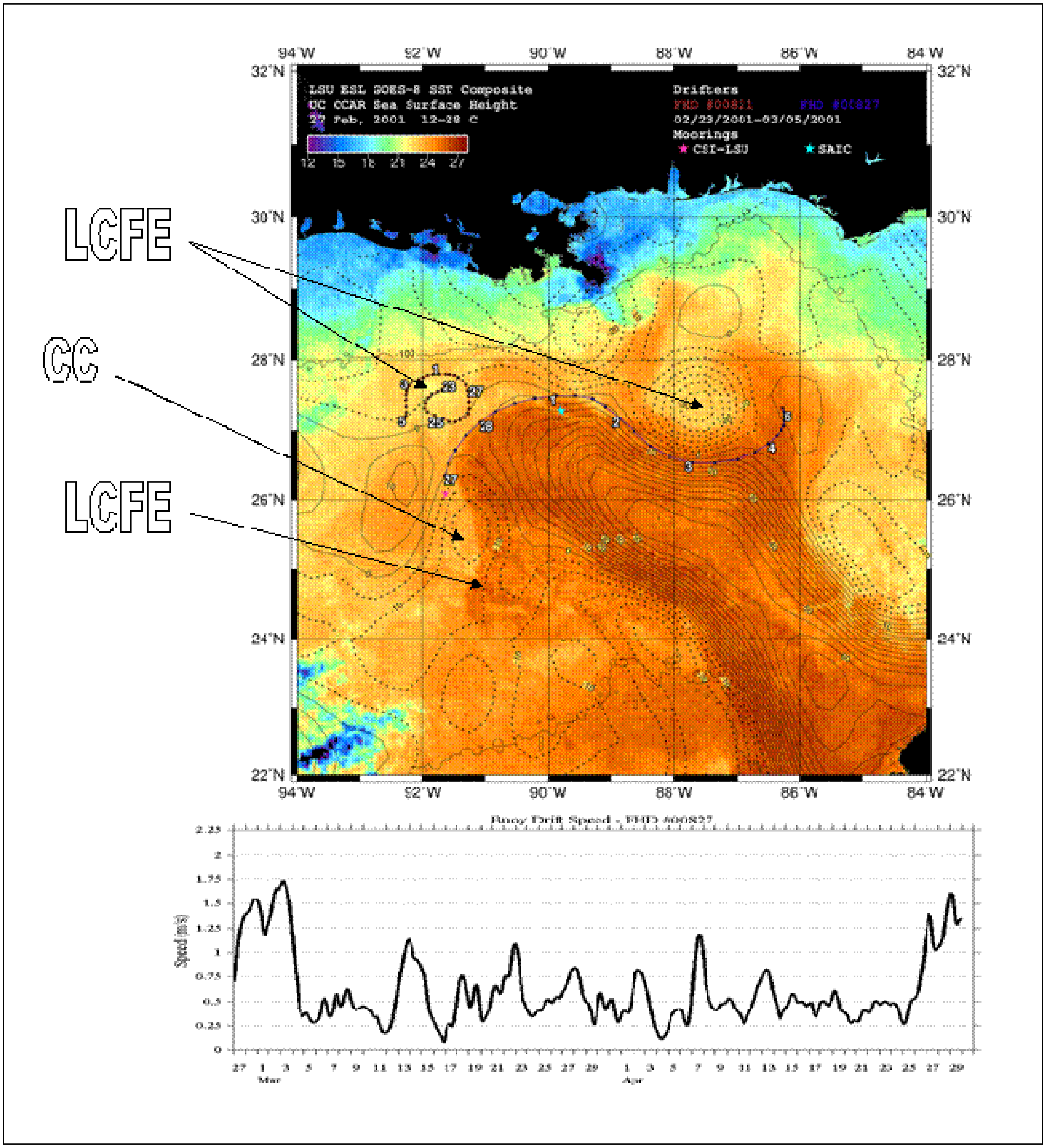


Figure 2C.11 (Top). GOES night-time SST composite image superimposed with interpolated/gridded/ contoured SSH data from 2/27/2001 and satellite-tracked two drifter tracks from 2/27-3/5/2001 and 2/23-3/5/2001. (Bottom) Maximum currents (1.5-1.75 m/s) for drifter #827 were measured in regions where LCFEs were closest to the LC (2/28, 3/3). Bottom currents at the LSU mooring (red star) reached maximum values when the annotated LCFE moved north into the area of cyclonic circulation (CC) as shown in SSH data (dashed lines are negative SSH; solid lines are positive SSH). The red line shown on speed graph corresponds with track of drifter #827 displayed on GOES SST image.

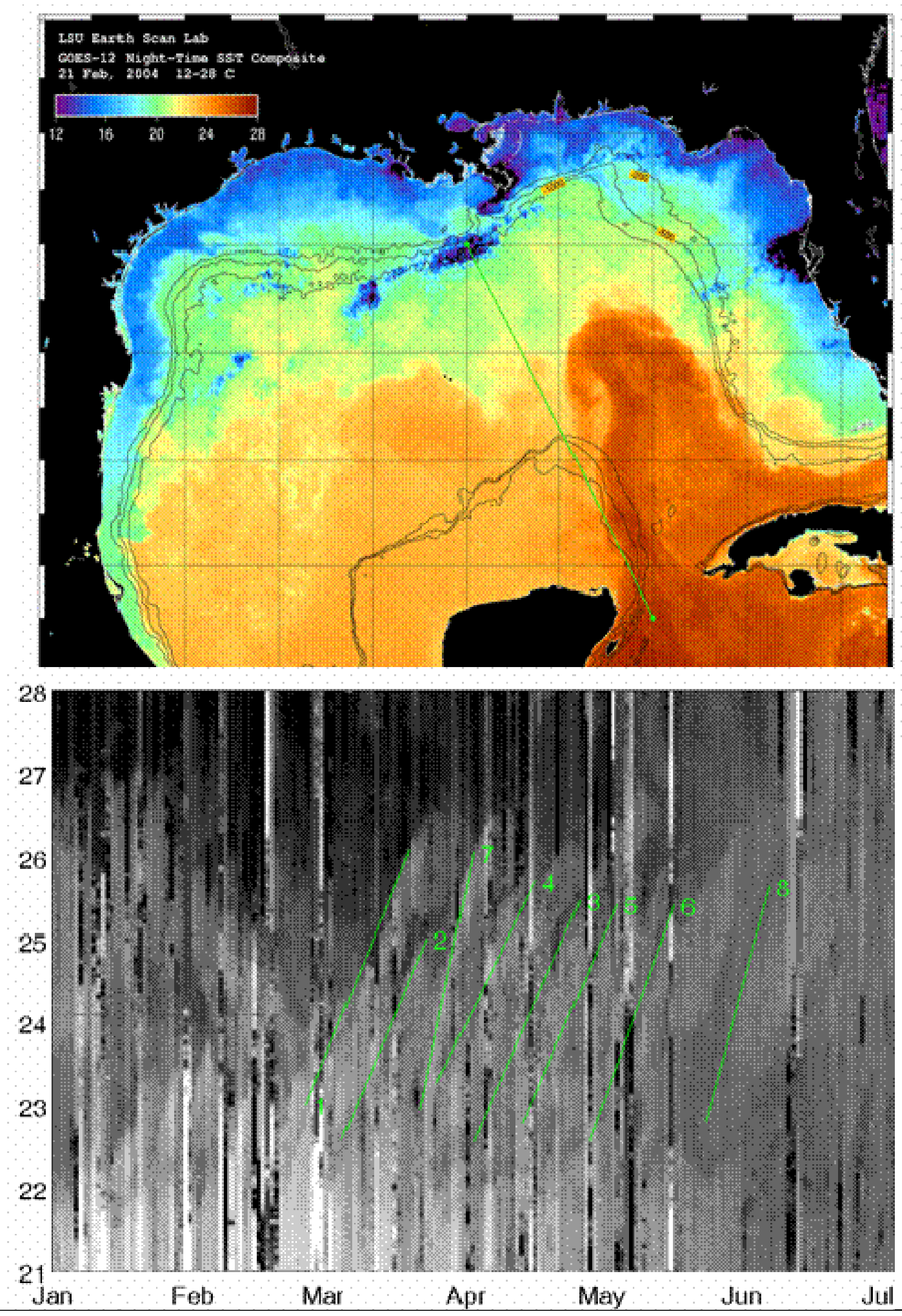


Figure 2C.12. (Top) GOES SST composite for 2/21/2004 showing line along which Ch 2 temperatures were extracted to construct the (bottom) time/latitude diagram. Sloped lines indicate northward movement of small LCFEs between 22º and 27º N latitude between 1/2004 and 7/2004. Green lines depict features for which speeds were computed. The 200, 500 and 1000m isobaths are depicted on the image. Notice that this technique captures two small LCFEs forming between 22º and 23º N but misses the large LCFE forming in the north.

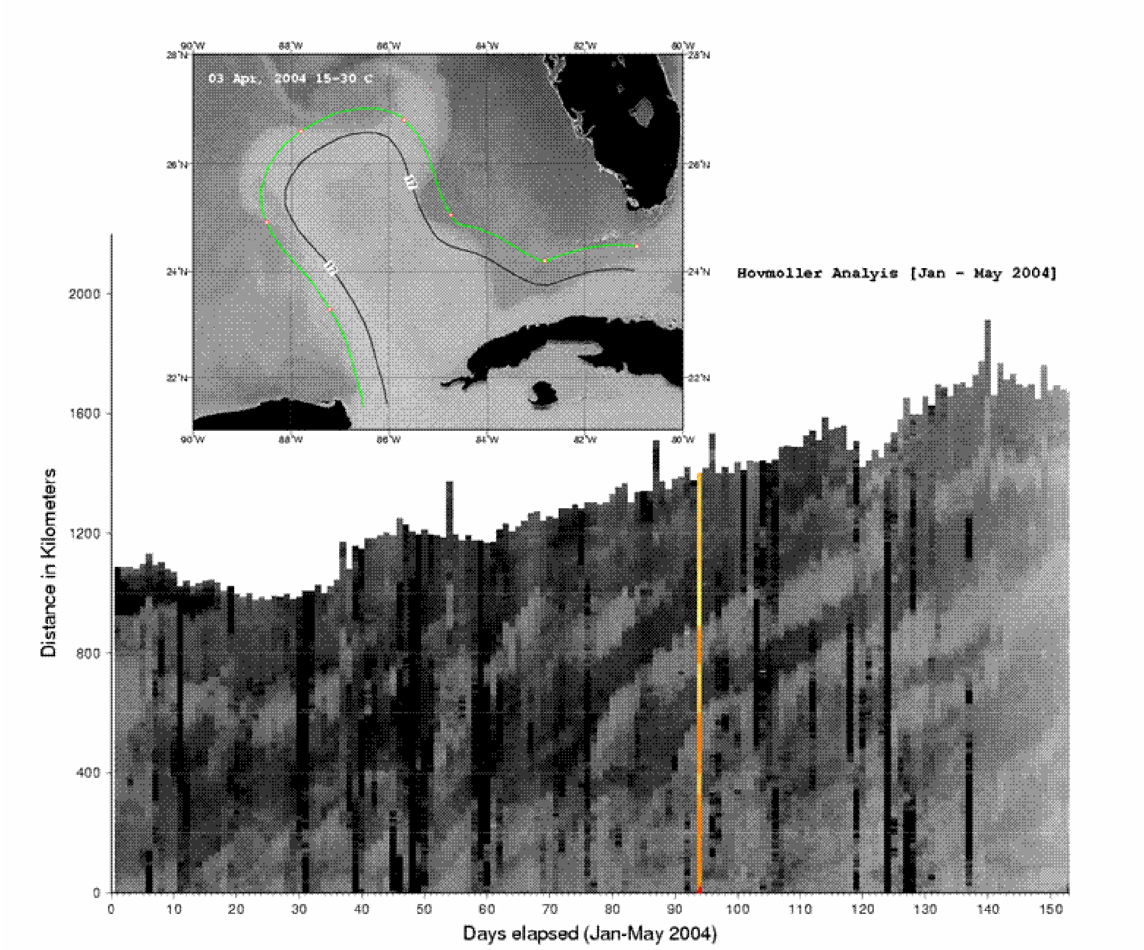


Figure 2C.13. One panel from an animation sequence showing a time/distance Hovmoller diagram (bottom panel) and image being sampled in the time period 1/2004 through 5/2004. The GOES SST image for 2 April 2004 is shown in the top panel. The orange line on the diagram corresponds to the green line on the SST image. The LC is defined with the 17 cm SSH contour, depicted on the SST image with a solid black line. The sloped lines on the diagram reveal along-current motion associated with LCFEs and LC meanders. Speed and frequency information can be quantified from these graphical outputs. Darker shades correspond to cooler water. The centers of large cyclones are relatively cool; however the smaller younger cyclonic eddies (shingles) formed along the Campeche Bank may appear warm due to the entrainment and mixing of LC water.

2004 when eight features were tracked (Figure 2C.12–bottom). LCFEs moved between 22.5º and 26 º N at a mean speed of 20 km/day, with a range of 14 to 33 km/day. Features developed near the Campeche Bank every 7–9 days during March 2004 and April 2004. The new technique worked well when the LC was relatively stationary and parallel to this line. We have since improved the auto-tracking technique by creating time/distance Hovmoller diagrams by sampling along a curved line, situated 50 km from the 17 cm SSH contour, which was chosen to define the

LC (Figure 2C.13). We plan to use this improved technique to develop a multi-year climatology for these dynamic features. Along-track SSH data and drifter data will be used to study cyclone intensity for selected time periods.

References

Bower, A. and T. Rossby. 1989. Evidence of cross-frontal exchange processes in the Gulf Stream based on isopycnal RAFOS float data. Journal of Physical Oceanography 19: 1177–1190.

Hamilton, P. and A. Lugo-Fernandez. 2001. Observations of high speed deep currents in the northern Gulf of Mexico. Geophysical Research Letters 28:2867–2870.

Leben, R., G. Born, and B. Engebreth. 2002. Operational altimeter data processing for mesoscale monitoring. Marine Geodesy 25:3–18.

Walker, N., 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:10.1029/2003GL017555.

Dr. Nan Walker is an associate professor in the Department of Oceanography at Louisiana State University. She directs the Earth Scan Laboratory, a satellite data reception station and image processing lab handling six unique data streams for emergency response, research and education. She has 25 years of experience in the field of satellite remote sensing of coastal and ocean processes. Her research interests include Loop Current and eddy circulation processes, estuarine-shelf exchange, coastal upwelling, hurricane forced upwelling, coastal sediment transport, physical-biological interactions, and ocean climatology. She received her B.S. in marine biology from Duke University in 1976, M.S. in marine sciences from Louisiana State University in 1982, and Ph.D. in physical oceanography from the University of Cape Town, South Africa in 1989.

Shreekanth Balasubramanian has completed his M.S. in computer science at Louisiana State University and is working as a computer analyst at the Earth Scan Laboratory. His interests primarily lie in satellite image visualizations, map server applications, web programming and design. He has assisted Dr. Nan Walker and others in several coastal publications and uses his expertise in image processing and programming to develop new techniques and algorithms for research and emergency response.

OCEANIC RESPONSE TO DIURNAL FORCING IN THE GULF OF MEXICO: OBSERVATIONS AND MODELS

X. Zhang, D. C. Smith, IV, S. F. DiMarco,
M.K. Howard, A. E. Jochens, and R. D. Hetland,
Department of Oceanography, Texas A&M University

Click here to view the slide show that accompanied this presentation.

Introduction

The existence of strong oscillatory currents in the Gulf of Mexico, with diurnal frequency during summer is well documented (DiMarco et al. 2000, Daddio et al. 1978). During summer, these currents are the largest non-storm generated flows on the shelf. DiMarco et al. (2000) concluded that the latitude of the shelf (near 30°N; i.e., the latitude where the inertial period is 24 hours) and diurnal wind forcing combine to produce conditions for a near-resonant response of the ocean currents. The current oscillations persist for a week or more when diurnal winds persist. Current speeds are almost an order of magnitude greater than those currents expected from steady Ekman drift. Oscillations predominately occur during summer months when there is a shallow mixed layer, strong vertical stratification, maximum insolation, and synoptic frontal passages are almost nonexistent. Diurnal current oscillations are in-phase from year to year and are 90 degrees out of phase with wind forcing (as expected from a near-resonant system).

Remarkably, strong diurnal current oscillations have been observed in locations that are over 150 km from the coast, indicating that commonly used paradigms of land/sea breeze as the responsible driving mechanism are not sufficient for fully describing this phenomena.

According to linear theory, the large-scale atmospheric response to the diurnal forcing from the land-sea temperature difference is tied to the relationship between the diurnal and the inertial frequencies. Poleward of 30°, sea and land breezes are typically confined to less than 100 km of the coastline, and are nearly in phase with the forcing. Equatorward of 30°, the atmospheric response takes the form of inertia-gravity waves that can propagate long distances up- and outward from the coast (Nielsen-Gammon 2001; 2002a,b). Horizontal scale increases as one approaches 30°; thus, the strongest atmospheric forcing of diurnal ocean currents over a broad area can be expected in basins such as the Gulf of Mexico.

In this study we investigate the relationship between summer seabreeze wind fields and the resulting oceanic response in the Gulf of Mexico. We present analysis of wind records taken from coastal land stations, ocean data buoys and gridded wind products to determine the structure and phasing of seabreeze winds. The interpretation of the observational analysis is also guided by numerical simulations of the ocean response to seabreeze forcing in hypothetical and realistic basin geometries.

Results

Results obtained thus far from the data analysis confirm that seabreeze forcing is not confined to the coastal perimeter of the Gulf, but extends significant distances seaward and appears to intensify and propagate in phase in the offshore direction. The oceanic response to these winds in summer is large in the diurnal band but we also see large energy in longer periods as well (e.g., the weather band, 2-10 days). This increased energy is not associated with synoptic weather as it is in winter, but instead related to shelf variability in coastal river plume flows, which impact the shelf in the summer.

Numerical experiments have confirmed that the oceanic response to seabreeze forcing depends significantly on the latitude of the coastal ocean and upon the curvature of the coastline and bathymetry. Inertial response in the form of propagating rotationally modified gravity waves (Poincare waves) occurs in the numerical simulations shown here but is limited to latitudes below 30°N. This makes the Gulf of Mexico unique in this regard. In addition to latitudinal dependence, the wave response is also largest in three regions in the Gulf where coastal bathymetry curvature is maximal. Regions of wave propagation transport energy offshore preferentially in the SW, NW and NE corners of the Gulf. These are also regions of strongest baroclinic wave produced shear at the base of the mixed layer and increased mixed layer deepening may occur in these regions.

Figure 2C.14 shows the spatial distribution of the diurnal ellipses during the period 22 July 1992 to 29 July 1992 in the northwestern region of the Gulf of Mexico, which is calculated from the LATEX gridded wind product (Wang et al. 1996). The gridded fields were produced from objectively analyzed observations (hourly wind data adjusted to 10 m height during 1 April 1992 to 30 November 1994). A Butterworth digital band-pass filter (0.95 cpd ~1.05 cpd) was applied to the wind data to isolate the diurnal wind component. A least-squares method was then used to fit the one-week diurnal wind timeseries between 22 July and 29 July 1992 to estimate the phase and amplitude of the east-west and north-south wind components, respectively. This period of measurement was selected because the diurnal wind was strong and the phase and amplitude of the diurnal wind was nearly constant. The diurnal ellipses in Figure 2C.14 were constructed from the phase and amplitude of the east-west and north-south diurnal wind components.

From Figure 2C.14, we can see that the diurnal wind is strong at the two stations along longitude 97°W due to the proximity to the western coast, with the major axes approximately 2.0 m s^{-1}. However, the major axes of the diurnal ellipses are less than 1.5 m s^{-1} at those stations along latitudes 29°N and 30°N, although they are close to the northern coast. As the stations go further offshore, the major axes of the diurnal ellipses increase between 1.5 m s^{-1} and 2.0 m s^{1}.

Phase information is displayed as a solid red triangle on each ellipse, which represents a synoptic snapshot of the wind vectors. Phase is leading at the stations near the coast and propagates offshore. The phase distribution indicates the diurnal wind is generated near the coast because of the land/sea temperature difference and takes a few hours for the diurnal wind to propagate from 30°N to 26°N. The green arrow in Figure 2C.14 signifies that all the diurnal wind vectors rotate clockwise.

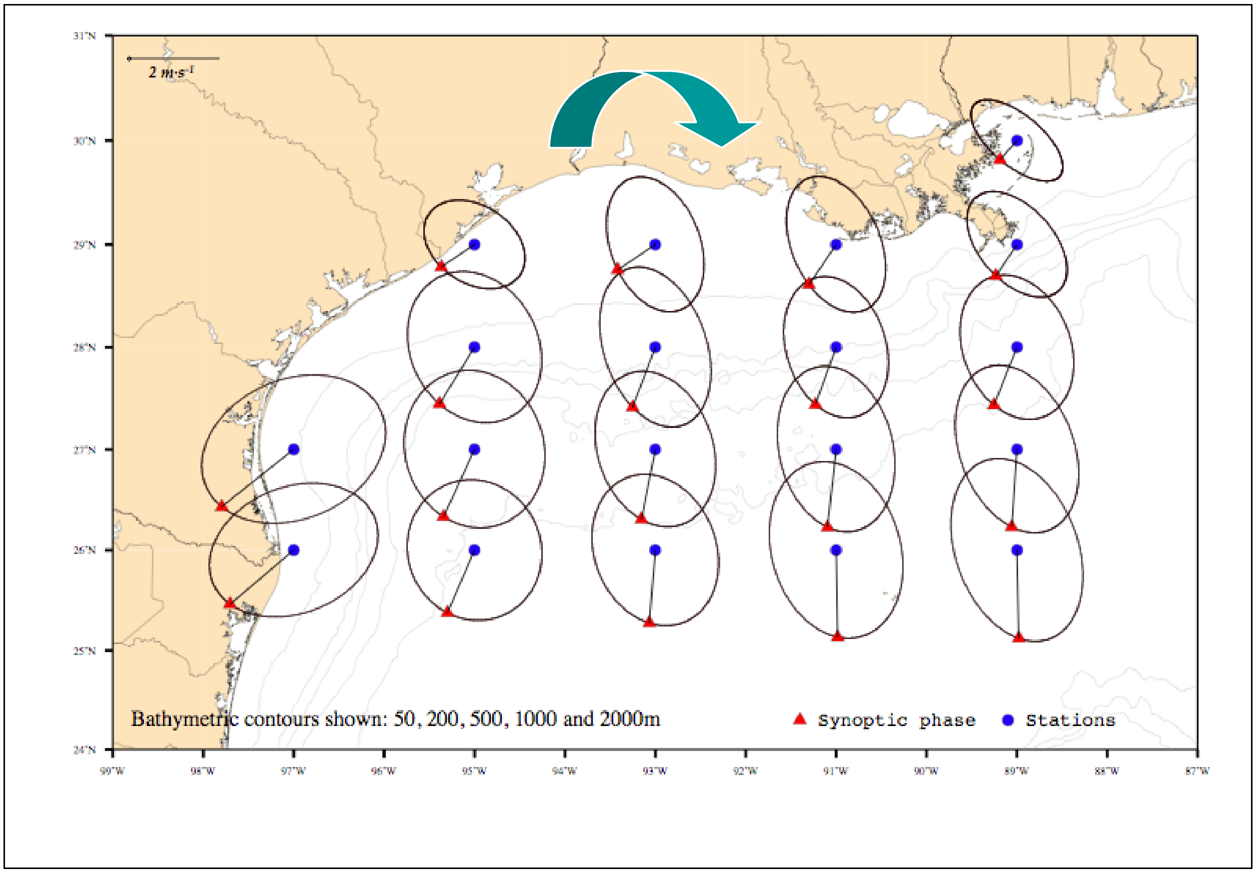


Figure 2C.14. Diurnal wind ellipses during the period 22 July 22 to 29 July 1992, calculated from the LATEX gridded wind product.

Figure 2C.15 (top) shows the wavelet power spectrum of the detided north-south current component at LATEX (Nowlin et al. 1998) mooring 21, near 28.8°N, 94.1°W. We have hourly current data during the period April 1992 to November 1994. Eight principal tidal constituents (O1, K1, P1, Q1, S2, M2, K2, and N2) were removed from the current measurement using the iterated least-squares method of cyclic descent to eliminate the influence of the tidal energy (DiMarco and Reid 1998). The wavelet analysis (Torrence and Compo 1998) was applied to the detided north-south current component.

From Figure 2C.15, we can clearly see that the diurnal current energy peaks during the summer months, which maximum peaks in June near the summer solstice of each year. The diurnal energy in the summer can be an order of magnitude greater than that in the non-summer seasons during each year. As for the annual variability, it is largest in summer 1994 and smallest in 1993 during the observation period. The diurnal current peaked in the summer is considered as the consequence of the latitude of the station and the strong diurnal wind forcing with the uninterrupted phase during the summer, which combine to produce the near-resonant conditions (Dimarco et al. 2000).

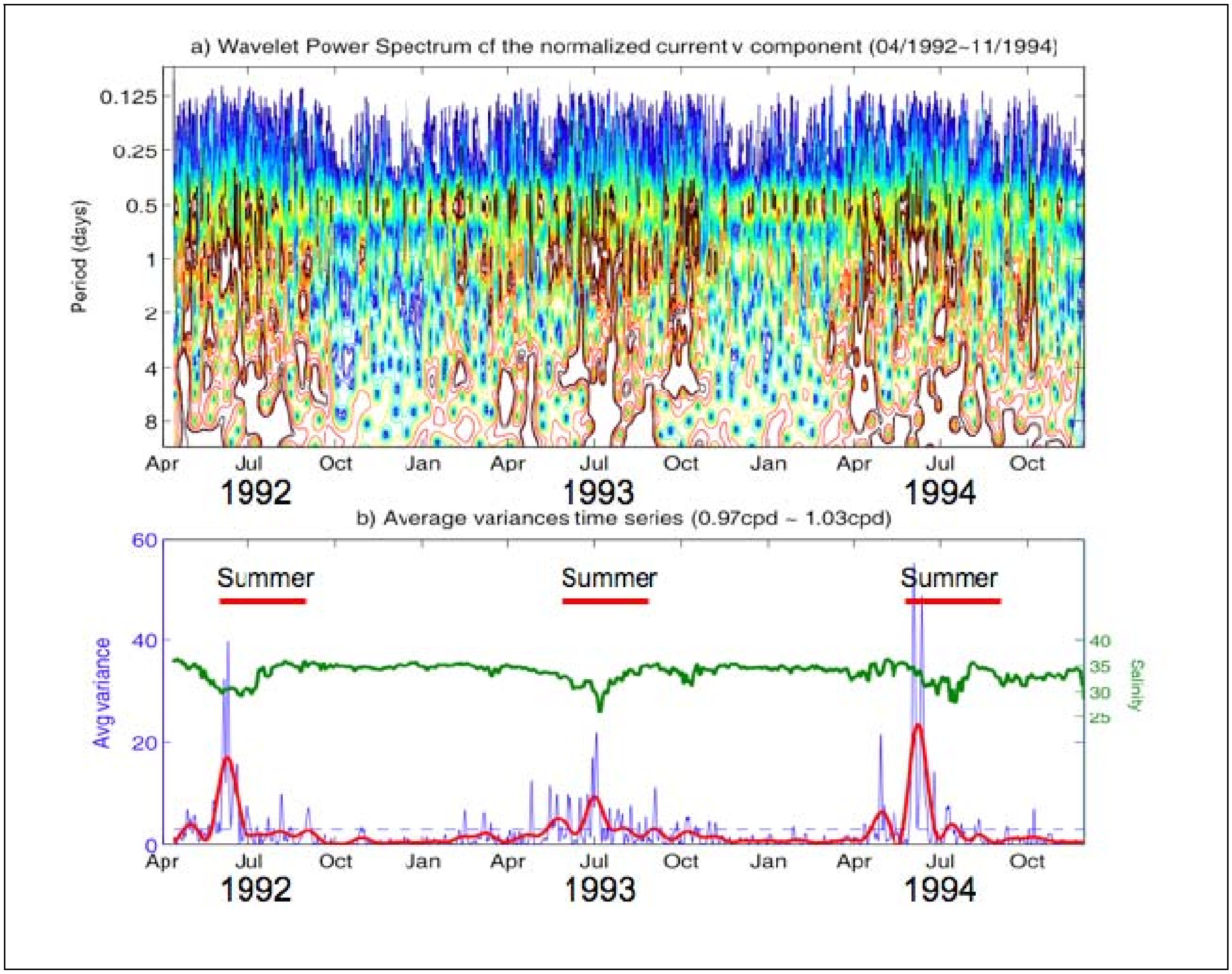


Figure 2C.15. (a) The wavelet power spectrum (using the Morlet wavelet) of the normalized north-south current component (mean value was subtracted from the timeseries and then normalized by the standard deviation) for the upper meter (14 m) at mooring 21 (94.1°W 28.8°N), where the local water depth is 24 m. The left axis is the Fourier period (in day). The bottom axis is the time. The contours are at normalized variances of 0.125, 0.25, 0.5, 1, 2, 4, 8 and 16. The thick contour encloses regions of greater than 90% confidence for a red-noise process with a lag-1 coefficient of 0.72. Those two curvy black lines on either end indicate the "cone of influence", where edge effects become important. (b) The blue solid curve is the frequency(period)-averaged wavelet power over the 0.97cpd~1.03cpd band during the observation period. The red curve is the one-month low-passed values of the blue curve. The blue dashed line is the 90% confidence level based on Torrence and Compo, 1998.

The numerical model used in this study (ROMS3.0; Haidvogel et al. 2000) is described in detail at http://www.myroms.org/. It is a hydrostatic three dimensional primitive equation finite difference model. It has prognostic equations for the three components of momentum. Density is specified through a full equation of state. Numerical simulations are integrated for periods of weeks to months. All lateral boundaries are no slip walls. The numerical domain is 1000km in length (x), 1000km in width (y) in the first case shown and has realistic coastlines and topography in the second example. We use the same model grid and bathymetry as used in the TABS autonomous buoy project at TAMU (http://tabs.gerg.tamu.edu/tglo).

Figure 2C.16 shows the sea surface signature of Poincare waves generated by seabreeze forcing in a hypothetical domain, which extends from latitude 30° to 40°N. In this simulation, the seabreeze is only applied on the western boundary and only out to 100 km. It illustrates, however, the evanescent latitudinal character and decay of the wave solution north of 30°N. Also seen in the figure is the increase in the phase speed with latitude of Poincare waves. Poincare waves also have the characteristic that the group speed decreases with latitude making them more efficient at transferring energy offshore in the southern portion of the simulation domain. The largest response in the southern portion of the basin is also a characteristic of the realistic geometry case shown below, but coastline and topographic curvature is equally important.

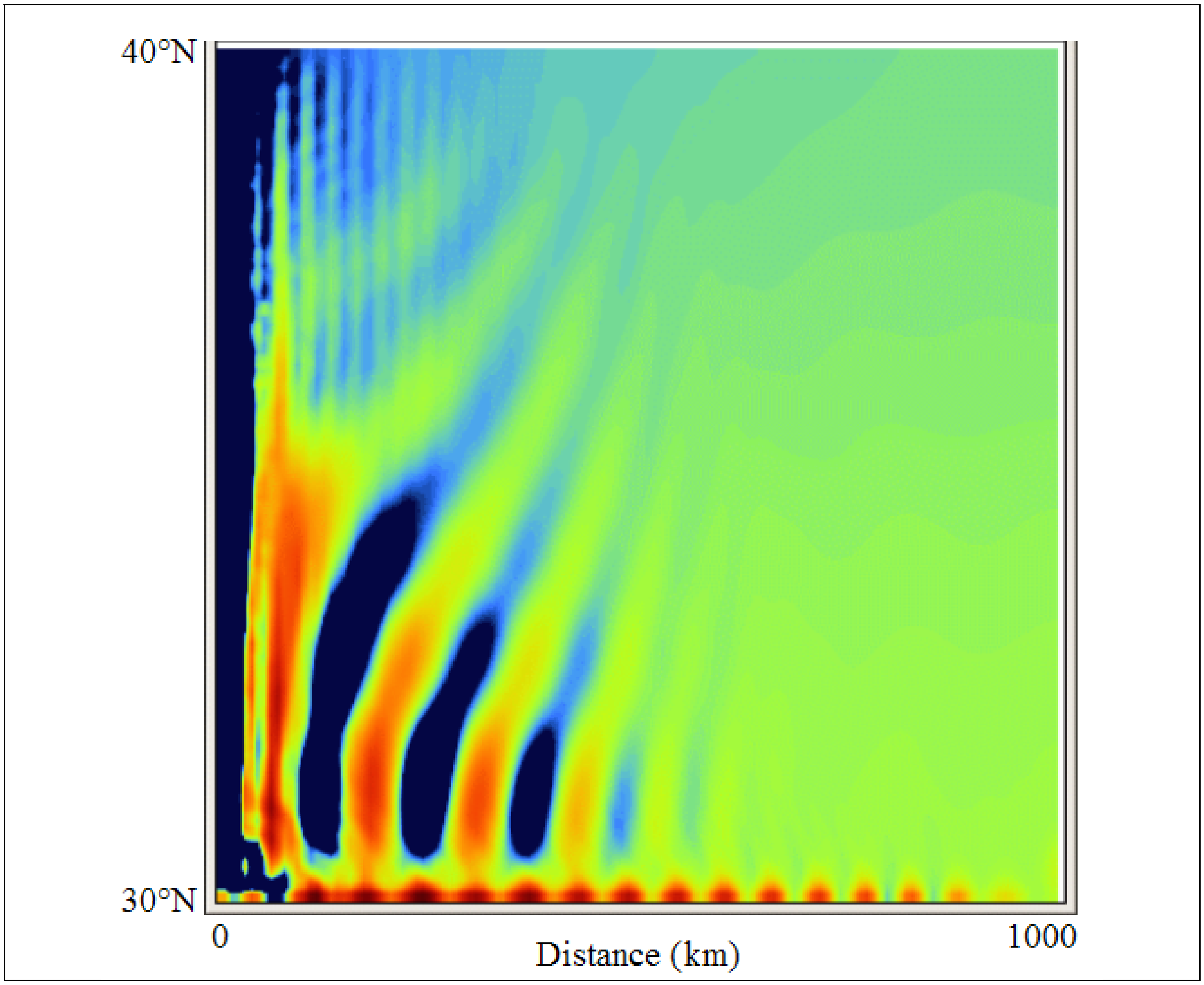


Figure 2C.16. Simulated sea surface height from idealized run with sea breeze forcing along western boundary only.

Figure 2C.17 shows the vorticity field at 20 m depth from a numerical simulation with realistic bathymetry in which forcing was applied in a coastal strip extending 100 km from the western and northern limits of the model grid. No other forcing is applied (e.g., tides, existing mesoscale flows, or buoyancy-driven river plume structures are excluded). Red (blue) indicates anticyclonic (cyclonic) vorticity and illustrates the Poincare wave field that results after 10 days of seabreeze forcing. The regions of enhanced wave variability mentioned above are clearly visible in the figure near DeSoto (28°N, 87°W) and Alaminos (27°N, 95°W) Canyons and east of the East Mexico Slope (between 21° and 25°N). The waves have wavelengths of 100 km and phase speed of ~50 km/day and are able to propagate into the interior of the Gulf on short time scales, i.e., order of 10 days. The website http://stommel.tamu.edu/~dcsiv/movie50.gif shows an animation of this experiment. These waves are also clearly seen in TABS buoy simulations, animations of which are available online (http://seawater.tamu.edu/tglo/RXanimation.gif).

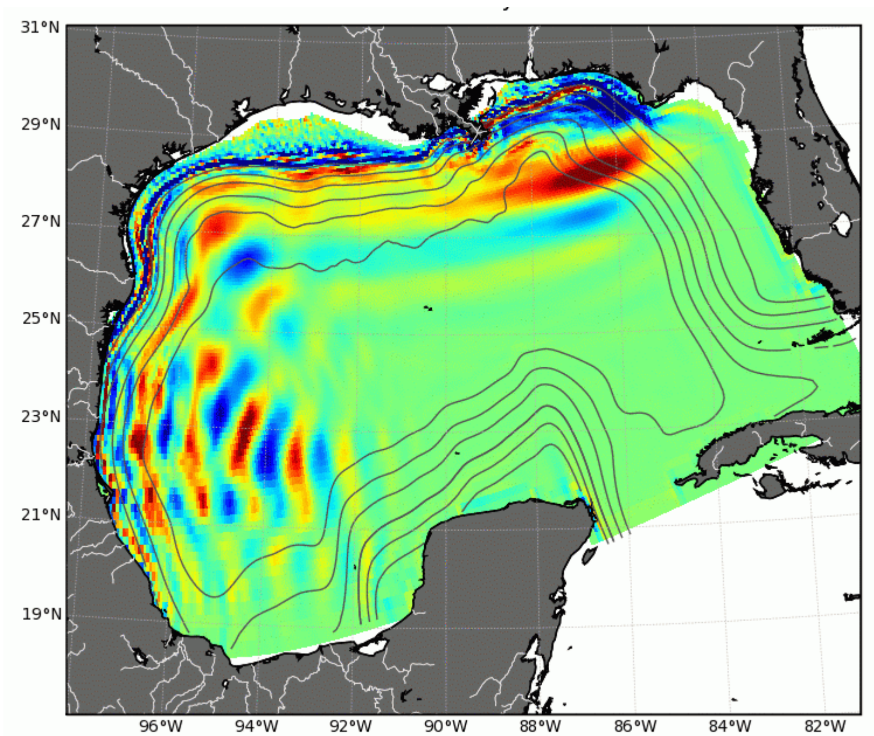


Figure 2C.17. Vorticity field at 20 m depth from realistic ROMS model run with diurnal wind applied as a 100-km wide strip along the northern and western boundary.

Conclusions

The analysis of observations presented here have provided some new details of the character of the seabreeze wind field over the Gulf. Specifically, we have determined that seabreeze winds are not trapped to the coast, as previously thought, but extend to at least 300km from the coast and also propagate with time from the coast outward with offshore observations lagging those at the coast by as much as 4 hours. The analysis, thus far, has not focused on the spatial structure of the oceanic response but indicates a strong correlation between the seabreeze forcing and inertial frequency response in the upper mixed layer. This oceanic seabreeze response is strongest during summer when the seabreeze forcing is also a maximum. Surprisingly, we find that the energy contained in the oceanic synoptic weather-band (2–10 days) is also larger during summer than in winter despite the fact that synoptic weather forcing is relatively weak during summer. An examination of salinity records on the shelf have indicated that this can be explained by the summer stratification associated with buoyant river plumes, which is strongest in summer. Since peak diurnal winds occur in July-August and peak freshening at mid-shelf (near 94°W) occurs in June, we note that it is a combination of diurnal winds and thermal and freshwater forcing that ultimately control the diurnal oceanic response through control of the stratification.

The numerical model has provided additional insight into the expected spatial structure in the ocean response indicating that maximal propagating inertial wave response should be seen in regions of maximum coastal and bathymetric curvature as well as enhanced wave variability extending southward along the western boundary. This response is unique to basins south of 30°N due to the spatial and temporal dependence of the waves on the latitude.

We are working to extend this work by examining the interaction of the propagating wave response with existing mesoscale eddy fields know to existing the western Gulf. Previous studies have indicated that existing flows can shift the frequency response of the wave by providing an effective Coriolis parameter that varies as much as +/-.5 f from a fluid at rest. This can have a significant impact of the wave fields seen in the experiments considered thus far and have been crucial in explaining the wave fields seen in other field programs involving seabreeze-driven internal wave motions.

Acknowledgments

This study is funded by the U.S. Minerals Management Service under contract No. 1435-01-05-CT-39051. The wavelet program used in this paper was based on the wavelet software provided by C. Torrence and G. Compo, and is available at URL: http://paos.colorado.edu/research/wavelets/. The authors would like to thank Dr. D.A. Brooks for useful comments on this research.

References

Daddio, E., W.J. Wiseman, Jr., and S.P. Murray. 1978. Inertial currents over the inner shelf near 30°N. J. Phys. Oceanogr. 8:728–733.

DiMarco, S.F., M.K. Howard, and R.O. Reid. 2000. Seasonal variation of wind-driven diurnal current cycling on the Texas-Louisiana Continental Shelf. Geophysical Research Letters 27:1017–1020.

DiMarco, S.F. and R.O. Reid. 1998. Characterization of the principal tidal current constituents on the Texas-Louisiana Shelf. J. Geophys. Res. 103(C2):3092–3109.

Haidvogel, D.B., H. Arango, K. Hedstrom, A. Beckmann, P. Malanotte-Rizzoli, and A. Shchepetkin, 2000. Model evaluation experiments in the North Atlantic Basin: Simulations in nonlinear terrain-following coordinates. Dyn. Atmos. Oceans 32:239–281.

Nielsen-Gammon, J.W. 2001. Initial modeling of the August 2000 Houston-Galveston ozone episode. Report to the Texas Natural Resource Conservation Commission (TNRCC). 71 pp. (Available from http://www.tceq.state.tx.us)

Nielsen-Gammon, J.W. 2002a. Evaluation and comparison of preliminary meteorological modeling for the August 2000 Houston-Galveston ozone episode. Report to TNRCC. 83 pp. (Available from http://www.tceq.state.tx.us)

Nielsen-Gammon, J.W. 2002b. Meteorological modeling for the August 2000 Houston-Galveston ozone episode: PBL characteristics, nudging procedure, and performance evaluation. Report to TNRCC, 109 pp. (Available from http://www.tceq.state.tx.us)

Nowlin, W.D., Jr., A.E. Jochens, R.O. Reid, and S.F. DiMarco. 1998. Texas-Louisiana shelf circulation and transport processes study: Synthesis report. Volume I: Technical report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 98-0035. 502 pp.

Torrence, C. and G.P. Compo. 1998. A practical guide to wavelet analysis. Bull. Amer. Meteor. Soc. 79:61–78.

Wang, W., R.O. Reid, and W.D. Nowlin, Jr. 1996. Analyzed surface meteorological fields over the northwestern Gulf of Mexico for 1992–1994; Mean, seasonal, and monthly patterns. Mon. Weather Rev. 126(11):2864–2883.

Xiaoqian Zhang is a Ph.D. student in the Department of Oceanography at Texas A&M University. His B.S. is in oceanography and his M.S. is in physical oceanography (Thesis title: *Internal Tides and Mixing in the South China Sea*). His research interests are air-sea coupling processes, shelf circulation, tides and coastal mixing processes, particularly in the Gulf of Mexico and the South China Sea.

David C. Smith, Assistant Research Scientist in the Department of Oceanography at Texas A&M University, has both an M.S. and Ph.D. in oceanography from Texas A&M. Dr. Smith has research experience in numerical modeling of geophysical fluid dynamics of mesoscale and laboratory flows. He has worked on problems related to the Gulf of Mexico eddy dynamics and has experience in small scale mixing.

Dr. Steven F. DiMarco has been with the Department of Oceanography at Texas A&M University since 1993. Originally trained as a theoretical physicist, DiMarco performed his dissertation research in quantum optics. He spent 1.5 years as a postdoc at the University of New Mexico, Max-Planck Institute for Quantum Optics (Germany), and Texas A&M University working on numerical models of laser beam propagation in nonlinear gases. Successfully making the transition to the field of physical oceanography, he has worked (often as PI or Co-PI) on many of the major observational oceanographic programs in the Gulf of Mexico for more than 13 years. Several of these programs—the MMS-funded LATEX, NEGOM, Jets, and Deepwater programs—have helped to define the circulation and transport processes of the northern slopes, shelves, and deep basin of the Gulf of Mexico. Dr. DiMarco is currently the Principal Investigator and Program Manager of the NOAA–funded study entitled "Mechanisms Controlling Hypoxia on the Louisiana Shelf" and Co-PI on the MMS-funded "Study of currents in the Eastern Gulf of Mexico" project. He also has worked closely with many representatives of the offshore oil and gas industry during the course of many government-sponsored and independently funded programs. This also involved the exchange of ideas and opinions considered relevant to industry and frequently involved accepting, processing, analyzing, and interpreting industry oceanographic data sets. Information concerning his publications and abstracts can be found at http://oceanography.tamu.edu/Directory/Faculty/Phys/dimarco.html.

Dr. Matthew K. Howard, Associate Research Scientist at Texas A&M University, is a physical oceanographer with 14 years of experience as data manager for six multi-year, multi-million dollar oceanographic field programs involving mixed data types and scientific disciplines for both the shallow and deep waters of the Gulf of Mexico. His work in data handling systems has involved everything from recovering legacy data sets on archaic media to ingesting and archiving high-bandwidth near real-time data streams. He has years of hands-on experience with QA/QC of all types of physical oceanographic data sets. Since 1998, he has kept the Texas coastal current nowcast/forecast supplied with near real-time winds and model products on a 24/7/365 basis—a daily download burden of over 3GB. For the past five years Dr. Howard has been increasingly involved in the Integrated Ocean Observing Systems (IOOS) and has been deeply involved efforts to design the cyberinfrastructure which will lead to automated and largely unattended observing systems for ocean observatories. He is a member of cyberinfrastructure steering teams for both the National Science Foundation's ORION program and for the NOAA/Navy IOOS programs. He is the technical lead for the Gulf of Mexico Ocean Coastal Observing System Regional Association (GCOOS-RA) and represents all of the Regional Associations to the Data Management and Communications group within Ocean.US.

Dr. Ann E. Jochens, Research Scientist in the Department of Oceanography at Texas A&M University, came to physical oceanography as a mathematician and attorney with extensive experience in environmental, safety, and permitting in the oil and gas and minerals industries. She received her J.D., with a background specialty in ocean law, from the University of Oregon (1977) and her M.S. and Ph.D. in oceanography from Texas A&M University (1989 and 1997, respectively). For over 15 years, Dr. Jochens has been a Principal Investigator on studies of the circulation and water properties over the Texas, Louisiana, Mississippi, Alabama, and Florida shelves and in the deep waters of the Gulf of Mexico. On each of these studies, she also served as Program Manager or Deputy Program Manager. Presently, she is the Principal Investigator and Program Manager for a multi-disciplinary, multi-institutional study of Gulf of Mexico sperm whales, their habitat, and their response to anthropogenic noise. Dr. Jochens is also Regional Coordinator for the Gulf of Mexico Coastal Ocean Observing System Regional Association. She has participated in over 10 oceanographic expeditions, has over 60 publications, reports, and abstracts, and has served on 11 graduate student committees. Her research interests are processes at the boundary of coastal and open oceans; Gulf of Mexico physical oceanography; meso- and large-scale ocean circulation and property distributions, with emphasis on shelf and slope regions; ocean law and policy; and research planning and management.

Dr. Robert D. Hetland is an Associate Professor in the Department of Oceanography at Texas A&M University. His principle area of research is the numerical simulation of estuarine, coastal, and continental shelf flow, buoyancy driven flow, and circulation in semi-enclosed basins using both realistic and idealized model configurations. He currently supervises the operation and improvement of a nowcast/forecast model of wind-driven surface currents off the Texas-Louisiana shelf. An element of the Texas Automated Buoy System, this model is funded by the Texas General Land Office and used to aid in response to regional oil spills. Dr. Hetland is Co-P.I. of a recently funded (NOAA) field/modeling project that will examine the low oxygen region south of Louisiana. He is developing a coupled biochemical/physical of the Mississippi and Atchafalaya River plumes to examine the relative roles of physics and biochemistry in creating hypoxic condition on the shelf. As a collaborator in the development of the Regional Ocean Modeling System (ROMS), he has created code to include fresh water sources (i.e., rivers) and tides in numerical ocean circulation simulations. These modules are now part of the standard ROMS releases. Dr. Hetland is part of the Terrain-following Ocean Modeling System (TOMS) team, a group that will help bring state-of-the-art numerical techniques to operational ocean models run by the U.S. Navy. Lastly, he has created two new courses in coastal dynamics and data assimilation for the physical oceanography curriculum at Texas A&M.

CHARACTERISTICS OF DEEP WATER CURRENTS ALONG THE SIGSBEE ESCARPMENT NEAR 92ºW

Kevin P. McKone, Nan Walker, and Eddie Weeks,
Coastal Studies Institute and Department of Oceanography & Coastal Sciences,
Louisiana State University

Click here to view the slide show that accompanied this presentation.

Introduction

The periodogram is a good reference spectral method, but is not an ideal estimator of the spectrum (Percival and Walden 1993). Since the periodogram is not an ideal estimator of the spectrum, other spectral methods were used to improve spectral estimation of the four LSU deployments. All methods used in this analysis are found in Percival and Walden (1993) along with McKone (2003). The other three methods used in the analysis include Welch's method or WOSA, Welch's overlapped segment averaging spectral estimator, the MTM or Multitaper spectral estimator, and an auto regressive or AR spectral estimator using Burg's method. Three out of four of these spectral methods are non parametric, with the AR or autoregressive method being parametric. The AR method, being parametric, is a good check of the robustness of a signal as it uses a completely different method in determining a spectral signal.

Confidence intervals of 95% are shown on all spectral plots except the periodogram, which is variance preserving. Also shown on all non-parametric spectral plots is an estimate of the bandwidth. Wavelet analysis was also used as a check of the time series signals (Torrence and Campo 1998). A 95% confidence level is also shown in the wavelet analysis. Wavelet analysis has the advantage of showing the temporal extent of a given signal.

Results

A weak 20–25 day signal was seen in the multiple methods of spectral analysis at the surface, Figure 2C.18, and at depth. This weak signal can be seen in the MTM method, and towards the end of the time series in Figure 2C.19 using wavelet analysis. With spectral analysis it is not possible to determine if a signal is continuous throughout a time series or if it is isolated in time. Wavelet analysis has the advantage of being able to isolate a signal in time. The 20-day signal is seen in the wavelet analysis to occur between 2/01/01 and 4/01/01 at all depths. This full column signal only happened when the mooring was in a frontal cyclonic eddy, Figure 2C.20. Other LSU deployments showed the same 20-day full column signal when the mooring was in a frontal eddy.

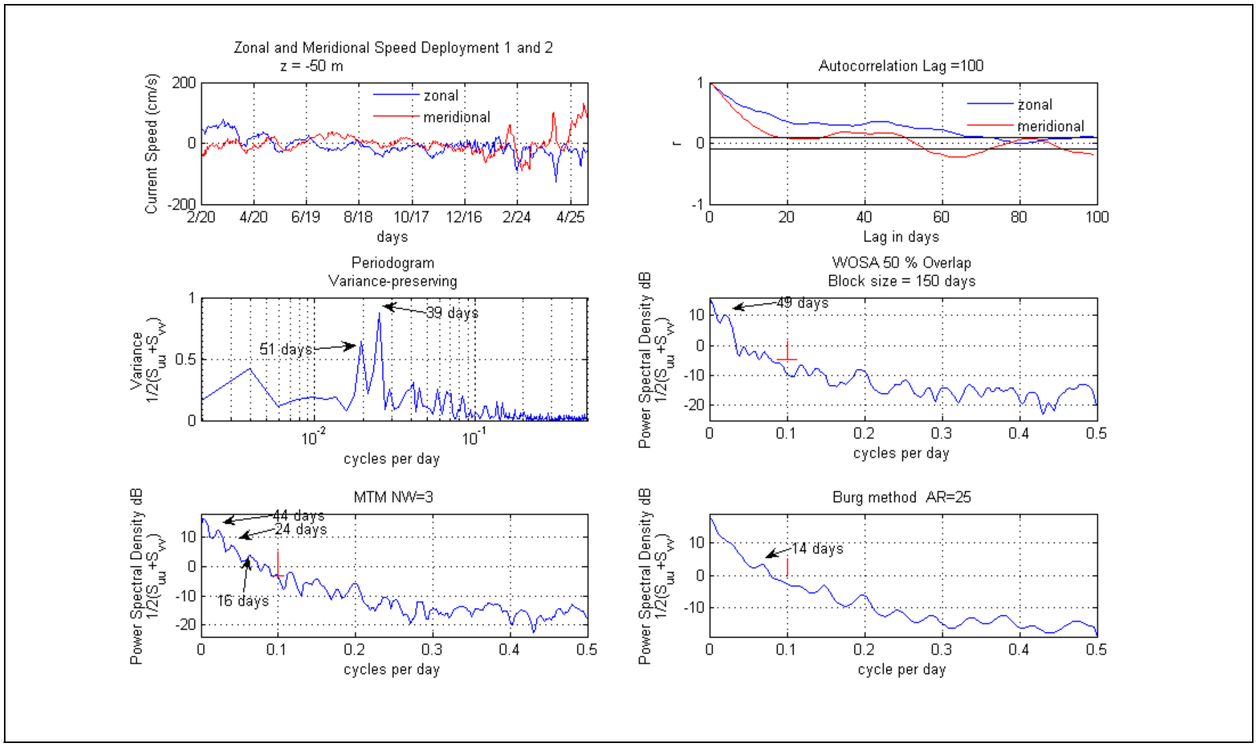


Figure 2C.18. Multiple methods of spectral analysis. Deployment 1 and 2 z = -50 m.

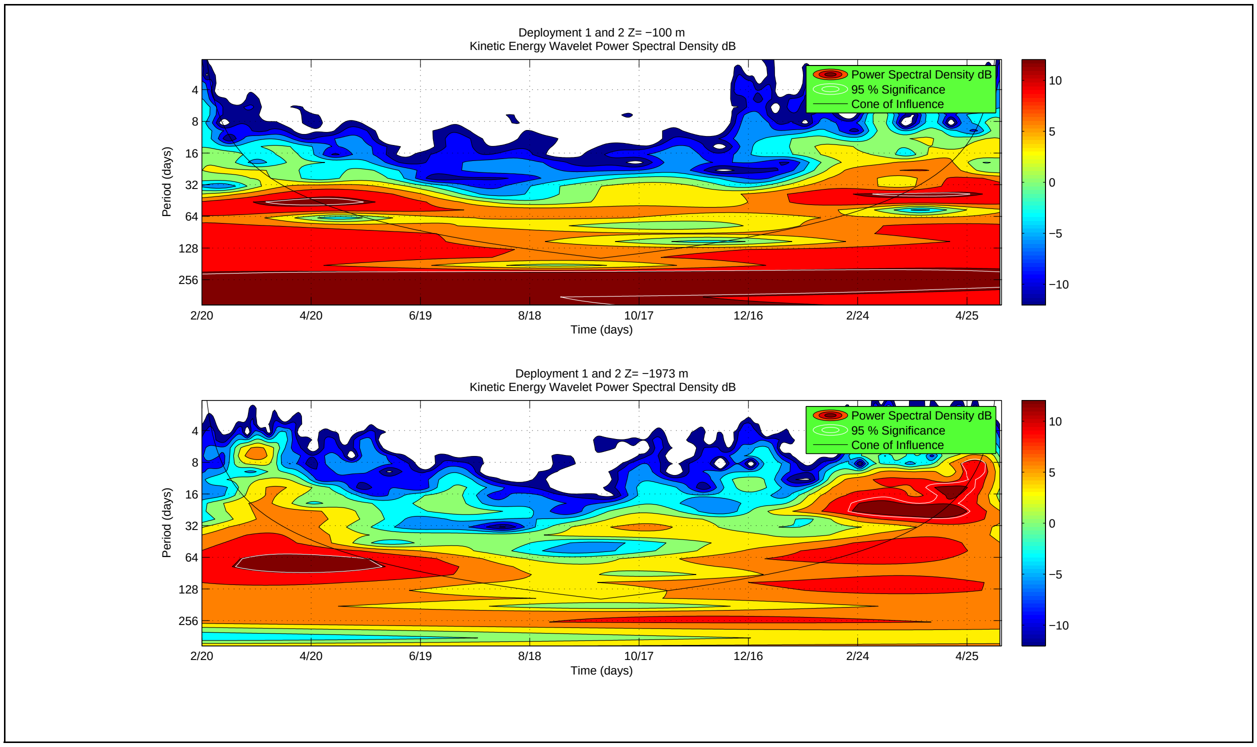


Figure 2C.19. Wavelet analysis Deployment 1 and 2 at z = -100 m and z = -1985 m.

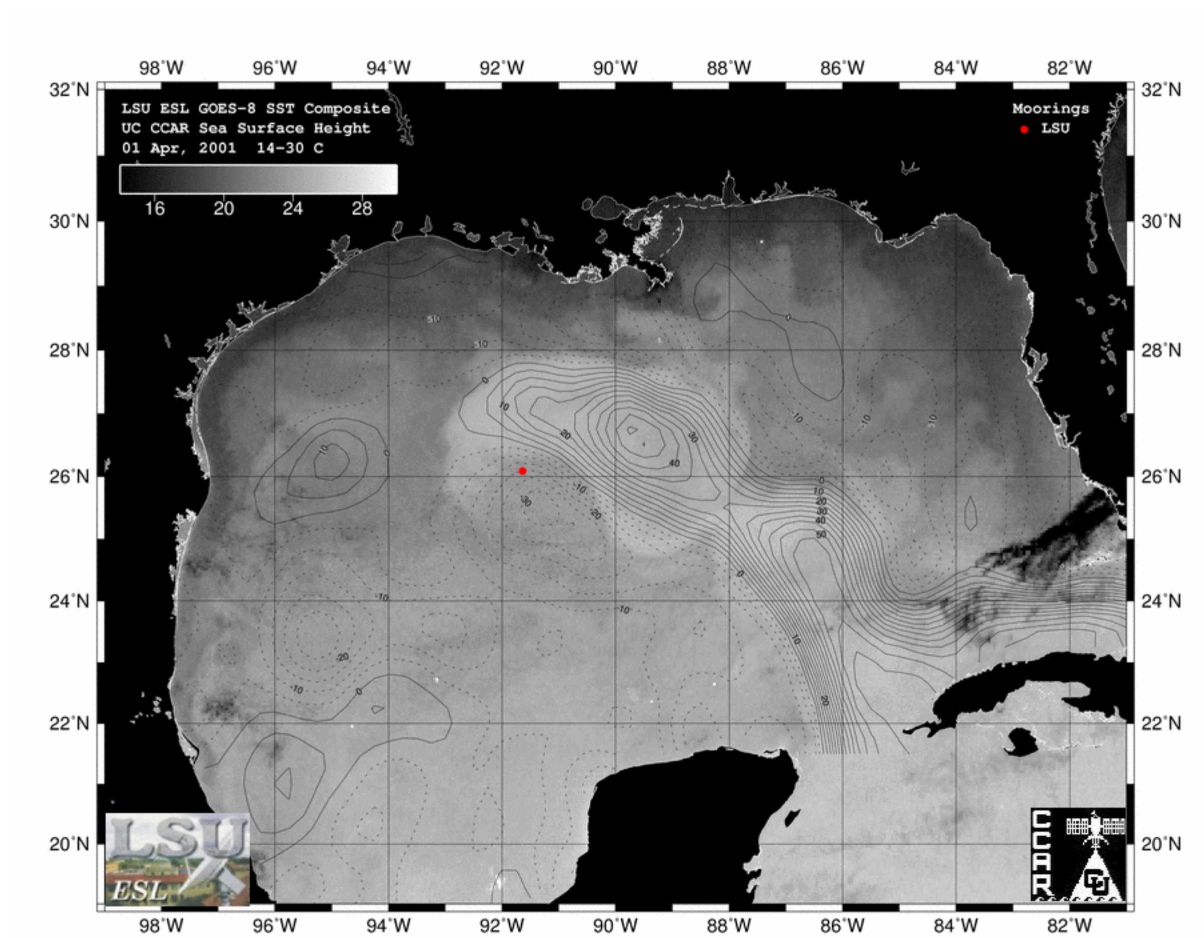


Figure 2C.20. GEOS SST/SSH Deployment 1 and 2, 1 April 2001.

References

McKone, K.P. 2003. Multiple methods of spectral analysis with applications to the Florida Current. Ph.D. Thesis, Dept. of Marine Science, University of Southern Mississippi, Hattiesburg, MS. 120pp.

Percival, D. and A.T. Walden. 1993. Spectral analysis for physical applications. New York: Cambridge. 583 pp.

Torrence, C. and G.P. Campo. 1998. A practical guide to wavelet analysis. Bull. Amer. Met. Soc.. 79(1):61–78.

Dr. Kevin McKone is a physics instructor at Copiah Lincoln Community College, Wesson, Mississippi. For the last two years he has worked as a postdoctoral research associate for the Coastal Marine Institute at Louisiana State University. His research interests include oceanographic time series data analysis and model validation. Dr. McKone received his B.S. in physics from Colorado State University, his M.S. in physics and math curriculum and instruction from the University of Southern Mississippi, and his Ph.D. in marine science from the University of Southern Mississippi.

EASTERN GOM CIRCULATION STUDY: OVERVIEW OF THE STUDY GOALS AND OBJECTIVES, MEASUREMENTS OBTAINED, AND FEATURES MEASURED

Jeff Cox, Evans-Hamilton Inc.

Click here to view the slide show that accompanied this presentation.

Introduction

In July 2005, the Minerals Management Service contracted with Evans-Hamilton, Inc. (EHI) and its team to conduct measurements and analysis of the circulation features in deep water within the eastern Gulf of Mexico (EGOM). EHI's team members and Principal Investigators for this project include the following:

SAIC – Dr. Peter Hamilton, Mr. Van Waddell
University of Colorado – Dr. Robert Leben
Texas A&M University – Dr. Steve DiMarco
University of Rhode Island – Dr. Randy Watts, Dr. Kathleen Donahue
Forristall Ocean Engineering, Inc. – Mr. George Forristall

The goals of the study were to

- Conduct measurements of currents in the EGOM to increase the knowledge of circulation features in this area
- Collect hydrographic, remote sensing, and other relevant measurements useful to understanding the regional circulation
- Assess the key processes energizing the circulation

Measurements

The area selected for study is located south of Mobile Bay in water depths ranging from 2000 to 2800 m (Figure 2C.21). Three tall (M1, M2, and M3) and one short (M4) moorings, along with seven PIES, were deployed from January 2006 to January 2007, with servicing of the moorings occurring in August 2006 just a few days prior to the arrival of hurricane Katrina. The tall moorings contained upward-looking 75 kHz ADCPs at 500 m depth, with single point current meters spaced at intervals from 750 m to near bottom (Figure 2C.22). The tall moorings also contained combinations of temperature, or temperature-conductivity-pressure sensors at various depths. The short mooring contained two single point current meters near bottom.

Hydrographic measurements consisting of CTD casts and XBT profiles were collected in January and August 2006, and January 2007 during deployment and recovery cruises. The hydrographic measurements were targeted to capture interesting loop current, eddy, or other related features affecting the study area. The final hydrographic survey was targeted to capture small scale interactions between the edge of a Loop Current Eddy (LCE) and a Cold Core Eddy (CCE) along its edge that lay over a portion of the study area.

Only minimal instrument problems occurred, resulting in an outstanding, nearly complete data set.

Conditions During the Measurement Year

Entering the study, there was concern that only one year of measurements would be insufficient to capture the effects upon circulation in the EGOM of the Loop Current, LCE's, or other key forcing conditions. It turned out that 2005 proved to be a robust year for such circulation drivers. The measurements show the effects of several loop current or LCE intrusions into the study area, as well as associated LC frontal eddies and CCEs. In addition, two tropical storms (Arlene-June 10-11; Cindy-July 4-5) and four hurricanes (Dennis-July 8-10; Katrina-August 26-29; Rita-September 20-23, Wilma-October 21-23) passed close to or over the study area. The paths of the storms and hurricanes, along with their tropical storm and hurricane force wind fields, as depicted by the National Hurricane Center, are shown in Figures 2C.23 – 2C.28.

Initial Results

The measurements show multiple instances of the circulation responding to either incursions by the Loop Current, or passages of the storms and hurricanes. This is particularly evident during the first deployment period (Figures 2C.29 – 2C.31), but also true during the second deployment (Figures 2C.32 – 2C.34). In these figures, the color contours of the current speed and direction over the top 500 m of the water column are displayed. Loop Current or LCE intrusions generated the strongest upper layer currents, as well as caused more significant mooring blow-over as shown by the black lines which depict the depths of the instruments based on their pressure sensor readings. The Loop Current or LCE generated currents also penetrated deeper into the water column than storm induced currents. Inertial oscillations of currents generated by the passage of some of the storms and hurricanes were also seen. This is particularly true from the passage of Hurricane Katrina in late August 2005 (Figure 2C.34).

The end result is that an excellent set of measurements in the EGOM has been obtained that show circulation responses to a robust set of conditions. A complete analysis of the measurements is presently underway.

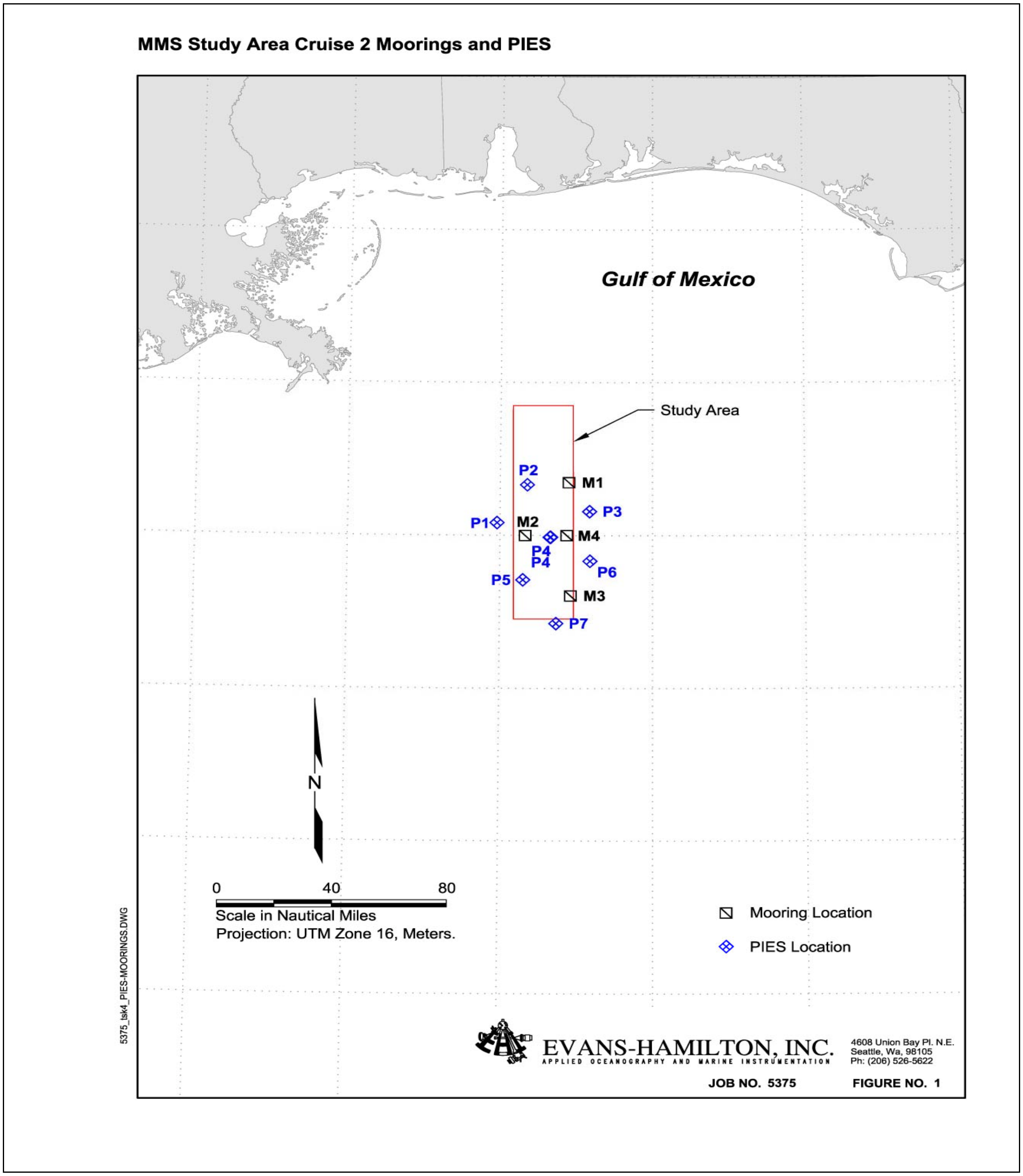


Figure 2C.21. Study area and locations of moorings (M1-M4) and PIES (P1-P7).

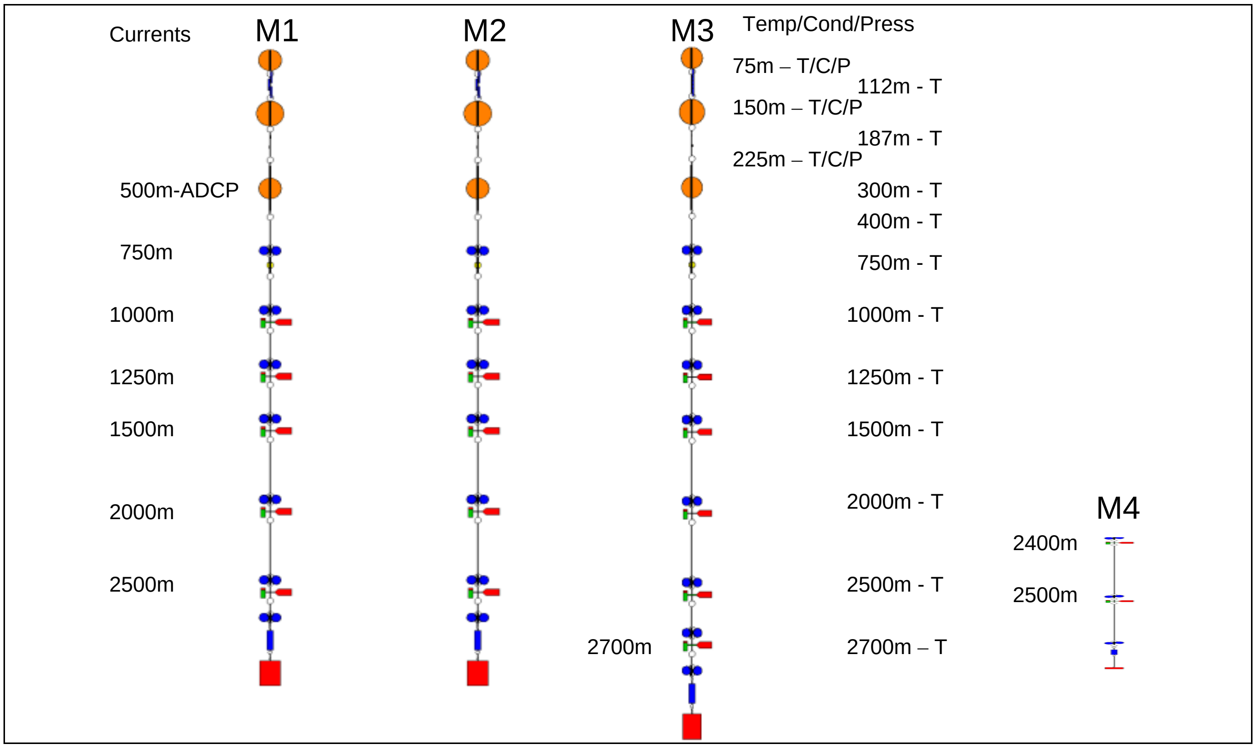


Figure 2C.22. Tall (M1, M2, M3) and short (M4) mooring designs.

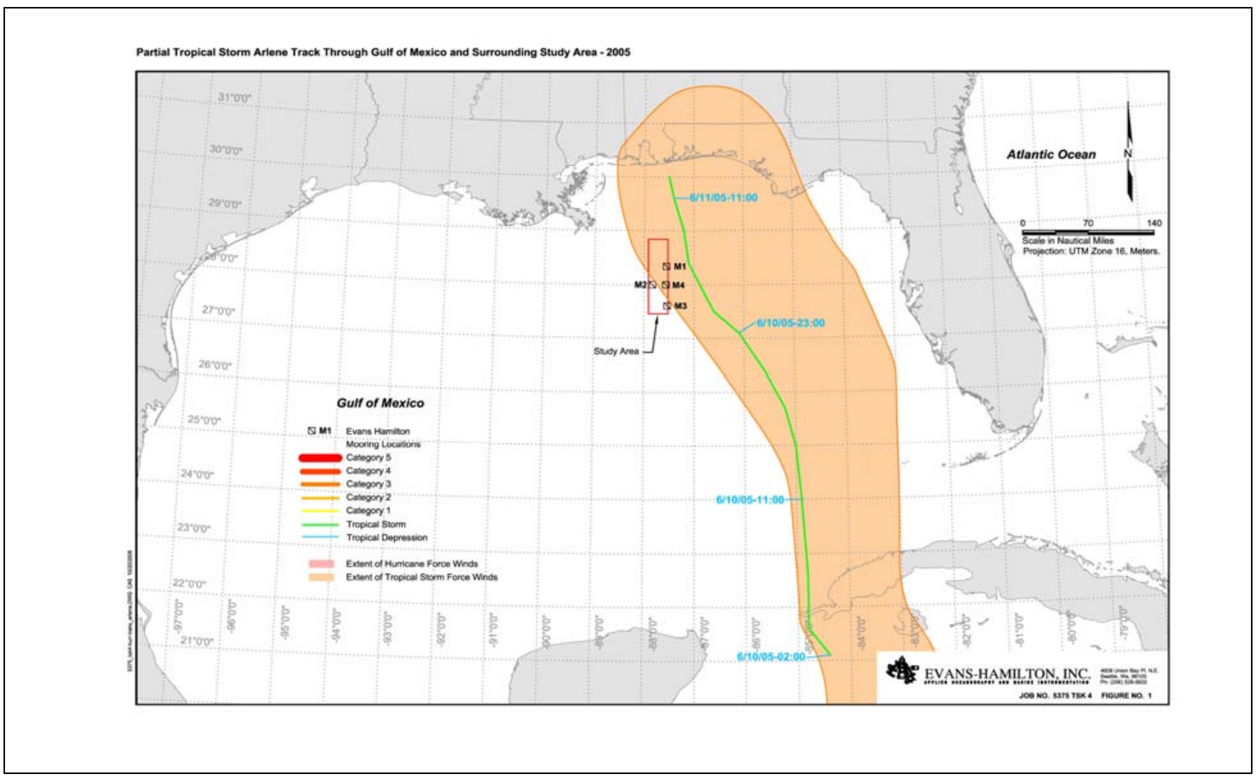


Figure 2C.23. Path of Tropical Storm Arlene, 10–11 June 2005.

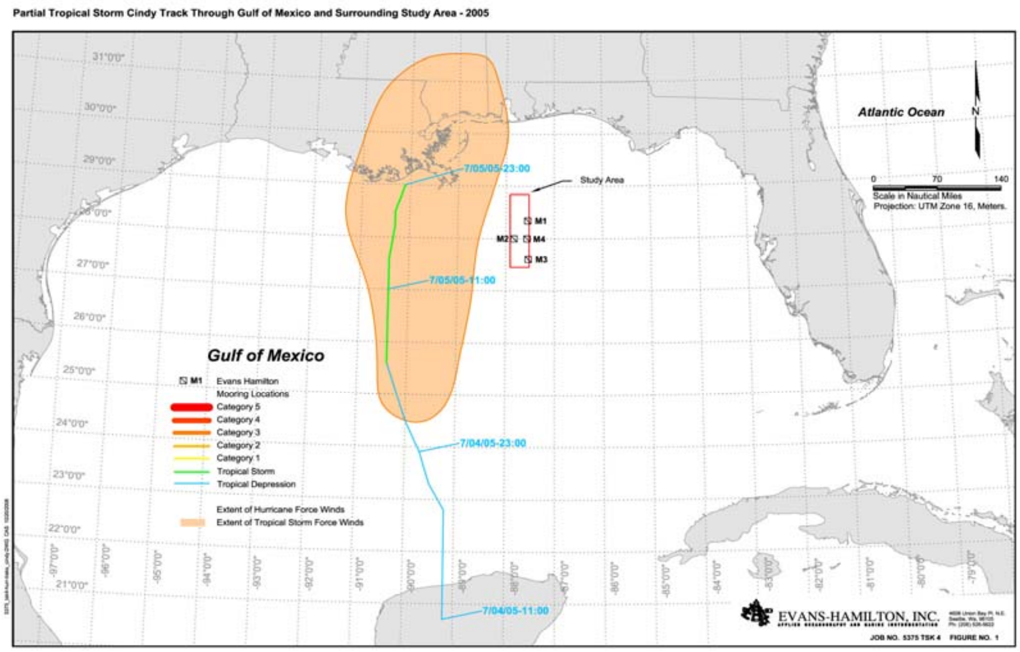


Figure 2C.24. Path of Tropical Storm Cindy, 4–5 July 2005.

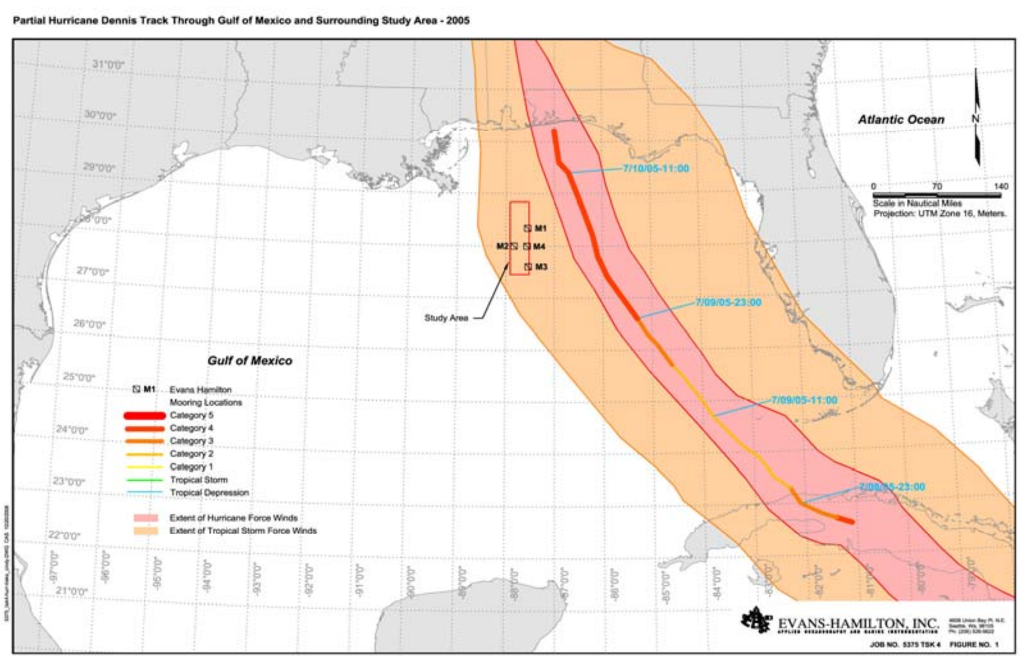


Figure 2C.25. Path of Hurricane Dennis, 8–10 July 2005.

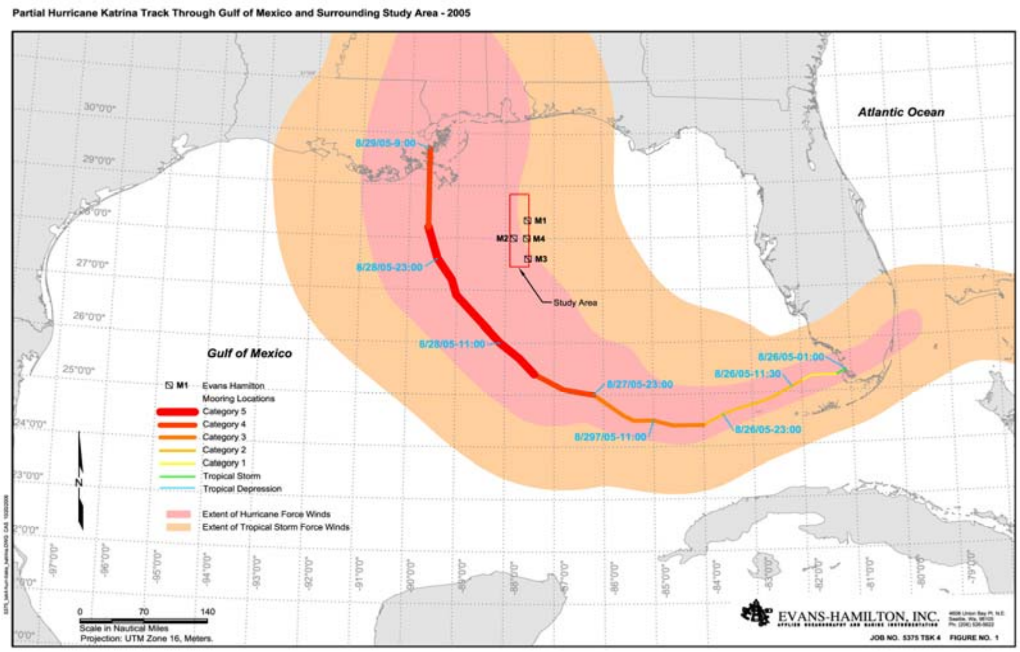


Figure 2C.26. Path of Hurricane Katrina, 26–29 August 2005.

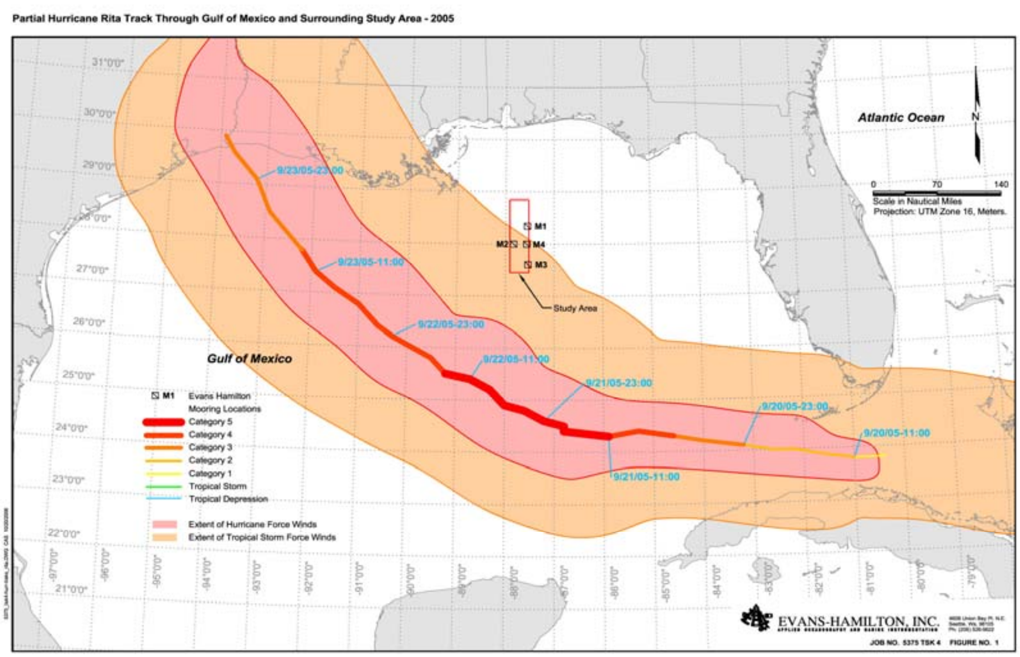


Figure 2C.27. Path of Hurricane Rita, 20–23 September 2005.

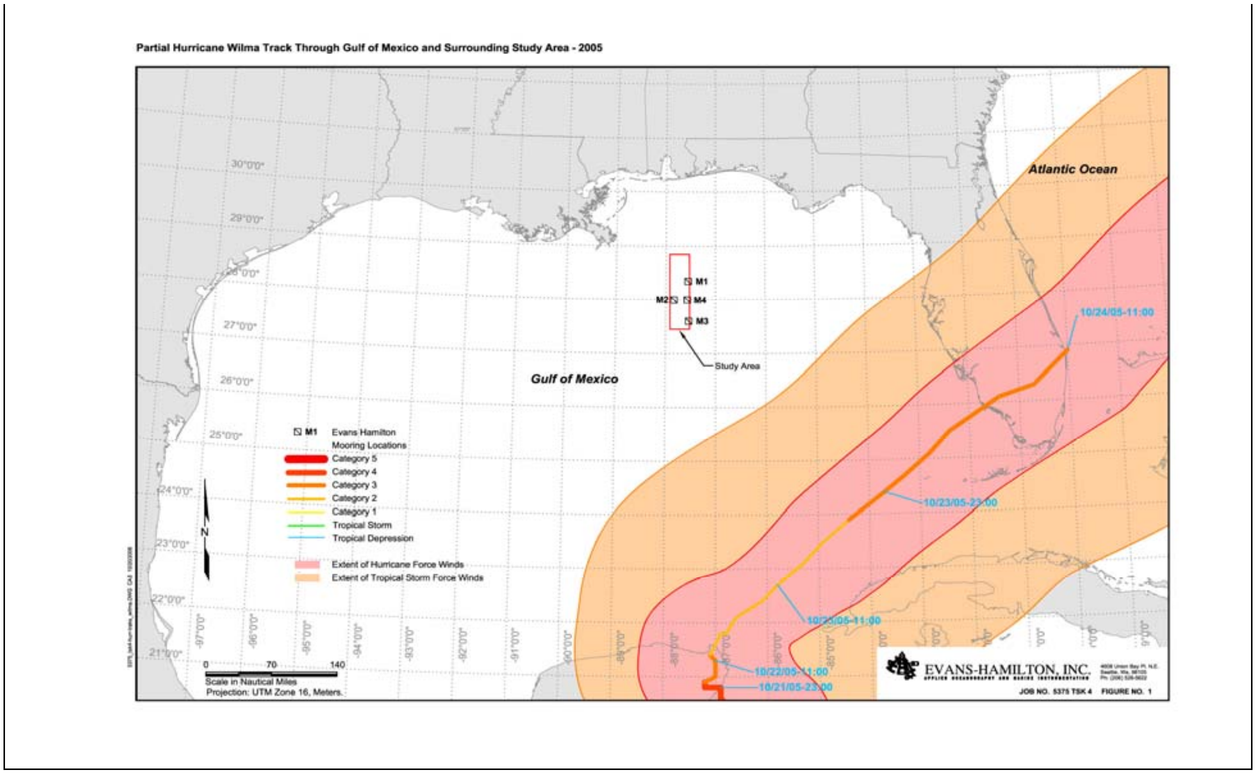


Figure 2C.28. Path of Hurricane Wilma, 21–24 October 2005.

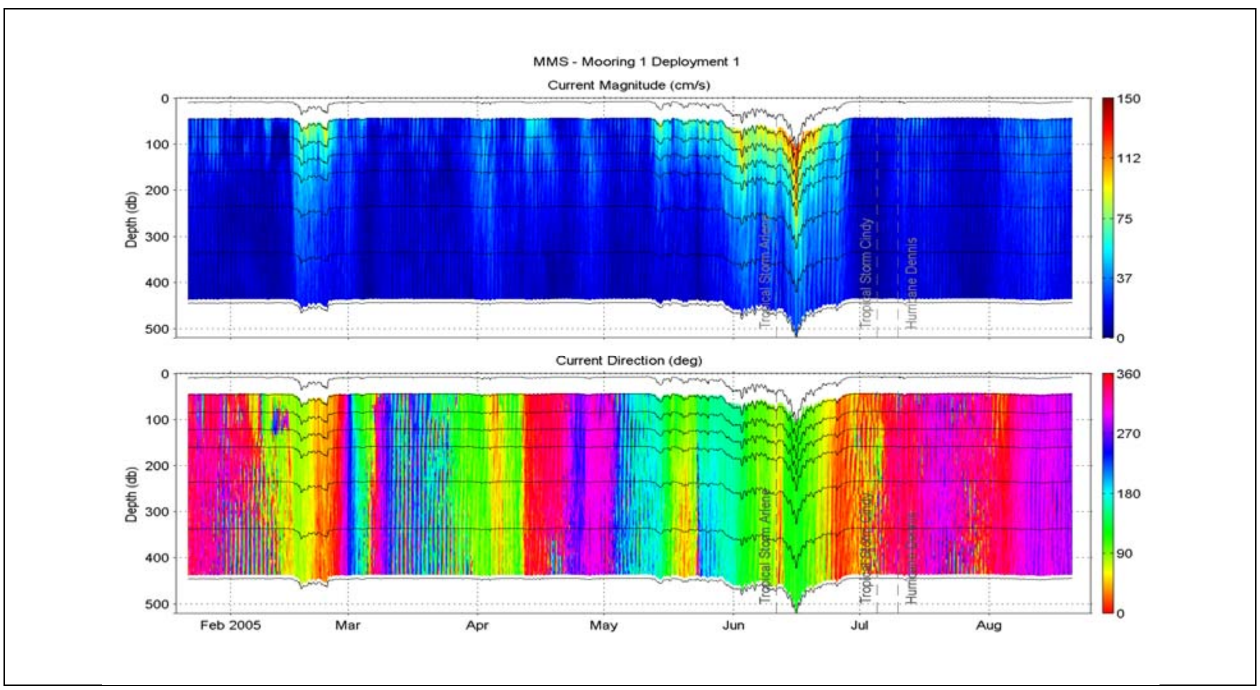


Figure 2C.29. Current speed (top) and direction (bottom) – Mooring 1, deployment 1.

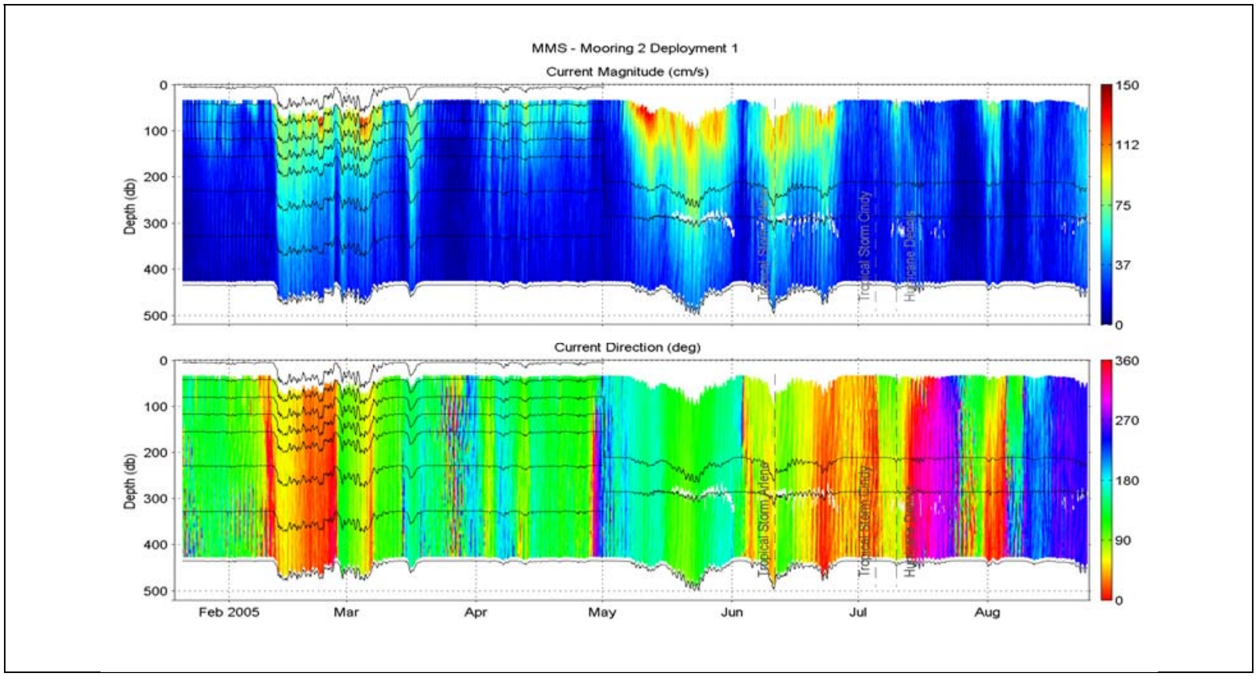


Figure 2C.30. Current speed (top) and direction (bottom) – Mooring 2, deployment 1.

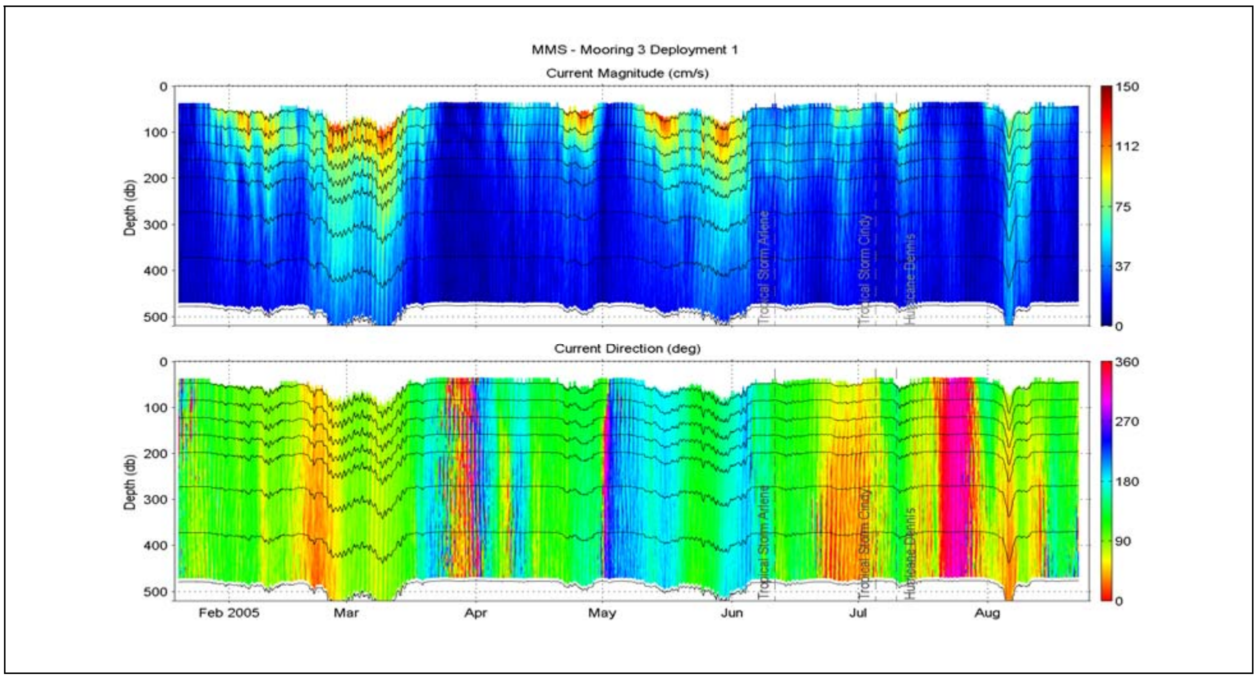


Figure 2C.31. Current speed (top) and direction (bottom) – Mooring 3, deployment 1.

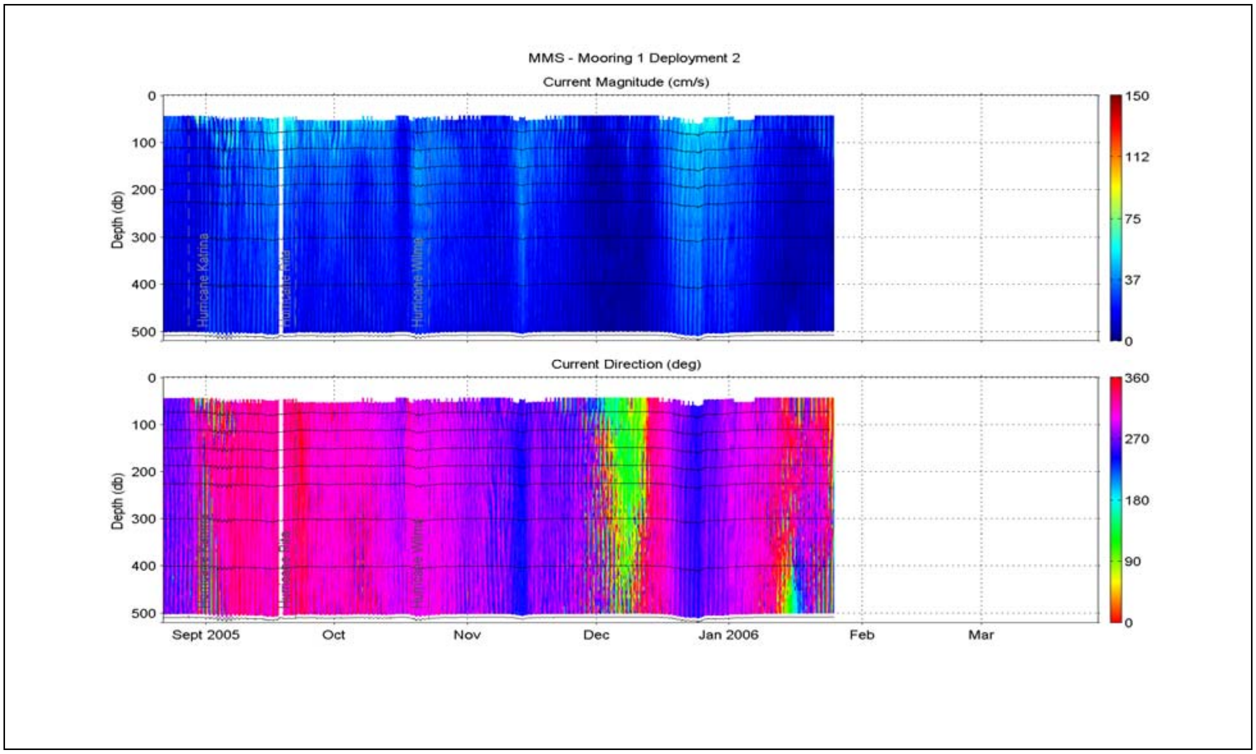


Figure 2C.32. Current speed (top) and direction (bottom) – Mooring 1, deployment 2.

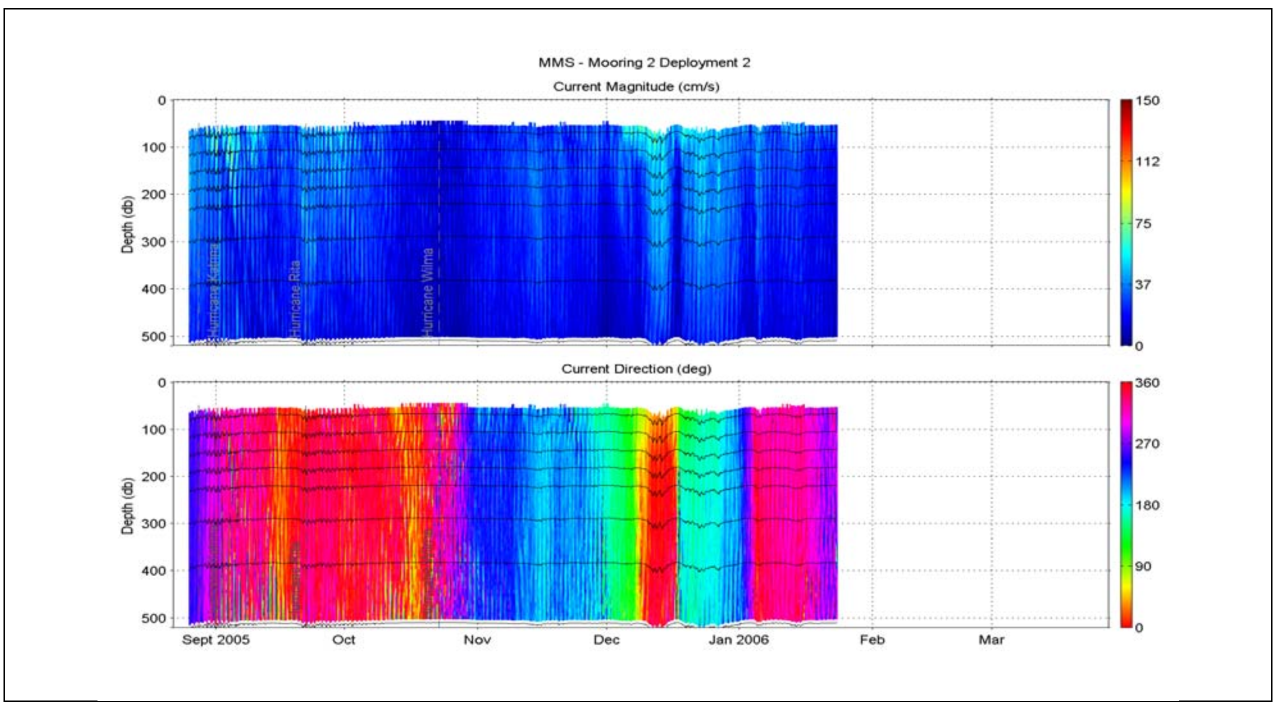


Figure 2C.33. Current speed (top) and direction (bottom) – Mooring 2, deployment 2.

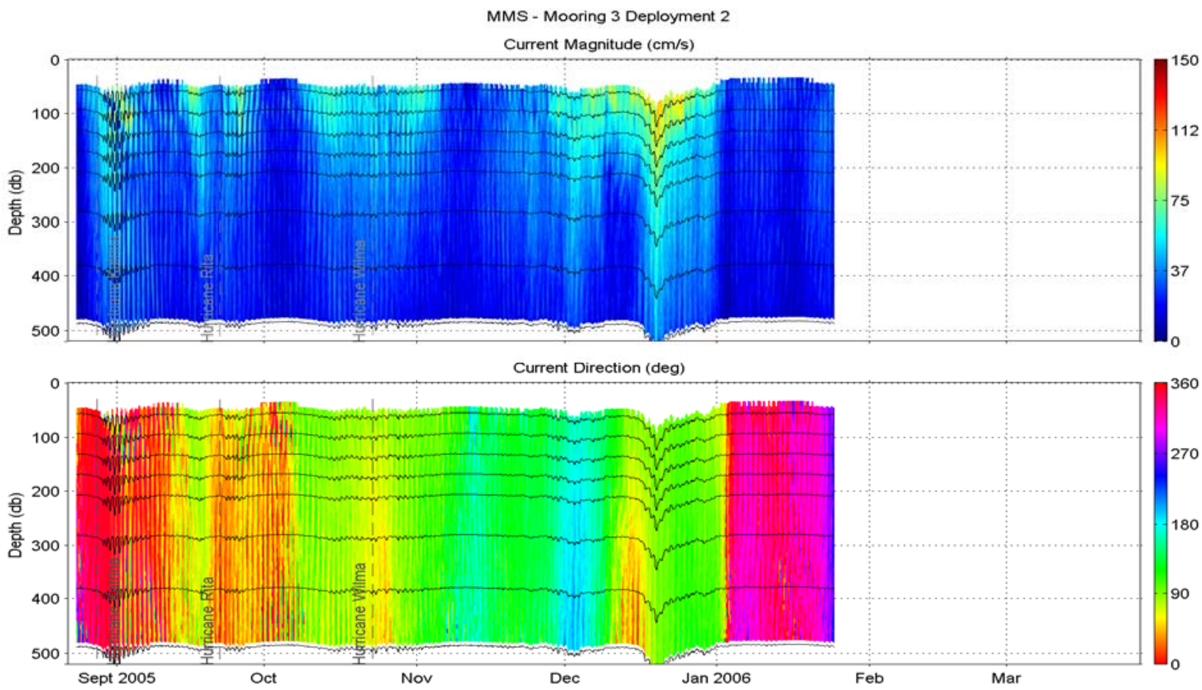


Figure 2C.34. Current speed (top) and direction (bottom) – Mooring 3, deployment 2.

Jeffrey M. Cox is President and a Senior Oceanographer at Evans-Hamilton, Inc., an organization he joined in 1977. His 29 years of experience with Evans-Hamilton includes conducting physical a variety of oceanographic, meteorological, and coastal water quality studies. Mr. Cox's present responsibilities include overall business development and company operations at Evans-Hamilton as well as the planning and oversight of large complex and multidisciplinary physical oceanographic projects. He is the Project Manager for the Eastern Gulf of Mexico Circulation Study. Over the years, Mr. Cox has conducted numerous physical oceanographic measurements. His work has occurred on all three U.S. coastlines, as well as in Alaska, and at other sites around the world, including off the east coast of India. Those efforts have included his participation in field studies of continental shelf and deep ocean physical processes. Additionally, he has been involved with POLYMODE program funded by the National Science Foundation, the Minerals Management Service (MMS) Gulf Stream Frontal Eddy Experiment (FRED) off North Carolina, and the MMS Louisiana-Texas Circulation Study (LATEX) program off Texas and Louisiana. Additional oceanographic studies conducted by Mr. Cox have included tracking of and current measurements within several Gulf of Mexico Loop

Current eddies. His experience in physical oceanographic measurement programs ranges from 3000m depth waters to coastal and inland waters.

NORTHEASTERN GULF OF MEXICO CIRCULATION STUDY: INTENSIVE HYDROGRAPHIC SURVEY OF LOOP CURRENT EDGE FINE SCALE FEATURES

Carol Coomes, Evans-Hamilton Inc.

Click here to view the slide show that accompanied this presentation.

Introduction

For perspective, three hydrographic cruises were planned for the 12-month measurement period of the Eastern Gulf of Mexico Circulation Study; at initial deployment, at the six-month service of the moorings, and during final retrieval. The hydrographic cruises would use a combination of CTD casts and XBT profiles designed to ensure sufficient data density, efficiency during the cruise, and coverage of the study area. A grid pattern of stations was devised consisting of deep CTD casts (~2000m), shallow CTD casts (~1000m), deep XBT profiles (T5 ~1830m,) and shallow XBT profiles (T7 ~760m). Grid spacing between stations was 10 nmi in the east to west direction and 5 nmi in the north to south direction. In addition, a grid pattern was devised with alternating lines of CTD and XBT stations where each west to east transect line would be the same type of probe (e.g., all shallow CTD, all deep XBT, etc). Deep CTD casts were to be taken at each mooring and PIES location and at the outer edges of the grid.

Hydrographic Cruise 1 (17–23 January 2005) followed the grid design and general station type. The hydrographic stations were timed around the daylight deployment of the moorings (PIES had been deployed in December 2004). Due to a lack of time, the far west N-S transect was not sampled. Hydrographic Cruise 2 (18–25 August 2005) again followed the grid design and the general station type. The hydrographic stations were timed around the daylight mooring retrieval and redeployments and the download of the PIES. The eight-day cruise allowed sampling of the far west N-S transect not collected during the first cruise. Additional XBT profiles were collected every 10 km as the ship crossed the loop eddy on the way back to shore.

Hydrographic Cruise 2 finished one day ahead of Hurricane Katrina's entering the Gulf of Mexico. Hurricane Rita followed less than a month later, and finally Hurricane Wilma came through the Gulf one month after Rita. Of the three hurricanes, Katrina had the most potential for impact to the study area. Storm tracks show hurricane force winds covered most of the study area and tropical storm winds covered the remainder. During Hurricane Rita, tropical storm force winds covered the southern half of the study area. Hurricane Wilma had the least direct impact to the study area having passed well to the south.

Because of these major storm events, additional funds were earmarked for a post-hurricane hydrographic cruise. However, no suitable vessels were available well past all three events. Vessel requirements included the capability for CTD casts.

Intensive Hydrographic Survey

A decision had to be made on how best to use the additional funds to benefit the program. The time was approaching for retrieval of all the moorings and PIES. LUMCON was able to extend our final cruise by a few days and so a fine scale (intensive) survey was planned for the final hydrographic cruise. This final survey would be designed to capture the edge of the Loop Current, edge of the eddy, and any frontal features within or near the study area. Satellite imagery two days prior to the cruise showed some interesting features. The edge of the Loop Current was moving northward toward the study area, possibly two cold core eddies were located in the southern half of the study area, and jets were possibly being produced by water squeezed by bathymetry at the north side of study area. Team members were assembled via teleconference to discuss strategies for the cruise plan. The end result was a pin wheel grid of stations (Figure 2C.35a).

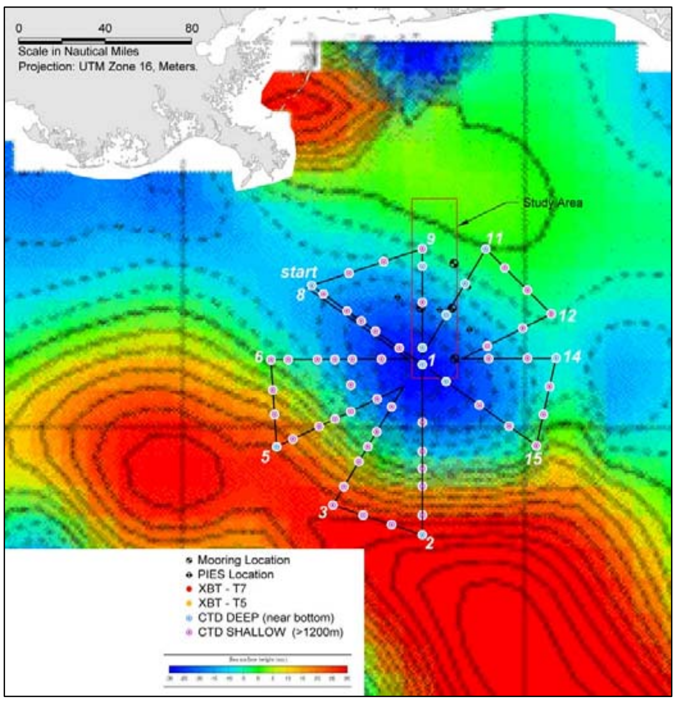


Figure 2C.35a

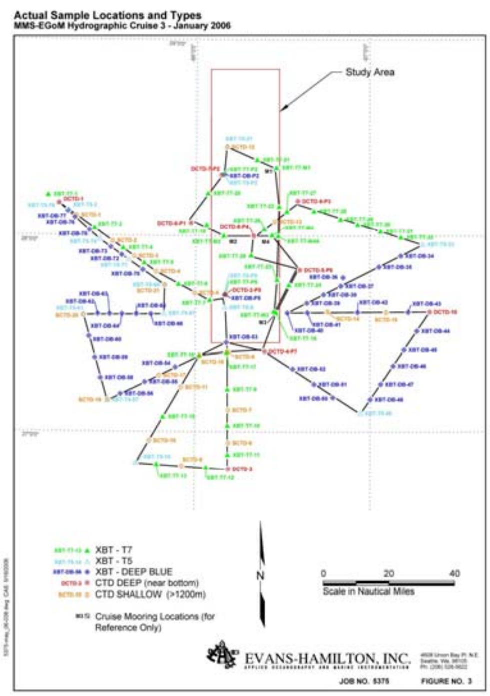


Figure 2C.35b

Figure 2C.35. Proposed (a) and final (b) station grid for intensive Hydrographic Cruise 3.

The cruise plan called for starting at the NW corner and following a transect toward the center of the grid to find the cold core eddy. Next the vessel would transit directly south until crossing the edge of the Loop Current. The vessel would continue transiting the pattern in clockwise rotation sampling “new” water as opposed to the possibility of sampling the same water if a counterclockwise rotation was scheduled. Sampling would be a combination of CTD casts and XBT profiles. Deep CTD casts were scheduled to be taken at each mooring and PIES location in addition to the outer corners of the pinwheel to maximize the area available for deep contours. The moorings and PIES would be retrieved as the vessel transited the grid pattern.

The actual cruise track pattern was modified once the vessel reached the study area (Figure 2C.35b). The edge of the Loop Current had slid northward so the legs along the south side of the grid pattern were shortened. The weather contributed to the modification of the cruise track as well. Immediately following completion of the most southern wedge of the pinwheel grid, the vessel headed north to take advantage of a good weather window to retrieve all moorings and PIES. Since this was the final cruise priority was given to retrieving all instrumentation. Retrievals had to be done during daylight hours. The station plan was also modified once on sight. Deep blue (DB) XBT probes (~870m range) were available for this intensive cruise. At two of the PIES stations (P2 and P5) multiple XBT profiles (one each of T7, T5 and DB) were taken in conjunction with a deep CTD cast. Because of the modification to the cruise track some stations were sampled more than once. An example is station 16 that was sampled with a T7 on 22 January 2006 and again five days later as a shallow CTD site. Preliminary results show good comparisons of the multiprobe stations.

The same transect line was sampled as the vessel transited into and out of the study area (NW quadrant). This transect gives an indication how far the edge of the Loop Current had migrated north during the cruise (Figure 2C.36). Profiles of the transects in the eastern section of the study area (center to east edge and center to SE edge) indicate a possible cold core eddy. The 15° isotherm rises in the water column as the transect moves from the center to the eastern edge of the sample area.

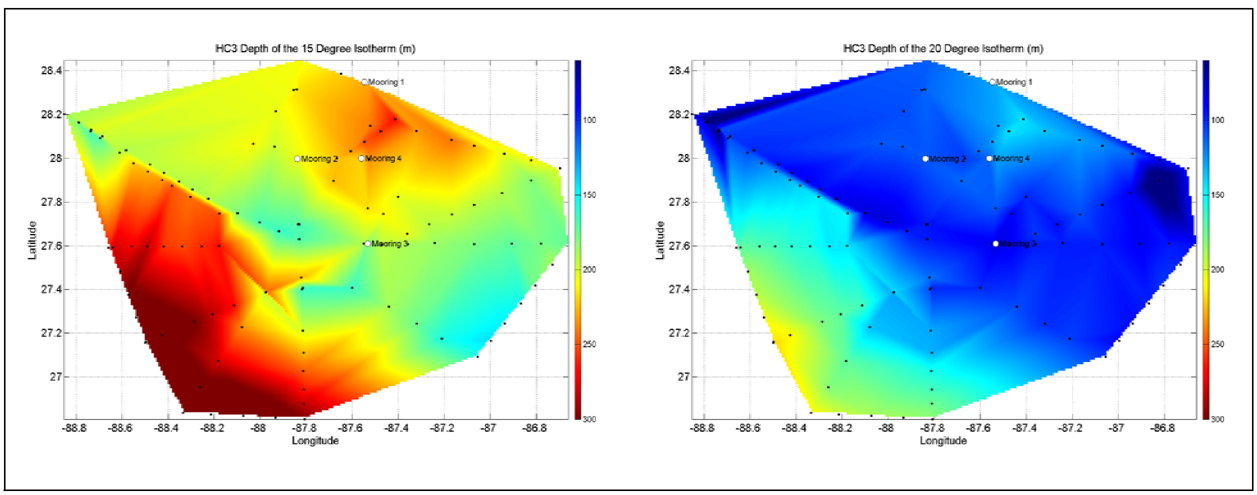


Figure 2C.36. Depth contour of the 15° (left) and 20° (right) isotherm. Depth scale ranges from near surface (deep blue) to 300 m (dark red).

Additional Analysis

Plots will be generated for the other transects measured during Hydrographic Cruise 3. Time series plots of temperature along all transects will also be generated. Further analysis and interpretation will be done on inter comparisons of all three hydrographic cruises collected during the twelve-month field effort for the Eastern Gulf of Mexico Circulation Study.

Ms. Carol Coomes, currently a Vice President of Evans-Hamilton, has been with the company for 27 years. She is an oceanographer and water quality specialist with experience in measuring and understanding coastal physical processes. Her work has centered on investigating circulation and water quality conditions. She has extensive experience and expertise in collecting and handling large oceanographic and meteorological databases, as well as and designing, managing, and conducting field projects in a wide array of current regimes. These projects have encompassed the use of a wide variety of oceanographic instruments for the measurements of waves, tides, currents, and various water properties, as well as a variety of navigation equipment. She has a wealth of experience measuring currents with acoustic Doppler current meters mounted in a variety of configurations and depth ranges from 5 meters to 3000 meters. Past projects she has worked on under the Minerals Management Service (MMS) include the Gulf Stream Frontal Eddy Experiment (FRED) off North Carolina, and LATEX program off Texas and Louisiana. She is currently the Assistant Project Manager for the Eastern Gulf of Mexico Circulation Study.

INDUSTRY PERSPECTIVE ON THE NORTHEAST GULF OF MEXICO CURRENT MEASUREMENTS

George Forristall, Forristall Ocean Engineering, Inc.

Click here to view the slide show that accompanied this presentation.

The oil industry uses current measurements to design facilities and plan for operations. Strong currents are the main concern. Experience has shown that the main sources of strong currents in the Gulf of Mexico are

- The Loop Current and its eddies
- Hurricanes
- Bottom currents enhanced by topography

These phenomena have generally been considered in isolation, but operations are now far enough out in the Gulf that attention is being paid to the possibility that a hurricane and eddy could affect a site at the same time.

Hurricane Katrina passed near the eastern Gulf of Mexico moorings while they were in a cold eddy on the periphery of a strong Loop Current eddy. Figure 2C.37 shows the current speed measured at Mooring 3 during Katrina. The measurements are compared to the results of a one-dimensional turbulence closure model. The initial response on 29 August is modeled rather well, but the one-dimensional model cannot represent the inertial oscillations after the storm passage.

The inertial oscillations are shown in more detail in Figure 2C.38. The pass band was from 12 to 48 hours. As expected, the oscillations have an upward phase propagation and downward energy propagation. Figure 2C.39 shows the oscillations at Mooring 1, just a few miles north of Mooring 3. The initial response is about the same, but the oscillations are much stronger at Mooring 3 than at Mooring 1. Hurricane Katrina passed about the same distance from the two moorings, but they were in a different situation with respect to the eddies shown in Figure 2C.40. Mooring 3 was in the middle of a cold eddy close to Loop Current Eddy Vortex. The enhanced inertial oscillations there are likely due to non-linear interaction between the eddies and the hurricane. These measurements will provide a good test case for three dimensional numerical models.

Figure 2C.41 shows the lowpass and bandpass speeds at Mooring 3 for the entire second deployment. The lowpass currents are dominated by several intrusions of the Loop Current or eddies. But strong diurnal currents only appear with the combination of an eddy and a hurricane.

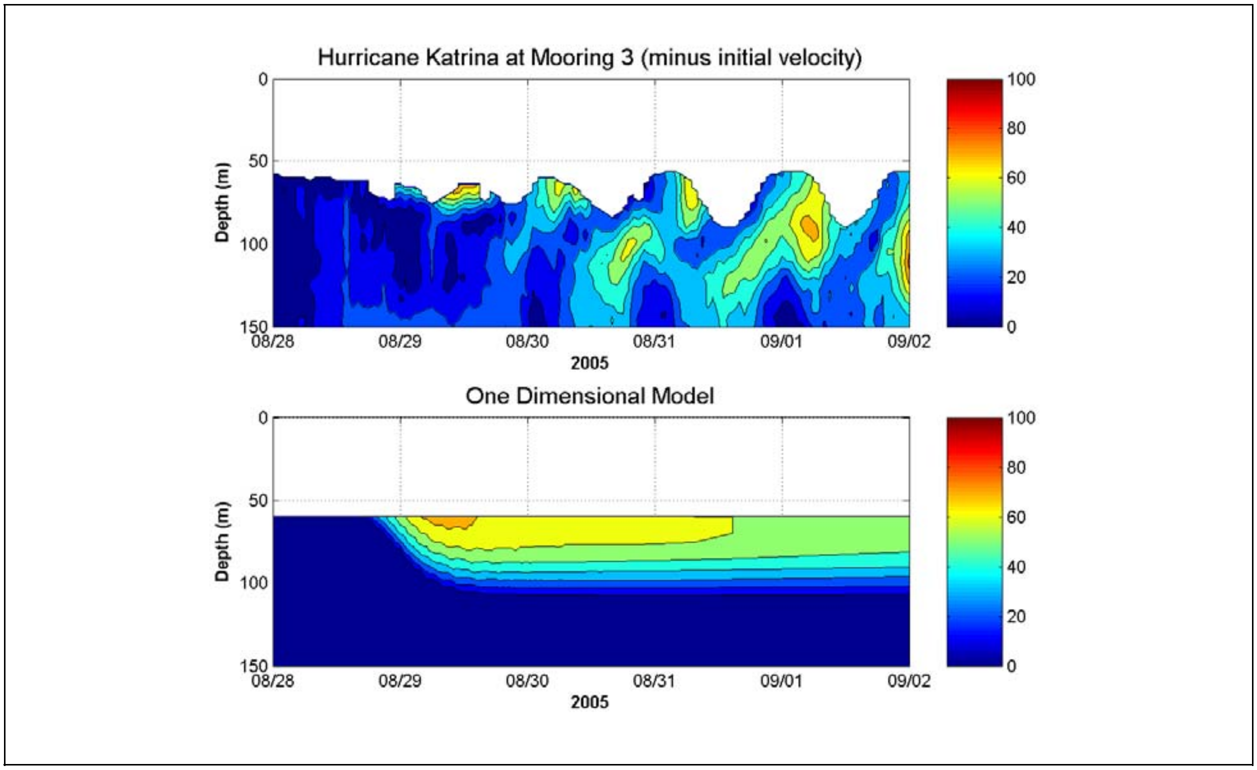


Figure 2C.37. Measurements at Mooring 3 compared to a one-dimensional turbulence model.

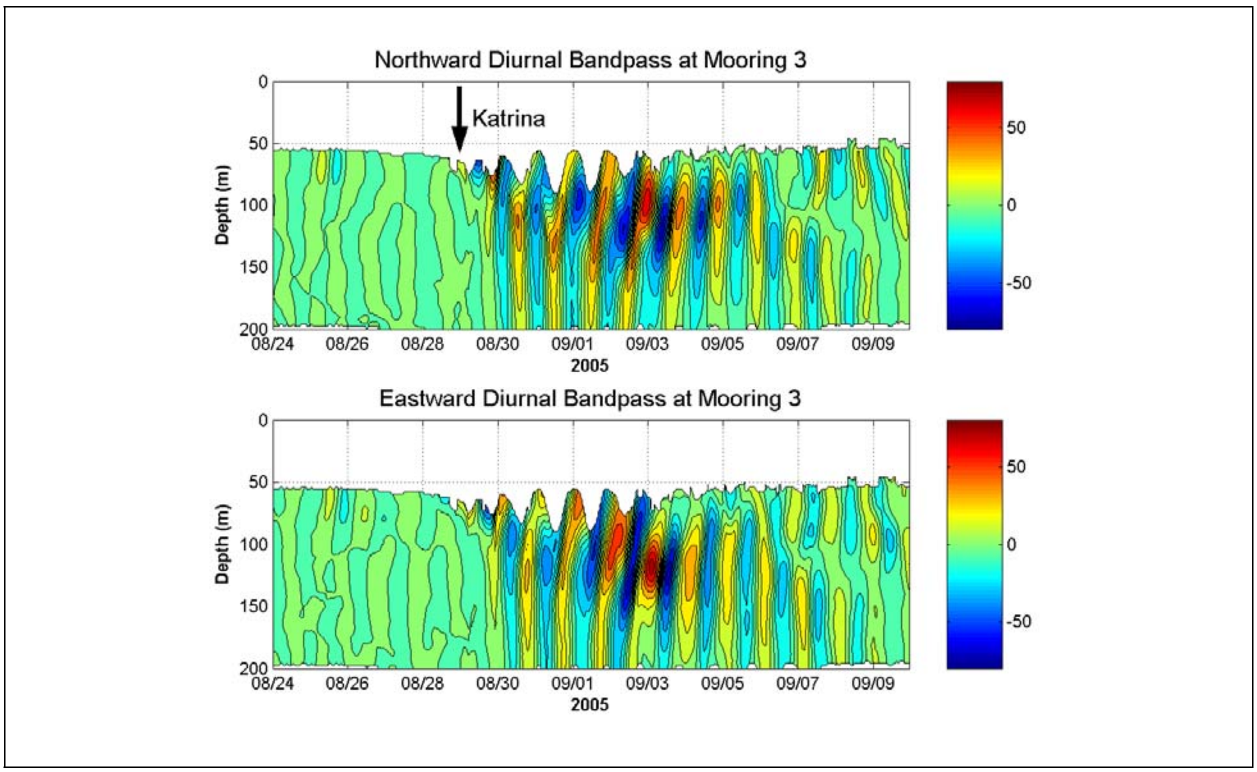


Figure 2C.38. Diurnal bandpass currents at Mooring 3.

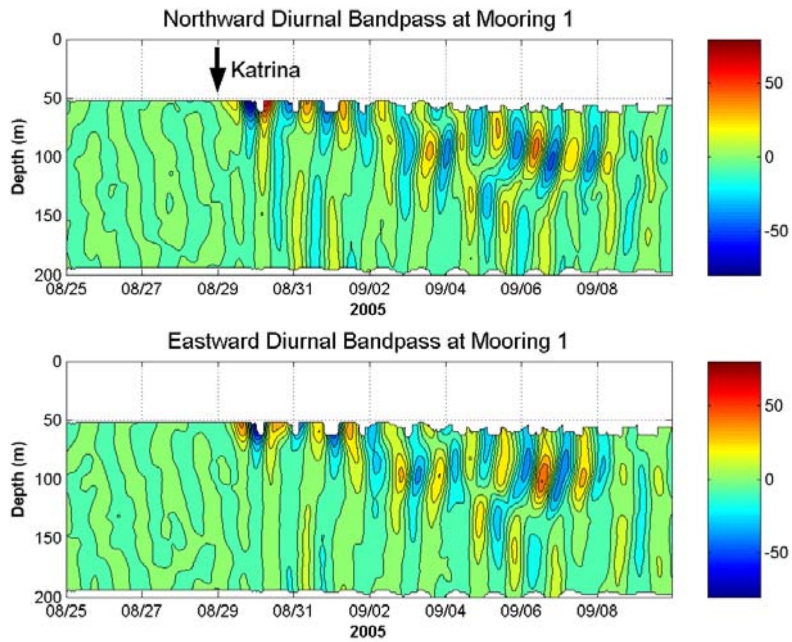


Figure 2C.39. Diurnal bandpass currents at Mooring 1.

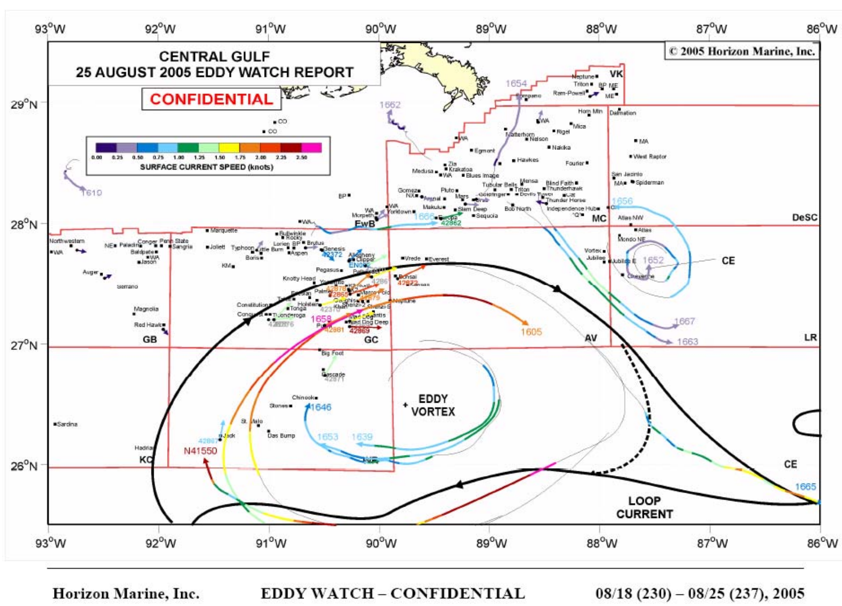


Figure 2C.40. Eddy Vortex just before Hurricane Katrina. Mooring 1 is the northern red star and Mooring 3 is the southern red star.

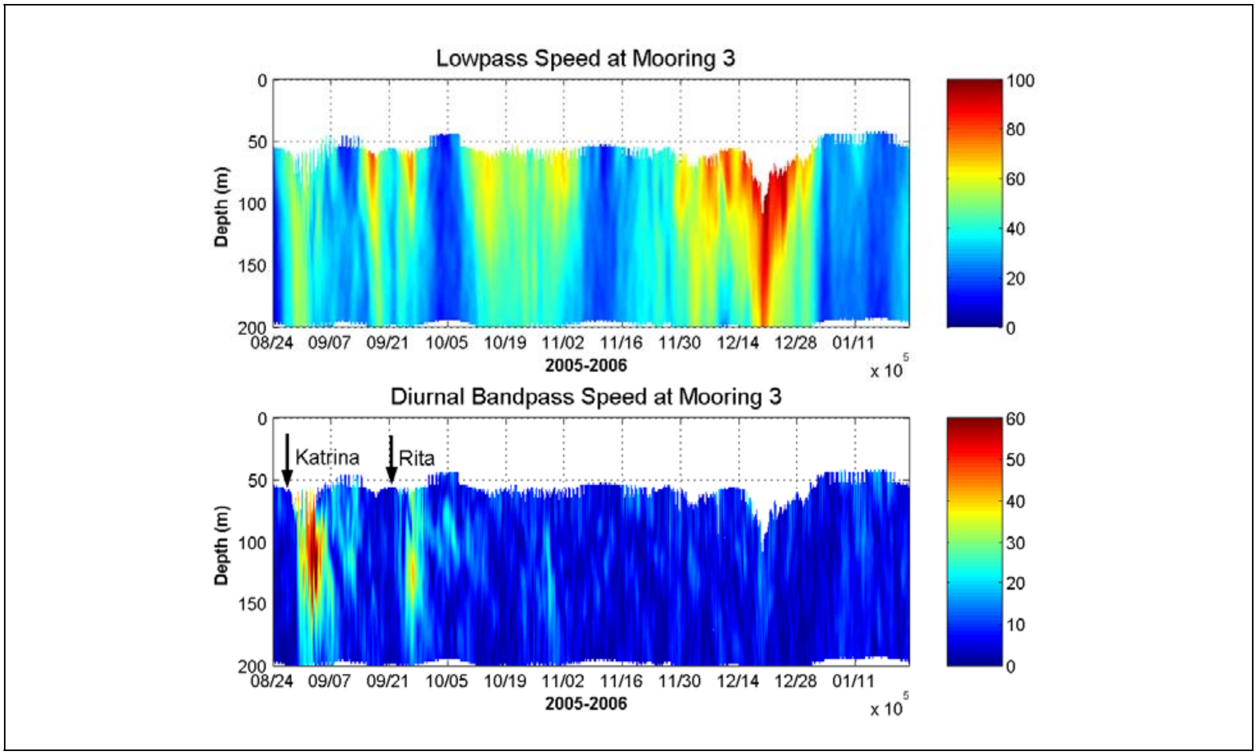


Figure 2C.41. Lowpass current speed at Mooring 3 compared to the diurnal bandpass speed.

Dr. George Z. Forristall formed Forristall Ocean Engineering, Inc. in 2004 to provide metocean services to the petroleum industry. He previously spent many years in various Shell companies specifying oceanographic design conditions for offshore structures worldwide. His work has involved fundamental research into the kinematics and statistics of storm waves and the structure of oceanic circulation as well as site specific investigations. He has a Ph.D. in mechanical engineering from Rice University.

SESSION 2D

SOCIOECONOMICS II

Chair: Asha Luthra, Minerals Management Service

Co-Chair: Kristen Strellec, Minerals Management Service

SPATIAL RESTRUCTURING AND FISCAL IMPACTS IN THE WAKE OF DISASTER: THE CASE OF THE OIL AND GAS INDUSTRY FOLLOWING HURRICANES KATRINA AND RITA

Tim Slack and Joachim Singelmann, Louisiana State University

Click here to view the slide show that accompanied this presentation.

REGIONAL ECONOMIC IMPACTS OF HURRICANES KATRINA AND RITA

Loren C. Scott, Loren C. Scott & Associates, Inc.

Click here to view the slide show that accompanied this presentation.

This presentation examines evidence of the economic recovery rate in the four coastal Metropolitan Statistical Areas heavily impacted by Hurricanes Katrina and Rita: New Orleans, Lake Charles, Biloxi-Gulfport, and Pascagoula. The data reveal that the New Orleans MSA has had the slowest recovery rate from the storms, primarily because major flooding destroyed a record number of homes and homeowner's insurance was not available to cover the losses. The Biloxi-Gulfport MSA has recovered at a slightly better rate because the passage of HB45 made it possible to rebuild the area's casinos on land. Both Pascagoula and Lake Charles have almost fully recovered from the effects of the storm, with schools and hospitals all reopened by the end of 2005.

Dr. Scott is the President of Loren C. Scott & Associates, Inc., a 24-year old economic consulting firm whose clients include such large national firms as BellSouth, Capital One Financial, Northrop Grumman, Entergy, ExxonMobil, J.P. Morgan Chase, and a diversity of others. He is one of the 32-member National Business Economic Issues Council, which meets quarterly to discuss issues of state, national, and international interest. This group has experts who cover international trade, Washington economic policy, retail trade, trucking, steel, chemicals, etc. Dr. Scott is an energy specialist on the NBEIC. He has been interviewed in the recent past on MSNBC, CNBC, and Bloomberg TV, and his work has been cited in such publications as the *Wall Street Journal*, the *Los Angles Times*, *USA Today*, and the *Moscow Times*, to name a few. Dr. Scott's career started at Louisiana State University in 1969, where he spent the next 33 years, rising through the ranks from assistant professor to the prestigious Freeport McMoran Endowed Chair of Economics and the Director of the Division of Economic Development and Forecasting. Over the thirteen-year period from 1983 to 1996, he was the chairman of the Economics Department at LSU. During that time, the department's ranking among the 3,000 economics departments in the U.S. rose from 101st to 38th. He is presently Professor Emeritus at LSU. He received seven awards at LSU for outstanding classroom teaching. His CD collection of humorous stories—"Laughter: The 'Economical' Way to Feel Great"—is available via his website www.lorencscottassociates.com . He gives 50–70 speeches a year on the state of the economy.

POST-HURRICANE ASSESSMENT OF OCS-RELATED INFRASTRUCTURE AND COMMUNITIES IN THE GULF OF MEXICO REGION

Maureen Kaplan and Andrew Laughland, Eastern Research Group, Inc.

Click here to view the slide show that accompanied this presentation.

Introduction

Louisiana State University's Center for Energy Studies is updating *OCS-Related Infrastructure in the Gulf of Mexico Fact Book* (MMS 24-027) to incorporate changes in these sectors after Hurricanes Katrina and Rita. As part of this work, Eastern Research Group (ERG) is preparing a socioeconomic analysis of communities with a high concentration of OCS-related infrastructure.

Project Goals

- Simple approach to show local impacts of OCS-related facilities
- Use approach to rank order geographic units by level of impact for more detailed study.
- Identify regions most affected by Hurricanes Rita and Katrina.
- Select and profile socio-economic characteristics of geographic units with high OCS impact and high hurricane impacts.

Project Approach

Integration of Geospatial and Socioeconomic Data

Using the LSU OCS infrastructure data, ERG created a base map with census geography (county, tract, block, labor market areas, and MMS-defined economic regions). ERG developed layers for 2000 Census data (population, poverty rates, etc.), OCS-related facilities, wind data for Hurricanes Katrina and Rita, and storm surge data from the hurricanes. The population within a one-mile buffer zone for each facility was incorporated into the weighting schemes.

Methodology to Estimate Infrastructure Concentration

In an earlier analysis, MMS counted the number of infrastructure facilities in each county and then classified each county as high, medium, or low concentration of infrastructure. ERG developed a series of weighting schemes developed on three parameters: employees, environmental releases (as reported to the U.S. EPA Toxics Release Inventory), and population surrounding the facility. ERG examined 125 potential combinations, two methods of combining the different ranks for each parameter in a combination, and different weights for each parameter. The selected ranking scheme is straightforward to calculate, easy to update, and robust (e.g., the group of the top twenty counties with heavy concentrations of OCS-related infrastructure stays consistent under alternative assumptions).

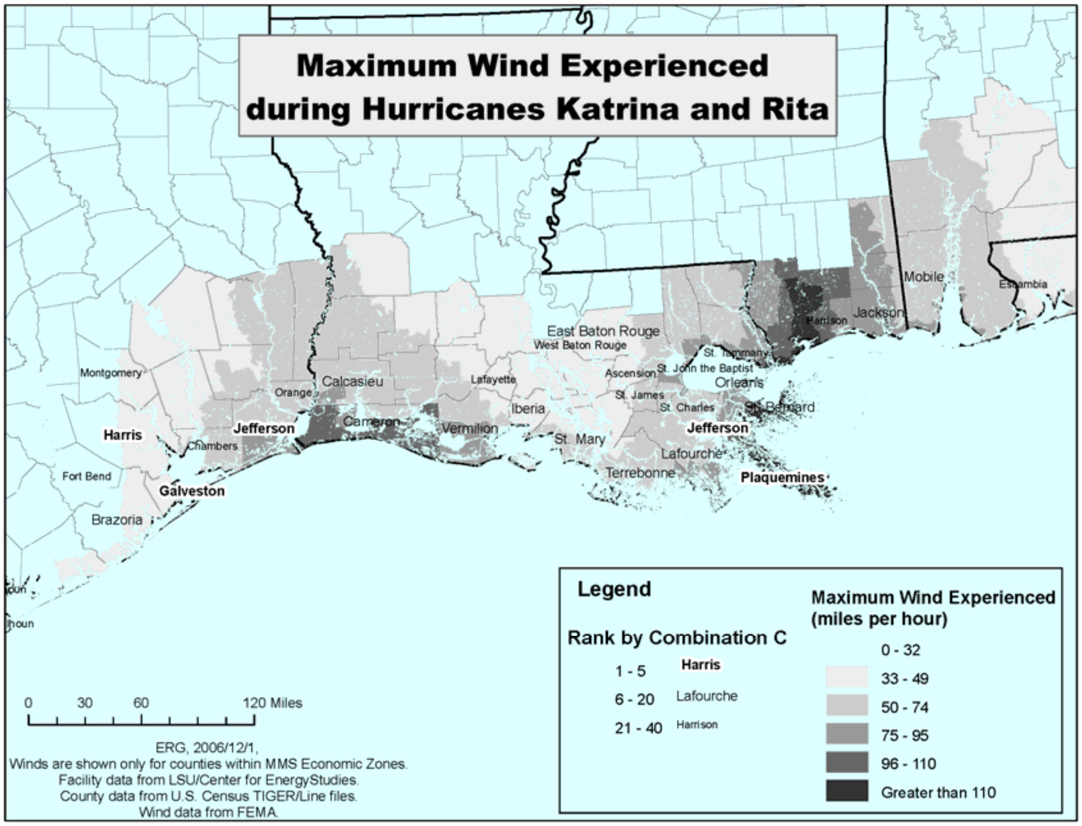


Figure 2D.1. Overlay of wind data and OCS-related infrastructure concentration.

Intersection of Hurricane Damage and Areas with High Concentrations of OCS-related Infrastructure

Based on the overlay of wind, storm surge, and infrastructure concentration, ERG identified six areas for further social impact analyses (Figure 2D.1). Harris County, Texas consistently ranked highest in OCS-related infrastructure under all weighting schemes examined. This county is also within the path of Hurricane Rita's wind damage, although a late change in direction spared the county the brunt of the impact. Jefferson County, Texas is one of the top five communities with respect to OCS-related infrastructure and in Hurricane Rita's path. The Louisiana parishes of Plaquemines, Jefferson, Orleans, and St. Bernard form a nexus of high concentration of OCS-related infrastructure and Hurricane Katrina's wind and storm surge damage.

Maureen Kaplan is a Vice President with ERG. For the past 20 years, she has researched and analyzed economic and policy issues of government regulations on the energy industry and other industry sectors. She built her first economic models of Gulf of Mexico oil and gas projects in 1987. Dr. Kaplan holds a Ph.D. from Brandeis University.

RESURRECTION OF THE BAYOU PEOPLE, 2006 A.D.: WETLANDS, HURRICANES, AND RESTORATION

Kerry St. Pé, Barrataria-Terrebonne National Estuary Program

Click here to view the slide show that accompanied this presentation.

The entire 4.2 million acre region between the Mississippi and Atchafalaya Rivers was established as the Barataria-Terrebonne National Estuary in 1990 by congressional action under Section 320 of the Clean Water Act. National Estuaries are areas of special national significance that are unusually threatened by multiple and complex environmental issues. The programs created under this act are charged with developing comprehensive plans using a consensus-driven approach with broad stakeholder involvement to restore the threatened region. Currently there are 28 National Estuary Programs (NEPs) in the United States.

The unique cultural mix and the incredible productivity of the Barataria-Terrebonne region are both products of the Mississippi River. The rich mix of flora and fauna, the oil and gas, and the very land that supports, protects, and sustains the region's communities and infrastructure are resultant of the actions of the deltaic processes of a river system that drains two-thirds of the United States. The culture of the region and its direct dependence on the productivity of the region has remained relatively undiluted largely because of the population's tendency to remain in the region for multi-generational time spans.

Due largely to regional and watershed-level human impacts to the hydrology of the Mississippi River and changes to the ecology of the delta, the Barataria-Terrebonne system is suffering from a level of wetland loss that is greater than any other in the world. In addition to the inevitable collapse of the fisheries in the region, the loss of coastal landscape features is threatening surface water sources as saline water intrudes from the Gulf of Mexico towards the north into drinking water supplies. Oil and gas pipelines and entire communities have become far more susceptible to damage from hurricane storm surges and even from lesser climatic events. Hurricanes Katrina and Rita devastated most of south Louisiana and resulted in an elevated national awareness and interest in Louisiana's wetlands loss.

Restoration planning in Louisiana is not a new phenomenon. The comprehensive restoration plan developed by the Barataria-Terrebonne National Estuary Program was completed and approved by the federal and state governments in 1996. The multiple stakeholder and broadly inclusive approach of the National Estuary Program resulted in an exceptionally high level of acceptance of the Comprehensive Conservation and Management Plan (CCMP). A broad level of agreement to the 51 restoration strategies of the CCMP is an essential component to our ability to return to same level of acceptable risk experienced by the regionally prevalent bayou-dependant culture for generations.

One recently evaluated strategy that could successfully deliver sediments to areas that have changed from marshes to open water is one that would harvest sediments with dredges from the Mississippi and Atchafalaya River beds and then direct the resulting sediment slurry to areas of need. The delivery of riverbed- harvested sediments would result in a much-needed, quicker rebuilding of wetlands without the huge water volumes normally needed to transport sediments to considerable distance. Diversions of harvested sediment would result in a lower magnitude of salinity regime change and fewer conflicts among the user groups that rely on the current fresh, brackish and saline bands of marsh types. Smaller volumes of water diversions would be needed to sustain the rebuilt wetland systems.

Kerry St. Pé is Program Director of the Barataria-Terrebonne National Estuary Program, a nationally recognized effort dedicated to preserving and restoring the 4.2 million-acre area between the Mississippi and Atchafalaya rivers in Southeast Louisiana. A graduate of Nicholls State University, he worked for 23 years as a field biologist and Regional Coordinator for the Louisiana Department of Wildlife and Fisheries and the Louisiana Department of Environmental Quality. Mr. St. Pé has conducted several major studies on the impacts of oilfield wastes on Louisiana wetlands as well as studies of clam shell dredging in several Louisiana lakes. He serves on numerous national, state and local advisory boards and is a frequent public speaker. His wetland restoration work has been featured in the best-selling book Bayou Farewell, The Rich Life and Tragic Death of Louisiana's Cajun Coast by Mike Tidwell and in the PBS documentary Washing Away: Losing Louisiana. He grew up in Port Sulphur during the 1950s and 1960s, where the vast coastal marshes surrounding his home inspired him to become a marine biologist.

SESSION 2E

DEEPWATER HABITATS: *LOPHELIA* II

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

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

CHARACTERIZATION OF NORTHERN GULF OF MEXICO DEEPWATER HARD-BOTTOM COMMUNITIES WITH EMPHASIS ON *LOPHELIA* CORAL—AN OVERVIEW, SYNTHESIS, AND RECOMMENDATIONS FOR FUTURE STUDIES

Charles Fisher, Pennsylvania State University

Click here to view the slide show that accompanied this presentation.

A basic objective of the Lophelia I project was to better understand the distribution, biology and ecology of *Lophelia pertusa* in the Gulf of Mexico. As evidenced by the presentations in the morning session, the program accomplished this objective. It also identified areas where further research will be fruitful and demonstrated the feasibility of a number of techniques that will continue to provide useful information on the biology and ecology of *L. pertusa* and other corals.

The basic approach of Lophelia I was first to identify multiple sites with significant *L. pertusa* coverage and then characterize the sites and describe the distribution of *L. pertusa* and other fauna within the sites. This task included image analyses, sediment and carbonate analyses, sediment and zooplankton trapping, water column hydrocarbon analyses, taxonomic and ecological analysis of collections, and current and temperature monitoring. Using a combination of *in-situ* observations, collections and laboratory analyses, the trophic relations within the communities were also documented and related to seep primary productivity. Finally experiments were conducted to measure growth rates of *L. pertusa in situ*, and a variety of laboratory experiments and analyses addressed the physiological ecology and reproductive biology of *L. pertusa*. Based on the results of Lophelia I, the project PIs have a number of recommendations that will significantly increase our understanding of deep water coral biology and ecology in areas critical to preparation of an informed management strategy for this deep-sea ecosystem.

Although substantial progress has been made in identifying habitat for *L. pertusa* and other ecosystem structuring deep corals from surface-derived data, we currently still lack a robust predictive capability for their occurrence. An important part of future research should include development of better protocols to identify specific areas where deep-water corals are likely to flourish. This research will involve a combination of data review, perhaps data gathering, and certainly ground-truthing predictions. Although confirmation of occurrence of coral communities should begin with remotely gathered imagery, collections at sites over a wide geographic and depth range are necessary to define the distribution patterns of all coral foundation species and the fauna associated with them. Very little is currently know about communities associated with corals other than *L. pertusa* in the GOM, and one finding of Lophelia I was that other hard and soft corals can form extensive aggregations in both the presence and absence of *L. pertusa*. It is important to note that molecular genetic analyses can distinguish between morphologically similar species, identify isolated populations, and provide considerable insight on the dispersal patterns of corals in the GOM.

Another useful *in-situ* approach is intensive study of one or two rich coral sites covering several square kilometers with variable coral coverage, substrates, and topography. This research should begin with acquisition of state-of-the-art, sub-meter scale resolution multibeam and sidescan maps of these sites. Then, all *in-situ* data and physical collections (including, for example, imagery, chemistry, current, zooplankton, sedimentation, substrate and biology) should be made in an equally well-defined (sub-meter scale) navigational space. This will allow detailed analysis of the distribution patterns of the corals and associated communities as well as robust statistical correlation with the driving physical, biological, or chemical variables not possible without high quality navigation and high resolution maps and imagery. These data will also help generate predictions about the occurrence of rich deep-coral communities.

Lophelia I demonstrated the feasibility of *in-situ* hard-coral growth studies. A Lophelia II project such include such studies, as they will both provide basic data on *L. pertusa* (or other hard coral) biology and experimental tests of hypotheses generated from the correlations between distribution patterns and environmental variables.

Lophelia I also helped us develop experimental protocols for laboratory experiments on *L. pertusa* tolerance and response to environmental variables and potential anthropogenic stressors. This technique can continue to provide valuable empirical information that will help define the range of *L. pertusa*, the environments it can inhabit, and its sensitivity to drilling activities.

Although no larvae were obtained during Lophelia I, the reproductive state data collected indicate that *L. pertusa* spawning in the GOM is likely to occur in October. We also note that larvae have been obtained from *L. pertusa* in other parts of the world. Studies of *L. pertusa* larval life cycles could provide important constraints for current-based models of coral dispersal. Studies of the larvae can also explain larval sensitivities to environmental variables and anthro–pogenic stressors, which may be quite different from those of the adults and be important drivers of coral distribution patterns.

Finally, the limited long-term monitoring conducted during *Lophelia* I emphasized that environmental data on rich coral habitats should be gathered year round. Constraining variables, important nutrient pulses, and periodic habitat use by large megafauna may not be evident during the relatively short period of time during field operations. Moreover, larger mobile fauna that may utilize deep coral habitats may well be affected by the presence of bright lights and noisy deep-sea vehicles. Image collection via long-term monitoring stations will provide important data on these remote ecosystems, data that cannot be obtained in any other way.

Dr. Fisher is a professor of biology at the Pennsylvania State University. He received his Ph.D. from the University of California Santa Barbara for his research on shallow coral reefs. He has been researching the communities associated with hydrocarbon seepage in the Gulf of Mexico for 20 years and has authored over 50 peer-reviewed publications addressing various aspects of the biology of these communities.

POPULATION GENETIC STRUCTURE IN *LOPHELIA PERTUSA*

Cheryl L. Morrison, Tim L. King, and Robin Johnson,
USGS Leetown Science Center

Steve W. Ross, University of North Carolina-Wilmington,
Center for Marine Science

Martha S. Nizinski, NOAA/NMFS Systematics Lab, Smithsonian Institution

Click here to view the slide show that accompanied this presentation.

Geographic patterns of genetic diversity in *Lophelia pertusa* were examined by quantifying genetic diversity present in populations, and assessing levels of genetic differentiation within the Gulf of Mexico (GOM)—5 sampling locations, 1–290 km apart). Patterns of differentiation observed within GOM *Lophelia* were compared to *Lophelia* populations from the northwest Atlantic Ocean (NWAO) continental slope off the Southeastern U.S. (six sampling locations, 18–990 km apart) and with northeast Atlantic Ocean (NEAO) populations off the coast of Europe (5,400–7,900 km away from sampled U.S. populations). Multilocus genotypes for 190 *Lophelia* individuals were determined using a suite of nine microsatellite markers developed for GOM *Lophelia*.

Populations of *Lophelia* harbored substantial genetic diversity. The majority of populations had unique alleles indicative of little gene flow. Pairwise chord distances were high among all populations and regional groupings of populations resulted from a neighbor-joining clustering analysis. North versus south *Lophelia* populations at Viosca Knoll (VK) 826, the most intensively sampled area, had fixation index estimates significantly greater than zero, suggesting little larval mixing. Comparisons of all GOM *Lophelia* populations with the shallowest site, VK862, produced significant fixation indices. Quantitative estimates of hierarchical gene diversity (AMOVA) indicated significant population structure at every level: between the three regions examined; between GOM and NWAO regions; and within the GOM and NEAO regions. Mantel tests identified significant correlations between geographic and genetic distance (an isolation-by-distance pattern) at larger spatial scales, but not within regions. Thus, dispersal of *Lophelia* larvae is generally localized, with occasional long distance dispersal occurring such that some genetic cohesion is retained regionally within the GOM and NWAO. Genetic differentiation observed between these regions indicates more restricted gene flow than expected, and that the most effective management plan for *Lophelia* may be regional reserve networks.

Cheryl Morrison received her B.S. degree in marine biology from the University of North Carolina-Wilmington and her Ph.D. from Florida State University. Presently, she is a geneticist at the USGS Leetown Science Center, where she works on conservation genetics issues in a variety of organisms, including freshwater fishes and unionid bivalve species and deep-sea corals. General research interests include the use of molecular techniques to characterize relationships and retrace historical patterns of dispersal in marine invertebrates.

MICROBIAL DIVERSITY ASSOCIATED WITH *LOPHELIA PERTUSA* IN THE GULF OF MEXICO

Christina Kellogg, U.S. Geological Survey

Click here to view the slide show that accompanied this presentation.

Microbes, including bacteria, archaea, and fungi, are recognized to be an important part of the total biology of shallow-water corals. Deep-sea corals have a fundamentally different ecology due to their adaptation to cold, dark, high-pressure environments, and as such have novel microbiota. The goal of this study was to characterize the microbial associates of the deep-sea coral Lophelia pertusa in the Gulf of Mexico. This is the first study to include both culture-based and molecular data on deep-sea coral-associated bacterial communities. It is also the first study to collect the coral samples in individual insulated containers and to preserve coral samples at depth in an effort to maintain in-situ microbial diversity by minimizing contamination and thermal shock.

There are a few links between Lophelia-associated bacteria and bacteria from shallow-water corals and deep-sea octocorals, but both cultured isolates and clone libraries revealed many novel bacteria associated with Lophelia. There are many bacteria and clone sequences that are similar to symbionts of fish, squid, and methane-seep clams. In particular, there is a sequence, VKLP1, present in all Lophelia colonies analyzed to date (n=6), which is related to a sulfide-oxidizing gill symbiont of a seep clam. This microbe may be a Lophelia-specific bacterium and links the coral to cold seep communities. Molecular analysis of bacterial diversity showed a marked difference between the two sites, Visoca Knoll 906/862 and Visoca Knoll 826. The 16S rRNA bacterial clone libraries from VK826 were dominated by a variety of unknown Firmicutes. The dissimilarity between the dominant members of the bacterial communities at these two sites may be evidence of diseased Lophelia or thermal stress at one site, or may indicate biogeographical differences.

There was no overlap between the bacteria identified in this study and those from a recent study of Lophelia in the Mediterranean. Although lack of commonality may indicate biogeographical differences, it is more likely due to the significant methodological differences in collection, extraction, and analysis of the Lophelia samples. No archaea have been detected to date, however, a fungus similar to marine species of Paecilomyces and Acremonium was found.

Christina Kellogg received her Ph.D. in marine microbiology from the University of South Florida for her work on the genetic diversity of environmental viruses. She did postdoctoral research on an NIH-funded fellowship at the Georgetown University Medical Center, using molecular methods to identify novel drug targets in pathogenic fungi. She also interned for several months at Human Genome Sciences, processing microarrays and using bioinformatics software to mine the data. She joined the U.S. Geological Survey as one of the first Mendenhall Fellows, characterizing the microbial communities in African dust, beach sediments, sea grass beds and coral reefs. In her current position as an environmental microbiologist, Christina applies molecular techniques and classical microbiological methods to study microbes in aerosols, the marine environment, tropical corals and deep-sea corals.

ARCHIVE IN THE DEEP: A 2000-YEAR HISTORY OF OCEANOGRAPHY AND CLIMATE CHANGE RECORDED IN WESTERN NORTH ATLANTIC DEEP-SEA BLACK CORALS

C. W. Holmes and N. A. Buster, U.S. Geological Survey

S. E. Ross, University of North Carolina-Wilmington

Noreen Buster, ETI Professionals

Click here to view the slide show that accompanied this presentation.

Introduction

In the analysis of antipatharian corals retrieved from Stetson and Savannah Banks in the western Atlantic Ocean off the southeastern United States, we used ^{210}Pb to date outer bands and ^{14}C to date inner bands. The specimen from Stetson Bank, collected live from 500 meters depth, began growing 900 years BP. The specimen from Savannah Bank was collected dead, but ^{14}C dates indicate that it grew from 650 BP to approximately 2850 BP. We verified ^{210}Pb age models with ^{14}C dates from the outer bands, which yield modern ages with a $\Delta^{14}C$ equal to atmospheric ^{14}C. The ^{210}Pb growth curve indicates a constant coral growth rate of 15µm/yr. Using that chronology, ^{14}C dated bands from the center (oldest) and outer (youngest) part of the skeleton lie on the growth-rate line, but intermediate ^{14}C samples were abnormally old. This dichotomy suggests the water mass in place during growth of the middle bands contained 'old' carbon. This coral grew on the Stetson bank, near the edge of the Blake Plateau, and we suggest that the source of this old carbon was up-welled water from the Atlantic Basin. The apparently old dates occurred during the Little Ice Age and may indicate changes in the strength of the thermohaline circulation of the region, likely a slowing or change in the Gulf Stream.

Results and Discussion

Chemical analysis (ICP/MS) of antipatharians showed that they are extremely enriched in metals. Measurements of the trace metal content of individual black coral bands demonstrate that micronutrient metals vary with time and may be correlated with the dust record from the GISP II ice core. The decrease in cadmium concentrations during the Little Ice Age may indicate decreased nutrient flux related to changes in oceanic circulation or productivity. The record of yttrium and cadmium correlates remarkable volcanic activity from 1000 BP to about 1850. From 1850 to the present, however, cadmium flux increases and the correlation disintegrates. This suggests that the increase is due to anthropogenic influences which are being recorded in the deep corals (Figure 2E.1).

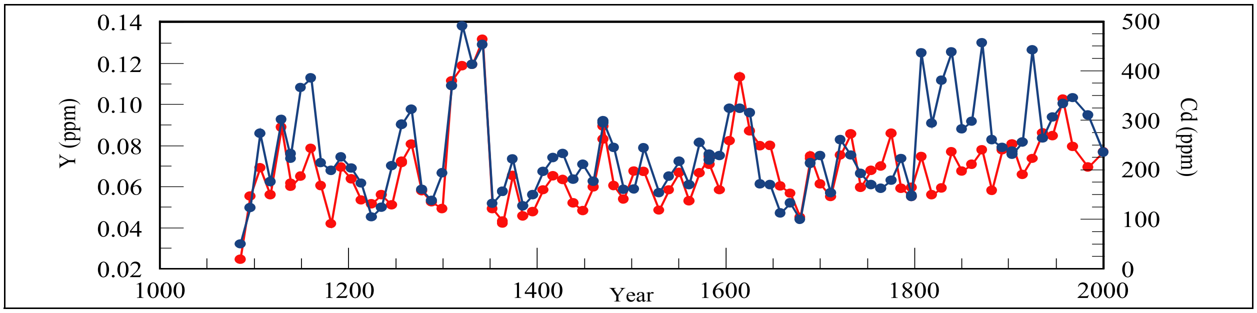


Figure 2E.1: Distribution of yttrium and cadmium in black coral. Note the correlation between the two elements from 1000 to 1800 BP. From 1800 to present the cadmium concentration increases relative to yttrium (Yttrium = blue; Cadmium = red).

Conclusions

The major conclusion for this effort is that these long-lived corals contain an incomparable chemical and climatic historical record of the Western North Atlantic Ocean. With annual concentric bands, these corals have been growing for hundreds to thousand years, recording oceanographic, climatic and atmospheric changes within their skeleton.

EFFECTS OF OIL AND GAS EXPLORATION AND DEVELOPMENT AT SELECTED CONTINENTAL SLOPE SITES IN THE GULF OF MEXICO: FINAL CONCLUSIONS

Alan D. Hart and Neal W. Phillips, CSA International, Inc.

Click here to view the slide show that accompanied this presentation.

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). To meet some of these challenges, this study was conducted to address one 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.[1] 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 Gulf of Mexico 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 muds 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 1000 m. GB 602 and MC 292 were located in water depths of about 1100 m. Both water based and synthetic based muds (SBM) were used in the drilling of the exploration and post-development wells.

[1] As of 1 January 2007, the company name of Continental Shelf Associates, Inc. was changed to CSA International, Inc.

Geophysical characterizations of the sites were conducted to determine the (1) areal extent and accumulation of muds and cuttings; (2) physical modification or disturbance of the sea bed due to impacts from anchors and their mooring systems, including chains or wire ropes; and (3) accumulation of debris attributable to oil and gas development activity. Chemical/biological sampling was conducted at each site to assess physical/chemical modification of sediments and the effects on benthic organisms.

The main conclusions of the study were as follows:

- Geophysical and chemical measurements indicated that a layer of SBM cuttings and muds was deposited within the near-field radius. Geophysically mapped cuttings zones ranged from 13 to 109 ha in area, with larger zones observed at post-development sites. Areas mapped as cuttings typically extended several hundred meters from wellsites, with the greatest extent (about 1 km) observed at GB 602 and GB 516. The cuttings deposits were estimated to be up to 45 cm thick at one site (VK 916).

- Concentrations of drilling fluid tracers (barium and synthetic based fluid [SBF]) were elevated by several orders of magnitude within near-field sites. Mean sediment concentrations of barium and SBF were positively correlated with estimated discharge volumes of SBM cuttings.

- Areas of SBM cuttings deposition were associated with elevated total organic carbon (TOC) concentrations and anoxic conditions, including low dissolved oxygen, negative Eh, and shallow depth of the oxidized layer. Sites with larger volumes of SBM cuttings discharges and higher mean sediment SBF concentrations had the greatest reduction in mean sediment oxygen levels.

- Sediment profile imaging indicated that the near-field sites had patchy zones of disturbed benthic communities, including microbial mats, areas lacking visible benthic macroinfauna, zones dominated by pioneering stage assemblages, and areas where surface-dwelling species were selectively lost.

- Macroinfaunal and meiofaunal densities generally were higher near drilling, although some faunal groups were less abundant in the near-field (amphipods, ostracods). Among megafauna, increased fish densities and reduced ophiuroid densities were noted in the near-field of two sites (VK 916 and GB 516).

- Microbial biomass (adenosine triphosphate [ATP]) was elevated in some samples near drilling and positively correlated with SBF concentrations above about 1,000 µg/g at VK 916 and GB 516, but not at GB 602 or MC 292. The ATP data were problematic, however, with major temporal changes and apparent far-field “outliers” complicating the interpretation.

- Meiofaunal densities in the near-field were not consistently correlated with drilling indicators (barium, SBF) or other sediment variables (TOC, grain size fractions).

- Annelid (predominantly polychaete) and gastropod densities in the near-field were positively correlated with drilling indicators (barium, SBF). Some near-field stations with barium concentrations higher than about 10,000 µg/g and/or SBF concentrations greater than about 1000 µg/g had elevated polychaete densities. A few near-field stations at GB 516 and GB 602 had very high gastropod densities, which were associated with barium concentrations of 55,000 µg/g or higher and SBF concentrations of 4500 µg/g or higher.

- Amphipod densities in the near-field were negatively correlated with drilling indicators (barium and SBF). Generally, near-field stations with barium concentrations higher than about 10,000 µg/g and/or SBF concentrations greater than about 1,000 µg/g had low amphipod densities. Separately, acute toxicity tests with near-field and far-field sediments from MC 292 and GB 602 showed that mean amphipod survival was significantly lower in sediments from near-field stations than in sediments from far-field stations. Amphipod survival in the toxicity tests was negatively correlated with drilling indicators.

- Detailed taxonomic analysis of a subset of the macroinfaunal samples showed some stations near drilling had lower diversity, lower evenness, and lower richness indices compared with stations away from drilling. Species composition varied in relation to both geographic location and drilling impacts. Station/cruise groups most likely affected by drilling were dominated by high abundances of one or a few deposit-feeding species, including known pollution indicators.

- At all four near-field sites, impacts were patchy, with some stations showing conditions similar to those at the far-field sites. Impacts generally were less extensive and less severe at post-exploration sites than at post-development sites.

- Impacts attributable to SBM cuttings such as elevated TOC, poor redox conditions, and associated biological changes were least severe at MC 292, where the smallest quantities of SBM cuttings were discharged. However, the time elapsed since drilling also was longer at this site (about 2 years) than at the other three sites (5 to 14 months), and the less severe impacts may reflect recovery of this site over time.

- Observations from the study sites and adjacent lease blocks suggest that geophysically detectable muds/cuttings deposits may persist for five years or more and anchor scars may persist for 14 years or more. Because no chemical or biological sampling was done in adjacent blocks, it is not known if the mapped mud/cuttings from older wells are associated with persistent elevations in barium, anoxic conditions, or altered benthic communities.

References

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.

Dr. Alan Hart is the Science Director of CSA International, Inc., located in Jupiter, Florida. He has over 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.

SESSION 2F

DEEPWATER PHYSICAL OCEANOGRAPHY II

Chair: **Alexis: Lugo-Fernandez, Minerals Management Service**

Co-Chair: **Carole Current, Minerals Management Service**

STUDY OF DEEPWATER CURRENTS IN THE NW GULF OF MEXICO

Evans Waddell, Science Applications International Corporation

Click here to view the slide show that accompanied this presentation.

In August 2003, Science Applications International Corporation (SAIC) was awarded a field measurement and analysis program titled "Survey of Deepwater Currents in the Northwestern Gulf of Mexico – American Sector." The broad objectives of this MMS-funded program are

- To collect current data to increase our deepwater database and knowledge of the deep circulation in the NW GOM.
- To gather information to estimate oceanographic parameters needed to make experimental designs of full-scale physical oceanography studies in deepwater.
- 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 contribute to the preparation of NEPA documents.

As proposed, 13 moorings were deployed by approximately 1 February 2004. As an exercised option to the basic program, SAIC recommended that Inverted Echo Sounders with Pressure (PIES) be deployed in conjunction with 13 full-depth moorings. The eventual placement of both the moorings and PIES is shown in Figure 2F.1. Observations in the American Sector were coordinated with five comparable moorings placed by CICESE within the Mexican EEZ (Figure 2F.1). The duration of all program observations is shown in the modified Gantt chart in Figure 2F.2. The originally planned one-year mooring deployment in the American Sector was extended three months to provide longer concurrent data sets in the American and Mexican Sectors and the moored instruments and PIES. The remote sensing task was also extended to ensure that those important observations were available to the science team.

Based on extensive review of observations throughout the deep Gulf of Mexico, placement of instruments on the 13 full-depth moorings was based on a well-documented two-layer structure of the deepwater velocity field. All moorings had an Acoustic Doppler Current Profiler (ADCP) positioned to provide current estimate between the instrument depth and the water surface. On moorings in water depths of 500 m, an upward directed 300-kHz instrument was placed at 90-m depth. On all deeper moorings, a 75-kHz ADCP was placed at 450-m depth. Above 1000 m, additional fixed-level current meters were placed at 250-m intervals. Below 1000 m, current meters were placed at 500-m intervals. Regardless of water depth, a current meter was always placed 50 or 100 m above the local bottom. As shown in Figure 2F.3, this distribution of instruments resolved well the vertical structure of the velocity field. In the upper 500 m of the water column,

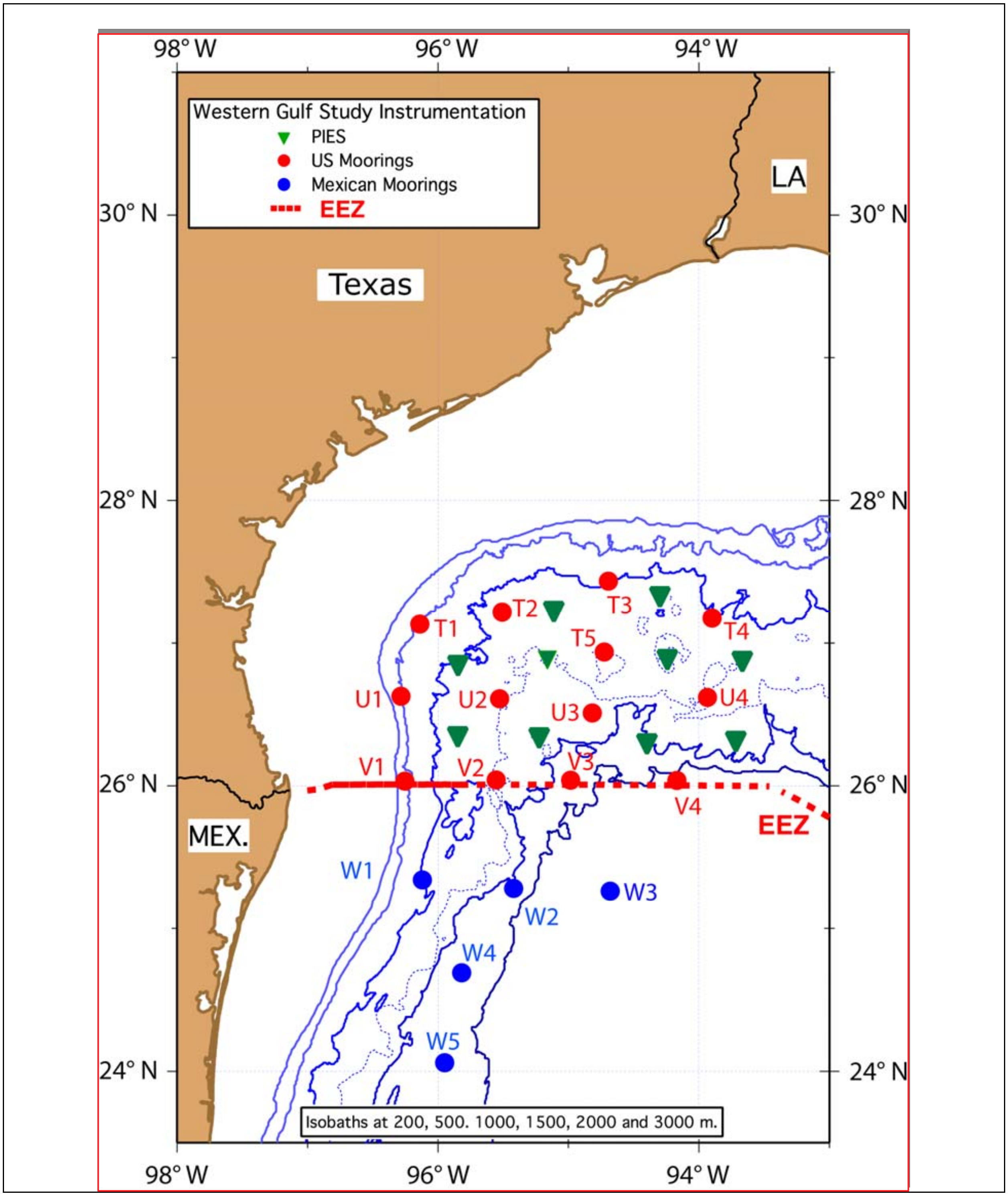


Figure 2F.1. Placement of full-depth moorings and PIES in the American Sector (north of the EEZ) and the full-depth moorings in the Mexican Sector (wought of the EEZ).

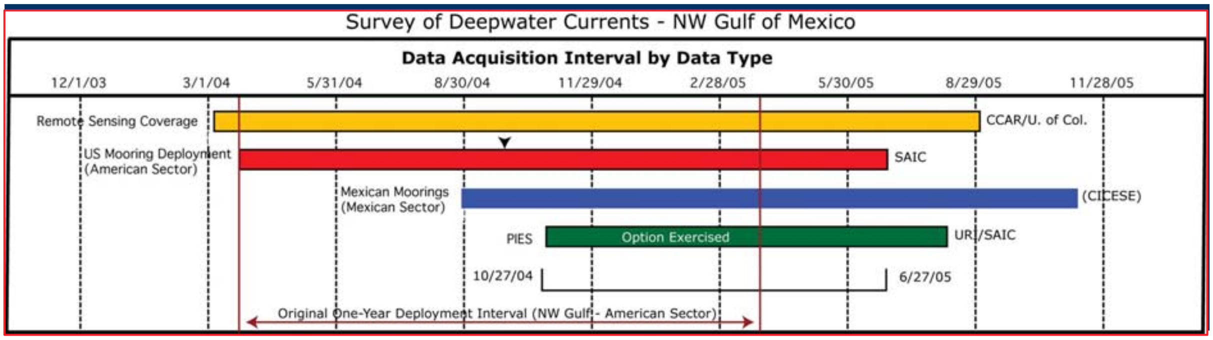


Figure 2F.2. Duration of the observational components of the NW Gulf Study.

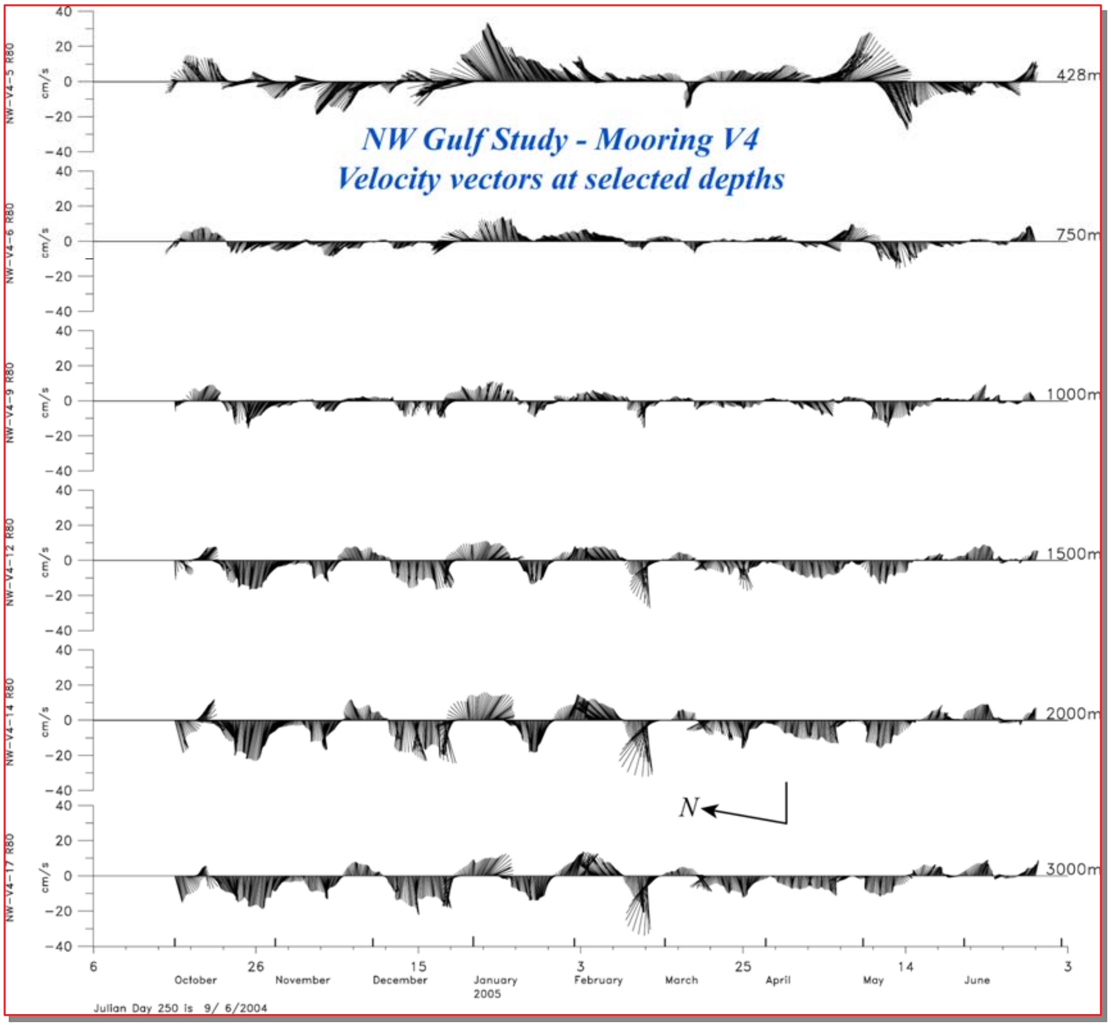


Figure 2F.3. Low-pass filtered currents as measured through vertical for the indicated interval at Mooring V4 as shown in Figure 2F.1.

Temperature sensors were placed at 100, 150, 250, 375 and 500 m. The sensor at 150 also measured salinity, so it might be possible to identify intervals when a salinity maximum indicated the presence of Subtropical Underwater, brought into the Gulf via the Loop Current (LC). If detected, it would be diagnostic of the presence of LC eddies in the western Gulf.

Data return for the field observations was very good, being better than 98%. There were no data losses from the American Sector hindering the ongoing data interpretation activities.

The Science Team/Principal Investigators (PI) for this study include:

- Dr. Kathleen Donohue – University of Rhode Island
- Dr. Peter Hamilton – SAIC
- Dr. Robert Leben – University of Colorado
- Dr. D. Randolph Watts – University of Rhode Island

The SAIC program support team consists of:

- Dr. Evans Waddell – Program Manager
- Mr. James Singer – Logistic Manager and Cruise Chief Scientist
- Mr. Paul Blankinship – Data Manager

The program and MMS are further supported by a Science Advisory Group that includes:

- Dr. John Bane – UNC
- Mr. David Driver – BP
- Dr. William Schmitz
- Dr. Wilton Sturges – FSU/FBN Oceanography

To help provide some initial direction as to processes of interest and hence help guide instrument placement, a total of 11 hypotheses were developed in three major process areas:

- high frequency or short duration events,
- deep circulation, and
- eddy-slope interaction.

These hypotheses were not meant to limit interpretation and synthesis activities, but rather to provide guidance regarding key concerns during the program development process.

At this ITM, program PIs are presenting some of the insights developed as part of the ongoing process characterization. Most of these presentations focus on either low-frequency currents associated with deepwater processes or patterns in the upper layer associated with LC eddies. Not covered in those presentations is information regarding jets as defined by DiMarco et al. (2004).

ACDP observations taken during the NW Gulf Study documented several events that appear to satisfy the criteria of speeds greater than 1 kt. (-50 cm/s), isolated from the ocean surface, occurring in the general depth range of 100–300 m, and of relatively short duration and not periodic (e.g. not inertial currents). One potential episode was measured at Mooring T5 and is shown in Figures 2F.4 and 2F.5. Peak currents were approximately 70 cm/s with the maximum lasting less than a day and isolated between 100 and 200 m (Figure 2F.4), which was a region where the 14°C and 16°C isotherms are diverging with time (Figure 2F.5).

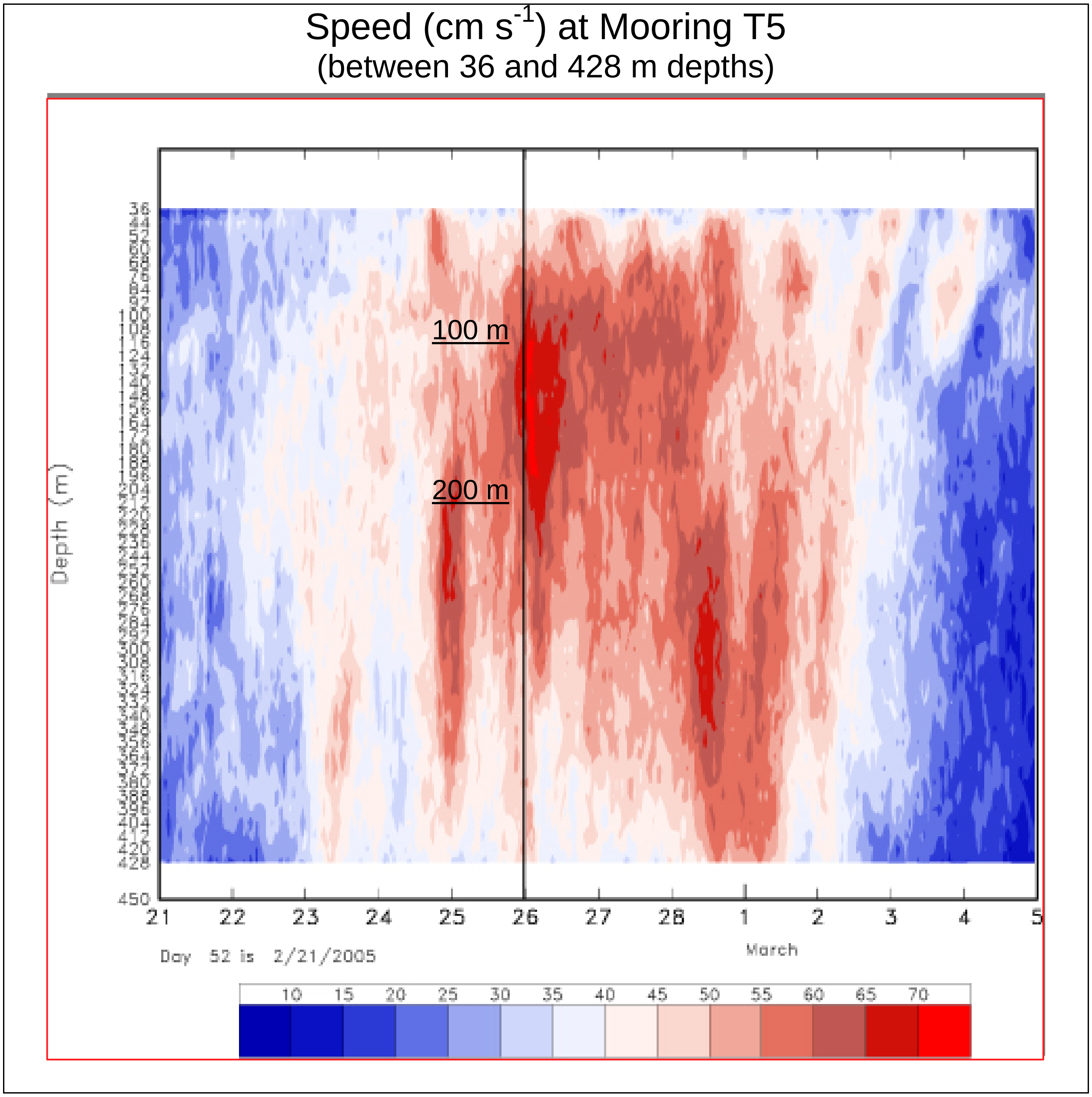


Figure 2F.4. Contour plot of speed as measured (no filtering) by the ADCP located at 450 m. Note the highest speed event is located between 100 and 200 m depth and lasts for less than a day.

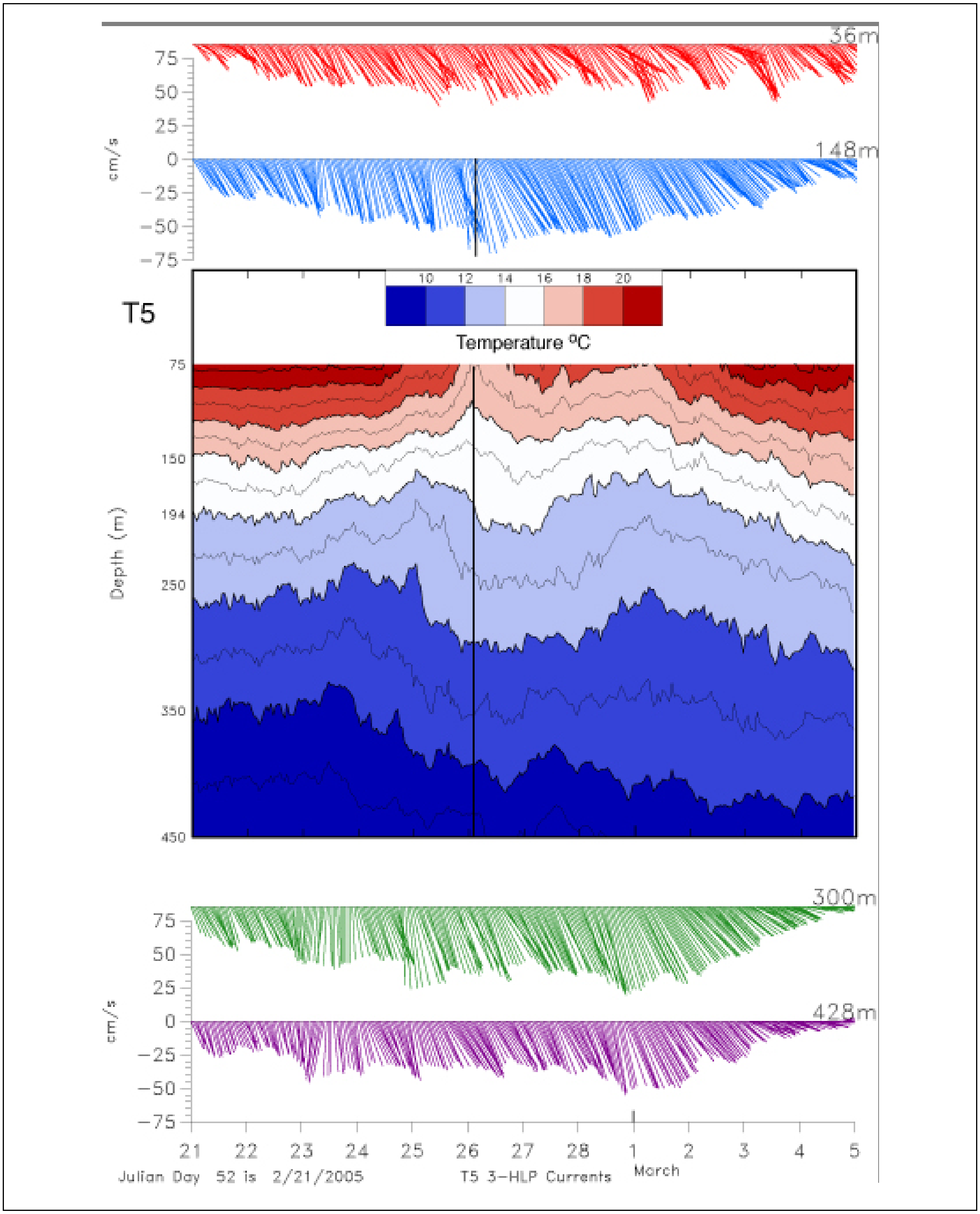


Figure 2F.5. Time series of current velocity at the indicated depth in combination with time time series of temperature using measured and interpolated values at each time step.

The program PIs continue to analyze and evaluate the program database that will be described in the program final report to be submitted on 31 August 2007.

Reference

DiMarco, S.F., M.K. Howard, W.D. Nowlin, Jr., and R.O. Reid. 2004. Subsurface, high-speed current jets in the deepwater region of the Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. OCS Study MMS 2004-022. 98 pp.

Dr. Evans Waddell has worked at SAIC for approximately 30 years, most often as the program manager of larger physical oceanographic field measurement and analysis programs, often in the Gulf of Mexico. He is presently the PM for the above study titled "Survey of Deepwater Currents in the Northwestern Gulf of Mexico." Dr. Waddell is an Assistant Vice President and a Senior Oceanographer for SAIC. He 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).

THE FLOW OFF THE NW GULF OF MEXICO SLOPE BEFORE ONCOMING LOOP CURRENT EDDIES

Antoine Badan, David Rivas, Julio Candela,
Julio Sheinbaum, and José Ochoa, CICESE

Click here to view the slide show that accompanied this presentation.

Abstract

Fourteen months of direct surface to bottom current measurements off the slope of the NW Gulf of Mexico capture the evolution of currents as an oncoming warm Loop Current eddy disintegrates off the coast and interacts with the near-shore flow. In general, current fluctuations, typically 20–25 $cm.sec^{-1}$, are about 2 to 4 times their mean. Currents at the edge of the shelf are strongly influenced by topography, often in the shape of a coastal flow, but with active exchange with deeper waters. In the upper layers, energy increases offshore, with a clear influence from eddies to a depth of about 800 m. Further at depth, a southward flow appears to be locked to the slope in the form of a countercurrent over the 2000 m isobath, whereas in deeper water motions are somewhat more energetic and support earlier investigations that showed the prevalence of bottom-trapped topographic waves. The spectrum of motions in the upper layers is very energetic in the 60 to 100 day bands, which are therefore marginally resolved. This casts some uncertainty on the direction of the mean flow. Some short-lived, high frequency events are well documented by our observations.

Introduction

The western Gulf of Mexico owes a large portion of its circulation variability to the propagation of motions that originate in the more energetic eastern Gulf, principally under the influence of the Loop Current, a precursor of the Gulf Stream that connects the Yucatan Current to the Florida Current. As the Loop Current evolves between its extreme positions within the eastern basin, it semi-periodically releases warm-core, upper-layer anticyclonic eddies. Also, through interactions with the western Florida slope, it forces packets of bottom-intensified, topographic Rossby waves. Both classes of motions propagate to the west, more or less along the slope of the northern Gulf of Mexico, and interact with the western shelf and slope off Texas and Mexico, in a region known as the 'eddy graveyard.' The present measurements are part of a large effort to document motions in the region where most of these eddies appear to disintegrate, forcing secondary motions in the remaining portions of the Gulf of Mexico. Trains of topographic Rossby waves also exist offshore, at depth. Both presumably induce considerable motions on the edge of the shelf and slope. The picture that emerges from our measurements is that of a weak mean coastal flow on the shelf and a well-defined southerly boundary undercurrent over the slope. Fluctuations are vigorous, and are stronger offshore, both near the surface, and closer to the bottom. Little interaction between the oncoming eddies, which break up father offshore, and the coastal currents.

The Data

The moorings deployed were designed to adequately sample the distribution of currents from the surface to the bottom and from the shelf edge to the bottom of the slope off the western Gulf of Mexico (Figure 2F.6). The shallowest mooring, in 500 m of water at the edge of the shelf, consisted of a single upward-looking 75 kHz (Longranger) ADCP moored at 10 m off the bottom. Three deeper moorings over the 2000 m isobath included one Longranger to sample the surface 500 m of the water column, a second Longranger sampling the transition levels from 800 to 1200 m depth, and a 300 kHz ADCP off the bottom to record motions in the bottom boundary layer. The levels intermediate between the ADCPs were filled with 4 RCM11 Aanderaa acoustic current meters that recorded temperature and salinity in addition to the current components. The deepest mooring, in 3500 m of water, included a similar configuration, but required six Aanderaas to fill the larger gaps between ADCPs. The instruments remained in the water from early September 2004 through late October 2005, a total of 14 months, except for the shallowest mooring, which released prematurely and had to be redeployed in December 2004. Unfortunately, two ADCP sensors malfunctioned, so records are unavailable for the surface of mooring 5 and the intermediate level of mooring 3. Otherwise, data recovery was excellent, and data exist to provide a detailed description of the motions during the deployment.

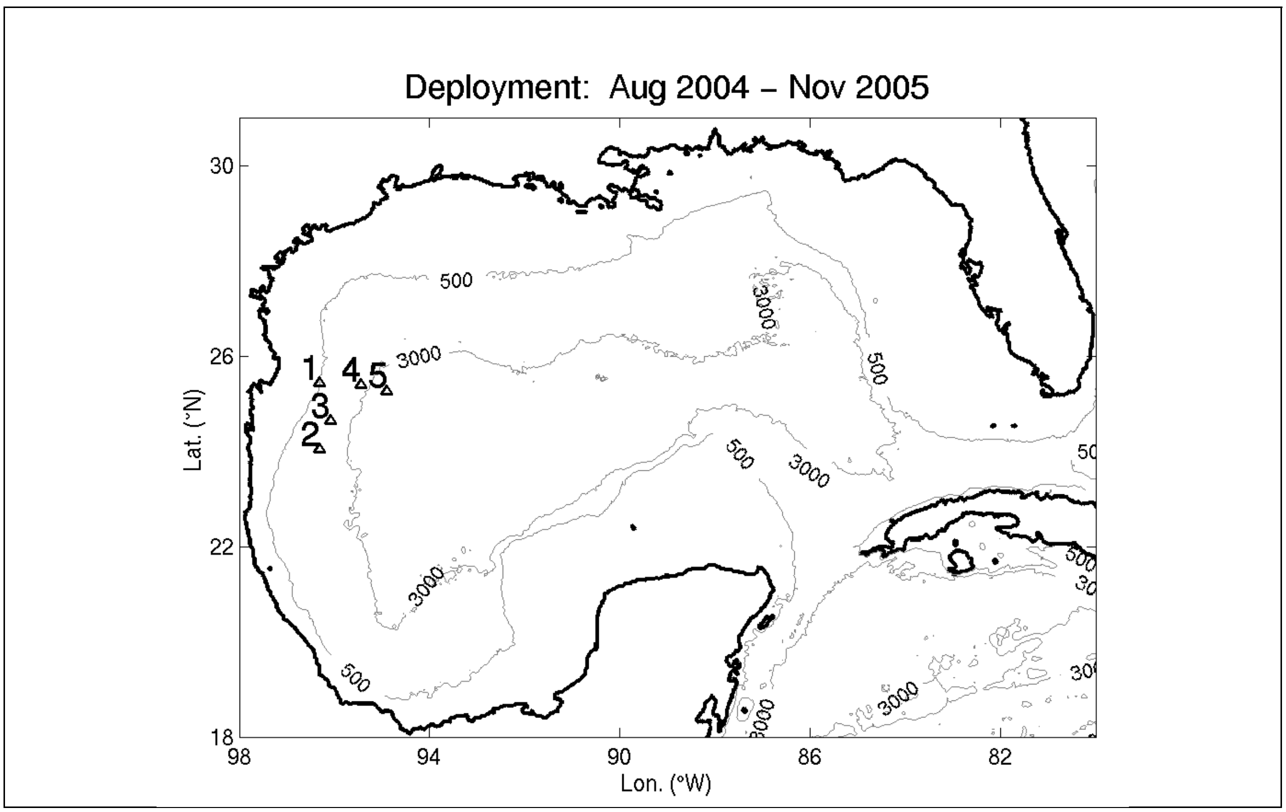


Figure 2F.6. Location of the moorings.

Results

The mean and standard deviations of the currents in the study area are exemplified by the near-surface and near-bottom values shown in Figure 2F.7. Near the surface (no sensor on mooring 5), the mean currents are to the north along the topography and progressively offshore. The current fluctuations are more elongated off the shelf and largest offshore. In the two southernmost moorings, the fluctuations are across the topography. For the sensors at 30 m off the bottom, the mean currents flow to the south, with a clear signature of a southerly current above the slope and shelf. Current fluctuations are strongly aligned with the topography and are largest off the edge of the shelf in 500 m of water, and at the deepest sensor in 3500 m of water. Mean currents are everywhere smaller than the standard deviations.

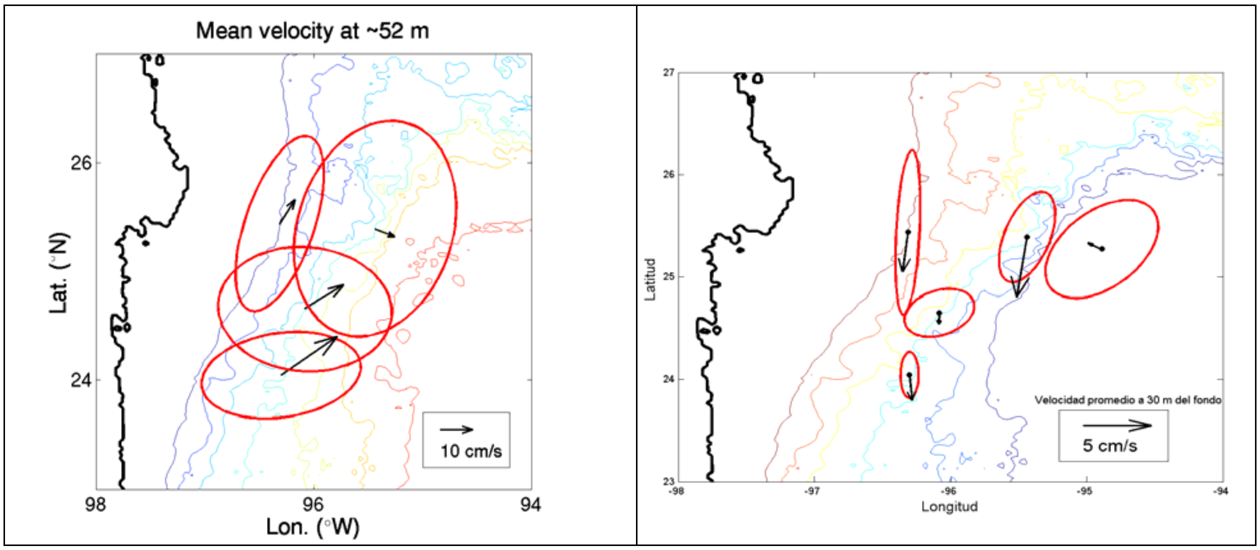


Figure 2F.7. Mean and standard deviation ellipses of the currents in the northwestern Gulf of Mexico.

The time series shows large rotating fluctuations dominate the low-frequency currents, as a result of the passage near the moorings of the large eddies released from the Loop Current, months earlier, which can be followed in the altimetry of the region. As an example, Figure 2F.8. shows the currents over the shelf in 2000 m of water. Near the surface, currents are well related to the altimetry and show large current fluctuations that can be identified with the passage or proximity of large anticyclonic eddies. These fluctuations are detected to depths of almost 1000 m. Closer to the bottom, currents appear much more unidirectional, probably as a manifestation of a southerly undercurrent along the slope. The spectra of motions at various levels on the moorings (Figure 2F.9) indicate a wide distribution of energy, with predominance of low-frequency motions in the 30, 60, and 100-day bands. Some are only marginally resolved, so care should be taken when considering the description of the mean flow.

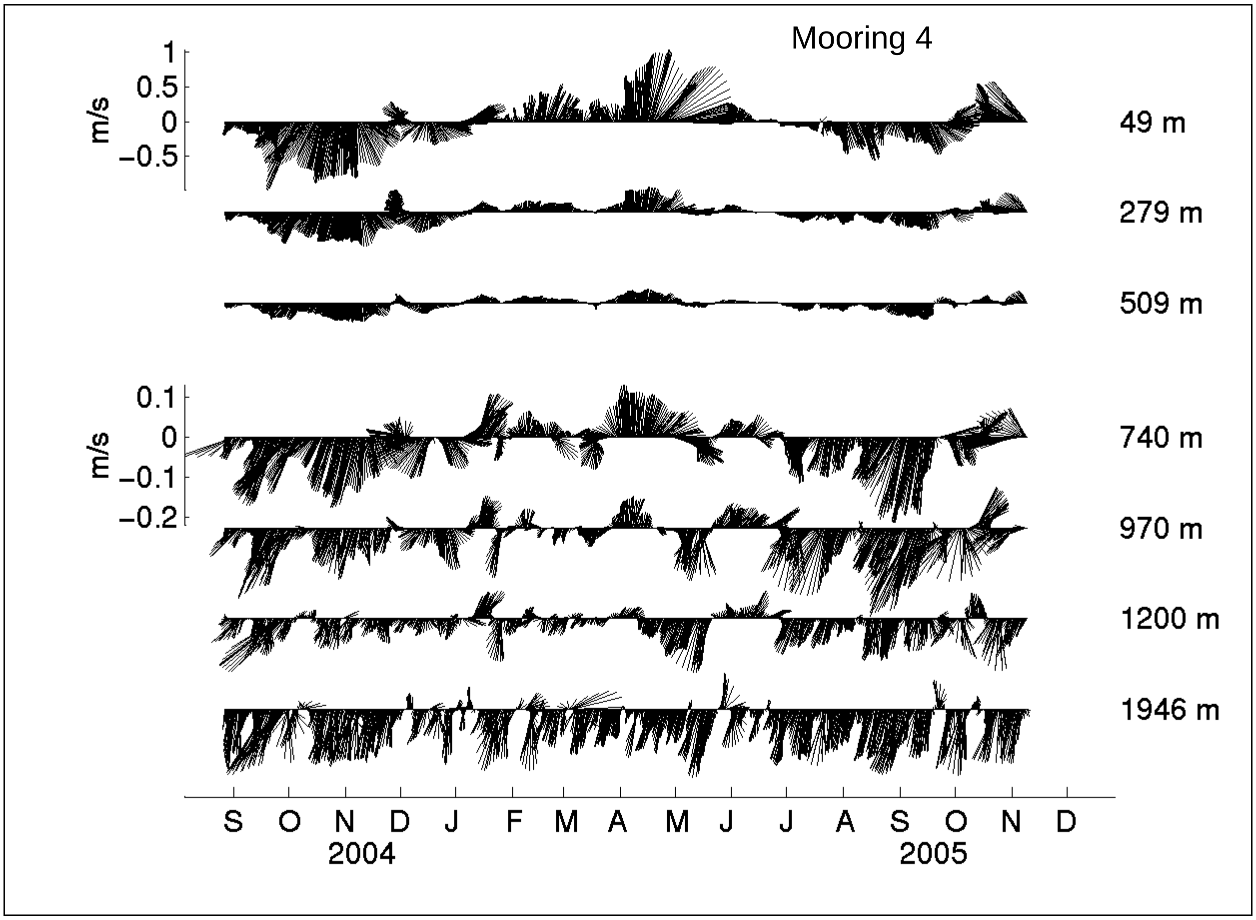


Figure 2F.8. Time series of current vectors at selected levels on mooring 4, in 2000 m of water.

High Frequency Motions

Supra-inertial motions are also quite prevalent in the records recovered form the Northwestern Gulf. As an example, Figure 2F.10 shows the time series of winds from a nearby NDBC buoy that documented the passage of a hurricane over the mooring array. The response in the currents is shown both as time series at various levels in mooring 1 and as time-depth contours of velocity at moorings 2 and 4. The surface layer to at least 500 m depth oscillated vigorously, ringing for over 20 days, or about 18 inertial periods. Various such events are documented in the region throughout the experiment.

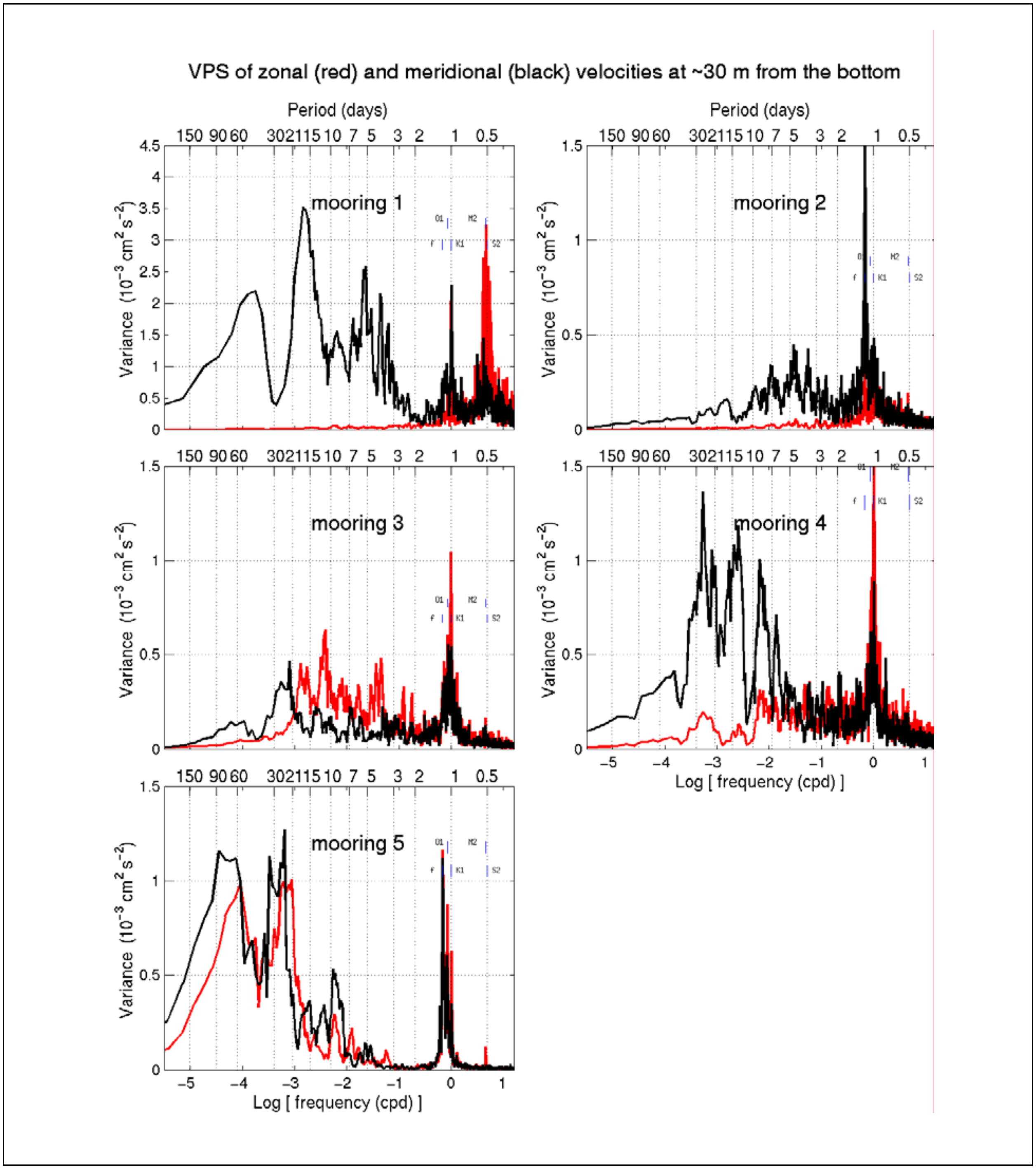


Figure 2F.9. Variance conserving spectra from data at 30 m off the bottom at all five moorings in the NW Gulf of Mexico.

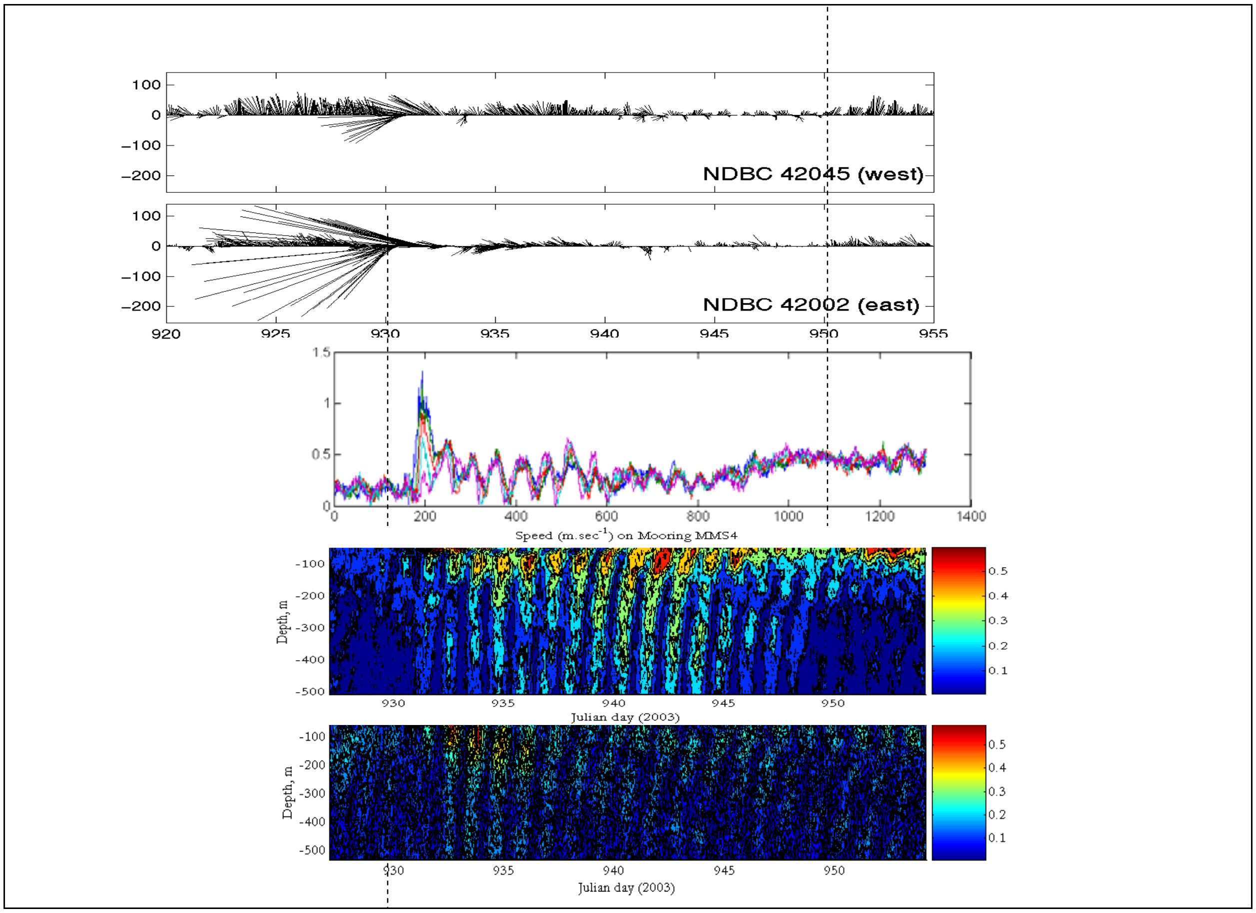


Figure 2F.10. Time series of currents in the surface layer following the passage of Hurricane Emily over the array.

Dr. Antonio Badan has been an Investigador Titular with a major research interest in oceanography at CICESE since 1987. He is a member of the Mexican Academy of Sciences and is a past chairman of the Department of Physical Oceanography at CICESE, with many years of experience in the field of physical oceanography. He received his B.Sc. in oceanography from the University of Baja California, Ensenada, in 1972, his M.Sc. in oceanography from Oregon State University, Corvallis in 1975, and his Ph.D. in physical oceanography from Oregon State University, Corvallis in 1981.

OBSERVATIONS AT 25.5°N AND 87°W: DEEPWATER CURRENTS IN THE EASTERN GULF OF MEXICO

Masamichi Inoue, Susan E. Welsh, and Lawrence J. Rouse, Jr.,
Coastal Studies Institute, Louisiana State University

Click here to view the slide show that accompanied this presentation.

Introduction

In contrast to the upper-layer circulation dominated by the Loop Current (LC) in the eastern Gulf of Mexico (GOM) and the Loop Current eddies (LCE) in the central and western GOM, deep water in the GOM is completely isolated below the sill depths (~1900 m) in the Yucatan Channel. Relatively energetic deep water over the northern slope water region has been attributed to ubiquitous topographic Rossby waves (Hamilton 1990; Hamilton and Lugo-Fernandez 2001; Oey and Lee 2002). Cyclonic eddies in deep water (e.g., Hurlburt and Thompson 1982) have also been suggested as agents of energetic forcing in deep water in various numerical model studies as well as in observations. In order to measure and monitor upstream variability in the eastern GOM, a single deepwater mooring was deployed successfully over four deployments at 25.5°N and 87°W over a relatively flat bottom at 3356 m. The mooring site turned out to be an ideal location for monitoring LC dynamics in the eastern GOM using a single mooring. It remained in the middle of the LC, and it appears to capture strong northward flow in deepwater associated with the formation of LC rings.

Methods

The mooring was equipped with two ADCPs, one upward-looking at 140 m and the other downward-looking at 3200 m, and six Aanderra current meters set at 155, 750, 1500, 2500, 3000, and 3200 m in order to sample the entire water column. The first observation of the upstream condition in the middle of the eastern GOM has been completed with a total of four deployments so far, the first two nearly continuous deployments covering a two-year period (from 31 May 2000 to 3 June 2002), the third one separated by slightly less than 11 months (from 19 April 2003 to 1 June 2004), and the fourth one recently completed (from 29 May 2005 to 15 June 2006).

Results

The observations indicate that the upper-layer flow above 700–800 m was dominated by the LC while the lower-layer flow appears to be generally decoupled from the upper-layer flow. Every deployment turned out to be unique for both upper-layer and lower-layer flow energetics (Figures 2F.11 and 2F.12). This is because the time scales associated with the LC in the eastern GOM are dominated by time scales associated with the formation of LC rings, which has shown to have significant power near 6, 9, and 11 months (Sturges and Leben 2000; Leben 2005). Consequently, one-year observation of currents in the eastern GOM is simply not long enough to capture basic statistics for generalization.

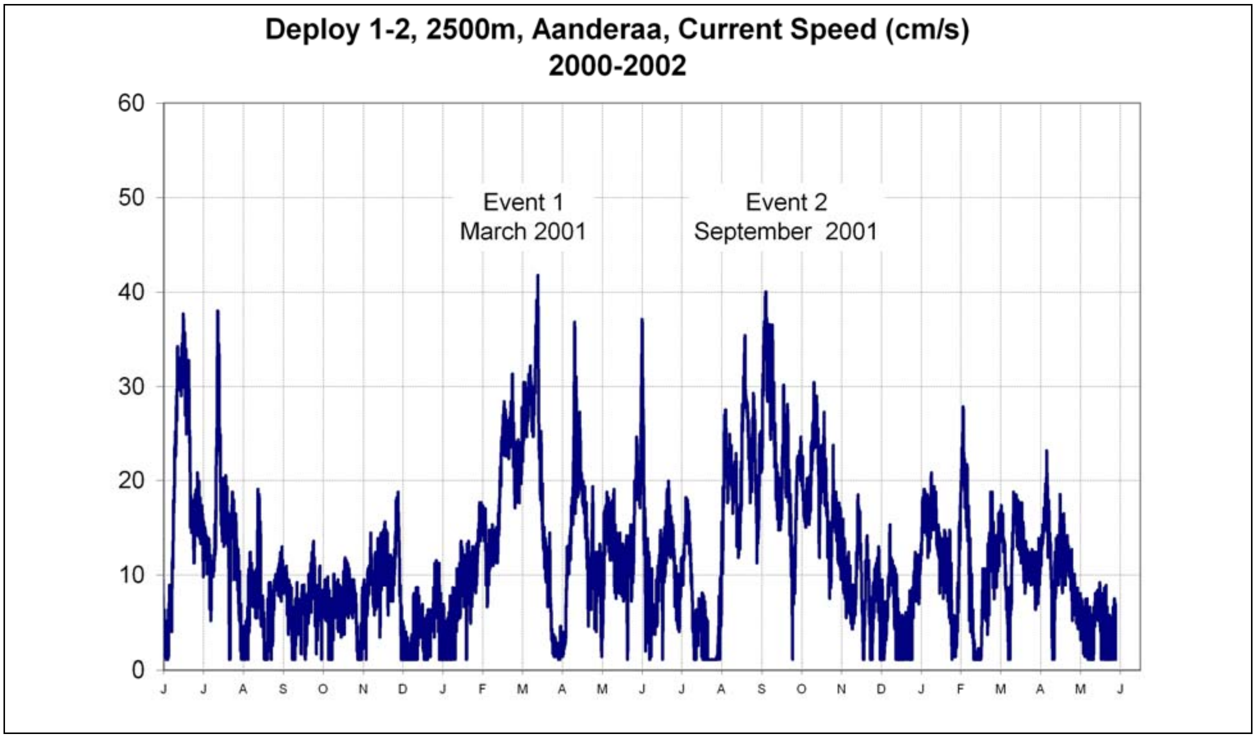


Figure 2F.11. Raw current speed (cm/s) at 2500m during Deployments 1 and 2.

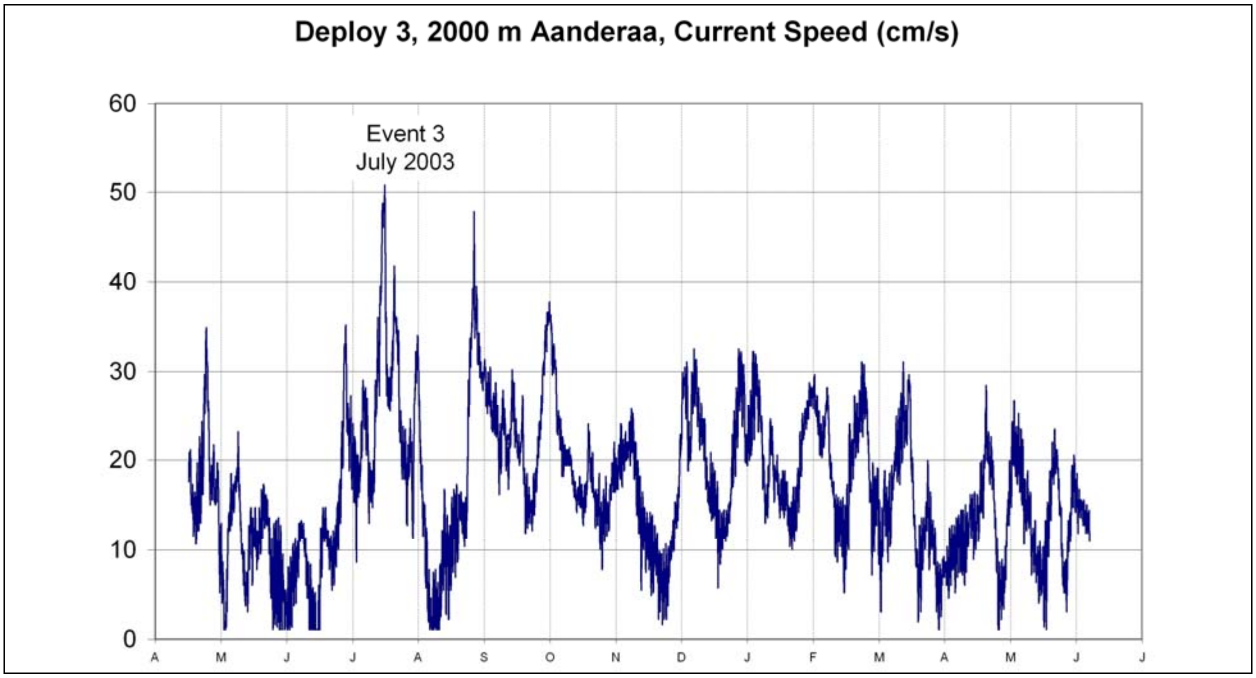


Figure 2F.12. Raw current speed (cm/s) at 2000m during Deployment 3.

In deep water, Deployment 3 exhibits much more energy in terms of background flow strength as well as peak energy levels than other deployments (Figures 2F.11 and 2F.12). A few short-duration energy bursts in deepwater lasting only a few days were observed. The strongest event observed had current magnitude exceeding 1 knot in deepwater during Deployment 3. The three most energetic events observed appear to coincide with concurrent northward extension of the LC, and they preceded the formation of LC rings reported by Leben (2005). The three most energetic events recorded showed very strong northward flow in deepwater regardless of the upper-layer flow. These energetic events were accompanied by significant temperature and salinity signal in deepwater.

It appears that deepwater currents observed at the mooring site could be interpreted as manifestations of the simulated deepwater flow (Welsh 1996; Welsh and Inoue 2000; Welsh and Inoue 2002). The general northward mean deepwater flow pattern measured at the mooring site for each of the deployments fits nicely into the similar mean northward flow simulated in deepwater in the model. The three most energetic events in deepwater observed could be interpreted as manifestation of anticyclones formed in deepwater as part of a modon pair underneath the LC rings (Figures 2F.13 and 2F.14). It is noteworthy that these northward currents were accompanied by the appearance of colder and saltier water at least for two of the three most energetic events during the first three deployments.

Conclusions

The first direct observations of currents in the middle of the eastern GOM suggest: 1) upper- and lower-layer currents are generally decoupled except occasional short-duration energetic events; 2) the most energetic short bursts of deepwater currents were always northward regardless of the upper-layer flow and preceded the formation of LC rings; 3) energetic events in deepwater are often associated with temperature and salinity variability. A major deficiency of previous models is their subdued flow regime in deepwater compared to observations. However, it appears that the present version of the model with 0.075º horizontal resolution with 100 vertical levels can simulate energetic deepwater flow at the mooring site much better than the older versions, so that the observations can be interpreted in greater detail.

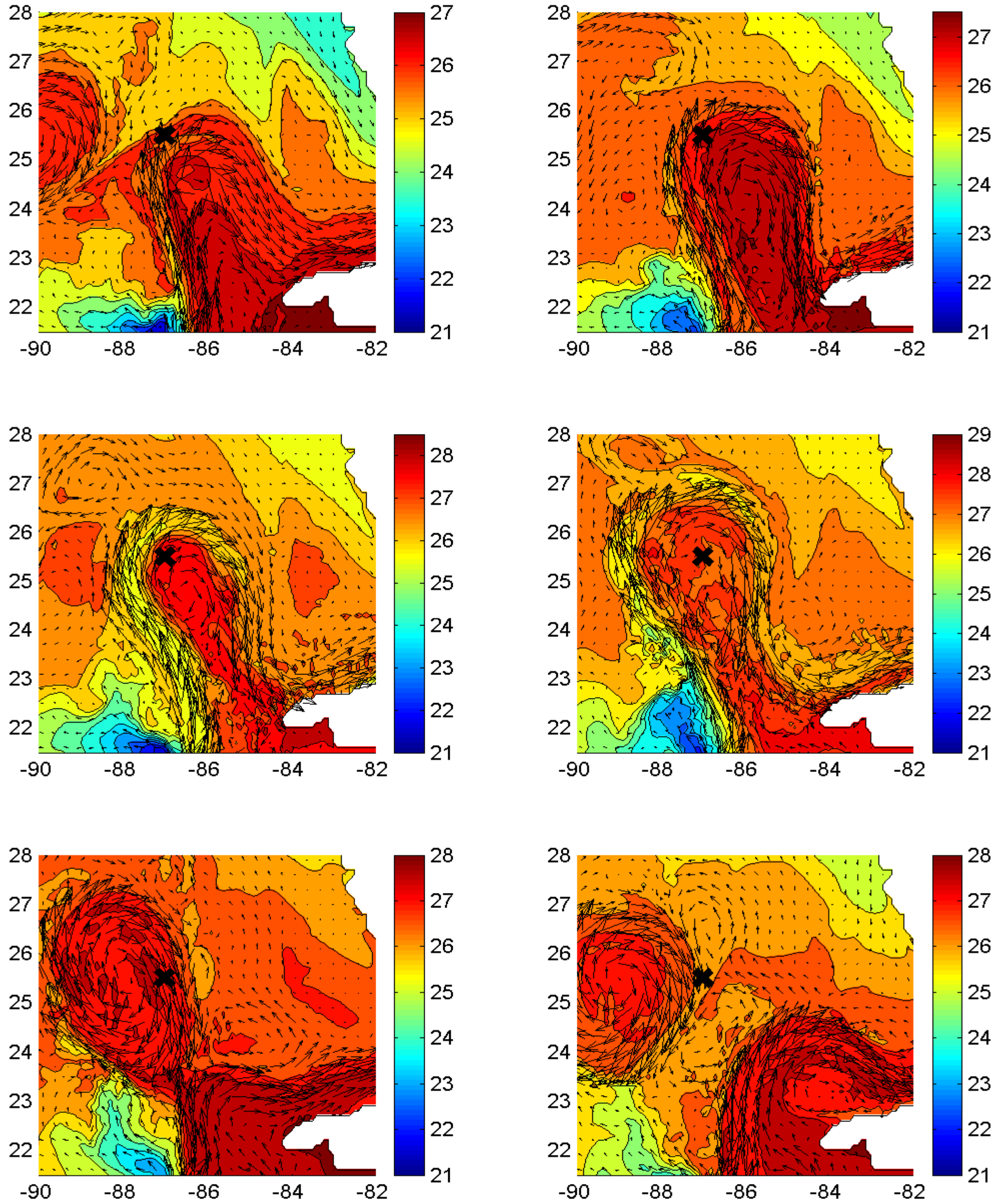


Figure 2F.13. Temperature and velocity vectors at 12.5 m depth in the eastern basin of the Gulf of Mexico for model days: (a) 120; (b) 150; (c) 180; (d) 210; (e) 240; and (f) 270. The 'x' indicates the location of the mooring.

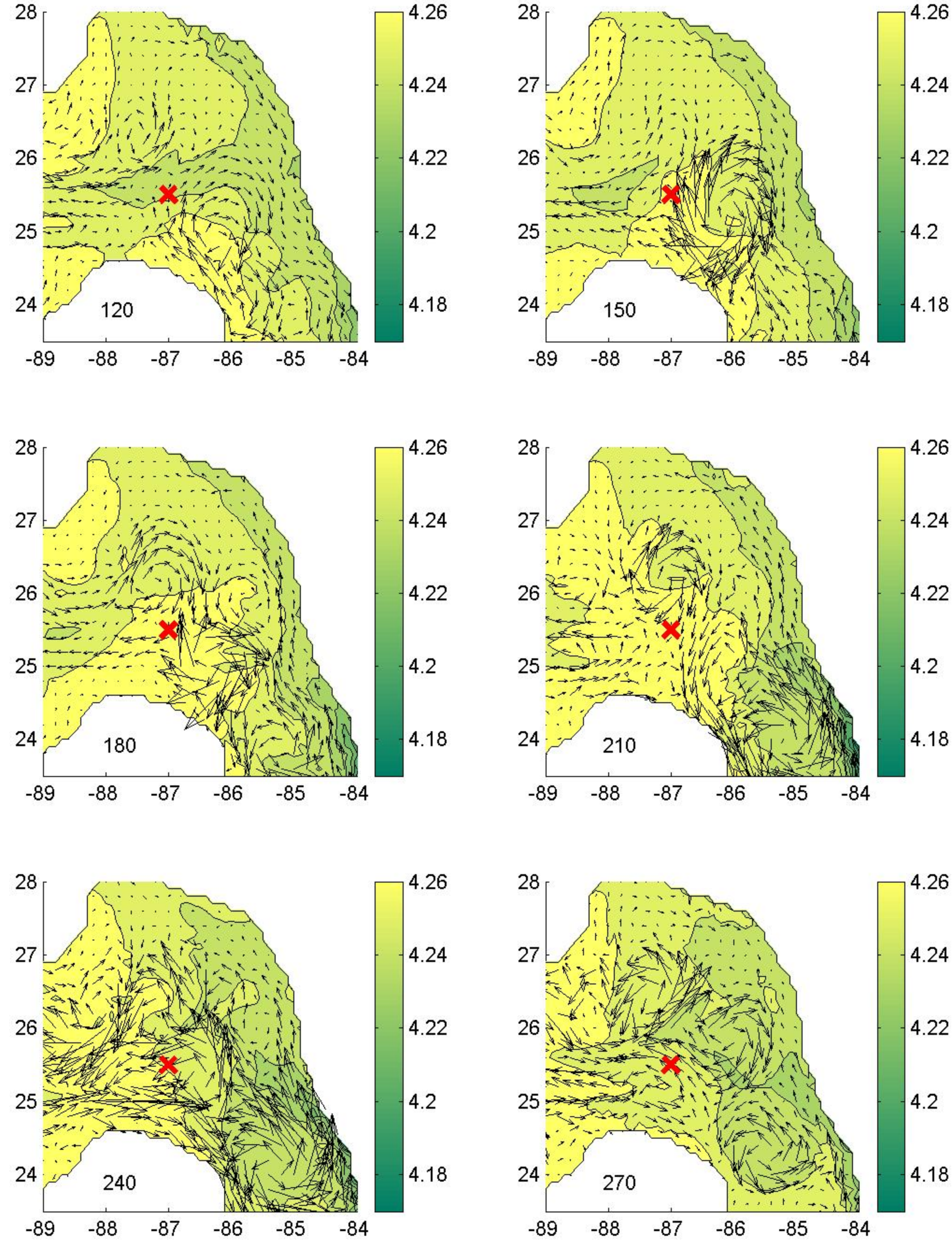


Figure 2F.14. Temperature and velocity vectors at 2500m depth in the eastern basin of the Gulf of Mexico. The model day is marked in the lower left of each figure. The red X indicates the location of the mooring.

References

Hamilton, P. 1990. Deep currents in the Gulf of Mexico. J. Phys. 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. Amsterdam, NY: Elsevier. Pp. 243–298.

Leben, R.R. 2005. Altimeter-derived Loop Current metrics. In Sturges W. and A. Lugo-Fernandez, eds. Circulation in the Gulf of Mexico: Observations and Models. AGU Geophysical Monograph 161:181–201.

Oey, L.-Y. and H.-C. Lee. 2002. Deep eddy energy and topographic Rossby waves in the Gulf of Mexico. J. Phys. Oceanogr. 32:3499–3527.

Sturges, W. and R. Leben. 2000. Frequency of ring separation from the Loop Current in the Gulf of Mexico: A revised estimate. J. Phys. Oceanogr. 30:1814–1819.

Welsh, S.E. 1996. A numerical modeling study of the Gulf of Mexico during present and past environmental conditions. Ph.D. dissertation, Louisiana State University, Baton Rouge, LA.

Welsh, S.E. and M. Inoue. 2000. Loop Current rings and the deep circulation in the Gulf of Mexico. Journal of Geophysical Research 105(C7):16,951–16,960.

Welsh, S.E. and M. Inoue. 2002. Langrangian study of the circulation, transport, and vertical exchange in 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 2002-064. 51 pp.

Dr. Masamichi Inoue has been at Louisiana State University for the past 19 years and is an associate professor in the Department of Oceanography & Coastal Sciences and Director of the Coastal Studies Institute. Previously. he worked at both Florida State University and the Australian Institute of Marine Science. His research interests include ocean circulation and transport processes. Dr. Inoue received his B.E. in naval architecture from Tokai University, an M.S. in ocean engineering from the University of Rhode Island, an M.E. in civil engineering, a Ph.D. in oceanography from Texas A&M University, and an M.A. in higher education from the University of Michigan-Ann Arbor.

LOOP CURRENT, CYCLONES AND DEEP CURRENTS OF THE NORTHERN GULF SLOPE

Leo Oey, Princeton University

Observations show energetic deep motions with characteristics of short-period (5~30 days) topographic Rossby waves (TRWs) at the Sigsbee escarpment in the north-central Gulf of Mexico. In addition to direct forcing, remote forcing by Loop Current and eddy variability has previously been proposed. In this paper, models incorporating the topography of the Gulf (Figure 2F.15), as well as process models, are used to explain the origin and nature of this forcing. It is shown that the slope region immediately north of the Campeche bank where the Loop Current leaves the Yucatan Channel into deep waters of the Gulf is a fertile ground for explosive growth of deeply-penetrated cyclones by baroclinic instability and stretching of the relatively vorticity (Figure 2F.16). Two preferred modes for the subsequent development of these small-scale (diameters ~150 km or less), vertically coherent cyclones (~1000m) are identified. One mode has the cyclones evolved into the relatively well-known frontal eddies or meanders that grow and propagate northeastward and around the Loop Current. The other, more dominant mode "sheds" the cyclones propagating west-northwestward approximately along the 3000m isobath, at speeds 10~20 km/day. These shed cyclones sometimes propagate in concert with shed warm-core rings above. TRW-ray analysis and process model experiments suggest that deep motions with periods shorter than about 20 days at Sigsbee originate from the cyclone birth place as well as from the westward-propagating cyclones, while motions with periods 20~30 days originate in the Loop's growing propagating meanders (Figure 2F.17). The waves are "channeled" onto Sigsbee by a deep ridge located over the lower slope. Additionally, the Sigsbee escarpment focuses TRW rays so that intense currents are produced. It also prevents energetic cyclones from crossing northward, hence depriving energy source for regions north of the escarpment. For very short periods (<H *10 days*), the forcing is a short distance to the south, which suggests that the TRWs are locally forced by cyclones that have intruded upslope, and that most probably have accompanied the Loop or a ring.

Acknowledgments

Support from MMS and encouragements from Alexis Lugo-Fernandez are gratefully acknowledged.

Dr. Oey is a research scholar at Princeton University. He received a B.Sc. from the University of London (1974) and M.S. and Ph.D. from Princeton (1976 and 1978). His interest is in ocean modeling and data analyses. Dr. Oey has served as PI and co-PI of various MMS projects: Gulf of Mexico, Santa Barbara Channel and Cook Inlet Alaska.

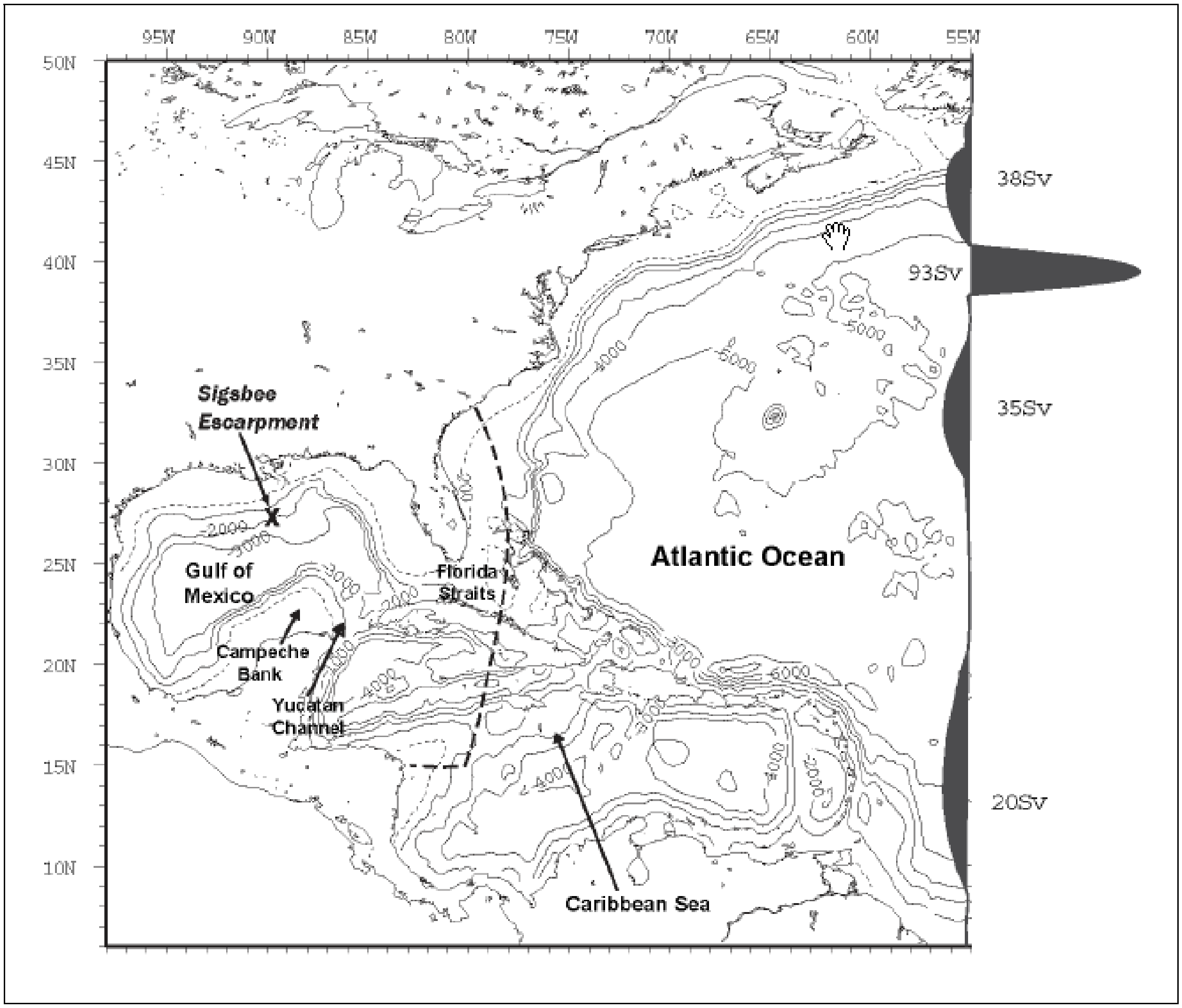


Figure 2F.15. A locator map of the study region. The whole domain shown is the parent model domain. Time-independent inflow and outflow that account for the large-scale transports (Svedrup + thermohaline) are specified across the open boundary at 55oW as a function of latitude. Contours show isobaths in *m*. Dashed lines enclose the nested double-resolution Gulf of Mexico domain.

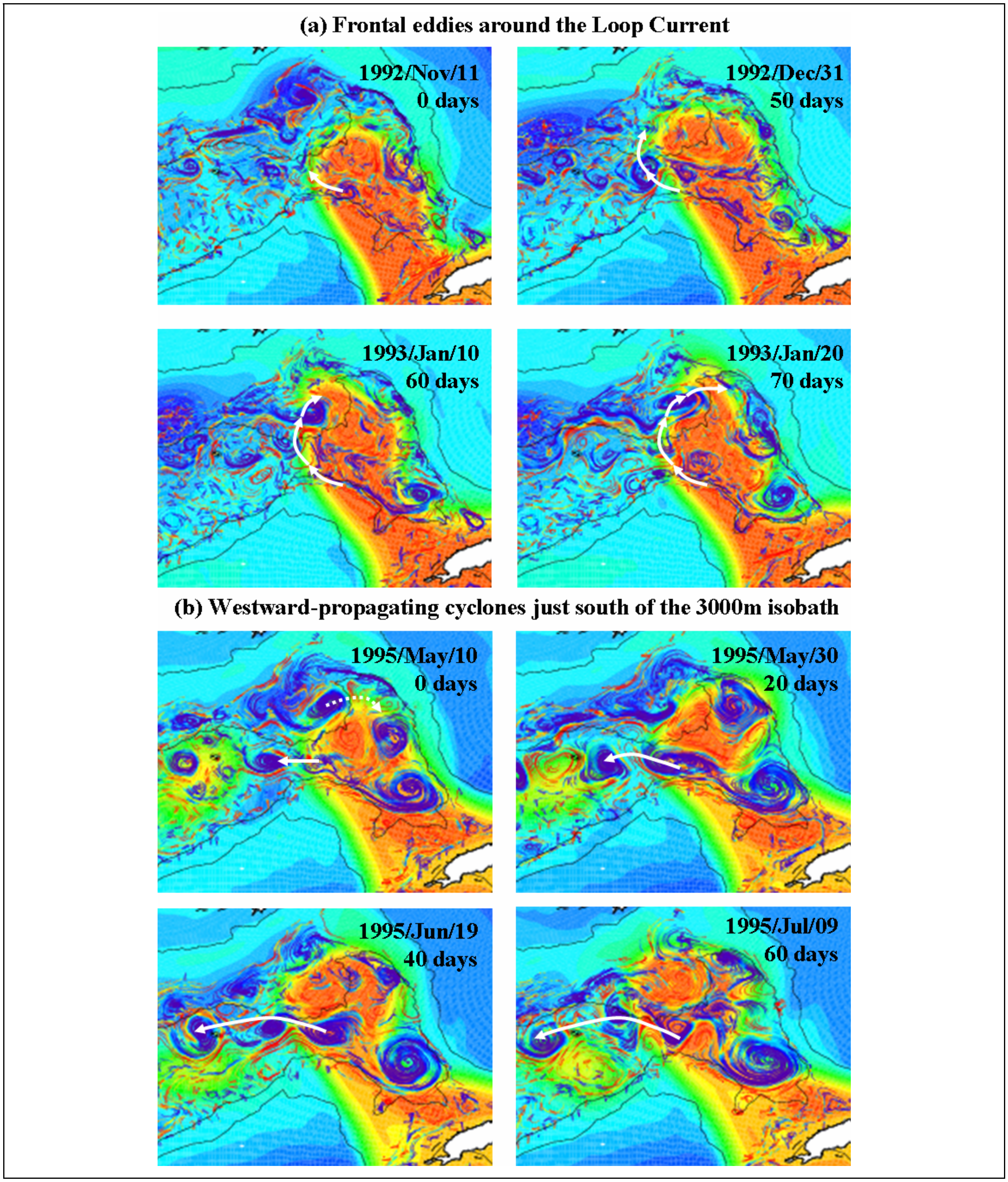


Figure 2F.16. Two paths (white lines) (a) and (b) taken by the cyclone produced north of Campeche Bank, illustrated here by *30-day* trajectories at *z=1500m* released from every *5* grid points and colored with the local value of relative vorticity ∫: blue cyclonic (∫ = *0.2f*, i.e. cyclones) and red anti-cyclonic (∫ = *-0.2f*). Background color is sea-surface height ⏐: red high (⏐ = *0.5 m*) and blue low (⏐ = *-0.5 m*) – it indicates the position of the Loop Current and warm rings.

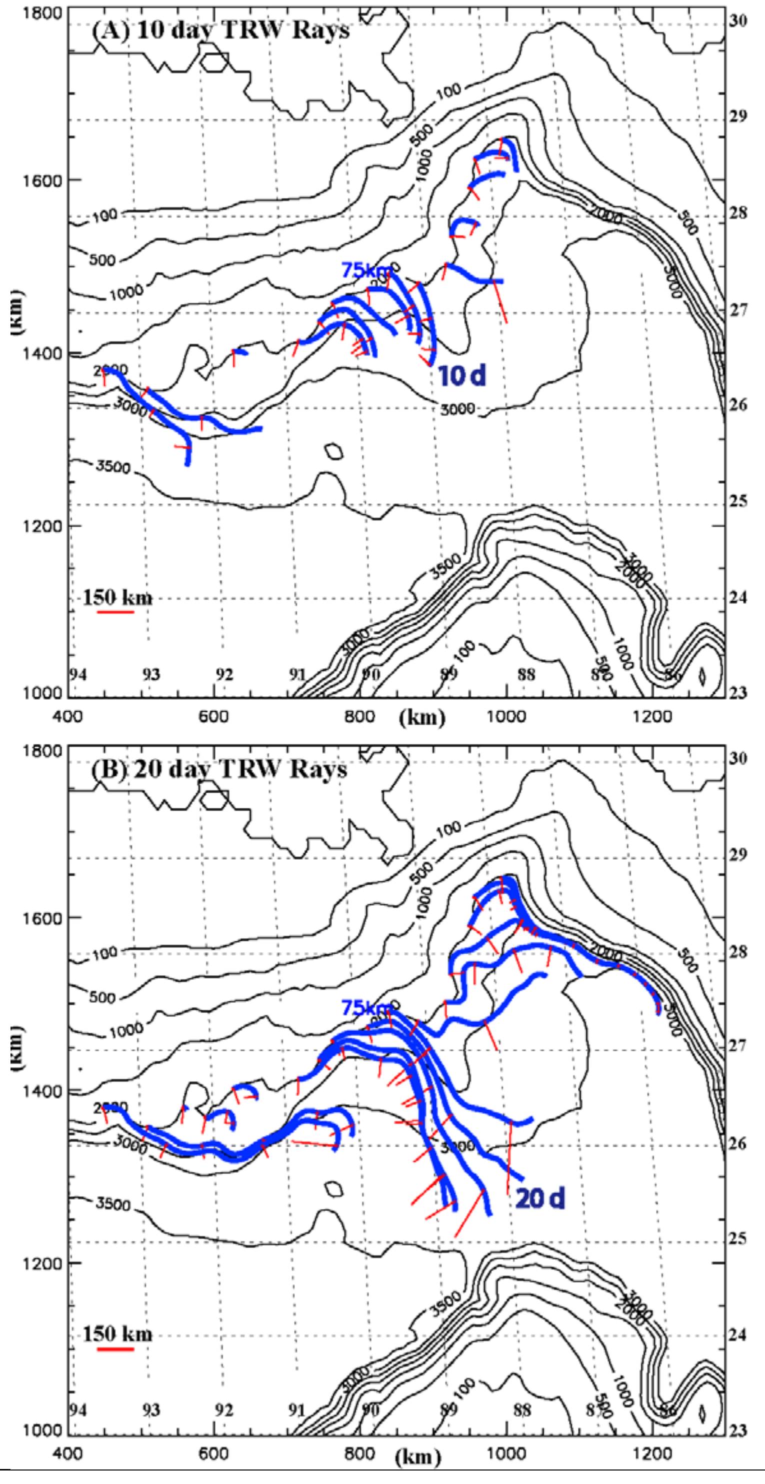


Figure 2F.17. TRW rays (thick blue) traced backward from the *2000 m* isobath with initial wavelength = *75km* (marked over the Sigsbee station) and periods (a) *10 days* and (b) *20 days*. Wave vectors with length proportional to wavelengths are shown in red.

A GULF-WIDE HISTORICAL PERSPECTIVE ON OCEAN FEATURES IN THE GULF OF MEXICO

Robert R. Leben,
University of Colorado, Boulder

Click here to view the slide show that accompanied this presentation.

Introduction

The Loop Current and its associated eddies are the most energetic component of the upper ocean circulation in the deepwater of the Gulf of Mexico (GOM). A gulf-wide historical perspective of these ocean features is required to better understand the context of the MMS deepwater measurement programs along the northern GOM continental slope over the time period from April 2003 through January 2006. Continuous sampling of the sea surface height (SSH) over the GOM since 1993 by satellite altimeters provides this perspective.

Historical Perspective

Processing of the altimeter data is based on a mesoscale altimetric analysis technique (Leben et al. 2002) designed to map SSH to a regular space/time grid over the GOM using multi-satellite sampling. These daily SSH maps are used to derive Loop Current (LC) metrics and systematically track the large anticyclonic Loop Current eddies (LCEs) that separate at irregular intervals from the LC. This extended time series of continuous maps provides a detailed historical perspective on the LC and LCEs over the 13.5-year altimetric record from January 2003 through June 2006.

Loop Current and Eddy Separation

An objective LC tracking technique (Leben 2005) is used to monitor the time-dependent behavior of the LC. This technique automatically tracks the 17-cm SSH contour that follows the edge of the high velocity core of the LC and calculates LC metrics such as extent, boundary length, enclosed area, volume and circulation. Timing of LC eddy separation events are identified using the LC length since the breaking of the 17-cm contour between the LC and a detaching LCE into separate contours causes a discrete change in LC boundary length. The day that this occurs is identified as the time of separation; however, sometimes the detached eddy will reattach to the LC. In those cases the time associated with the ultimate detachment of the eddy is referred to as the eddy separation time. A total of 20 LC intrusions and eddy separation events have been identified. The LC length time series and SSH maps of each of these events at the time of separation are shown in Figure 2F.18.

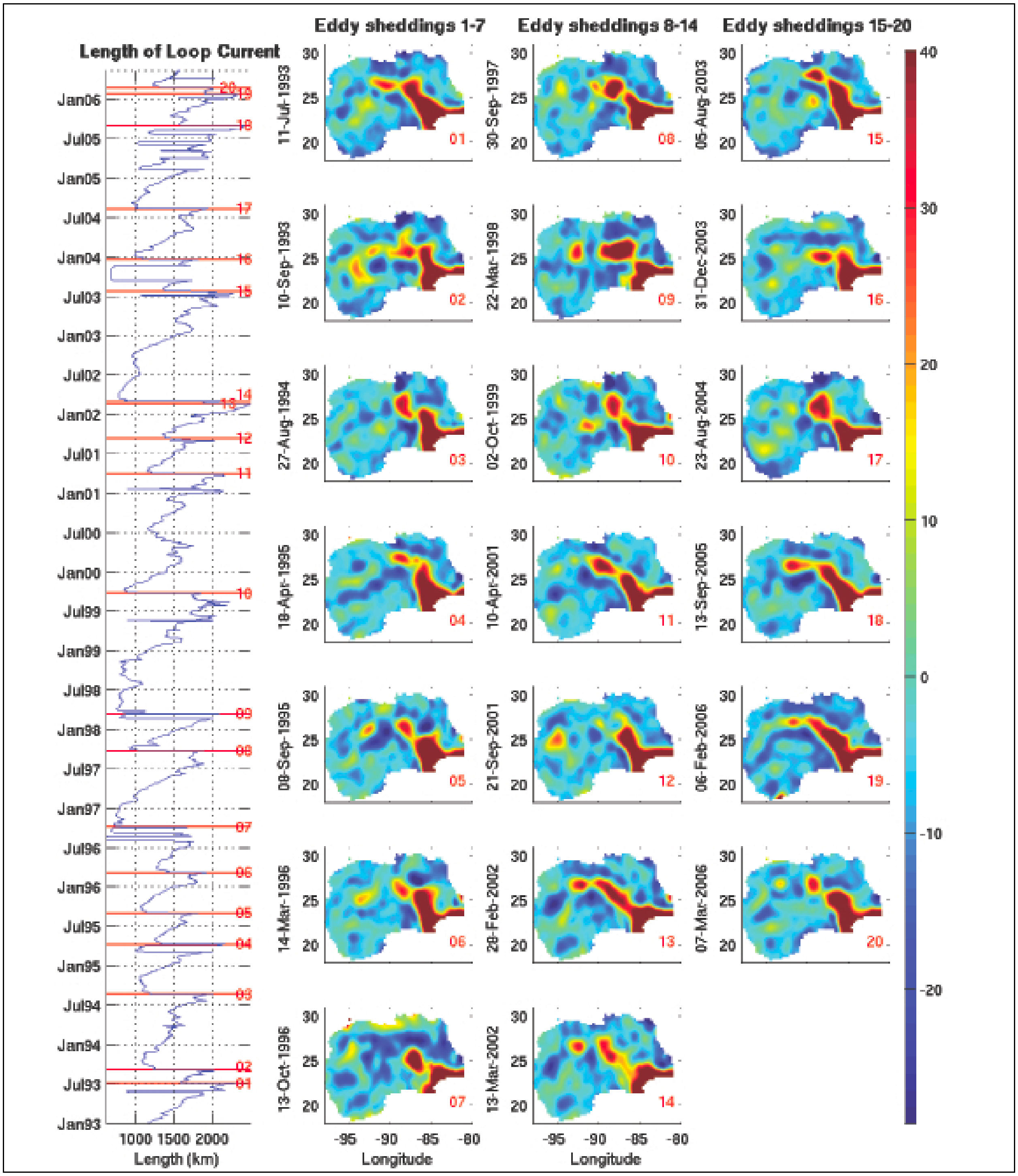


Figure 2F.18. The 20 LC eddy separation events identified in the altimeter record. SSH maps on the separation dates are shown in the panels to the right (note that the values above 40 cm and below 30 cm have been clipped). Eddy separation dates were objectively determined by breaking of the 17-cm tracking contour, which causes a discrete change in the LC length (left panel). The length time series is overlaid with red lines corresponding to the 20 events identified.

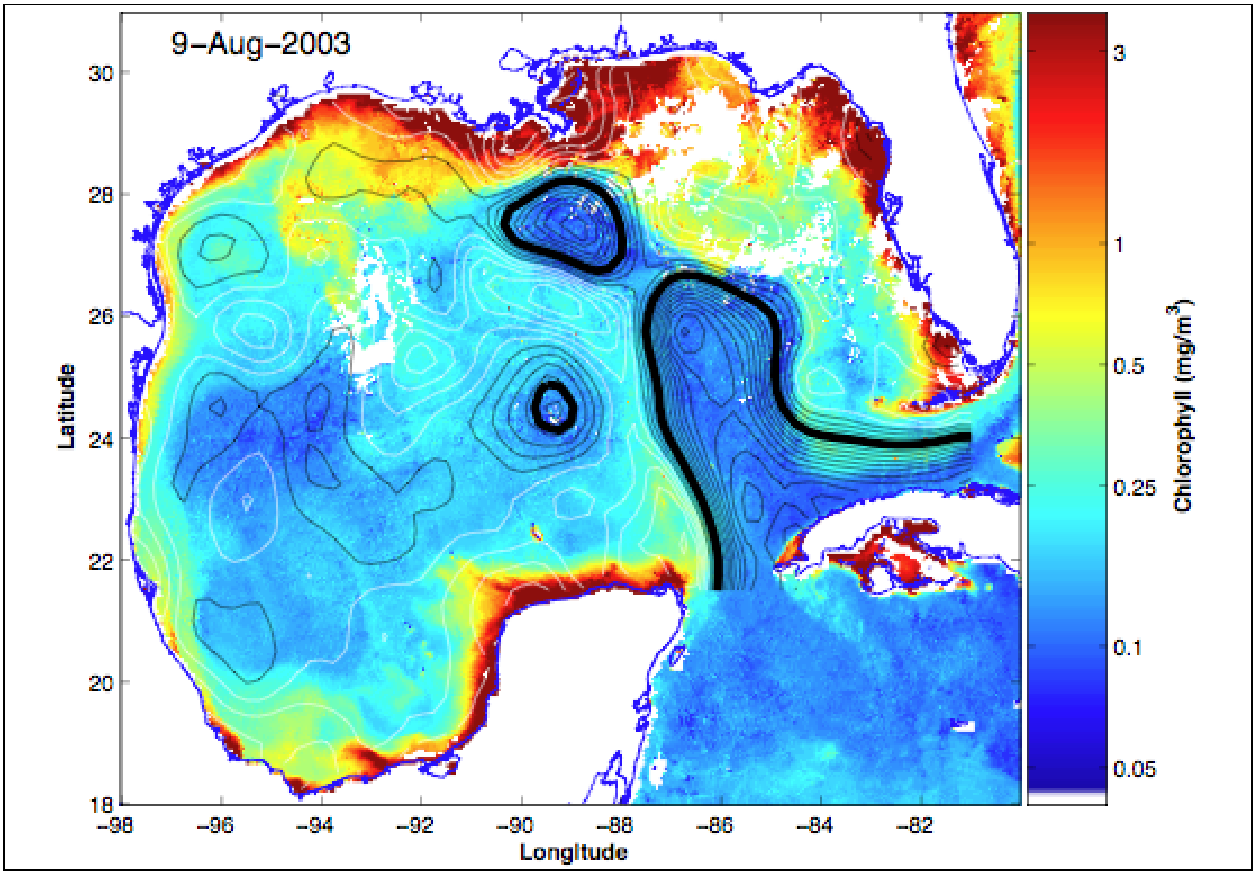


Figure 2F.19. An 8-day composite image of chlorophyll concentration overlaid with the SSH contour map from 9 August 2003 shows the separation of LCE Sargassum from the Loop Current. The SSH contour increment is 5 cm. Black contours are positive and white contours are negative. The 17-cm Loop Current and eddy tracking contour is shown by the thick black line. An unnamed anticyclonic eddy is directly south of Eddy Sargassum.

Loop Current Eddies

Large LCEs associated with eddy separation events are identified by a closed 17-cm SSH contour that forms after an eddy separates from the LC (see Figure 2F.19). A total of 20 LCEs were observed; the separation date, separation period, eddy name and eddy area at the time of separation are tabulated for each of the events (Table 2F.1). Horizon Marine, Inc.

names eddies in alphabetical order as anticyclones separate from the LC and/or impact on offshore operations in the northern GOM. The names appear in the EddyWatch™ reports provided to the Gulf of Mexico offshore oil and gas industry by subscription. All LCEs identified in the altimeter record using the SSH 17-cm tracking contour to date have been monitored by the EddyWatch™ service, although a number of smaller anticyclonic eddies (seven total) were also named, which results in breaks of the alphabetical sequence. Only one marginal eddy separation event is identified by the objective tracking procedure (Eddy Odessa/Nansen, Eddy 12), which dissipated so quickly that an estimate of the eddy area could not be made using the tracking contour. These smaller eddies are of Loop Current origin, but form on the outer edge of the LC

Table 2F.1

Loop Current Eddy (LCE) Separation Events from the Altimetric Record: 1 Jan 1993 through 30 June 2006

Eddy Number	Separation Date	Separation Period (months)	Industry Eddy Name	Area (km^2)	Eddy Maximum SSH (cm)
1	11 Jul 1993	11.5	Whopper	24,183	33
2	10 Sep 1993	2.0	Xtra	38,481	39
3	27 Aug 1994	11.5	Yucatan	43,022	39
4	18 Apr 1995	7.5	Zapp	21,337	36
5	8 Sep 1995	4.5	Aggie	24,899	36
6	14 Mar 1996	6	Biloxi	24,912	32
7	13 Oct 1996	7	Creole	49,644	69
8	30 Sep 1997	11.5	El Dorado	49,229	56
9	22 Mar 1998	5.5	Fourchon	89,143	72
10	2 Oct 1999	18.5	Juggernaut	40,325	39
11	10 Apr 2001	18.5	Millennium	45,705	44
12	22 Sep 2001	5.5	Odessa/Nansen	?	12
13	28 Feb 2002	5.5	Pelagic	22,119	41
14	13 Mar 2002	0.5	Quick	49,936	41
15	5 Aug 2003	17	Sargassum	25,302	49
16	31 Dec 2003	5	Titanic	33,278	43
17	23 Aug 2004	8	Ulysses	68,633	42
18	13 Sep 2005	12.5	Vortex	29,541	38
19	6 Feb 2006	5	Walker	11,366	29
20	7 Mar 2006	1	Xtreme	22,111	37

through interaction of frontal cyclones with the current. Ideally these anticyclones should not be counted as LCEs since they are better categorized as minor, peripheral eddies. Other anticyclonic eddies originate as primary LCEs split and/or form smaller anticyclonic eddies after separation. An example of this type of event is the unnamed anticyclonic eddy that split off from the southwest quadrant of Eddy Sargassum during the final detachment of Sargassum from the LC (Figure 2F.19.)

Instances when LCEs detach and later reattach to the LC are common even when using the stringent detachment definition based on breaking of the 17-cm SSH contour. Eight of twenty LCEs in the altimeter record detach and reattach before final separation according to this criteria. These detachment periods are usually brief, but have been as long as two months. Some LCEs exhibit multiple detachment/reattachment events before separation. After separation from the LC, the LCE propagation paths through the central and western GOM are estimated by tracking closed SSH contours around the eddy core. Climatological LCE pathways proposed by Vukovich (2005) are shown in Figure 2F.20 overlaid with tracking of LCEs Ulysses and Vortex.

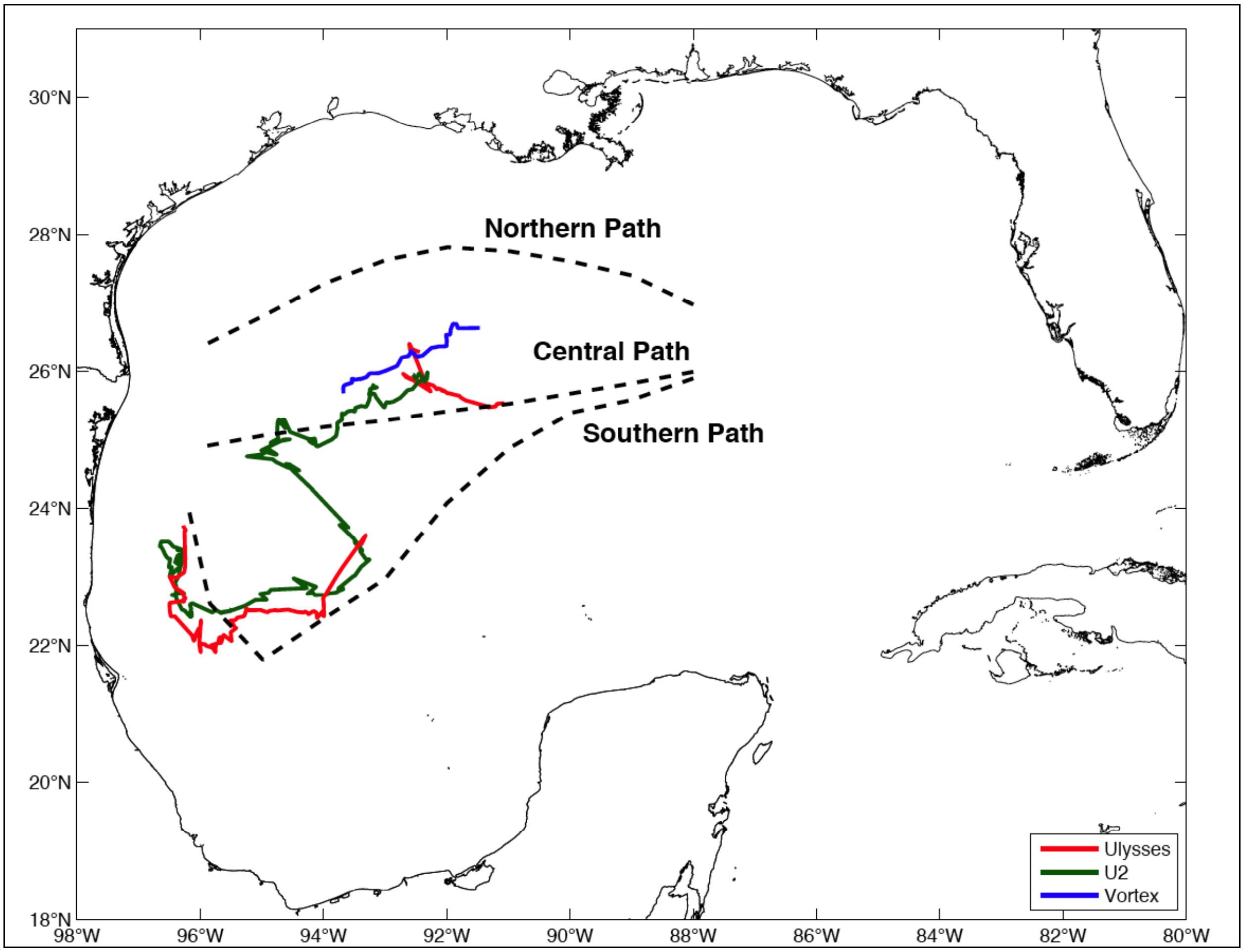


Figure 2F.20. Paths of LCEs Ulysses, U2, and Vortex, during NW Gulf program compared with climatological pathways proposed by Vukovich (2005). The LCE Ulysses split into two eddies in late 2004. The northernmost piece was named U2.

Deepwater Studies in the Context of the Historical Record

The altimeter-derived LC metrics and eddy statistics provide a benchmark to compare Gulf-wide conditions during the MMS deepwater programs' field measurements to those observed in the historical record. A brief summary of the events affecting the study programs and their context in the historical record is provided below. More details can be found in program technical reports such as Donohue et al. (2006).

Exploratory Study (3/2003 – 4/2004)

During this program the study region in the north-central GOM was dominated by circulation associated with two strong LC events, Sargassum and Titanic, which resulted in energetic LC and LCE activity in and around the program measurement array. The overall intensity of the Sargassum and Titanic intrusion events can be put into historical context by comparing the areal extent within the 17-cm tracking contour and maximum SSH height for each eddy at the time of initial detachment from the LC to the same metrics calculated for LCEs at the time of separation

(Table 2F.1). At the time of its initial detachment on 13 July 2003, Eddy Sargassum covered an area of 63,635 km^2 and had a SSH maximum of 54 cm. Eddy Titanic at the time of its initial detachment on 25 September 2003 was 80,034 km^2 and had a maximum height of 73 cm. These metrics would have ranked both Sargassum and Titanic near the top of all LCEs in terms of eddy size and intensity if the eddies had not reattached to the LC. Typically, large detached LCEs reattach to the LC, as was the case for both Sargassum and Titanic. As a result the individual eddies that ultimately separated during the program were relatively compact; however, both were more energetic than LCEs on average based on the maximum SSH within the eddy core. At the time of separation, Sargassum was one of the most northerly LCE separation events while Titanic was one of the more southerly.

The first intrusion of the LC/LCE Sargassum into the array occurred in late March 2003. It subsequently influenced the study region through repeated detachment and reattachment cycles before finally separating in August 2003. The eddy exited from the study area on 20 November 2003. Eddy Titanic detached and reattached to the LC on 25 September 2003 and 28 November 2003, respectively, which was the longest LCE detachment observed in the altimeter record. The detachment and reattachment of Eddy Titanic, however, was remote from the study region. Nevertheless, an energetic companion cyclone to the north of Titanic had a significant influence on the study region. As Eddy Sargassum propagated through the study region, the western margin of this cyclone moved into the eastern part of the array from October through November 2003 behind Sargassum.

Eddy Titanic separation occurred on 31 December 2003. The eddy propagated directly westward after separating from the LC with the majority of the eddy remaining south of the study region. In January 2004, the eddy elongated into an elliptical shape and rotated clockwise, passing the northern flank of the eddy eastward through the southeast corner of the array. Throughout February 2004, the eddy was entirely south of the array. The surface flowfield within the array was dominantly cyclonic with a large -15 cm amplitude cyclone of unknown origin positioned near the center of the array. In March, the elongation and rotation of Eddy Titanic again brought the northern edge of eddy into the array, this time in the southwest corner.

Northwest Gulf Study (3/2004 – 10/2005)

During this program a single strong LCE event, Ulysses, impacted the circulation within the study array. At the time of separation Eddy Ulysses was the second largest LCE in terms of area covered of the 20 LCEs observed in the altimeter record. A piece of Eddy Ulysses, which was named U2 by Eddywatch™, reached the program measurement array in the far northwestern corner of the GOM deepwater basin in November 2004 when Eddy Ulysses split in two as it collided with a strong cyclonic eddy centered on the program moorings in Mexican waters in the southern part of the array. Detailed observations of large eddy splitting events are relatively rare. Only one other splitting of an LCE by a deepwater cyclonic eddy in the western Gulf has been reported (Biggs et al. 1996). Eddy U2 influenced the circulation in and around the study area until April 2005 when it merged with what remained of Ulysses. By the end of May, the reorganized anticyclonic eddy propagated east and south out of the study region as it was pinched between strong cyclonic circulation on both its southern and eastern margins.

Historically, direct propagation of a LCE into the NW Gulf study region is relatively rare. More typically LCE eddies arrive in this region only after significant interaction with the Mexican continental slope and/or the ambient eddy field. In fall of 2006 Eddy Vortex followed a similar direct path, but arrived at the array just as the last moorings were recovered. Eddy Vortex was one of the most westward separation events observed in the altimeter record. A summary plot of the eddy paths during the program is shown in Figure 2F.20 along with the proposed LCE pathways determined by Vukovich (2005).

Eastern Gulf Study (1/2005 – 1/2006)

During this study program Eddy Vortex detached and reattached four times from the LC based on the SSH maps 17-cm contour before ultimately separating on 13 September 2005. The initial detachment was on 21 February 2005 after the reintrusion of the LC into the northern GOM six months after separation of Eddy Ulysses. The detached eddy reattached to the LC on 12 April 2005. Three brief detachments of one to two weeks duration occurred on 14 May 2005, 16 Jun 2005, and 21 August 2005. The extended intrusion of the LC into the northern GOM was one of the most northerly in the record, only exceeded by an intrusion associated with Eddy Sargassum during the Exploratory Study. The far northerly intrusion of the Loop Current and Eddy Vortex also contributed to the intensification of Hurricanes Katrina and Rita. After the separation of Eddy Vortex, the LC remained intruded into the northern GOM affecting circulation in the measurement array throughout the remaining duration of the study. Instruments were retrieved in January 2006. The next two LCEs, Walker and Xtreme, separated on 6 February 2006 and 7 March 2006, respectively.

Summary

It is simplistic to characterize the gulf-wide oceanographic conditions associated with the LC and LCEs impacting the study regions as unique during the recent MMS-funded deepwater programs. Nevertheless, the LC and/or LCEs in and around the measurement arrays were very energetic and were some of the most westerly and northerly intrusions observed in the altimetric record. In each case the yearlong studies encountered conditions that would not typically be observed in one-year time intervals. The conditions, however, were not so atypical that statistics computed over each of the study time periods would be remarkably different from the long-term average computed over the 13.5-year altimeter record. Still, care must be taken when interpreting the measurements collected given some of the extreme events sampled during these programs.

References

Biggs, D.C., G.S. Fargion, P. Hamilton, and R.R. Leben. 1996. Cleavage of a Gulf of Mexico Loop Current eddy by a deep water cyclone. J. Geophys. Res. 101(C9):20,629–20,642.

Donohue, K., P. Hamilton, K. Leaman, R. Leben, M. Prater, D.R. Watts and E. Waddell. 2006. Exploratory study of deepwater currents in the Gulf of Mexico, volume II: Technical report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2006-074. 399 pp.

Leben, R.R. 2005. Altimeter-derived Loop Current metrics. In: Sturges W. and A. Lugo-Fernandez, eds. Circulation in the Gulf of Mexico: Observations and Models. AGU Geophysical Monograph 161:181–201.

Leben, R.R., G.H. Born, and B.R. Engebreth. 2002. Operational altimeter data processing for mesoscale monitoring. Marine Geodesy 25:3–18.

Vukovich, F.M. 2005. Climatology of ocean features in 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 2005-031. 58 pp.

Dr. Robert R Leben received his B.S., M.S., and Ph.D. in aerospace engineering sciences from the University of Colorado, Boulder. Since 1986, he has been employed at the Colorado Center for Astrodynamics Research at the University of Colorado, Boulder, where he is a research professor. His research interests include satellite altimetry and its application to monitoring ocean circulation. He has served as a satellite oceanographer on many MMS programs in the Gulf of Mexico.

DEEPWATER CURRENTS OVER THE NORTHERN SLOPE, BELOW 1000 M, FROM MOORINGS AND DRIFTERS

Peter Hamilton, Science Applications International Corporation

Click here to view the slide show that accompanied this presentation.

Introduction

The database of deep current observations has had recent major additions from several MMS studies over the lower slopes and abyssal depths of the northern Gulf. The mooring positions are given by the dots in Figure 2F.21 with the indicated studies being the Eastern Gulf (*E*: 4 moorings, January 2005 – January 2006), Exploratory Program (*X*: 19 moorings, March 2003 – April 2004), Northwestern Gulf (*W*: 13 moorings, April 2004 – June 2005), Mexican sector (*C*: 1 mooring in the central Gulf, May 2003 – August 2004, and 5 moorings in the western Gulf, September 2004 – November 2005), and Western Loop Current (*L*: 1 mooring, April 2003 – June 2004). The Exploratory program also deployed deep RAFOS lagrangian floats at depths below 1000 m. In the central and western Gulf, the moorings have shown that there are bottom intensified low-frequency fluctuations with periods of ~10 to 60 days that are highly coherent in the vertical for depths greater than ~800–1200 m. These motions are characteristic of Topographic Rossby waves (TRWs) as shown by Hamilton (1990), Hamilton and Lugo-Fernandez (2001), and Hamilton (2007). Analyzed wavelengths are generally in the range of ~70 to 200 km and group speeds of order 10 to 20 cm/s are prevalent. Modeling studies (Oey and Lee 2002) indicate that energetic fluctuations in the lower layer are generated by Loop Current (LC) fluctuations and also westward translating anticyclones (LC eddies) shed from the LC. However, the mechanisms for the generation of TRWs by the LC or LC eddies have not yet been clearly observed or elucidated from model and theoretical studies. Model studies have also shown that westward translating LC eddies may generate a companion lower-layer cyclone/anticyclone pair that remain coherent into the far western Gulf (Welsh and Inoue 2000). These lower layer eddy-like circulations have not yet been observed, and present indications from the observations are that if such deep eddies are generated by a LC eddy shedding event, then they may disperse into more rapidly propagating TRWs.

Statistics

Figure 2F.21 shows the mean and standard deviation ellipses calculated for 40-HLP current records at generally 100-m above the bottom, where the water depth is greater than 1000 m. Records are at least one-year long with the western Gulf having ~15-month durations. At some locations, the height above the bottom is 500 m; however, these are all in water depths greater than 2000 m, and because the currents are nearly depth independent in the lower part of the water column, the statistics are not significantly affected, when compared with the 100 m above the bottom level. Means are generally anticlockwise with enhanced flows at the base of the slope ~2000–2500 m where the topographic slope is step. This generally corresponds to the base of

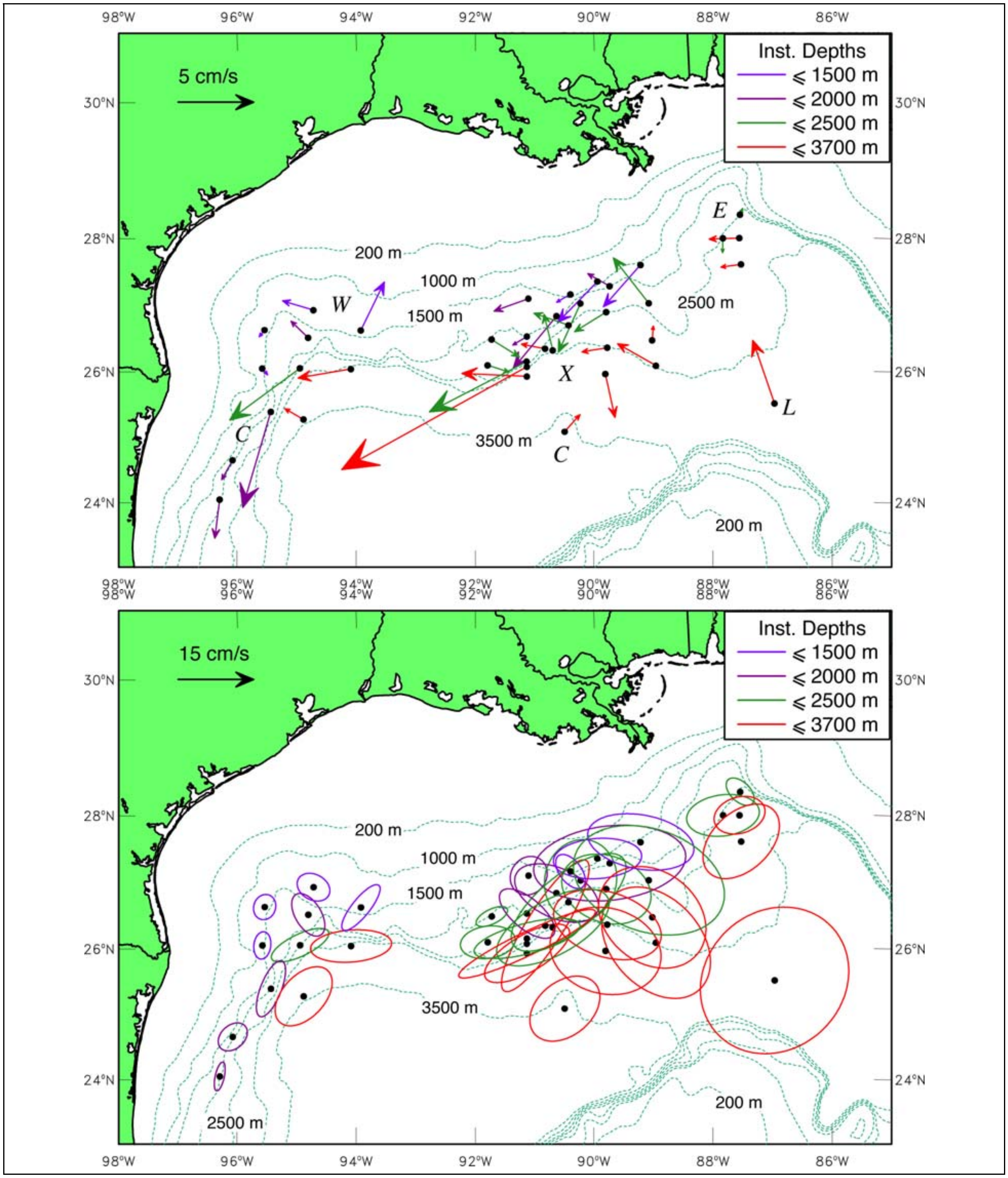


Figure 2F.21. Mean (top) and standard deviation ellipses (bottom) of 40-HLP currents at 100 to 500-m above the bottom from recent MMS studies (see text). The mooring locations marked by a color (not black) dot are used in Figure 2F.24.

the Sigsbee Escarpment in the central and western Gulf. In the central Gulf, there is a strong mean jet directly above the steepest part of the escarpment slope around 91°W, where maximum speeds are ~12 cm/s. This is the only location, to date, where an array of bottom current meter moorings was placed across the escarpment (the SEBCEP array, which was industry's contribution to the Exploratory program). Most of the other moorings were above or below the escarpment. Nevertheless, it is clear there is an enhanced clockwise flow in the central and western parts of the northern Gulf along the escarpment. The means also indicate that flows converge towards the escarpment, particularly on the deeper basin side both for the Exploratory and Western Gulf studies. The enhanced escarpment mean flows are also observed in the float trajectories. Away from the escarpment, the deep floats tend to oscillate around in the same general area. If they go close to the escarpment, then they move rapidly to the west. Thus, fluctuating TRW flows, which are energetic below the escarpment, have some of their energy converted to mean flows by the reflection mechanism of Mizuta and Hogg (2004) through topographic rectification by the shoaling topography (DeHaan and Sturges 2005).

The eddy kinetic energy, represented by the standard deviation ellipses (Figure 2F.21), has a high degree of spatial variability. The largest magnitudes are on the west side of the LC, represented by "L" and the southeastern part of the Exploratory array. Energy decreases from this region in all directions, including south. The Eastern Gulf array, "E," was situated on the northern edge of the LC front for most of the deployment interval, yet the energy levels are less than for the observations immediately to the west. In the central Gulf below the escarpment, variance decreases towards the west, and there is a further small decrease in the western array, where the highest energies are in the northwest corner for the moorings deeper than 2000 m. There is a sharp reduction in variance above, compared to below the escarpment in both the central and western Gulf. Thus in both the western and central Gulf arrays, there are similar patterns with energy highest at the upstream (in the sense of TRW propagation with shallower water on the right) end with decreasing energy levels in downstream direction and a sharp reduction in energy in the shallower water above the steep topographic feature. Otherwise, the ellipses have their major axes nearly aligned with the topography, particularly where the slope is steep. This is consistent with TRW dynamics.

Figure 2F.22 shows the tracks of two RAFOS floats below the LC. The LC during this period, was extended and in the process of shedding eddy Titanic. The floats are below any direct LC flows. Both floats have both cyclonic and anticyclonic loops and remain in the same general area for the six-months of the record, neither migrating to the western basin nor to the west Florida slope under the east side of the LC. It could be argued that these types of water parcel displacements are characteristic of TRWs, which, to first order, transport momentum but not mass, unlike a true eddy with a closed circulation. The velocities of the drifters are compared with the nearest deep current meter, where the records overlap (Figure 2F.23). They are quite similar in magnitude with the floats having more high frequency content than the velocities from the mooring. This is an indication of the non-linear nature and spatial in-homogeneity of the wave field.

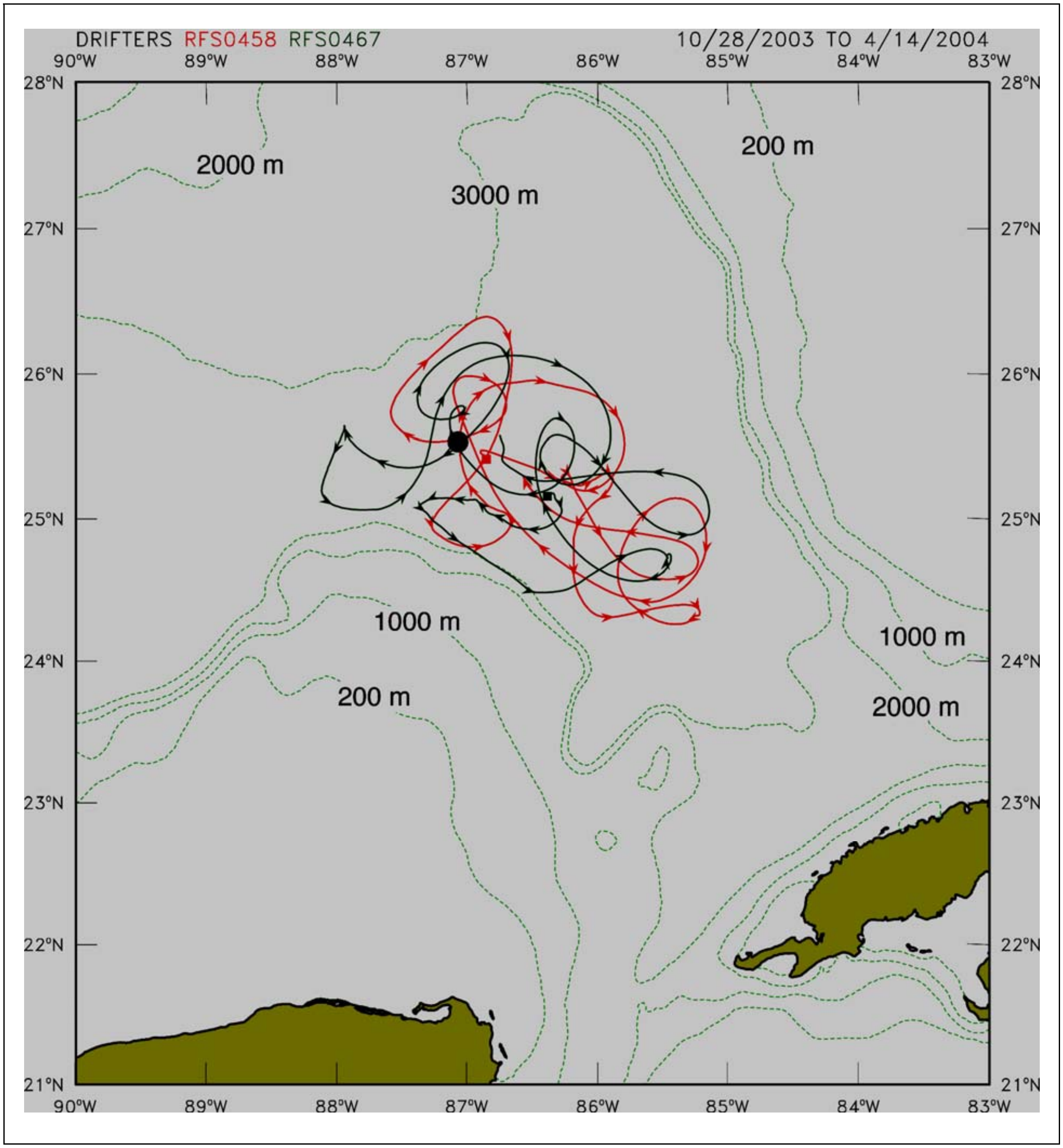


Figure 2F.22. Smoothed lagrangian drifter tracks from two Exploratory RAFOS floats at 1500 m. Arrow heads at 5-day intervals. The black dot is the position of the LSU mooring L07.

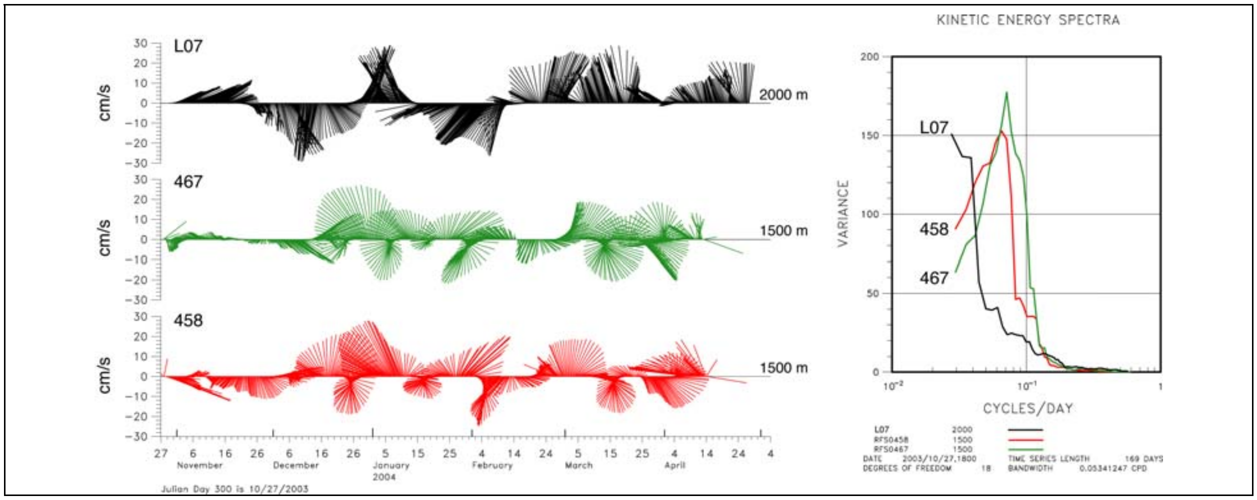


Figure 2F.23. 40-HLP currents from the 2000-m level of mooring L07 (location given in Figure 2F.22), and current vectors derived from the tracks of the two RAFOS floats shown in Figure 2F.22. The RHS shows the KE spectra (in variance preserving form) of these current records.

Spectra

As an illustration of the decay of EKE from east to west, the KE spectra are shown for four moorings (see Figure 2F.21 for locations) that are in the deepest water except for the far western one, with the two central ones (L6 and W3) being approximately on the 3500 m isobath. Note the change of scale between the two plots with the L6 spectra being repeated as a reference. L7 on the west side of the LC has the highest energy levels with prominent peaks at 30- and 50-day periods. L6 and W3 have similar spectral content but much lower energy levels. However, the decrease between L7 and L6 is much greater than between L6 and W3. W2 is at the bottom of the steep Mexican slope and has a peak at 12–14 days. The shifting of spectral peaks with location was noteworthy for the Exploratory currents below the escarpment, with highly energetic high frequency motions (~10 days) in the northeast section, lower frequency motions (~60 days) in the southwest part of the array with relatively smooth changes between the two along the escarpment. The southeast corner of the array had energetic motions at most of the frequencies observed in the rest of the records. It appears that, in the central Gulf, incoming TRWs from the east and southeast with a range of frequencies are reflected and refracted by the escarpment topography which acts as a kind of filter, trapping the 10-day fluctuations in the northeast and allowing the longer period fluctuations to propagate out towards the deeper water in the western part of the Gulf.

Much remains to be explored in developing an understanding of how TRWs propagate through the Gulf and where the preferred generation zones are. The connections to LC and surface layer eddy variability at various scales have yet to be determined. Developing the correct physics of these generation and propagation processes is going to be crucial for nowcast and forecast numerical predictions of deep currents in the Gulf.

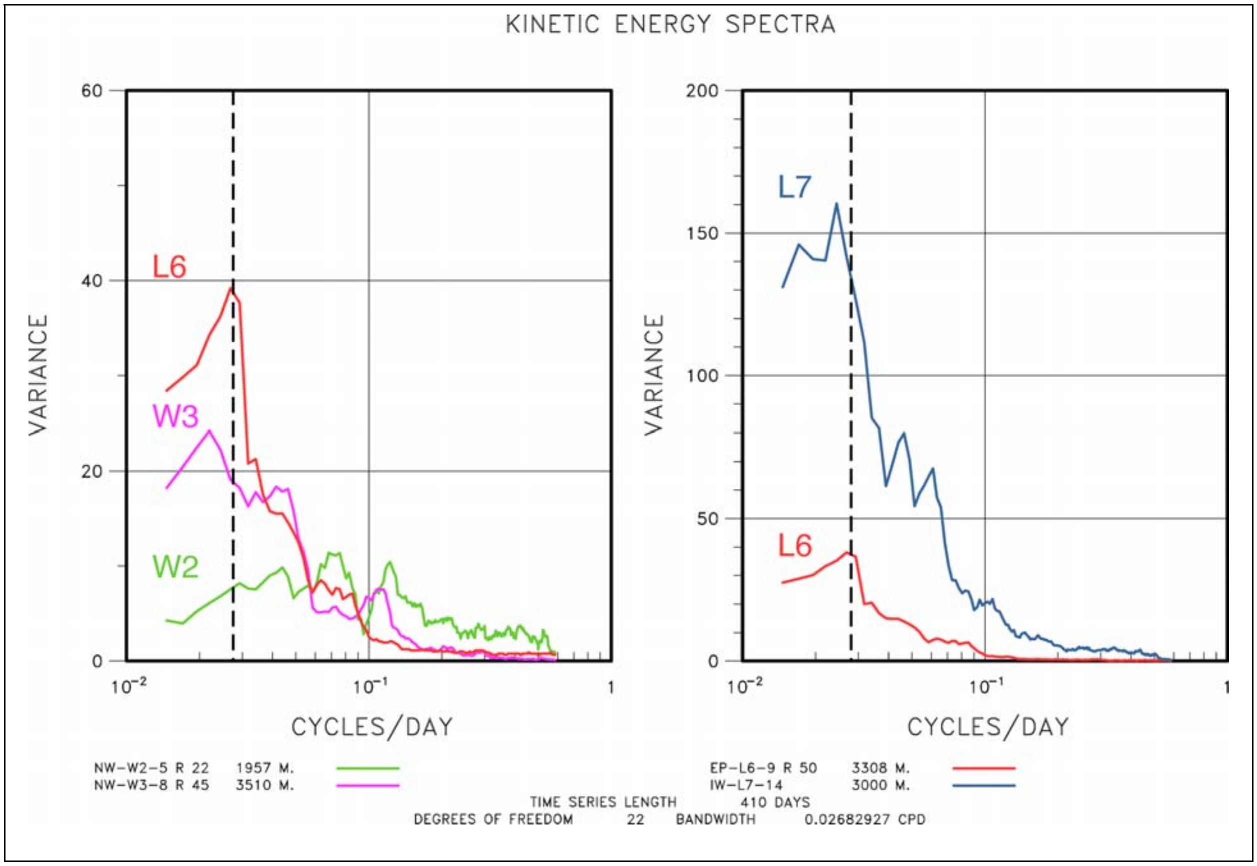


Figure 2F.24. Kinetic eddy spectra in variance preserving form for the near-bottom current records across the center of the Gulf. The mooring locations are color coded the same as plot lines on Figure 2F.21.

References

DeHaan, C.J. and W. Sturges. 2005. Deep cyclonic circulation in the Gulf of Mexico. J. Phys. Oceanogr. 35:1801–1812.

Hamilton, P. 1990. Deep currents in the Gulf of Mexico. J. Phys. Oceanogr. 20:1087–1104.

Hamilton, P. 2007. Deep-current variability near the Sigsbee Escarpment in the Gulf of Mexico. J. Phys. Oceanogr. 37(3): 708–726.

Hamilton, P. and A. Lugo-Fernandez. 2001. Observations of high speed deep currents in the northern Gulf of Mexico. Geophys. Res. Lett. 28:2867–2870.

Mizuta, G. and N.G. Hogg. 2004. Structure of the circulation induced by a shoaling topographic wave. J. Phys. Oceanogr. 34:1793–1810.

Oey, L-Y. and H-C. Lee. 2002. Deep eddy energy and topographic Rossby waves in the Gulf of Mexico. J. Phys. Oceanogr. 32:3499–3527.

Welsh, S.E. and M. Inoue. 2000. Loop Current rings and deep circulation in the Gulf of Mexico. J. Geophys. Res. 105(C7):16,951–16,959.

Dr. Peter Hamilton is a Senior Oceanographer with Science Applications International Corporation, a position he has held since 1979. 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 (U.K.) in 1973 and followed this with a postdoctoral position at the University of Washington.

EDDIES AND CURRENT STRUCTURES FROM SURFACE TO BOTTOM IN THE DEEP NORTHERN GULF OF MEXICO: FULL DEPTH CURRENT FIELDS OVER THE SLOPE IN THE NORTHERN GULF OF MEXICO

Kathleen Donohue and D. Randolph Watts,
University of Rhode Island

Introduction

Three mesoscale-resolving arrays of inverted echo sounders with pressure gauges (PIES) and current meters moorings deployed in waters deeper than 1000 m depth in the Northern Gulf of Mexico measured and coherently mapped currents and eddies daily through the water column (Figure 2F.25). Mineral Management Services funded all three projects. The North Central Gulf array was deployed first in March of 2003 and recovered April 2004. Subsequent deployments were in the North West Gulf (October 2004 to August 2005) and the North East Gulf (December 2004 to January 2005). Science Applications International Corporation (SAIC) led the North Central and North West projects while Evans Hamilton Inc. led the North East project.

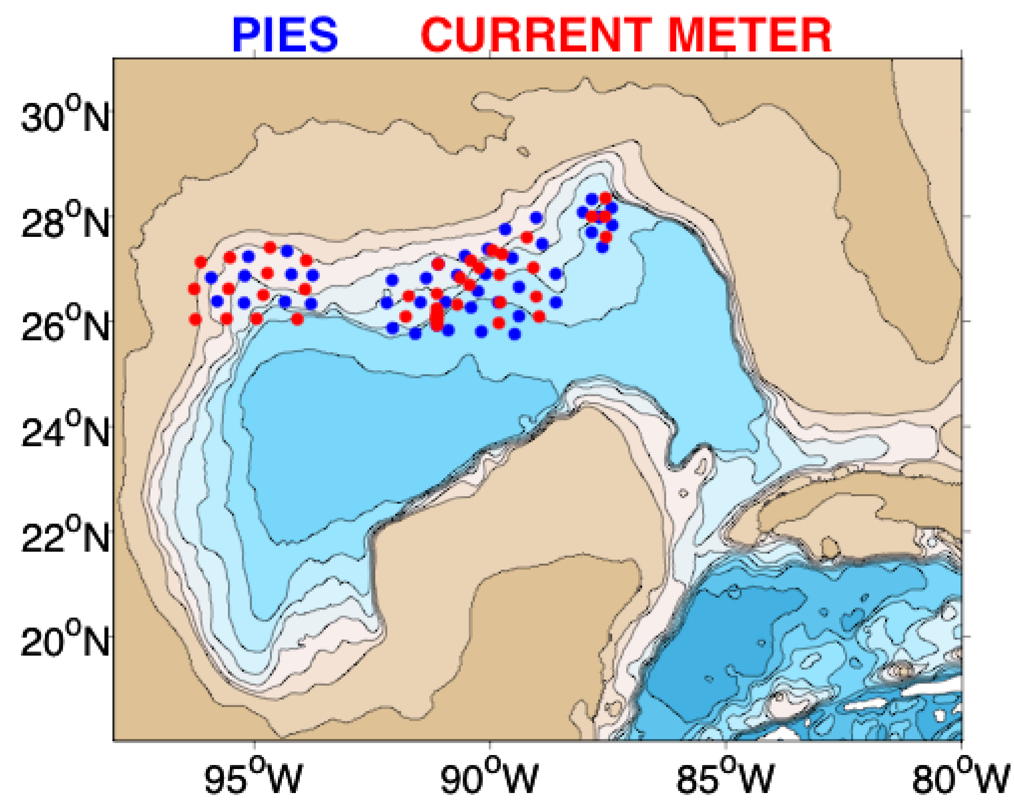


Figure 2F.25. Map of the three MMS-sponsored arrays of inverted echo sounders with pressure gauges (PIES), blue, and current meters moorings, red, deployed in the northern Gulf of Mexico. Bathymetry contoured every 1000m depth.

PIES Methodology

With the three arrays we produced 4-D maps of temperature, salinity, density, and velocity. Round-trip acoustic travel time measured by the inverted echo sounder allowed estimates of vertical profiles of temperature, salinity, and density, utilizing empirical relationships established with historical hydrography. Pressure was leveled via geostrophy using mean current measurements. Deep pressure records combined with estimated horizontal density gradients yielded referenced geostrophic velocities. Maps were produced with optimal interpolation techniques adapted from Bretherton et al. (1976) and outlined in Watts et al. (2001).

Tall moorings provided independent measurements to evaluate our PIES-derived fields of temperature and velocity in each experiment. Comparisons between PIES-estimated and directly-measured mooring temperatures indicate that the empirical relationship holds well in the Gulf of Mexico, the percent variance explained by the PIES in thermocline near 80%. A more stringent test of the PIES methodology and mapping is the comparison with measured velocities since the PIES velocities are second-order quantities determined via differentiation. Again, the agreement between measured and PIES-estimated series was excellent. The average variance explained by the PIES-derived velocity is near 70%.

Currents and Eddies across the Gulf of Mexico

The majority of mesoscale eddy variability in the deep-water northern Gulf of Mexico is related to the Loop Current, Loop Current Eddies and frontal cyclones and strongly affected by the topography of the deep continental slope, especially the Sigsbee Escarpment (Figure 2F.26). In each of the three arrays, the strongest surface currents and eddies outside the Loop Current itself were in Loop Current Eddies. The Loop Current mainly remained outside the reach of the measurements. In the North Central Gulf two Loop Current Eddies, Sargassum and Titanic, passed directly through the eastern portion of the array where they traced to the southwest out of the array. The resulting eddy kinetic energy (EKE) was high in the eastern portion and diminished to the west. EKE is defined as $(1/2)\ [\ (u')^2 + (v')^2\ ]$, $u' = (u - U)$, $v' = (v - V)$ and $(U, V) = (\langle u \rangle, \langle v \rangle)$ and indicates the average over the observation period. In the North West Gulf one Loop Current Eddy, Ulysses, entered its eastern portion while other smaller and weaker cyclones and anticyclones appeared. The resulting EKE was high in the eastern portion and diminished to the west. Loop Current and Loop Current Eddies skirted the southwest corner of the North East Gulf array: surface EKE is not as high as the other experiments.

The strongest deep currents and eddies among these three experiments were found in the North Central Gulf array (Figure 2F.27). Deep eddies entered from the eastern edge and translated west and northwest to impinge upon the Sigsbee Escarpment. The deep currents become concentrated along the steep Sigsbee topography, especially near 90-91W. Most eddies from the deep Gulf do not enter into the region northwest of Sigsbee. We note that region is distinct from the shallower-yet continental shelf. In the North West Gulf the deep eddies were much weaker, but they too were partly steered along the topography. Compared within the North West Gulf array, the deep eddies were more energetic offshore of the 2000m isobath. Deep eddies propagated in from the east and did not appear to originate locally from vertical coupling to the upper ocean. In the

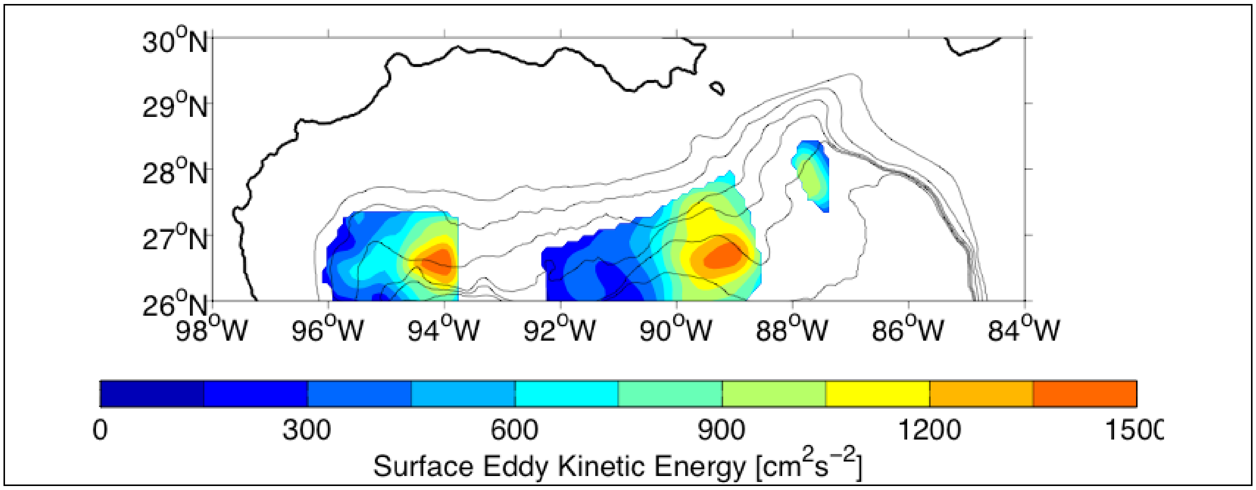


Figure 2F.26. Surface eddy kinetic energy determined from the three PIES arrays in the northern Gulf of Mexico. Bathymetry is contoured every 1000 m depth.

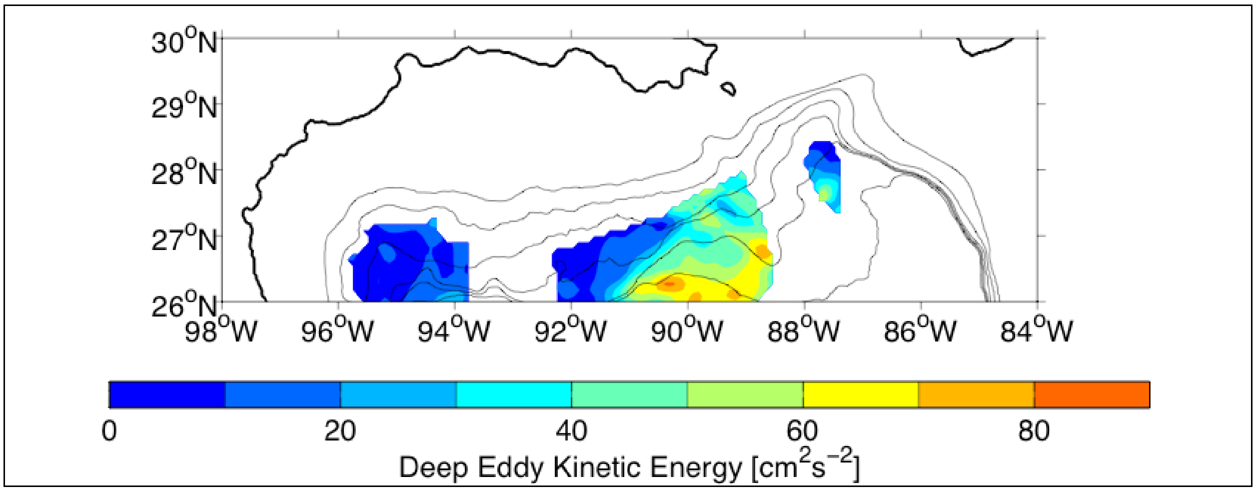


Figure 2F.27. Deep eddy kinetic energy determined from the three PIES arrays in the northern Gulf of Mexico. Bathymetry is contoured every 1000 m depth.

North East Gulf, deep eddies were strongest at the southern deeper portion of the array. The deep eddies are episodic in association with occasions when upper Loop Current and Loop Current Eddies swept southeast through the array.

Influence of Sigsbee Escarpment on Deep Eddy Propagation

Here we note two examples of the influence of the Sigsbee Escarpment on deep eddy propagation. Cyclones approach Sigsbee and are deflected westward while anticyclones approach the escarpment, stall, and decay as filaments tear off to the east-northeast. This behavior results from the complimentary (cyclones) or competing (anticyclones) effects of dipole self-advection and topographic beta. In the case of a cyclone (anticyclone), dipole self-advection and topographic beta reinforce (counteract) each other.

Case Studies of Vertical Coupling Between Upper and Deep Circulation

The Central and East Northern Gulf Arrays exhibited several examples of interaction between the upper and deep ocean: blocking, joint propagation of upper and lower layers, and baroclinic instability. In the blocking example [9 September – 3 October 2005], the propagation of a deep cyclone is temporarily halted when it encounters Eddy Sargassum's deep-reaching and opposing flows. The deep cyclone remains locked to Eddy Sargassum until it rotates and flow is no longer counter to the natural path of the deep cyclone. Our second category of upper and lower layer interaction represents the more dynamic vertical coupling that results when propagating upper-ocean features stretch or squeeze the lower layer. The lower-layer response to vortex stretching/squeezing requires the acquisition of respectively positive/negative relative vorticity to balance the changes in thickness in order to conserve total potential vorticity. Consider the idealized case of a propagating upper-ocean anticyclone. As the upper-ocean anticyclone propagates it alters the lower-layer vorticity. The lower layer shrinks ahead of the eddy and stretches behind the eddy. In order to conserve potential vorticity, shrinking must be accompanied by a decrease in relative vorticity. Hence, a lower-layer anticyclone advances ahead of the upper-ocean anticyclone. Behind the upper-ocean anticyclone, the stretching and increase in relative vorticity results in a lower-layer cyclone. Note that this scenario is highly idealized: we have neglected the effects of topography, a spherical earth or a lower-layer background flow field, for example. We refer the reader to Cushman-Roisin et al. (1990) for a more in-depth discussion and point out that Welsh and Inoue's (2000) modeling study reveals the joint spin-up of lower layer eddies beneath strong translating upper-ocean features. An example occurred in the North Central Array in early April 2003 as the Loop Current propagated westward and slightly northward a lower layer anticyclone resided ahead of the Loop Current center and its direction of propagation. In the North East Gulf Array, a deep anticyclone lead and deep cyclone trailed as the Loop Current or Loop Current Eddy swept southeast through the array (Figure 2F.28). This pattern repeated itself five times in 2005.

Future Work

The North West Gulf array did not exhibit any local vertical coupling yet the upper-eddy stretching appears to be of similar magnitude to that observed in the North Central and North East arrays. We intend to perform a careful analysis of lower-layer potential vorticity to improve our dynamical understanding.

The North East Gulf array indicated local dynamical coupling between upper and deep ocean. This deep energy is not, however, the source region for deep energy found along the Sigsbee escarpment (P. Hamilton, personal communication). An observational array placed under the Loop Current neck region would be well placed to determine the structure of deep eddies and their likely feedback to pinch off Loop Current Eddies.

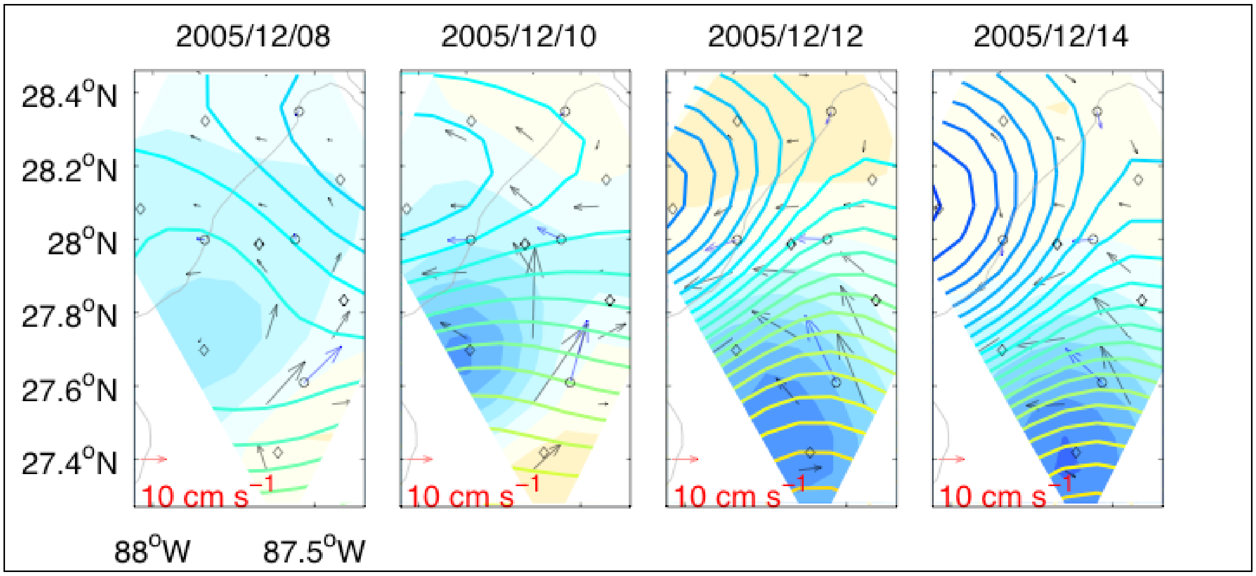


Figure 2F.28. Case study of a lower-layer anticyclone leading and a lower-layer cyclone trailing an upper-ocean anticyclone [08-14 December 2005] in the East Gulf Array. Maps of surface stream-function (bold contour lines) superimposed upon shaded contours of 1500 m depth pressure for four separate days. In both fields highs are represented by red hues and lows represented by blue hues. Bathymetry contoured every 1000 m depth is denoted by the gray lines. PIES sites indicated by diamonds; current meters by circles.

References

Bretherton, F.P., R.E. Davis, and C.B. Fandry. 1976. A technique for objective analysis and design of oceanographic experiments applied to MODE-73. Deep Sea Research 23:559–582.

Cushman-Roisin, B., E.P. Chassignet and B. Tang. 1990. Westward motion of mesoscale eddies. Journal of Physical Oceanography 20:758–768.

Watts, D.R., X. Qian, and K.L. Tracey. 2001. Mapping abyssal current and pressure fields under the meandering Gulf Stream. Journal of Atmospheric and Oceanic Technology 18:1052–1067.

Welsh, S.E. and M. Inoue. 2000. Loop Current rings and the deep circulation in the Gulf of Mexico. Journal of Geophysical Research. 105(C7): 16,951–16,959.

Kathleen Donohue received a Ph.D. degree in oceanography from the University of Rhode Island in 1995. In 2000, after a post-doctoral appointment at the University of Hawaii, she returned to the University of Rhode Island where she worked as an assistant marine research scientist from 2000 to 2006, and presently has an ADVANCE research professor position. Kathleen is a

physical oceanographer whose research interests include describing the global ocean velocity structure with particular focus on western boundary current regimes.

D. Randolph Watts is a professor of oceanography at the University of Rhode Island. His current research interests are dynamic and descriptive physical oceanography, with an emphasis on dynamics and energetics of strong current systems and their large scale eddies.

SESSION 3A

COASTAL WETLANDS AND OFFSHORE ECOLOGY I

Chair: Herb Leedy, Minerals Management Service

Co-Chair: Quazi Islam, Minerals Management Service

IMPACTS OF PIPELINES AND NAVIGATION CANALS AND MITIGATION EFFECTS ON WETLAND HABITATS OF COASTAL WESTERN AND CENTRAL GULF OF MEXICO

James B. Johnston, Donald R. Cahoon, and Megan K. La Peyre,
U.S. Geological Survey, National Wetlands Research Center

Click here to view the slide show that accompanied this presentation.

Project Goals and Approach

Pipeline and navigation canal construction activities impact coastal habitats directly through the dredging of land, creation of spoil banks, and other hydrodynamic alterations; in addition, they impact coastal habitats indirectly through alterations in hydrologic, soil, and salinity conditions, resulting in changes to vegetation and land formation. Quantifying indirect impacts has proven highly contentious. In theory, indirect impacts are all remaining losses of wetland areas, subsequent to the direct impacts, that can be attributed to pipeline and navigation canals. In practice, teasing out indirect impacts of OCS pipelines and canals from all other losses remains a challenge.

The study goal was to prepare a factual array of data and data analyses in order to quantitatively determine the direct and indirect effects, or lack thereof, 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 the use of a literature review and qualitative analyses of selected case studies.

The study area boundaries incorporated the Western (Mexico/Texas border to Texas/Louisiana border) and Central (Texas/Louisiana border to a point south of the eastern edge of Mobile Bay, Alabama) Planning Areas of the Gulf of Mexico as designated by the Minerals Management Service. The study area was further subdivided 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 coastal Mississippi/Alabama (MS/AL).

This project builds on the findings of Turner and Cahoon (1987) OCS Study MMS 87-0199 by (1) expanding the geographic coverage of Louisiana to include Texas, Mississippi, and Alabama, (2) identifying and analyzing the entire population of pipelines and navigation canals for all states, and (3) expanding temporal analyses of the 1950s to the 1970s to include the 1970s to the 1990s. The project was organized around four tasks: literature review, GIS analysis, statistical analysis of land loss and habitat change, and evaluation of mitigation effectiveness. Three different scales of analyses were used to evaluate OCS pipeline and navigation canal impacts on land loss, wetland loss, and habitat change:

Regional Analysis: A spatially extensive, quantitative evaluation of GIS-derived land loss, wetland loss, and habitat change data from within the immediate vicinity of the entire population of OCS pipelines and navigation canals, which is compared to regional trends of loss and change, where available (i.e., Louisiana).

Intensive Impact Analysis: A spatially intensive, quantitative evaluation of GIS-derived land loss, wetland loss, and habitat change data from within the immediate vicinity of a select sample of OCS pipelines and navigation canals, which is compared to reference sites located up to 1.5 km away, and includes comparisons of trends over time and pre and post construction.

Case Studies: A qualitative (semi-quantitative) evaluation of GIS-derived land loss, wetland loss, and habitat change data from within the immediate vicinity of individual pipelines and navigation canals, supplemented with data from monitoring reports, which is compared to reference sites and includes a comparison of pre and post construction data.

The findings from these analyses were used to answer four questions:

Question 1: *Are the rates and patterns of land loss within the immediate vicinity of OCS pipelines and navigation canals similar to regional rates and patterns of land loss?*

Question 2: *Do the rates and patterns of land loss, wetland loss, and habitat change within the immediate vicinity of OCS pipelines and navigation canals differ over time and among the five subareas of the Western and Central Planning Areas?*

Question 3: *What is the impact of OCS pipelines and navigation canals on wetland habitats within their immediate vicinity?*

Question 4: *Are the dominant mitigation and construction techniques used for OCS pipelines and navigation canals effective in minimizing the effects of OCS pipelines and navigation canals on land loss, wetland loss and habitat change?*

Summary of Findings

Regional Analysis

Question 1: *Are the rates and patterns of land loss within the immediate vicinity of OCS pipelines and navigation canals similar to regional rates and patterns of land loss?*

The analyses revealed strong temporal and spatial trends in land loss within the LDP and LCP subareas and within the vicinity of the entire population of OCS pipelines (150 m either side) and navigation canals (500 m either side). Land loss was consistently higher in the vicinity of pipelines compared to both the LDP and LCP subarea trends, and in the vicinity of navigation canals compared to the LDP subarea trend. Thus these OCS pipeline and navigation canal locations were associated with enhanced land loss, suggesting that they contributed to the loss. Land loss decreased over time, and the pattern was the same for both the subareas and the population of pipelines and navigation canals. This question was not answered for Texas, Mississippi or Alabama because regional data were not available for comparison.

Question 2: Do the rates and patterns of land loss, wetland loss, and habitat change within the immediate vicinity of OCS pipelines and navigation canals differ over time and among the five subareas of the Western and Central Planning Areas?

Strong temporal and spatial trends in land loss, wetland loss, and habitat change existed within the immediate vicinity of OCS pipelines and navigation canals in the Western and Central Planning Areas of the Northern Gulf of Mexico from the 1950s to the 1990s. Note that the regional analysis does not account for differences in construction date and does not compare population trends to a reference site, other than the regional comparison described in Question 1 above for Louisiana.

<u>Pipelines</u>: Land and wetland loss rates were highest and habitat change trends were strongest in Louisiana, and lowest and weakest in MS/AL. The high loss rates for the LDP can be explained, at least in part, by the high density of pipelines located there, the relatively large number of open pipeline canals, and high rates of subsidence coupled with reduced riverine sediment input. The lower loss rates for Texas Barrier Island (TBI) and MS/AL can be explained, at least in part, by the use of more environmentally friendly construction methods (e.g., directional drilling, push-pulling with back filling) in the sensitive environments located there. In MS/AL, there was an 8% gain in wetland area from the 1950s to the 1990s. In Louisiana, open water increased while non-fresh marsh decreased. In the LDP, fresh marsh also decreased, but increased in the LCP.

<u>Navigation Canals</u>: Annual land loss rates were highest in the TCP and lowest in the TBI. The rates decreased dramatically over time in the chenier plains (TCP and LCP) but increased in MS/AL and TBI. Many of the navigation canals were constructed prior to 1956, the first year of GIS data collection. Thus the decrease in loss rate could reflect a slowdown in canal-widening processes from shoreline stabilization efforts along the older canals, or from a decrease in erodable land in the vicinity of the canals. The increased loss rate in MS/AL was related largely to loss of developed land and upland forest. Reasons for the doubling of the loss rate in the TBI are not clear from this analysis. Annual wetland loss rates were highest in MS/AL and lowest in TBI. The rate in MS/AL is likely an artifact of the very small amount of wetlands in the subarea, such that a small absolute change leads to a large relative change. Loss rates decreased with time in all subareas except TBI, where they increased.

Intensive Impact Analysis

Question 3: What is the impact of OCS pipelines and navigation canals on wetland habitats within their immediate vicinity?

The findings from the intensive impact analyses compared with a reference site up to 1.5 km away (REFERENCE model), over time (YEAR model), and before and after construction (PHASE model), and the evaluation of individual pipeline and navigation canal impacts revealed several significant patterns in habitat loss and change that were related to OCS pipelines and navigation canals.

Pipelines: The REFERENCE analysis yielded no significant results. That is to say, OCS-related impacts, if any, were indistinguishable from all other activities occurring within the vicinity over the same time period. But the YEAR and PHASE model analyses yielded significant results, which varied among regions.

> *Louisiana*: The date of pipeline construction (PHASE) provided a better explanation for the trends in habitat loss and change than did time-dependent processes (YEAR), such as subsidence.
>
> *Texas*: The results were mixed for Texas, where some habitat change trends were explained better by the date of construction (PHASE), while others were explained better by time-dependent processes (YEAR).
>
> *Mississippi/Alabama*: The patterns of habitat change were explained best by time-dependent processes (YEAR) and apparently were not related to pipeline construction date.

Evaluation of individual pipelines revealed that habitat impacts associated with construction and maintenance were severe for some pipelines and negligible for others. Impacts were observed in Louisiana and the Texas Barrier Island subarea, and were of two main types: (1) conversion of wetland to open water through either trenching or flank subsidence, and (2) conversion of wetland to scrub-shrub by creation of spoil banks and overfilling of trenches.

Navigation Canals: The assessment of OCS navigation canal impacts on wetland habitat change trends is more limited than the pipeline assessment because many navigation canals were built prior to 1956. Consequently, the PHASE analysis could not be conducted, and the YEAR analysis included only post-construction trends for many canals. In addition, data on regional trends were not available for comparison with the navigation canal trends from Texas and Mississippi – Alabama. Given these data constraints, our answer to Question 3 for navigation canals is based on the in-depth qualitative analyses of individual navigation canals, including evaluations of maps, monitoring reports, and data trends.

Evaluation of individual navigation canals revealed four types of habitat impacts associated with construction and maintenance, including the conversion of (1) wetland habitats to open water from creation of the canal, and subsequent widening of the canals from erosion, (2) open water and/or wetland habitats to upland habitat through the deposition of spoil material alongside canals, (3) open water habitat to wetland habitat through the deposition of spoil material in open water to an elevation that resulted in marsh creation, and (4) fresh marsh to non-fresh marsh resulting likely from the pathway created by the canal, which lead to increased salt water intrusion. These impacts are seen across all five subareas examined in this study.

Case Studies

Question 4: Are the dominant mitigation and construction techniques used for OCS pipelines and navigation canals effective in minimizing the effects of OCS pipelines and navigation canals on land loss, wetland loss and habitat change?

Pipelines: The magnitude of the OCS pipeline impacts is inversely proportional to the quantity and quality of mitigation techniques applied. OCS pipelines that were constructed using extensive mitigation measures appear to have had minimal impact on the landscape. Of the pipelines examined, the ones that we could attribute significant habitat changes to were those that were not backfilled, and/or had spoil banks that remained after construction. This finding appears to hold true across different subareas and habitat types examined. In more sensitive habitats, such as the barrier islands (i.e., Texas Barrier Island subarea), OCS pipelines appear to have been constructed in such ways as to effectively minimize damage by using multiple mitigation techniques on each line. However, as pipeline construction (OCS and non-OCS) is widely distributed across the Gulf coast, leaving no areas unaffected by pipeline construction from 1956 to 1995, it is difficult to say with certainty that pipelines do not contribute to habitat change. Given the large number of pipelines built, it is possible some of the regional patterns of habitat change are a result of the cumulative impacts of pipelines.

Navigation Canals: Navigation canals all had significant habitat impacts beyond the direct impact of open water canals being built through a variety of habitat types. All of the canals, regardless of subarea or habitat crossed, had significant widening from their construction width, although many had reduced widening rates in recent years, which likely reflects more aggressive management and restoration of the canal edges to prevent erosion. Many of these canals also had indirect impacts and likely contributed to interior marsh loss from changes in salinity by providing a pathway for both fresh and salt water to move. Management activities, including erosion protection and restoration along the edges of these canals, can significantly reduce canal-widening impacts on wetland loss. What is not addressed is the impact of salt water intrusion into previously freshwater areas; innovative techniques to reduce this exchange of water are necessary to provide solutions to this problem.

Management Summary

The construction of OCS pipelines through coastal ecosystems of the Western and Central Planning Area of the northern Gulf of Mexico can cause locally intense habitat changes, thereby contributing to the loss of critically important land and wetland areas (e.g., conversion to open water or upland, or the conversion of fresh to non-fresh marsh). Some construction methods create a greater impact per unit length than others (e.g., floatation canals versus push ditch backfill, or directional drilling). Direct impacts result from dredging activities, while indirect impacts occur through local hydrologic changes (e.g., altered flooding patterns created by spoil banks, or salt water intrusion). Although pipeline impacts can be severe, they can be greatly minimized or avoided with proper application of mitigation techniques; this is the case even with the impacts from floatation canals. The degree of impacts associated with specific pipeline canals varied widely, with some pipelines contributing to habitat loss and others not, depending largely on the extent and quality of mitigation applied, regardless of region or habitat crossed. The analyses also suggest that the cumulative effect of hundreds of pipelines contributes to the regional trends in land loss.

Pipelines: The key to avoiding, or at least minimizing, habitat impacts from OCS pipeline construction is to reestablish and maintain the marsh elevation and local hydrologic regime that existed prior to construction. This entails the use of techniques such as backfilling and avoiding the creation of spoil banks.

Navigation Canals: Accepting the direct, uncontrollable impacts of a functioning navigation canal (e.g., salt water intrusion), the key to mitigating additional impacts is bank stabilization, and where possible, beneficial use of dredged material from maintenance dredging activities to create wetland or upland habitats (e.g., Calcasieu Navigation Canal).

Reference

Turner, R.E. and D.R. Cahoon, eds. 1987. Causes of wetland loss in the coastal central Gulf of Mexico. Volume I: Executive summary; Volume II: Technical narrative; Volume III: Appendices. Final report to Minerals Management Service, New Orleans, LA. Contract No. 14-12-0001-30252. OCS Study/MMS 87-0119, 0120, 0121. 432 pp. + appendices.

Dr. James B. Johnston is the Section Chief, Spatial Analysis Branch of the National Wetlands Research Center in Lafayette, Louisiana. He currently 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. Donald R. Cahoon is a research ecologist with the U.S. Geological Survey, Patuxent Wildlife Research Center located in Beltsville, Maryland. He received his B.A. degree, with honors in

botany, from Drew University (1972), and 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 prior to moving to Maryland in 2001.

Dr. Megan La Peyre is Assistant Unit Leader of the Louisiana Cooperative Fish and Wildlife Research Unit at Louisiana State University. Her research interests include restoration and management of coastal/estuarine ecosystems, quantifying/identifying characteristics of fish habitat, and ecology of coastal vegetation. She received her B.A. in political science and biology from Duke University (1992), M.A. in marine science from the College of William and Mary (1995), and Ph.D. in oceanography and coastal sciences from Louisiana State University (2000).

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

Click here to view the slide show that accompanied this presentation.

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 10 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 gain a better understanding of the patterns of change and wetland loss in order 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 GOM (GOM), 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 GOM. 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 GOM, 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 GOM. 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 underway 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 where 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 FWS/OBS-82/59. 256 pp.

Good, B., J. Buchtel, D. Meffert, J. Radford, K. Rhinehart, and R. Wilson. 1995. Louisiana's major coastal navigation channels. Unpublished report. Louisiana Department of Natural Resources, Office of Coastal Management and Restoration, Baton Rouge, LA. 57 pp.

Gosselink, J.G. 1984. The ecology of delta marshes of coastal Louisiana: A community profile. U.S. Dept. of the Interior, U.S. Fish and Wildlife Service, Office of Biological Sciences, Washington, D.C. FWS/OBS 84/09. 134 pp.

Louisiana Coastal Wetlands Conservation and Restoration Task Force (LCWCRTF). 1993. Louisiana coastal wetlands restoration plan. Coastal Wetlands Planning, Protection and Restoration Act, U.S. Army Corps of Engineers, New Orleans, LA. 256 pp. + appendix.

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. Final report prepared for Louisiana Department of Natural Resources, Baton Rouge, LA. 113 pp.

Turner, R.E. and D.R. Cahoon, eds. 1988. Causes of Wetland loss in the coastal central Gulf of Mexico, vol. 1: Executive summary. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 87-0119. 32 pp.

Wang, F.C. 1988. Dynamics of saltwater intrusion in coastal channels. Journal of Geophysical Research 93(C6):6937–6946.

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 where 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 earned a B.A. in 1972, M.S. in 1977 (both from Louisiana Sate University), and Ph.D. in 1994 (University of Utrecht). He 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. He is currently a wetland ecologist with the USGS National Wetlands Research Center. 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 investigating the role that storms and other episodic events 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 its response to natural drivers and human impacts. Other research interests include measurement (monitoring design, QA/QC) and analysis of water flows, water levels, and salinity in shallow water, coastal and estuarine systems. He 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. He 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 (University of Houston) and M.S. in 1990 (Louisiana State University). She has worked for the past 26 years as a wetland ecologist with LSU, including benthic ecology and ecological work using Geographic Information Systems as well as 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, M.S. in 2002 from Louisiana State University, and is currently a Ph.D. candidate at Louisiana State

University 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. He is currently a research associate for the Louisiana State University Agricultural Center Department of Agronomy, where his research is focused on water quality monitoring and modeling and the use of Geographic Information Systems to assess landscape patterns and develop ecological and landscape models.

LOUISIANA COASTAL VEGETATIVE TYPE CHARACTERIZATION

Steve B. Hartley, and John Barras, James B. Johnston
U.S. Geological Survey

Greg Linscombe, Louisiana Department of Wildlife and Fisheries
Fur and Refuge Division

Click here to view the slide show that accompanied this presentation.

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 and Linscombe 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. However, because of the technology used in the past to map the vegetative types we cannot reflect, within reason, the "true" amount of marsh acreages. To make better usage of the 2001 and others (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

- o pipeline assessments
- o natural resource damage assessments
- o vegetative assessments
- o 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.

Reference

Chabreck, R. and G. Linscombe 2001. Vegetative type map of the Louisiana coastal marshes. Louisiana Department of Wildlife and Fisheries, New Orleans, LA.

Steve Hartley, Senior Geographer at the USGS National Wetlands Research Center, 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. He received his B.S. degree from Louisiana Tech University (1985) and his M.S. in geology from the University of Louisiana at Lafayette (2000).

John Barras is a Senior Geographer at the USGS National Wetlands Research Center responsible for managing the NWRC's Coastal Restoration Field Station (CRFS), housed on the Louisiana State University campus in Baton Rouge. 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. He received his B.S. in geology from Nicholls State University (1984) and M.N.S. in geography from Louisiana State University (1991).

Greg Linscombe is a Program Manager for the Fur and Refuge Division of the Louisiana Department of Wildlife and Fisheries. During his career he has been responsible for management of 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. He received his B.S. in forestry and wildlife management (1970) and M.S. in wildlife management, both from Louisiana State University (1972).

INCORPORATION OF GULF OF MEXICO BENTHIC SURVEY DATA INTO THE OCEAN BIOGEOGRAPHIC INFORMATION SYSTEM

Robert S. Carney, Department of Oceanography & Coastal Sciences, Louisiana State University

Click here to view the slide show that accompanied this presentation.

Minerals Management Service (MMS) has been one of the primary sources of oceanographic data since it first began supporting offshore sampling of the biota and environment. It has been a stipulation in all such studies that data be filed with the National Oceanographic Data Center (NODC) of the National Oceanic and Atmospheric Administration (NOAA). In addition, voucher specimens of all species collected are to be deposited with a repository museum, usually the U.S. National Museum of Natural History. Over the past 10 years there has been a greatly increased interest in the biological diversity of the seafloor. Making use of informatics, scientists are actively re-examining older studies in the search for ecological patterns. The information on benthic community distributions supported by museum specimens comprises one of the best data sources for the study of seafloor ecology available anywhere in the world.

The NODC is noted for its exceptional work with archived physical and chemical data, but it lags behind other archiving programs with respect to biological survey data. Innovation in this area lies primarily in the academic and museum communities. The Ocean Biogeographic Information System (OBIS) is under development in the U.S., both as a primary repository of data and a gateway to fully integrated databases elsewhere in the world. Therefore, to assure that MMS-collected data is available for continued analysis, it must be transferred from discontinued NODC formats into OBIS format while there is still some understanding of the older data content.

This project has been a trial effort at carrying out transfer from four Gulf of Mexico data sources: the published results of deep sampling by W.E. Pequegnat, contractor's data archives for the Northern Gulf of Mexico Continental Shelf Study, NODC archives of the South Texas OCS Study, and NODC archives of the Southwest Florida Benthic Community Study. Entry, proofing, and reformatting of the published results proved to be the easiest undertaking. Conversion of all archived data was seriously hampered by the lack of available documentation for the NODC Species Code that has been discontinued. Once Species Code information was finally located, conversion of the NODC MULDARS format required a great deal of manual intervention due to inconsistent use of format standards. Unfortunately, this inconsistency makes it impractical to reformat all data sets with a single computer program. Conversion requires study-by-study custom processing of the data archives.

Data from four major MMS studies were converted to digital database format compatible with the Census of Marine Life's Ocean Biogeographic Information System and spreadsheet format.

These are available for study at www.iobis.org. The Final Report for this project serves as a manual for conversion of NODC and other archived benthic data. Project reports should be considered the primary source if species-level sample-by-sample data are provided. A percentage of records in the final digital file should be manually checked against the hardcopy reports.

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 (1976). Professionally, he has been a Smithsonian Fellow, Director of Biological Oceanography at NSF, Director of Coastal Ecology at LSU, and Director of the Coastal Marine Institute, a joint MMS/LSU program,. He has participated in several MMS projects in the Gulf of Mexico, off California, and in Panama. Most recently, he has been appointed U.S. Coordinator for CoMargE, an international effort in Continental Margin Ecology.

SESSION 3B

PLATFORM ECOLOGY

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

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

BIOLOGICAL INFORMATION FOR USE IN MANAGEMENT DECISIONS CONCERNING OFFSHORE PLATFORM DECOMMISSIONING

Jon Vølstad, Versar

G. Ault, University of Miami

J. Cowan, Louisiana State University

B. Gallaway, LGL Associates

M. Love, University of California at Santa Barbara

E. Weber, AquaBio, Inc.

Click here to view the slide show that accompanied this presentation.

The number of oil and gas platforms on the outer continental shelf of the Gulf of Mexico is expected to decrease rapidly during the next ten years as the number of decommissioned platforms outpaces the rate of new installations. This may have important effects on the ecosystem because platforms have created the largest defacto reef system in the world. The purpose of this project is to evaluate the likely effects of decommissioning large numbers of platforms and identify gaps in the state of knowledge about potential effects of decommissioning based on published literature. We compiled a database of relevant literature consisting of more than 800 manuscripts related to platforms, artificial reefs, and natural reefs. This database will be made available to other researchers at the conclusion of the project. We are assessing the degree to which individual fish species are dependent on platforms or reefs using four levels of evaluation similar to NOAA procedures for EFH identification. Levels of evaluation range from simple presence/absence (level 1) to quantitative community dynamics models (level 4) depending on the adequacy of information in the literature. A limitation of existing information is that few studies related to platforms have included controls in comparable areas without platforms. One means of measuring effects of platform removals would be to conduct removal experiments using a before-after control-impact design. We illustrate a potential approach using SEAMAP data.

Dr. Vølstad is Principal Scientist with Versar, Inc, and adjunct faculty member (biometrics) at the Department of Animal and Avian sciences, University of Maryland (UMD). He has a Ph.D. in quantitative fisheries biology (biometrics) from the University of Bergen, Norway, and over 20 years of international experience in research and consulting, specializing in statistical survey methods, ecological statistics, experimental design, and fisheries stock assessment and

management. He has directed the compilation, analysis, and dissemination of fisheries statistics on key aspects of commercial and recreational fisheries in temperate and tropical waters. Dr. Vølstad has developed experimental design and analysis methods to identify Essential Fish Habitat for fish and benthic species for MMS and NOAA. He is currently the Principal Investigator on a project conducted for MMS to synthesize biological information for use in management decisions concerning offshore platform decommissioning. His research interest includes the design of marine resources assessment and monitoring programs and ecological experiments.

ASSESSING TROPHIC LINKAGES BETWEEN PLATFORMS AND PELAGIC FISHES USING ULTRASONIC TELEMETRY AND ACTIVE ACOUSTICS

Harmon Brown and Mark Benfield, Department of Oceanography and Coastal Sciences, Louisiana State University

Sean Keenan, Florida Fish and Wildlife Commission, Fisheries Independent Monitoring Program

Sean Powers, University of South Alabama/Dauphin Island Sea Lab

Click here to view the slide show that accompanied this presentation.

Introduction

The offshore petroleum platforms in the northern Gulf of Mexico (Gulf) provide a unique reef-like habitat for encrusting organisms, reef-associated and pelagic fish species. Because the majority of substrate over the mid-shelf off Texas and Louisiana is comprised of sand and mud, platforms provide virtual oases of hard structure associated with their vertical relief (Kasprzak 1998). Gallaway and Lewbel (1982) estimated that platforms provided an additional 5000 km^2 of reef habitat in the northern Gulf, when all their surface area is taken into account. The Gulf platform complex has been described as the largest unplanned artificial reef complex in the world (Stanley and Wilson 1998).

High densities of fish are associated with offshore platforms. Though these high fish densities have been well documented, the reasons behind the fish-platform association are unclear. Understanding this linkage is a core-component of our research. Given the wide variety of fish species at offshore platforms, selection of an appropriate target species is an important step. Stanley and Wilson (2000) stated that six to seven species made up approximately 95% of all fishes at platforms they sampled, and that species composition was usually dominated by a single species. In their study, the most abundant fish species near a platform located in 60m of water (GI94B) was the blue runner, *Caranx crysos*. This pelagic species is commonly found in large schools in open water, as well as near platforms, and is one of the most common medium-sized fish in the Gulf. Blue runner are likely important in the diets of large predatory fishes, such as tuna and billfish, and appear to be consumed by many of the gamefish that are common around platforms, such as amberjack, jack crevalle, cobia and king mackerel.

Adult blue runner were previously considered to be piscivorous (Randall 1967, Christmas et al. 1974); however, research conducted on the feeding habits of these fish near platforms revealed that zooplankton were major components of their diet. From 1996–2002, Keenan (2002) investigated the role of zooplankton in the diets of blue runner associated with offshore petroleum platforms in the north central Gulf. That study revealed that zooplankton are an important component of the diets of subadult and adult blue runner. It further indicated that although blue runner are primarily visual predators, they are capable of nocturnal foraging, presumably due to the artificial light field around platforms. Quantification of this light field indicated that nocturnal illumination levels were sufficiently bright to permit foraging at night to depths of 25m or deeper (Keenan et al. 2007). Hydroacoustic surveys of the upper 14m of the water column suggested that zooplankton densities may be elevated close to platforms. The results of that study raised several questions, which the current study is designed to address.

Our study examines the three-dimensional movements and distributions of blue runner around a petroleum platform in relation to hydrography and the distributions of their zooplankton prey. The site fidelity and movement patterns of acoustically tagged blue runner among a constellation of platforms has also been monitored. The specific objectives of our study are

1. To quantify the three-dimensional distribution of zooplankton prey within the water column around a representative mid-shelf platform;
2. To measure the three-dimensional movement patterns of blue runner around a platform, and to correlate blue runner and zooplankton vertical distributions; and
3. To quantify the site fidelity of blue runner to various platforms within a platform complex.

Methods

The study was conducted in the South Timbalier (ST) block of the Gulf. The ST151 complex (28° 37.000’ N, 90° 15.367’ W) is a series of platforms connected by catwalks. The complex is located about 50 kilometers south of Port Fourchon, Louisiana. The ST151 complex sits at the southern edge of a larger group of platforms known as “The Circle” which includes several satellite platforms and artificial reefs over an area of about 35 km^2 (Figure 3B.1). The water depth around the platforms ranges between 30– 42 m.

Our approach toward studying the movements and distributions of blue runner employs acoustic localization. This technique utilizes small tags that transmit an ultrasonic sound pulse at regular intervals. Each pulse includes an encoded transmitter identity and broadcasts on alternating pulses, the pressure and temperature. By using the differences in times of arrival of the tag pulse at a series of three or more hydrophones, it is possible to estimate the location of the tag (and consequently the fish carrying the tag). This provides a 2D position estimate for the fish. Using the additional pressure data transmitted by the tag, we can arrive at a 3D position for the fish.

On 30 July 2005 installation of a Lotek MAP_600 acoustic localization system around the ST151 complex began. The hydrophones on the main complex were connected to marine rugged electrical cable, which was run along the stairwells and catwalks connecting the platforms to the MAP_600 system in a building on the Old Quarters platform. The MAP_600 system allows the simultaneous use of up to eight hydrophones to calculate two- and three-dimensional positions of tagged fish. In addition, Lotek MAP_RT units were installed on three satellite platforms (ST134 Sugar, ST135 Mike and ST151 Kilo). These stand-alone units had a single cabled hydrophone, which allowed us to detect the presence of tagged fish that left the main ST151 complex and

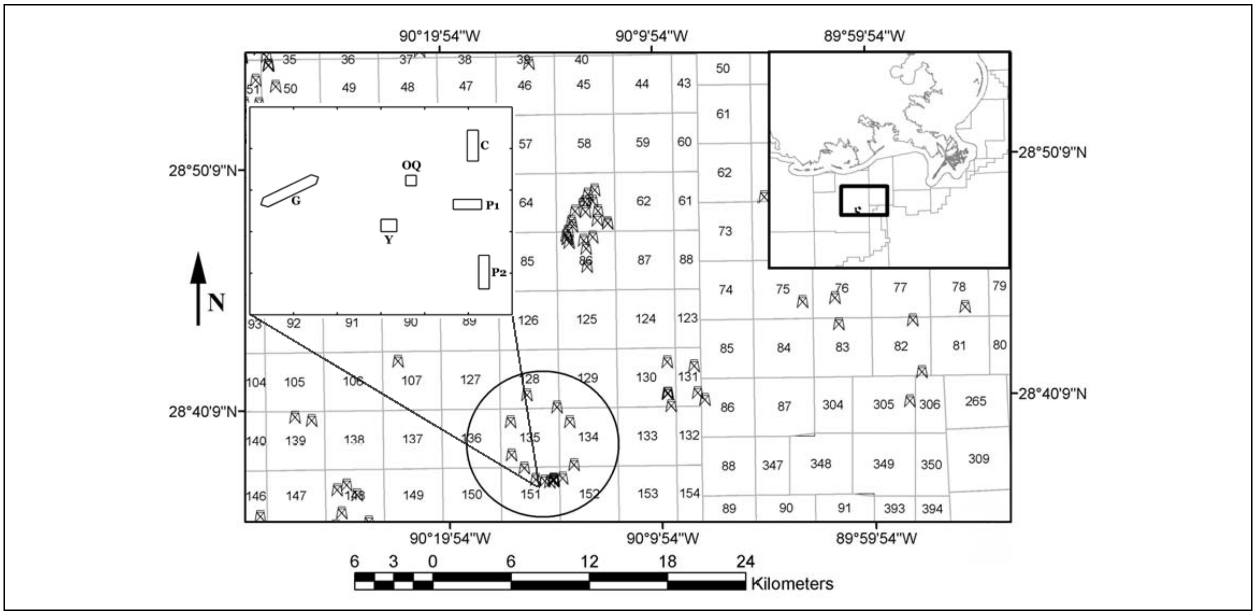


Figure 3B.1. Location of the South Timbalier (ST) field with relation to the Louisiana coast. The upper left inset shows the configuration of the ST151 main complex platforms.

moved to other unmanned platforms within the circle. Blue runner were tagged with Lotek Wireless CTP_M11_12 tags. Each tag is coded with an individual tag number so that multiple fish can be tracked simultaneously. All tags contained temperature and pressure sensors that transmitted the temperature and pressure data in an alternating pulse sequence. We used tags that tranmitted at 2s intervals (2s) and 4s intervals (4s). Blue runner were caught using barbless hook and line angling and anesthetized using an 80ppm solution of MS-222 and seawater.

Beginning on 5 August and continuing through 15 August 2005, the tags were surgically implanted in the peritoneal cavity and most fish were allowed to recover for a period of at least eight hours before being released. A total of 46 blue runner were tagged during this period. Thirty-three fish were tagged with 4s tags and the remaining thirteen were tagged with 2s tags. The hydrophones at the three satellite platforms were removed from the water and the receivers were shut down on 25 August 2005 and the MAP_600 system was shut down on 26 August 2005 due to the evacuation from Hurricane Katrina. No data were lost as a result of the hurricane although some of our equipment and supplies suffered serious damage and loss.

The damage caused by Hurricane Katrina to the platforms in the South Timbalier region required a different methodology in 2006. On 14–15 August 2006 six submersible, battery-powered, data-logging hydrophones (Lotek WHS3050) were installed around the ST151 complex, and three more were deployed beneath three satellite platforms (ST128 Romeo, ST151 Kilo, and ST152 Poppa). Fish were again caught using hook and line angling and surgical implantation of tags was performed aboard M/V Different Drummer. On 21, 22, and 24 August 2006 nineteen blue runner, one juvenile amberjack (*Seriola dumerili*) and three mangrove snapper (*Lutjanus griseus*) were tagged and released. All fish were tagged with ten-second pulse interval tags. Ten of the blue runner were caught and released in the same location (ST151 Kilo or ST151 main complex), while nine of the blue runner, the amberjack and the mangrove snapper were caught at (ST151 Kilo or ST134 Whiskey) and released at different locations (ST151 main complex). Two of the hydrophones were recovered from the ST151 complex on 4 October 2006 and the remaining eight hydrophones were recovered on 1 November 2006.

In addition to the ultrasonic telemetry tagging, active acoustic surveys were performed using a 1200 kHz ADCP. The side-looking ADCP was lowered from the M/V Different Drummer and provided acoustic backscatter data for a 15m range. The side-looking orientation of ADCP allowed us to examine backscatter from zooplankton within the entire water column out to 15m. Surveys were taken every two hours with a 6h gap, over a 24-hour period on 21–22 August 2006. Additional surveys will be undertaken in 2007.

Results

The first objective of this study was to quantify the three-dimensional distribution of zooplankton prey within the water column. The ADCP surveys provide a snapshot of the zooplankton distribution over a 24-hour period and demonstrate the changes in the distribution of prey within that time period. Analysis of these data is currently being performed. An example of the data collected can be seen from the cast showing the distribution at noon on 22 August 2006 (Figure 3B.2). The pattern of acoustic backscatter suggests that zooplankton were abundant near the surface (upper 5m) and below 20m (Figure 3B.2)

The second objective of the study was to measure the three-dimensional movement and distribution patterns of blue runner around a platform, and to correlate blue runner and zooplankton vertical distributions. The distribution of zooplankton is being estimated from the data collected by the ADCP, while the vertical distribution of blue runner was obtained from the depth sensor on the acoustic tags implanted in the fish. Preliminary analysis of the depth data from 2005 shows that blue runner are typically found in the upper 5m during the day with a migration to 20–25m at dusk where they remain overnight until they return to the surface at dawn (Figure 3B.3). An interesting but as yet unexplained migration from the surface to approximately 10m depth occurs around noon with a return to the surface within an hour or two.

The third objective of the study was to quantify the site fidelity of blue runner to various platforms within a platform complex. The data collected in 2006 is to be used for this purpose. These data are in the early stages of analysis, but the pattern seems to suggest that blue runner collected and released from the ST151 complex prefer to remain there. Blue runner caught and released at a nearby satellite platform (ST151 Kilo) migrated to the main complex within a couple of weeks of release and stayed there for the remainder of the study period (approximately 30 days). The blue runner and mangrove snapper that were caught at a nearby satellite platform (ST134 Whiskey) and released at the ST151 complex all remained at the complex for the duration of the study. The amberjack caught at ST134 Whiskey and released at the ST151 complex stayed at the main complex for a few days before migrating to, and remaining at, a distant (4.6 km) satellite platform (ST128 Romeo).

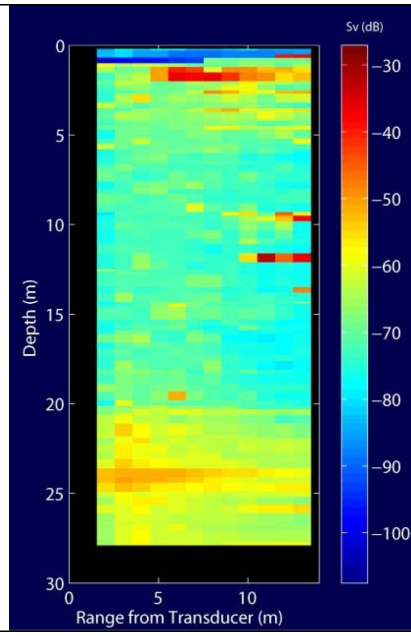


Figure 3B.2. This plot shows the pattern of acoustic backscatter from the deployment of the ADCP at 1200 on 22 August 2006. The backscatter intensity suggests zooplankton were abundant above 5m depth and below 20m depth.

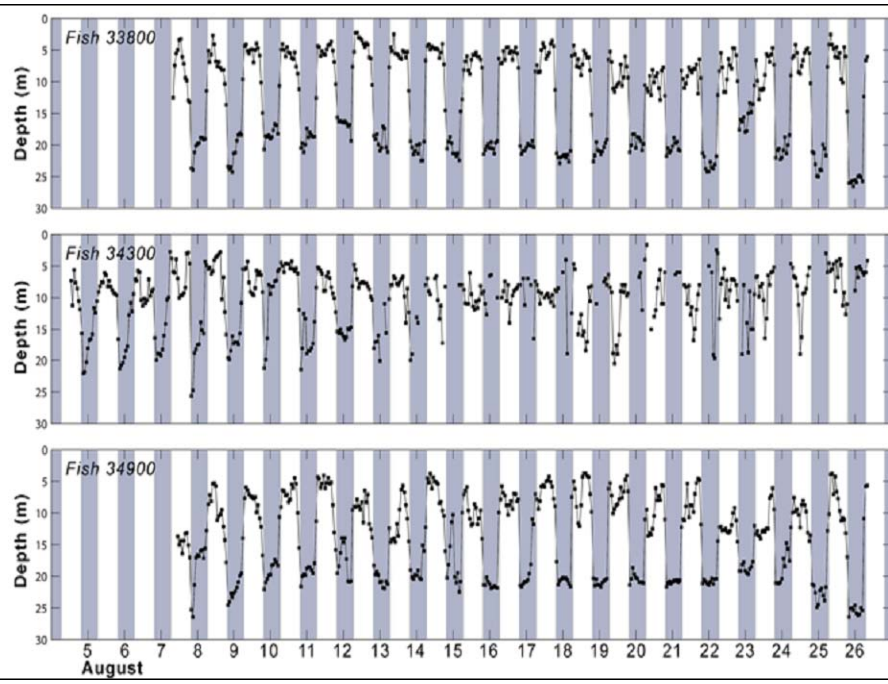


Figure 3B.3. Vertical distribution of three tagged blue runner in August 2005. All three fish show patterns of reverse diel vertical migration throughout the study period. In addition, each fish displayed a migration to about 10m depth in the middle of the day with a return to the surface in early afternoon. Note: These data were not collected at the same time as the acoustic data in Figure 3B.2.

Further Data Analysis

In addition to the continuation of the above mentioned data analysis, the data collected will answer more questions about the association of blue runner with petroleum platforms. The localization data obtained in 2005 will help to answer questions regarding the schooling behavior of blue runner around platform complexes. The three-dimensional data will allow for calculation of relative distances of tagged fish throughout the study period and help to determine the schooling behavior of fish during day and night periods.

The localization data from 2005 and the broad-scale movement data from 2006 will be used to look at vertical and horizontal movements of blue runner throughout the study periods. These data can be used to investigate vertical migration patterns over 24-hour periods, movement patterns between manned and unmanned platforms and movement to and away from the physical structure of platforms.

Furthermore the localization data from 2005 can be used to investigate the nighttime behavior of blue runner. Specifically, the data can show whether blue runner school at night and whether they utilize the structure of the platforms more during the nighttime than during the daytime, perhaps to avoid the larger predatory fishes present at night.

Finally, the bioenergetics of the blue runner will be investigated using data from the two- and four-second pulse rate tags and the tag's temperature sensors. The swimming speed of the blue runner can be estimated based on the three-dimensional localization calculations. These data can show whether the blue runners are using different foraging strategies during the day versus the night. In addition, the temperature sensors can be used to investigate whether the blue runner prefer a particular temperature range, which can affect metabolic rates.

Acknowledgments

The authors would like to thank Chevron and the crew of ST151, Captain Myron Fischer and the crew of M/V Different Drummer, and Nate Geraldi from Dauphin Island Sea Lab for their assistance with this research. This research was funded by a grant from Minerals Management Service/Coastal Marine Institute.

References

Christmas, J.Y., A. Perry, and R.S. Waller. 1974. Investigations of coastal pelagic fishes, completion report. Gulf Coast Research Laboratory, Ocean Springs, MS

Gallaway, B.J. and G.S. Lewbel. 1982. The ecology of petroleum platforms in the Gulf of Mexico: A community profile. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. Bureau of Land Management, Gulf of Mexico OCS Regional Office. FWS/OBS-82/87. 92 pp.

Kasprzak, R.A. 1998. Use of oil and gas platforms as habitat in Louisiana's artificial reef program. Gulf of Mexico Science 16:37–45.

Keenan, S.F. 2002. The importance of zooplankton in the diets of blue runner (*Caranx crysos*) near offshore petroleum platforms in the northern Gulf of Mexico. Master's Thesis, Louisiana State University, Baton Rouge, LA.

Keenan, S.F., M.C. Benfield, and J.K. Blackburn. 2007, in press. Potential importance of the artificial light field around offshore petroleum platforms for the associated fish community. Marine Ecology Progress Series.

Randall, J.E. 1967. Food habits of reef fishes of the West Indies. Studies in Tropical Oceanography 5:665–847.

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 1:73–82.

Stanley, D.R. and C.A. Wilson. 2000. Seasonal and spatial variation in the biomass and size frequency distribution of the fish associated with oil and gas platforms in the northern Gulf of Mexico. Coastal Marine Institute, Louisiana State University, Baton Rouge, LA

Harmon Brown is a Ph.D. student in the Department of Oceanography and Coastal Sciences at Louisiana State University. He received his B.S. and M.A. from San Francisco State University. He was a Louisiana Board of Regents Fellow in Environmental Economics before pursuing his Ph.D. in fisheries oceanography. His research focuses on the relationship of petroleum platforms and pelagic fishes.

OIL PLATFORMS AND RED SNAPPER MOVEMENT

Michael McDonough and James H. Cowan, Jr.,
Department of Oceanography and Coastal Sciences, Louisiana State University

Click here to view the slide show that accompanied this presentation.

Understanding the movement and behavior of red snapper (*Lutjanus campechanus*) around and among the many oil and gas platforms in the northern Gulf of Mexico (GOM) is crucial to the management of this important commercial and recreational species. It has long been known that artificial reefs such as oil platforms are good fishing localities. Several scientific studies have confirmed that platforms are common sites for red snapper aggregation; however, current knowledge of how red snapper use platforms is scarce.

Estimates of abundance can only show that red snapper do associate with platforms, but not why. Telemetry enables researchers to investigate site fidelity and observe temporal and spatial patterns in red snapper movement and behavior. Site fidelity can serve as a proxy for the suitability of a platform to red snapper. Temporal patterns often correspond to feeding behavior and may give insight into whether platforms play some role in feeding by red snapper.

We performed experiments at two platforms, ST 135-M in 2005 and ST 134-S in 2006. We collected red snapper with hook and line and then implanted an ultrasonic transmitter into the fish. We tagged 16 fish in 2005 and 20 fish in 2006.

Prior to releasing the fish, we deployed the VEMCO radio-acoustic positioning (VRAP). For this paper, we performed analyses on detections. We plotted total fish detected in an hour for the length of the study. We also ran a Fourier transform analysis on the number of fish detected per hour to determine if there was any periodicity in the data (PROC SPECTRA, SAS Institute). We also performed LOESS fits to the fish detections by hour of day to observe any obvious trend (PROC LOESS, SAS Institute).

The VRAP system was able to detect 13 of the 20 individuals in 2006 and 13 of the 16 fish tagged in 2005. The data indicate that in 2006 seven fish left immediately (before being tracked by VRAP); another two left after two days; and another two after eight days. Ten stayed near the platform for at least 12 days, but only five remained until the end of the study. In 2005, three fish left immediately, and another left before the end of day two; the remaining 12 fish were still around the platform when the experiment was interrupted. Only five fish remained when we redeployed in August, and all five remained for the rest of the experiment. A periodogram from the Fourier transform analysis reveals a strong peak at 24 hours. The periodogram from the May 2005 data shows a strong peak in the neighborhood of 24 hours, and the August 2005 periodogram shows peaks at both 12 and 24 hours.

The LOESS fits show trends that are inconsistent among the different periods but do seem to reveal that any 24-hour periodicity is the result of daily increases and decreases in the number of fish detections.
Our study is one of a few to apply a real-time telemetry system to the movement and behavior of red snapper. Population estimates that have shown that red snapper congregate near oil platforms in large numbers; and site fidelity studies on a variety of artificial reef types and sizes have reported widely varying results, from <25% to >60%. However, some tag-and-release studies show the one-way, long-term movements of red snapper that are at large for many days post tagging, and no one has been able to ascertain what red snapper are doing when they associate with artificial reefs. These facts, sometimes conflicting, have contributed to the confusion over whether artificial reefs attract or produce fish.

The number of fish detected each hour decreased and increased at regular intervals; the Fourier periodogram indicates a diel pattern. It is likely that this periodicity represents feeding behavior. This would be consistent with several diet studies that suggest the red snapper, and other reef-associated species, feed on non reef-associated prey items.

Fish in this study also exhibited low site fidelity, particularly considering the brevity of the study. Only five of 20 implanted red snapper remained after 14 days in 2006; and in 2005 only five remained after two months. The number of snapper inhabiting oil platforms might create rather large foraging haloes, forcing red snapper to make long searches for available prey. We hypothesize that once they move such distances, returning is not desirable due to energy costs, or they have been exposed to elevated predation risk and consumed by piscivorous predators.

This fact necessitates a discussion of how detection radius affects site fidelity estimates. Some studies, both telemetry and mark-recapture, have considered movement less than 1.6-2 km to be an exhibition of site fidelity. Movements this far would have put red snapper not only beyond our detection radius but at other platforms anyway. At question is how far a fish can move and still be considered site “faithful.” We must define site fidelity in a way that is biologically meaningful. It is also not beyond question that a fish may derive benefit from platforms (emphasis on the plural) if not from a particular platform. In such a case, site fidelity would be only one indicator of the role of oil platforms in red snapper ecology. Further study is necessary, particularly more definitive work on diets around platforms.

Mike McDonough was born in Harrisburg, Pennsylvania, and grew up in Louisiana. He graduated from the University of Notre Dame with a B.S. in biology and then returned to Louisiana to work as a research associate at LSU. Mike's thesis research consists of tagging red snapper (*Lutjanus campechanus*) with acoustic transmitters and tracking their movements continuously to investigate why they are so commonly seen at oil platforms.

PLATFORM RECRUITED REEF FISH, PHASE I AND II: DO PLATFORMS PROVIDE HABITAT THAT INCREASES THE SURVIVAL OF REEF FISHES?

Lauren K. Nowling, James H. Cowan, Jr., and Richard F. Shaw,
Department of Oceanography and Coastal Sciences, Louisiana State University

Click here to view the slide show that accompanied this presentation.

We have several ongoing research projects that are related to oil and gas platforms in the northern Gulf of Mexico (GOM). All projects are funded by MMS and focus on the value of platforms as habitat for recreationally and commercially important finfish species such as red snapper. Briefly, it has been hypothesized that oil and gas platforms provide exceptionally high quality habitat, such that fishes located there have a survival advantage over conspecifics located in other artificial and natural environments. Increased habitat quality on oil and gas platforms is believed to be derived from increased food production associated with encrustation by fouling organisms, and by increased physical habitat via structures that extend from the bottom to the surface of the water column. However, this hypothesis remains to be tested at spatial and temporal scales relevant to juvenile red snapper production, even though estimates suggest that high numbers of reef fishes are located in "refuge" around platform legs.

In this approach, we first felt it necessary to demonstrate a "proof of concept." In the first phase of the project (Phase I) we proposed a novel test of the hypothesis that oil and gas platforms provide high quality habitat for juvenile red snapper in the northern GOM, and we tested whether association with oil and gas platforms during early life imparts a detectable "trace element isotope ratio fingerprint" in the otoliths of juvenile reef fishes. Because of the success of Phase I (summarized briefly below), we obtained funds to expand our geographic coverage of oil and gas platforms in the GOM, and to test whether adult fishes containing the "platform fingerprint" in their otoliths contribute disproportionately to adult stocks on nearby and distant natural and artificial reefs.

Results from Phase I

There are currently over 4000 functioning oil and gas platforms in the northern GOM. Platform operations, and their prior drilling operations, produce trace amounts of lead, barium, vanadium, and lanthanum residues that are leached into the surrounding waters and are deposited on the sea floor. These residues have isotopic ratios different from those typical of the GOM seafloor and can be used as harmless "fingerprints" if they become incorporated into hard-parts or tissues in fishes associated with oil and gas platforms. From 2002 to 2004, 115 red snapper were collected from oil and gas platforms and artificial reefs off Louisiana and Alabama. Otoliths were removed and analyzed using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The objective of Phase I was to determine if a trace element isotope ratio fingerprint could be detected and described as unique to red snapper inhabiting the platforms. Stepwise and canonical discriminant function analyses were used to compare red snapper otolith fingerprints from on and off platforms, and from east and west of the Mississippi River. Classification accuracies based on the probability of an individual fish being correctly classified into the habitat from which it was sampled were over 90% for each of the two main comparisons. When comparing the elemental composition of red snapper otoliths from Louisiana oil and gas platforms and Louisiana artificial reefs, the classification accuracy was 93.75%. When comparing the elemental composition of red snapper otoliths from Louisiana artificial reefs and Alabama artificial reefs, the classification accuracy was 91.06%. Vanadium 51, Lead 206, Lead 207, and Lead 208 all appear to be linked with oil and gas platforms or their prior drilling operations, as the concentrations of these four elements or isotopes were significantly higher in otoliths sampled on platforms in Louisiana than in otoliths sampled from artificial reefs in either Louisiana or Alabama. Results from Phase I indicate that it may be possible in future studies, if the platform signatures prove to be temporally and spatially stable, to determine if oil and gas platforms contribute disproportionately to the survival of juvenile and adult red snapper, and as such can be considered viable management tools for stock rebuilding (for more details see Shaw and Cowan, in press.)

Phase II

In Phase II, which began in January of 2007, we have been funded to determine if the trace metal fingerprint successfully identified from oil and gas platforms in Phase I is present in otoliths of red snapper collected from a broader geographical range over multiple (two) years, including additional samples from Louisiana, and new samples from platforms off Texas and Mississippi/ Alabama. This step is necessary to determine if the element fingerprint identified in Phase I is geographically and temporally stable, thus codifying its value as a marker of platform association. We are confident that this will be the case because the trace metal fingerprints arise from ongoing activities of oil and gas platforms (such as elements derived form the dissolution from the metal platform structure), as well as chemical signals created by the original drilling operations that remain in the substrate below the platform and continue to be mobilized in small quantities in the water column beneath the platform. We will collect 1000 individual juvenile red per year for two years from oil and gas platforms; 500 from Louisiana, 300 from Texas, and 200 from Mississippi/Alabama per year.

In Year 3, our focus will shift to adult snapper, where we will examine the otolith core to determine if fish that are recruiting to other habitats in the western, and especially the eastern GOM appear disproportionately to have been reared on platforms during early life. We will collect 300 fish in Year 3 from dockside locations in the eastern GOM as far south as Tampa, Florida, and 200 fish from Louisiana and/or Texas locations that were captured on habitats other than platforms. From a subsample of the adult otoliths, we will not only examine the core of the otolith that was deposited when the red snapper were young, we will precisely mill material from individual annual increments to determine the age at which red snapper move from more structured habitats such as platforms. We have recently purchased a laser-guided micromill for this purpose.

Results of this project will enhance our understanding of reef fish life history and provide much needed EFH information to state and federal fishery managers. Additionally, this project will establish methods and protocols for future research concerning essential fish habitat. We will continue to employ the latest analytical techniques to develop “elemental isotope ratio fingerprints” of juvenile reef fish otoliths, and the compare the elemental fingerprints between fishes collected in association with, and distant from, oil and gas platforms in the northern and eastern GOM. We have used similar techniques to distinguish between juvenile red snapper collected in different nursery regions of the shallow GOM. We reason that if oil and gas platforms provide high quality habitat and refuge from shrimp trawls, then high numbers of adult recruits should be derived from the pool of individuals that utilize said habitat, particularly off Louisiana and other areas where natural habitat is scarce. By focusing on recruits and adults in Phase II, our quantitative approach will provide a more direct assessment of the relative contribution of different juvenile red snapper habitat than is possible via traditional habitat suitability approaches. As such, we will be able to determine if the new adult recruits now expanding into the eastern GOM as the red snapper population rebuilds were associated with oil and gas platforms during some portion of their early life.

Reference

Shaw, R.F. and J.H. Cowan, Jr. In press. Platform recruited reef fish, phase I: Do platforms provide habitat that increase the survival of juvenile reef fishes? U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 81 pp.

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. Among many other professional activities, he has served on four National Research Council study committees and technical review panels concerning fisheries issues, resulting in the publication of two books. He has also served on the Ocean Sciences Division, Biological Oceanography and Arctic Natural Sciences Review Panels for the National Science Foundation four times and served as a U.S. delegate both to the International Council for the Exploration of the Sea (ICES) and the Pacific Marine Sciences Organization (PICES). He was chairman of the Reef Fish Stock Assessment Panel (1992–2004) and is a member of the Standing Scientific and Statistical Committee (1993–present) for the Gulf of Mexico Fishery Management Council. He has served as president of the Early Life History Section and on the Outstanding Chapter Award and Distinguished Service Award committees for the American Fisheries Society (AFS). In addition, in 2007 he received an Award for Excellence in Fisheries Management from AFS. He has almost 20 years of experience conducting fisheries research in marine and estuarine ecosystems and on artificial reefs. Dr. Cowan has authored more than 80 refereed publications in the primary fisheries literature. He served four years as an associate editor for *Estuaries*, the

journal of the Estuarine Research Federation, six years as an associate editor for *Gulf of Mexico Science*, and four years as an associate editor for *Transactions of the American Fisheries Society*. In 2007, he was selected by the AFS to be the development/managing editor of a new on-line journal focusing on marine fishery and ecosystems sciences.

CORAL DISTRIBUTION, ABUNDANCE, AND GENETIC AFFINITIES ON OIL/GAS PLATFORMS IN THE NORTHERN GULF OF MEXICO: A PRELIMINARY LOOK AT THE BIG PICTURE

P. W. Sammarco, Louisiana Universities Marine Consortium (LUMCON) and Department of Oceanography and Coastal Science, Louisiana State University

D. A. Brazeau, Department of Pharmaceutical Sciences, University of Buffalo

A. D. Atchison, Department of Oceanography and Coastal Science, Louisiana State University and Louisiana Universities Marine Consortium (LUMCON)

G. S. Boland, Environmental Sciences Section, Minerals Management Service

A. Lirette, Louisiana Universities Marine Consortium (LUMCON)

Abstract

The Flower Garden Banks (FGB), Gulf of Mexico (GOM), are highly isolated corals reefs. The surrounding continental shelf possesses ~3,600 oil/gas platforms. Questions: What is 1) the range of coral occurrence on these platforms in the northern GOM; 2) the pattern of species diversity; 3) the abundance of corals on the platforms; 4) the depth distribution of corals; 5) the genetic affinity of coral populations on platforms, on the FGB, and on in the eastern GOM; and 6) the difference between these characteristics in brooding vs. broadcasting corals? Thirteen platforms were surveyed around the FGB. Platforms on two transects spanning from 20 km offshore to the edge of the continental shelf were also surveyed off Corpus Christi, Texas; Lake Sabine, Texas; Terrebonne Bay, Louisiana; and Mobile, Alabama. Tissue samples of dominant corals were collected for genetic analysis and analyzed via AFLP to examine genetic affinities between populations. Twelve coral species were found on the platforms: nine hermatypic—the most abundant being *Madracis decactis, Diploria strigosa*, and *Montastraea cavernosa*; and three ahermatypes—the most abundant being *Tubastraea coccinea*, an Indo-Pacific invasive species.

Species diversity peaked at the FGB. The highest diversity on platforms was on platforms directly surrounding the FGB. Corals were found on many platforms within all transects, particularly at the shelf edge. They were absent in inshore waters, probably due to the low salinity of Mississippi River plume. Depth distribution was highly variable across the shelf. Depth of occurrence decreased with distance from shore in *Madracis decactis* off Lake Sabine and Terrebonne Bay, possibly as a result of lower salinities in the shallower waters there. Depth of occurrence in *T. coccinea* tracked off Corpus Christi indicated its lack of sensitivity to environmental variables. Genetic affinities were relatively low between the FGB and nearby platforms. Densities and genetic affinities were higher in the brooder *M. decactis* and lower in the broadcaster *D. strigosa*. This suggests that brooders are more effective at successful larval dispersal and recruitment than broadcasters where suitable habitat is distributed patchily at the scale of kms. Genetic affinities were moderate within the 3rd and 4th cross-shelf transects,

respectively, in *T. coccinea* than *M. decactis*. Affinities were near-zero between transects, suggesting that the Mississippi River is a formidable geographic barrier to dispersal in this region.

Introduction

14,000 yrs ago, when sea level was ~120 km below its present level in the Gulf of Mexico (Curray 1965; Blum et al. 2001), a number of islands or banks occurred at the shore and would have been good candidates for coral reef development (Rezak et al. 1985). As sea level rose, most banks were drowned, but two occurring on the caps of salt diapirs (salt domes) developed into what are now the only true, substantial coral reefs in the northern Gulf of Mexico (GOM)—the E- and W-Flower Garden Banks (FGB), located 190 km S-SE of Galveston, Texas.

In the 1940s, the oil and gas exploration program of the U.S. extended offshore onto the continental shelf of the northern GOM. This represented the first introduction of new hard substratum to the region since the Pleistocene, extending from the bottom, through the euphotic zone, and into the atmosphere. There are currently 3,600 platforms in this region (Francois 1993; Knott 1995; Dauterive 2000; GSB). Reef ecosystems developed on these structures, including fish, sponges, ascideans, hydrozoans, etc. There were early reports of scleractinian hermatypic corals occurring there (Bright et al. 1984, 1991; Adams 1996; Boland 2002; K. Deslarzes, pers. comm.), and such has now been confirmed for the region around the FGB (Sammarco et al. 2004). The extent of their distribution across the GOM, however, was unknown.

The objectives of this study were to determine: 1) the range of coral occurrence in the northern GOM; 2) the pattern of species diversity; 3) coral abundance on the platforms across the continental shelf; 4) their depth distributions on the platforms; 5) the genetic affinities of the platform coral populations to those on the FGB and in the eastern sector; and 6) a comparison of brooders and broadcasting corals (reproductive strategies) with respect to these patterns to make inferences about their dispersal and recruitment capabilities. Due to space limitations, this paper is not presented as a comprehensive technical report. We will present a general overview of major program results to date. Technical details with full documentation will be published elsewhere.

Materials and Methods

This study has thus far been executed in two phases. The first consisted of visual surveys conducted from 7–30 m depth on 13 platforms surrounding the FGB—from 15 km west to 45 km east (see Sammarco et al. 2004). Tissue was also collected from the corals, returned to the vessel, preserved in high-salt buffer, and later subjected to molecular genetic DNA analysis by Amplified Fragment Length Polymorphisms (AFLP; see Barki et al. 2000; Brazeau et al. 2005 for details). Data were analyzed by AMOVA (Excoffier et al. 1992) and AFLPOP (Duchesne and Bernatchez 2002).

In Phase II, these surveys were extended to an additional series of 28 platforms covering the northern GOM. Surveys were conducted along transects extending from ~20 km offshore to the edge of the continental shelf or beyond. Four transects were run, respectively, off Corpus Christi, Texas (T-I), Lake Sabine/Port Arthur, Texas (T-II), Terrebonne Bay, Louisiana (T-III), and Mobile, Alabama (T-IV). Coral tissue samples were also collected from the dominant corals there, and depths of occurrence were recorded.

Results

Coral Species Composition

In all, 12 species of corals were found on the platforms—nine hermatypes (reef-building corals) and three ahermatypes (non-reef building corals). The dominant hermatypic corals were *Madracis decactis* (Lyman 1859), a brooder; *Diploria strigosa* (Dana 1846), a broadcaster; and *Montastraea cavernosa* (Linnaeus 1767), another broadcaster. The other hermatypic species were *Colpophyllia natans* (Houttuyn 1772), *Madracis formosa* (Wells 1973), *Millepora alcicornis* (Linaeus 1758), *Porites astreoides* (Lamarck 1816), *Stephanocoenia intersepta* (Lamarck 1816), and *S. michelenii* (Edwards & Haime 1848). The two most abundant ahermatypic corals were *Tubastraea coccinea* (Lessen 1929), a brooder and invasive species from the Indo-Pacific (Fenner 1999; Fenner and Banks 2004; Figuera de Paula and Creed 2004; Sammarco et al. 2004), and *Oculina diffusa* (Zlatarski and Estalella 1982). The other ahermatypic species was *Phyllangia americana* (Milne, Edwards, & Haime 1849).

Species Diversity

With respect to species diversity, 24 spp. of hermatypic corals have been reported to occur on the FGB and two ahermatypes. In this study, a peak in diversity was found on the FGB, generally falling off precipitously in all directions. A higher diversity occurred shoreward in T-II, however, off Lake Sabine, Texas. Species diversity of ahermatypic corals was relatively equitable across the continental shelf.

Coral Density

In T-I, off Corpus Christi, Texas, corals occurred from 35 to110 km offshore, although densities were quite low. Densities were much higher in T-II, peaking at the shelf edge, near the FGB and were very high in T-III. In T-III, however, the inner shelf, from 0-80 km offshore, was devoid of corals. T-IV, located to the east of the Mississippi River, possessed very few corals, much like T-I in the west.

Only one to two colonies of *Madracis decactis* were found in T-I, and these at the shelf edge. In T-II, it appeared at the mid-shelf and increased dramatically towards the shelf edge and beyond. In T-III, *Madracis* was absent within 80 km of shore; after this point, its densities exceeded those in T-II, exhibiting the highest in the survey. *Madracis* was rare or absent on platforms in T-IV, as in T-I.

Although *Diploria strigosa* was the second most abundant hermatypic coral in the study, it was absent in T-I, III, and IV. Even in T-II, it did not appear until 175 km offshore, near the FGB, and there it was only present in low numbers. M*ontastraea cavernosa* exhibited a similar distribution, being present in low densities at the shelf edge in T-II.

Tubastraea coccinea, the invasive ahermatypic coral, occurred in T-I, but only in small numbers. In T-II, it was absent until 150 km offshore, after which its densities increased greatly, peaking at the shelf edge. In T-III, some colonies occurred at the mid-shelf, with densities peaking at the shelf edge—higher than in T-II. Similar densities were observed in T-IV, although occurrence was generally restricted to the shelf edge.

Depth Distribution

Coral depth distributions varied significantly between platforms. In T-II and III, the average depths of all hermatypic corals became shallower with distance from shore, particularly towards the shelf edge. This pattern occurred in *Madracis decactis*, but was only clear in T-II. In the ahermatypic coral *Tubastraea coccinea*, variance in depth distribution was high in T-I, II, III. In T-II, however, depth of coral tracked shelf depth with distance from shore. A similar pattern was observed in *Oculina diffusa*, also ahermatypic.

Genetic Affinities

The AFLP data as analyzed by AFLPOP revealed self- and cross-recognition patterns of corals between platforms. The W-FGB and the platform WC-630 will be used here as examples of patterns. At the W-FGB, *Diploria strigosa* exhibited relatively high self-recognition and a high proportion of “unknown” colonies (or colonies with potential multiple assignments). At WC-630A, 45 km to the east of the FGB, there was 100% self-assignment and recognition, with no cross-recognition or unknown or ambiguous assignments.

In *Madracis decactis*, there was high self-site recognition in the populations. Cross-site recognition was higher than in *Diploria*, but there was still a large proportion of “unknown” or colonies with potential multiple assignment. On WC-630A, unlike the case in *Diploria strigosa*, the pattern was actually similar to that on the FGB, where there was cross-recognition between all sites, with many “unknown” or multiple assignments.

At the time of this report, samples had only been processed for genetic affinity in T-III and T-IV. These analyses revealed that *Madracis decactis* exhibited moderate same-site recognition within a sector (transect), but very little cross-transect recognition. *Tubastraea coccinea* exhibited higher inter-platform recognition within a transect/sector and a much lower self/site-recognition. There was almost no cross-sector (T-III vs. T-IV) recognition.

Discussion

All corals observed here were Caribbean species (including one invasive) reported previously. All of them except one occurred on the FGB (Rezak et al. 1985; Gittings 1998; Pattengill-Semmens et al. 2000; Pattengill-Semmens and Gittings 2003; Precht et al. 2005). The exception was *Oculina diffusa.* Its origin at this point is unknown; it represents an as-yet unexplained anomaly.

The three dominant hermatypic corals found on the platforms are all well-represented on the FGB (see above references). *Tubastraea coccinea* occurs on the FGB but is rare there (Fenner 2001; Fenner and Banks 2004; E. Hickerson and G.P. Schmahl, pers. comm.)—unlike on the platforms, where it can occur its abundances reach into the tens of thousands (Sammarco et al. 2004; this paper). *T. coccinea* is apparently an opportunistic species, doing well in early seres and on artificial reefs, but not in later seres and on natural, well-established reef communities. Agaricia and Porites were rare or absent on the platforms. These are known to be pioneer species on Caribbean reefs (Sammarco 1980, 1982, 1987). They are common on the FGB as adults (Rezak et al. 1985; Gittings 1998; Pattengill-Semmens et al. 2000; Pattengill-Semmens and Gittings 2003; Precht et al. 2005) and as newly settled spat and juveniles (Sammarco et al. 2005).

The pattern of dissipation in density of hermatypic corals is consistent with the spread of species from a single point predicted by MacArthur and Wilson (1967), see also Robertson 2001. The diversity center for hermatypic species at the FGB suggests that they were most likely a primary source for species expansion in the northern GOM. The flat pattern of species diversity in the ahermatypic corals indicates that they were most likely already present on other banks and outcrops (Rice and Hunter 1992; Fenner 2001; Fenner and Banks 2004; Reed et al. 2006). Since the latter group does not require light, future work on the deeper distribution and genetics of scleractinian corals will help to elucidate this question (Sammarco et al. work in progress).

The lack of corals in the western sector (T-I) indicates that this area probably represents the northwestern limit for scleractinian corals in the GOM. The increased density around the FGB at the shelf edge is logical, particularly if the FGB are acting as a larval source. The fact that coral density is even higher at the shelf edge in T-III, further east, suggests that the FGB may be acting as a larval source for this region (see Lugo-Fernandez 1998; Lugo-Fernandez et al. 2001). Primary currents in that region travel from the FGB following the shelf-edge isobath from T-II to T-III (Salas-de-Leon et al. 1998; Vidal Lorandi et al. 1999) and may be acting as an important vector of dispersal in this region. The lower densities of corals in the eastern sector (T-IV) indicate that this may be approaching the northeastern limit for corals in the GOM. The lack of corals on the inner shelf in T-II and T-III suggest that the Mississippi River plume, which travels primarily inshore to the west in this region (Walker 1996; Dortch et al. 1998; Green et al. 2006b), is limiting coral distribution there. Influencing factors might include lower salinity (Ladner et al. 2006), higher turbidity (Green et al. 2006a), higher nutrient concentrations (N and P) (Rabalais et al. 1996; Powell 2006; Rinker and Powell 2006; Sylvan et al. 2006), winter temperatures extending below the tolerances for scleractinian corals (< 18^{o}C; Muller-Karger 2000; Zavala-Hidalgo et al. 2006), and low oxygen concentrations—hypoxia—known to be prominent in this region (Rabalais et al. 1996; Dortch et al. 1998; Dagg and Breed 2003; Green et al. 2006b; Sylvan et al. 2006).

The relatively broad distribution of *Madracis decactis,* particularly in the central region of the northern GOM, indicates that this species is very effective at colonizing new habitats distributed patchily at this scale—on the order of kms apart. This species is a brooder (Vermeij et al. 2003), and its planulae can settle within hours of release (Harrison and Wallace 1990), placing them in close proximity to other platforms in reasonable densities while ready to settle. *Diploria strigosa* and *Montastraea cavernosa*, however, were highly concentrated around the FGB in a substantially restricted distribution. Both of these species are broadcasters (Wyers et al. 1989; Szmant 1991; Hagman et al. 1998; Steiner 1995; Acosta and Zea 1997; Gittings et al. 1992, 1994; Soong 1993), with larvae requiring a 72–96 hr planktonic development period before they are competent to settle. This period of time would allow for their advection over much longer distances and for diffusion of the larvae to lower densities in the water column (Okubo 1994; Sammarco 1994).

In addition, exposure to the array of potential environmental conditions at spawning varies greatly between the two reproductive types. As a brooder, *Madracis decactis* releases fully developed planulae each month for 8–10 months per year, over a period of 10–14 days per month. In this way, the larvae are benefiting from advection by currents that vary daily, weekly, monthly, and seasonally in direction and velocity over the year. *Diploria strigosa* and *Montastraea cavernosa*, on the other hand, follow a mass spawning mode of reproduction, whereby all propagules are released once per year and are subjected only to one seasonal current and one set of weather conditions surrounding the spawning period. The brooder considered here is much better adapted to colonize successfully patchy habitats distributed at this spatial scale than the two co-occurring broadcasters.

The fact that the average depths of all corals, and in particular *Madracis decactis*, were shallower in T-II and T-III indicates that something is excluding hermatypic corals from the shallower inshore waters, most likely the less saline waters associated with the plume of the Mississippi River (D'Sa and Miller 2003; Vinogradov et al. 2004; Jolliff 2005). The reverse trend observed in *Tubastraea coccinea* in T-I indicates that this species is more hardy and may be less affected by many of the environmental variables associated with inshore waters. It is most likely simply taking advantage of added depth as it becomes available across the shelf (Rezak et al. 1985).

The genetic affinity patterns observed in the two primary hermatypic species, *Madracis decactis* and *Diploria strigosa*, near the FGB indicate striking differences in their respective abilities to disperse successfully to and colonize new habitats. The platform field in the northern GOM represents individual patches of habitat on the order of kms from each other. *M. decactis* has a shorter dispersal distance, is a more effective colonizer, and uses a "stepping stone" strategy for colonization and gene flow (Futuyma 1998). *D. strigosa*, on the other hand, a broadcaster, is a less effective colonizer in a patchy environment but appears to have a higher capability for long-distance dispersal, albeit on a stochastic basis and at lower levels. It is more likely to utilize and "island hopping" strategy (Futuyma 1998).

Comparisons between the genetic affinity patterns observed in T-III and T-IV add a new dimension to this. *Madracis decactis* and *Tubastraea coccinea* are both brooders, but the former exhibits a limited gene flow between platforms, even in close proximity, indicating either a high level of self-seeding (Sammarco and Andrews 1988, 1989; Black et al. 1991; Sammarco 1994; Wolanski et al. 2003; Santangelo et al. 2004; Whitaker 2006) and possibly founder effect (e.g., Planes and Lecaillon 1998). The patterns of *T. coccinea*, on the other hand, an invasive species, indicated that it has higher dispersal capabilities at this scale than its native counterpart, a critical contrast. This may help to explain why this species has been so successful in colonizing the western Atlantic once introduced.

The fact that neither species exhibited genetic affinities between T-III and T-IV indicates that the Mississippi River plume represents a formidable geographic barrier to dispersal of populations in this region. This raises questions regarding the biogeographic province of "The Gulf of Mexico," recently confirmed by Engle and Summers (2000), as that region spanning the Rio Grande, Texas, to Cape Romano, Florida (also see Felder and Staton 1994; Staton and Felder 1995). Although the species groupings may be generally consistent, the data here suggest that breeding populations may be separate on either side of the Mississippi River, with little or no gene flow across the plume. It also indicates that the eastern sector of the northern GOM may be receiving larvae from a different source than the western sector—perhaps the Caribbean via the Loop Current (Sturges and Blama 1976; Hamilton et al. 1999), as opposed to the Yucatan Peninsula and the Bay of Campeche via the coastal current in the western Gulf (Salas-de-Leon et al. 1998; Vidal Lorandi et al. 1999; also see Lugo-Fernandez et al. 2001; Lugo-Fernandez 1998, 2006).

Acknowledgments

Many thanks to the many people and organizations who assisted us in this study: U.S. Department of the Interior, Minerals Management Service – D. Ball, S. Childs, L. Dauterive, T. Dempre G. Kozlowski, H. Leedy, J. Sinclair, (diving); LSU Coastal Marine institute – L. Rouse; Anadarko Petroleum; Apache Oil; Callon Petroleum Operating Co; Chevron-Texaco Exploration and Production; Coastal Oil and Gas; Devon Oil; Dominion Exploration and Production; El Paso Energy; Forcenergy/Forest Oil; Kerr-McGee Oil and Gas; Manta Ray Offshore Gathering Co; Merit Energy; Newfield Exploration; Noble Energy; Offshore Energy; Petro Ventures, Inc; Samedan Oil; Shell Offshore; Stone Energy Corp; UNOCAL; W&T Offshore; LSU Oceanography – K. Wheelock, D. Woodard; Gulf Diving, Inc. – R. Adkins, R. Bailey, J. Bruce, K. Bush, J. Byron, P. Combs, L. DeWeese, J. Dibble, D. Fanning, K. Foster, G. Harding, J. Heiser, S. Hodges, Jason, B. Joy, S. Kerr, T. Kilpatrick, M. McReynolds, G. Phillips, S. Richman, J. Smale, R.Travis, R. Widaman; USAF/NASA – Lt. Col. D. Perrenod; Times-Picayune – S. Langennig, D. Rogers; 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; University of Louisiana at Lafayette – R. Harris, J. Van der Ham; Aquarium of the Americas – A. Sebastian; Southern University at New Orleans – D. Hill-House; Ecorigs.org – S. Kolian; Caribbean Dive – D. Delger; OceanVision – J. Flagg , D. Schweinler; C. Chauffe, J. Conklin, R. DeFelice, D. Dowdy, T. Epney, C. Gentry, L. Logan, D. Marcel, G. Rainey, J. Sammarco, and G. Speyrer. 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

Acosta, A. and S. Zea. 1997. Sexual reproduction of the reef coral *Montastraea cavernosa* (Sclerlactinia: Faviidae) in the Santa Marta area, Caribbean coast of Colombia. Mar. Biol. 128:141–148.

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 Univ.-Corpus Christi, Center for Coastal Studies.

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. Mar. Biol. 136:37–41.

Black, K.P., P.J. Moran, and L.S. Hammond. 1991. Numerical models show coral reefs can be self-seeding. Mar. Ecol. Prog. Ser. 74:1–11.

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. J. Sed. Res. 71:4

Boland, G.S. 2002. Fish and epifaunal community observations at an artificial reef near a natural coral reef: Nineteen years at Platform High Island A389-A, from bare steel to coral habitat. In: McKay, M., J. Nides, and D. Vigil, eds. Proceedings: Gulf Mexico Fish and Fisheries: Bringing Together New and Recent Research, October 2002. 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.

Brazeau, D., P.W. Sammarco, and D.F. Gleason. 2005. A multi-locus genetic assignment technique to assess local recruitment of *Agaricia agaricites* on coral reefs. Mar. Biol. 147:1141–1148.

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. Bull. Mar. Sci. 23:461–476.

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 Sci. 12:55–60.

Curray, J.R. 1965. Late Quaternary history, continental shelves of the United States. In: Wright, H.E., Jr. and D.G. Frey, eds. The Quaternary of the United States. Princeton, NJ: Princeton University Press. Pp. 723–735.

Dagg, M.J. and G.A. Breed. 2003. Biological effects of Mississippi River nitrogen on the northern Gulf of Mexico – A review and synthesis. J. Mar. Syst. 43:133–152.

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.

Dortch, Q., C.E. Ebbesmeyer, W.D. Gardner, O.K. Huh, D.J. McMillin, S.P. Murray, N.N. Rabalais, M.J. Richardson, L.J. Rouse, R.F. Shaw, R.W. Sternberg, R.E. Turner, N.D. Walker, M.L. White, and L.D. Wright. 1998. An observational study of the Mississippi-Atchafalaya coastal plume: Final report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 98-0040.

D'Sa, E.J. and R.L. Miller. 2003. Bio-optical properties in waters influenced by the Mississippi River during low flow conditions. Remote Sens. Environ. 84:538–549.

Duchesne, P. and L. Bernatchez. 2002. AFLPOP: A computer program for simulated and real population allocation using AFLP markers. Mol. Ecol. Notes 2:380–383.

Engle, V.D. and J.K. Summers. 2000. Biogeography of benthic macroinvertebrates in estuaries along the Gulf of Mexico and western Atlantic coasts. Hydrobiologia 436:17–33.

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.

Felder, D.L. and J.L. Staton. 1994. Genetic variation in trans-Floridian species complexes of *Sesarma* and *Uca* (Crustacea: Decapoda: Brachyura). J. Crustac. Biol. 14:191–209.

Fenner, D. 1999. New observations on the stony coral (Scleractinia, Milleporidae, and Stylasterida) species of Belize (Central America) and Cozumel (Mexico). Bull. Mar. Sci. 64:143–154.

Fenner, D. 2001. Biogeography of three Caribbean corals (Scleractinia) and the invasion of *Tubastraea coccinea* into the Gulf of Mexico. Bull. Mar. Sci. 69:1175–1189.

Fenner, D. and K. Banks. 2004. Orange cup coral Tubastraea coccinea invades Florida and the Flower Garden Banks, northwestern Gulf of Mexico. Coral Reefs 23:505–507.

Figuera de Paula, A. and J.C. Creed. 2004. Two species of the coral Tubastraea (Cnidaria, Scleractinia) in Brazil: A case of accidental introduction. Bull. Mar. Sci. 74:175–183.

Francois, D.K. 1993. Federal offshore statistics: 1992. Leasing, exploration, production, and revenues as of December 31, 1992. U.S. Dept. of the Interior, Minerals Management Service, Herndon, VA. OCS Study MMS 93-0066. 155pp.

Futuyma, D.J. 1998. Evolutionary biology. Sunderland, MA: Sinauer Assocs.

Gittings, S.R. 1998. Reef community stability on the Flower Garden Banks, northwestern Gulf of Mexico. Gulf Mex. Sci. 16:161–169.

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. Bull. Mar. Sci. 51:420–428.

Gittings, S.R., W.A. Inglehart, G.S. Rinn, and Q.R. Dokken. 1994. Coral mass spawning on the Flower Garden Banks, NW Gulf of Mexico. Bull. Mar. Sci. 54:1076.

Green, R.E., T.S. Bianchi, M.J. Dagg, N.D. Walker, and G.A. Breed. 2006a. An organic carbon budget for the Mississippi River turbidity plume, and plume contributions to air-sea CO_2 fluxes and bottom-water hypoxia. Estuaries Coasts 29:579–597.

Green, R.E., R.W. Gould, R.A. Arnone, and P.M. Martinolich. 2006b. Application of optical water mass classification to carbon cycling in the northern Gulf of Mexico. EOS Trans. Am. Geophys. Union 87(36) suppl.

Hagman, D.K., S.R. Gittings, and P.D. Vize. 1998. Fertilization in broadcast-spawning corals of the Flower Garden Banks National Marine Sanctuary. Gulf Mex. Sci. 16:180–187.

Hamilton, P., G.S. Fargion, and D.C. Biggs. 1999. Loop current eddy paths in the western Gulf of Mexico. J. Phys. Oceanogr. 29:1180–1207.

Harrison, P.L. and C.C. Wallace. 1990. Reproduction, dispersal, and recruitment of scleractinian corals. In: Dubinsky, Z., ed. Ecosystems of the World, Volume 25: Coral Reefs. Amsterdam: Elsevier Press.

Jolliff, J.K. 2005. The influence of coastal effluent and deep-water masses on surface optical properties and margin productivity in the northeastern Gulf of Mexico: A three-dimensional simulation analysis. Ph.D. dissertation, Department of Marine Science, University of South Florida. 146 pp.

Knott, D. 1995. U.S. lessons for U.K. platform disposal. Oil and Gas J. 93:17–18.

Ladner, S.D., R.W. Gould, R.A. Arnone, R.R. Parsons, D.S. Ko, and V.M. Wright. 2006. Using ocean color imagery to monitor salinity in the northern Gulf of Mexico. EOS Trans. Am. Geophys. Union 87(36), suppl.

Lugo-Fernandez, A. 1998. Ecological implications of hydrography and circulation to the Flower Garden Banks, northwest Gulf of Mexico. Gulf Mex. Sci. 16:144–160.

Lugo-Fernandez, A. 2006. Travel times of passive drifters from the western Caribbean to the Gulf of Mexico and Florida-Bahamas. Gulf Mex. Sci. 24:61–67.

Lugo-Fernandez, A., K.J.P. Deslarzes, J.M. Price, G.S. Boland, and M.V. Morin. 2001. Inferring probable dispersal of Flower Garden Banks coral larvae (Gulf of Mexico) using observed and simulated drifter trajectories. Cont. Shelf Res. 21:47–67.

MacArthur, R.H. and E.O. Wilson. 1967. The theory of island biogeography. Princeton, NJ: Princeton University Press. 203 pp.

Muller-Karger, F.E. 2000. The spring 1998 northeastern Gulf of Mexico (NEGOM) cold-water event: Remote sensing evidence for upwelling and for eastward advection of Mississippi water (or: How an errant Loop Current anticyclone took the NEGOM for a spin). Gulf Mex. Sci. 18:55–67.

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, D.C.: Am. Geophys. Union. Pp. 35–72.

Pattengill-Semmens, C.V. and S.R. Gittings. 2003. A rapid assessment of the Flower Garden Banks National Marine Sanctuary (stony corals, algae, and fishes). Atoll Res. Bull. 496:500–511.

Pattengill-Semmens, C., S.R. Gittings, and T. Shyka. 2000. Flower Garden Banks National Marine Sanctuary: A rapid assessment of coral, fish, and algae using the AGRRA protocol. Marine Sanctuaries Conservation Series MSD-00-3. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Marine Sanctuaries Division, Silver Spring, MD. 15 pp.

Planes, S. and G. Lecaillon. 1998. Consequences of the founder effect in the genetic structure of introduced island coral reef fish populations. Biol. J. Linn. Soc. 63:537–552.

Powell, R. 2006. High resolution sampling of nutrient concentrations in the Mississippi River plume. EOS Trans. Am. Geophys. Union 87:(36) suppl.

Precht, W.F., M.L. Robbart, G.S. Boland, and G.P. Schmahl. 2005. Establishment and initial analysis of deep-reef stations (32–40m) at the East Flower Garden Bank. Gulf Mex. Sci. 23:123–127.

Rabalais, N.N., W.J. Wiseman, Jr., R.E. Turner, D. Justic, B.K. Sen Gupta, and Q. Dortch. 1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. Estuaries 19:386–407.

Reed, J.K., D.C. Weaver, and S.A. Pomponi. 2006. Habitat and fauna of deep-water *Lophelia pertusa* coral reefs off the southeastern U.S.: Blake plateau, Straits of Florida, and Gulf of Mexico. Bull. Mar. Sci. 78:343–375.

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.

Rice, S.A. and Hunter C.L. 1992. Effects of suspended sediment and burial on scleractinian corals from west central Florida patch reefs. Bull. Mar. Sci. 51:429–442.

Rinker, K.R. and R.T. Powell. 2006. Dissolved organic phosphorus in the Mississippi River plume during spring and fall 2002. Mar. Chem. 102:170–179.

Robertson, D.N. 2001. The implications of the target-area hypothesis on the population dynamics of the spotted spiny lobster, *Panulirus guttatus*. University of Florida, Gainesville, FL. Florida Sea Grant Report No. FLSGP-X-01-003.

Salas-de-Leon, D.A., M.A. Monreal-Gomez, L. Sanvicente-Anorve, and C. Flores-Coto. 1998. Long-term influence of currents on zooplanktonic organisms distribution in the Bay of Campeche. Oceanol. Acta 21:87–93.

Sammarco, P.W. 1980. *Diadema* and its relationship to coral spat mortality: Grazing, competition, and biological disturbance. J. Exp. Mar. Biol. Ecol. 45:245–272.

Sammarco, P.W. 1982. Echinoid grazing as a structuring force in coral communities: Whole reef manipulations. J. Exp. Mar. Biol. Ecol. 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. UNESCO Reports Mar. Sci. 46:127–166.

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, D.C.: American Geophysical Union. Pp. 35–72.

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. Limnol. Oceanogr. 34:898–914.

Sammarco, P.W., A. Atchison, and G.B. Boland. 2004. Offshore oil and gas platforms and expansion of coral communities within the Northern Gulf of Mexico. Mar. Ecol. Prog. Ser. 280:129–143.

Sammarco, P.W., A.D. Atchison, and G.S. Boland. 2005. Distribution of corals colonizing oil and gas platforms in the northwestern Gulf of Mexico: A preliminary report. In: McKay,

M. and J. Nides, eds. 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.

Santangelo, G., E. Maggi, L. Bramanti, and L. Bongiorni. 2004. Demography of the over-exploited Mediterranean red coral (*Corallium rubrum* L. 1758). Sci. Mar. (Barc.) 68:199–204.

Soong, K. 1993. Colony size as a species character in massive reef corals. Coral Reefs 12:77–83.

Staton, J.L. and D.L. Felder. 1995. Genetic variation in populations of the ghost shrimp genus *Callichirus* (Crustacea, Decapoda, Thalassinoidea) in the western Atlantic and Gulf of Mexico. Bull. Mar. Sci. 56:523–536.

Steiner, S.C.C. 1995. Spawning in scleractinian corals from SW Puerto Rico (West Indies). Bull. Mar. Sci. 56:899–902.

Sturges, W. and J.P. Blama. 1976. A western boundary current in the Gulf of Mexico. Science 92:367–369.

Sylvan, J.B., Q. Dortch, D.M. Nelson, and J.W. Ammerman 2006. Seasonal phosphorus limitation on the Louisiana shelf during periods of high biomass and productivity: A result of nitrogen loading from the Mississippi River? EOS Trans. Am. Geophys. Union . 87(36) suppl.

Szmant, A.M. 1991. Sexual reproduction by the Caribbean reef corals *Montastraea annularis* and *M. cavernosa*. Mar. Ecol. Prog. Ser. 74:13–25.

Vermeij, M.J.A., E. Sampayo, K. Broeker, R.P.M. Bak. 2003. Variation in planulae release of closely related coral species. Mar. Ecol. Prog. Ser. 247:75–84.

Vidal Lorandi, F.V., V.M.V. Vidal Lorandi, P.F. Rodriguez Espinoza, L. Sambrano Salgado, J. Rotrilla Casilla, J.R. Rendon Villalobos, B.J. de la Cruz. 1999. Gulf of Mexico Circulation Rev. Soc. Mex. Hist. Nat. 49:1–15.

Vinogradov S., N. Vinogradova, V. Kamenkovic, and D. Nechaev. 2004. Temperature and salinity variability in the Mississippi Bight. Mar. Technol. Soc. J. 38:52–60.

Walker, N.D. 1996. Satellite assessment of Mississippi River plume variability: Causes and predictability. Rem. Sens. Envt. 58:21–35.

Whitaker, K. 2006. Genetic evidence for mixed modes of reproduction in the coral *Pocillopora damicornis* and its effect on population structure. Mar. Ecol. Prog. Ser. 306:115–124.

Wolanski, E., R.H. Richmond, G. Davis, E. Deleersnijder, and R.R. Leben 2003. Eddies around Guam, an island in the Mariana Islands group. Cont. Shelf Res. 23:991–1003.

Wyers, S.C., H.S. Barnes, and S.R. Smith. 1991. Spawning of hermatypic corals in Bermuda: A pilot study. Hydrobiologia 216/217:109–116.

Zavala-Hidalgo, J., A. Gallegos-Garcia, B. Martinez-Lopez, S.L. Morey, and J.J. O'Brien. 2006. Seasonal upwelling on the western and southern shelves of the Gulf of Mexico. Ocean Dyn. 56:333–338.

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.

ASSESSING OIL AND GAS PLATFORMS FOR SETTLEMENT OF JELLYFISH POLYPS IN THE NORTHERN GULF OF MEXICO

William M. Graham and Keith M. Bayha,
Dauphin Island Sea Lab and University of South Alabama

Click here to view the slide show that accompanied this presentation.

The so-called "Australian spotted jellyfish," *Phyllorhiza punctata,* drew wide-spread attention when it appeared suddenly and in spectacular numbers in the northern Gulf of Mexico during the summer of 2000 (Graham et al. 2003). Since then, regional spreading has occurred into Texas and Florida, and a permanent population appears established in southern Louisiana. *Phyllorhiza punctata* was first described from Pt. Jackson, Australia, and, presumably due to its large medusa phase, has a relatively well-documented history of invading tropical and subtropical environments around the globe over the past 200 years (Graham et al. 2003). This well-documented history of invasion may make *P. punctata* a particularly instructive model for understanding invasions of jellyfish in particular, and of invasive marine species in general. The potential ecological and economic impacts of *P. punctata* were judged as high, and it was feared that its invasion would permanently alter the ecology of the northern Gulf of Mexico along with the valuable fishing industry that depends on it. These fears were fueled by the costs of *P. punctata* to the shrimp industry—for Mississippi alone, these have been estimated to be U.S. $10 million for 2000 (Graham et al. 2003 and references therein).

The very large population estimated at 10×10^6 medusae across the north-central Gulf of Mexico (Alabama, Mississippi, and Louisiana) in the summer of 2000 was unexpected, as the species had never been documented north of the Caribbean Sea (Graham et al. 2003, reviewed in Graham and Bayha 2007). The timing of the occurrence was coincident with the incursion of tropical water from the Caribbean into the Gulf of Mexico, suggesting that medusae were transported out of the Caribbean Sea by the northward-flowing Loop Current in the Gulf of Mexico, but dissimilar morphologies between populations in the Caribbean and northern Gulf of Mexico contradict this hydrographic connection (Bolton and Graham 2004) and suggest that an established population exists somewhere in the northern Gulf of Mexico (Johnson et al. 2005).

Questions of invasion history and possible modes of translocation can only be answered in the context of the entire life-history of this jellyfish. *Phyllorhiza punctata*, like most scyphozoans, has a bipartite life history involving both pelagic (medusa) and benthic (scyphistoma = polyp) stages. Because of this complex life-history, successful invasion of *P. punctata* requires that benthic polyp populations have become established in the northern Gulf of Mexico. However, locating polyp colonies is difficult owing to their small size (~1–2 mm total length).

The available literature suggests that a universal requirement for settlement and polyp growth appears to be stable hard substrate. In the northern Gulf of Mexico, hard substrate is limited to sparsely distributed natural hard-bottom or highly distributed artificial substrate. Estimates of natural hard-bottom coverage of the northern Gulf of Mexico shelf are around 5% (Parker et al. 1983, Continental Shelf Associates, Inc. 1992, Thompson et al. 1999). Only half of all live-bottom substrate was estimated to be high-relief (>1 m in vertical height). Due to the susceptibility of scyphistomae to sedimentation, it is likely that higher relief substrate (i.e., substrate that extends above nephaloid layers and above near-bottom resuspension of sediments) is needed to support population survival and growth. Therefore, we asked whether artificial substrates (e.g., artificial fish reefs and oil and gas production structures) play a role in survival of benthic polyp stages of jellyfish.

A one-year field assessment was made during 2001 using settlement plate arrays and depth-stratified scrapings of three platforms (two in Alabama, one in Louisiana) in similar water depths (~20 m). The study was carried out during the summer and fall to overlap with medusa seasonality and reproduction. Triplicate arrays consisting of six 10 cm x 10 cm PVC plates were placed at three depths on each platform. Arrays were recovered and replaced at approximately two- to three-week intervals and immediately viewed using stereo microscopy. Despite this labor-intensive approach, no scyphozoan polyps were confirmed at any of the platform arrays or scrapings. While disappointing, these negative results may be explained by the following hypotheses: 1) polyps do not settle on platforms; 2) polyps did not settle/survive at any of the platforms or depths chosen, 3) polyps settled/survived, but were not detected visually due to heavy fouling by other organisms. While the first is possible, a review of literature indicating generalization of settlement across habitats would suggest that settlement somewhere on a platform is possible. The second hypothesis suggests a more likely possibility that spatial "patchiness" of settlement (horizontal or vertical) was high, and we simply missed polyp settlement events due to under-sampling. The third hypothesis is also a likely explanation since fouling rates were high and the dense overgrowth on our plates made visual inspection very difficult.

To address this third hypothesis, our lab has been developing molecular genetic probes to identify and possibly quantify several species of jellyfish polyps that occur in the northern Gulf of Mexico. The technique using quantitative polymerase chain reaction (qPCR) targets species-specific regions of DNA and then releases a fluorescent probe upon each successful amplify-cation cycle. We are assaying frozen scrapings collected from the plate arrays of this study.

In conclusion, this study illustrated the difficulty associated with rapid visual surveys of platforms for small, cryptic fouling organisms. This is especially true if distribution is non-uniform across the Gulf or over depth. One recommendation from this study is the continued development of non-visual means (i.e., molecular genetic markers) to identify presence of possible nuisance species such as native or non-native jellyfish.

Acknowledgments

This *Phyllorhiza punctata* study was funded by MMS Cooperative Agreement number 1435-01-01-CA-31145. We express our thanks to D. Martin, H. Fletcher, J. Hill, A. Gunter and

M. Dardeau for their technical assistance in the field. Thanks also to B. Ortman for assistance in the laboratory.

References

Bolton, T.F. and W.M. Graham. 2004. Morphological variation among populations of an invasive jellyfish. Marine Ecology Progress Series 278:125–139.

Continental Shelf Associates, Inc. 1992. Compilation of existing data on the location and areal extent of reef fish habitat on the Mississippi/Alabama/Florida continental shelf – eastern Gulf of Mexico. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, St. Petersburg, FL. 25 pp.

Graham, W.M. and K.M. Bayha. 2007. Biological invasions by marine jellyfish. Ecological Studies 193:239–255.

Graham, W.M., Martin, D.L., Felder, D.L., Asper, V.L. and H.M. Perry. 2003. Ecological and economic implications of a tropical jellyfish invader in the Gulf of Mexico. Biological Invasions 5:53–69.

Johnson, D.R., H.M. Perry, and W.M. Graham. 2005. Using nowcast model currents to explore transport of non-indigenous jellyfish into the Gulf of Mexico. Marine Ecology Progress Series 305:139–146.

Parker, R.O., D.R. Colby, and T.D. Willis. 1983. Estimated amount of reef habitat on a portion of the U.S. South Atlantic and Gulf of Mexico continental shelf. Bulletin of Marine Science. 33:67–86.

Thompson, M.J., W.W. Schroeder, and N.W. Phillips. 1999. Ecology of live-bottom habitats of the northeastern Gulf of Mexico: A community profile. U.S. Dept. of the Interior, U.S. Geological Survey, Biological Resources Division, USGS/BRD/CR—1999–0001 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 99-0004.

Dr. William (Monty) Graham is a Senior Marine Scientist at the Dauphin Island Sea Lab and Associate Professor of Marine Sciences at the University of South Alabama in Mobile. He received his doctorate in biology from the University of California Santa Cruz in 1994 and spent a year and a half in a post-doctoral fellowship at the University of California, Santa Barbara. He has broad expertise in the field of biological oceanography. In recent years, his research has focused on the ecology jellyfish blooms in the Gulf of Mexico and ecological and economic impacts that result from increasing frequency of jellyfish blooms and from exotic jellyfish invasions.

SESSION 3C

DEEPWATER TECHNOLOGY

Chair: **Ed Richardson, Minerals Management Service**

Co-Chair: **Mike Conner, Minerals Management Service**

INTRODUCTION TO THE DEEPWATER TECHNOLOGY SESSION

G. Ed Richardson, Minerals Management Service

Click here to view the slide show that accompanied this presentation.

Presentations for this session included the following:

- Deepwater Technology: Technical Assessment by Mike Conner
- Petrobras America Inc.: Early Production System for the GOM Ultra-Deep Waters by Carlos Mastrangelo
- Effects of Subsea Processing on the Deepwater Environments in the Gulf of Mexico by Tom Grieb
- Development and Approval of High Integrity Pressure Protection Systems (HIPPS) for application in the Gulf of Mexico by Christopher Lindsey-Curran
- Deepwater Operations: A Coast Guard Perspective by LCDR Jeff Wolfe

With the enactment of the Gulf of Mexico Energy Security Act of 2006, two “new” areas were designated for future lease sales the in Gulf of Mexico—the 181 Area and the 181 South Area. That portion of the 181 Area that lies within the Central Planning Area of the Gulf is addressed in the current Draft Environmental Impact Statement (EIS), and blocks within its bounds will be available for lease in Sale 205 (scheduled for early October 2007). The segment of the 181 area that is located in the Eastern Planning Area will be covered by a separate environmental review and available in the next appropriate lease offering. The 181 South Area will be covered by a separate environmental review and blocks within this area will be available for lease in a subsequent lease sale (likely in 2009).

The MMS is currently preparing a comprehensive Environmental Assessment (EA) for the Grid 5 area of the Gulf of Mexico. The EA will also examine the potential environmental effects that may arise from Shell’s Perdido Development Project that is also located in Grid 5. The EA will be completed and be available to the public in a few months.

G. Ed Richardson is a Senior Environmental Scientist with the Minerals Management Service's Gulf of Mexico OCS Region who specializes in the environmental assessment of deepwater projects. He also conducts environmental evaluations of "new and unusual" technologies proposed for use by the oil and gas industry within the Gulf. He serves as senior author of the

MMS Deepwater Report series that characterizes deepwater trends in the Gulf. The report is the most popular MMS public document.

His civilian career spans over 34 years of environmental and regulatory experience in state and federal government agencies and in the oil and gas industry. A retired Colonel, he served as a Senior Environmental Science Officer with the U.S. Army. He received undergraduate and graduate degrees from Clemson University in microbiology, environmental health, and biochemistry.

DEEPWATER TECHNOLOGY: TECHNICAL ASSESSMENT

Mike Conner, Minerals Management Service

Click here to view the slide show that accompanied this presentation.

This presentation consisted of the following:

- The term "new technology" was defined and some examples were provided to give further perspective.
- An explanation was given of how the MMS approaches the implementation of new technology.
- A discussion was provided on a high integrity pressure protection system (HIPPS), a floating production, storage, and offloading system (FPSO), a subsea boosting system, and a vertical riser system.
- Improving MMS guidelines on several topics was discussed.
- The subsea manifold leak at the Thunder Horse project was briefly examined.
- Hydrogen induced cracking was discussed.
- Major damage that occurred to the tendon porches at the Typhoon production facility after Hurricane Rita was noted.
- Examples of major deepwater project milestones show the progression into the deeper water in the Gulf were provided.
- The contribution of deepwater subsea production to the overall Gulf production was discussed.

Mike Conner was appointed Section Chief of the Technical Assessment and Operations Support Section of the Field Operations Branch for the Minerals Management Service, Gulf of Mexico Region on 15 January 2005. Prior to his appointment, Mike served with the MMS as the production engineer for the New Orleans District and pipeline engineer for the Regional Pipeline Section. He has been with the MMS for 15 years. His work in the petroleum industry since 1970 includes the following: Ocean Drilling and Exploration Company as a production engineer; Teledyne Merla as a district manager; a small independent company as a drilling/production engineer; Conoco Mining Research as a manager of various research projects; and owner and president of a small land-based drilling company. He holds a B.S. degree from Louisiana State University.

PETROBRAS AMERICA INC.: EARLY PRODUCTION SYSTEM FOR THE GOM ULTRA-DEEP WATERS

Carlos Mastrangelo, Petrobras America, Inc.

Click here to view the slide show that accompanied this presentation.

This presentation describes the Early Production System recently approved by MMS for the exploitation of the ultra-deep water fields of Cascade and Chinook, in the Gulf of Mexico (GOM). Petrobras America will discuss their experience and the increasing selection of FPSOs as part of deepwater solutions.

Petrobras America has selected a development option based on worldwide field-proven solutions. Solutions which are new for the GOM are the following:

- Production from a subsea facility and gathering system to a disconnectable Floating Production, Storage and Offloading Vessel (FPSO);
- Use of free standing risers to transport crude from the seabed to the FPSO and gas from the FPSO to the export pipeline system; and
- Product transport from the FPSO to shore via dedicated shuttle vessels.

Petrobras America believes that a FPSO offers a reliable, efficient solution for this application.

Cascade and Chinook Development Aspects

The Cascade and Chinook fields are located 165 miles from the Louisiana coastline in ultra deepwater (~8,500 ft wd) in the Walker Ridge area of the GOM. Devon is the partner for the Cascade field, and Total is the partner for the Chinook field.

The development scheme consists of a subsea drill center with subsea wells connected to manifolds in each drill center. Production flows through dual flowlines to subsea electric boosting pumps then into Free Standing Hybrid Risers (FSHRs) connected to a disconnectable moored FPSO. Gas, after treatment and compression, is exported from the field via a FSHR to an export pipeline.

Environmental and Regulatory Considerations

FPSOs

Since the 1970s, FPSOs have been used throughout the world. Petrobras has the largest number of FPSOs operating offshore Brazil. No recordable oil spills and production losses have occurred due to offloadings.

FPSO Disconnectable for Hurricanes

Significant damages to offshore facilities from hurricanes occurred after the FPSO EIS was published.

The FPSO will operate in conditions up to a 100-year winter storm. For named storms and hurricanes it will disconnect and sail to a safe location. The disconnected submerged mooring and riser system will be able to handle any sea state during storm conditions.

Free Standing Hybrid Risers (FSHRs)

General

During operations, the turret mooring system is attached to the FPSO and production is received from the subsea flowlines via the FSHRs and flexible jumpers to the turret of the FPSO.

The advantages of a FSHR in this field configuration is that the FSHR is decoupled from FPSO motions when connected. Therefore, there is a significant reduction in hang off loads, and the installation and retrievability of the jumpers are less complicated.

Configuration

The FSHR consists of a section of vertical pipe tensioned at the top by an air-filled buoyancy can, anchored to the seabed with a flexible jumper to the FPSO.

Floating Production Storage and Offloading Vessel (FPSO)

General

The principal advantage of the type of vessel being deployed is that it can disconnect prior to a hurricane and seek safety.

FPSO and Production

The nominal production capacity of the facility is 80,000 bopd, and gas compression capacity of 16 mmscfd. The gas will be compressed, dehydrated and used for fuel gas, with the balance exported via a pipeline.

The maximum production water capacity will be 20%. The water will be treated, then discharged to sea.

The storage capacity of the FPSO will be similar to an AFRAMAX size vessel, with a minimum of 500,000 barrels of crude oil.

This FPSO will be classed by a society from the International Association of Classification Societies (IACS).

Offloading

Offloading will be from the stern of the FPSO to the bow of a shuttle vessel with a separation of 150 meters.

Subsea Pumping

Flow Assurance has established that subsea boosting of a production stream will provide a significant commercial benefit to the development in terms of recoverable reserves. Subsea production boosting is relatively new, having gained acceptance in the last ten to fifteen years.

Single Point Mooring – General

Design Requirements

The turret mooring connection system will be designed for complete disconnect and reconnect. It will be able to "cycle" individual components of the connector mechanism without buoy release, and the design ensures that no fluids will be discharged to the environment;

Swivel. Fluid transfer from the riser system to the piping on the topsides of the FPSO will be through a 360 degree rotation fluid swivel.

Turret/Mooring Connection System. The system will be equipped with mooring buoy retrieval equipment, turret/mooring buoy connection device(s) and sealing capability, and all necessary instrumentation to monitor and control the system;

Mooring System

The passive mooring system will be arranged and designed, to comply with API RP 2SK, API RP 2FPS and CS rules.

Carlos Ferraz Mastrangelo holds B.S. degrees in civil and petroleum engineering from the Federal University of Rio de Janeiro, where he graduated in 1984. He has 22 years of involvement in offshore production gathering the following skills:

- Completion engineering (field engineering, company representative, and offshore completion);
- Offshore installation manager of FPSOs and semi-submersible units (of floating units installed both, shallow and deep-water depth);
- Basic engineering development of offshore oil field development;
- Detail engineering design of production floating units including mooring, subsea facilities, production facilities, utility facilities as well as lightering system;
- Commissioning of offshore production units;
- Installation of offshore units;

- Organization and management of operation training and operation procedures for off-shore units;
- Project management of offshore production units;
- New technology development for deep-water depth;
- Setting safety, maintenance and operation procedures for offshore production units.

He was Offshore Installation Manager for 13 years, Engineering Manager for Petrobras-leased FPSOs, Executive Coordinator of the Petrobras Operational Excellence Program and Facilities Manager for Petrobras-owned units basic design. He now acts as Facilities Manager of the Walker-Ridge Assets.

EFFECTS OF SUBSEA PROCESSING ON DEEPWATER ENVIRONMENTS IN THE GULF OF MEXICO

Thomas Grieb and Theodore E. Donn, Jr., Tetra Tech, Inc.

Gilbert Rowe, Texas A&M University, Galveston

Stuart Scott, Texas A&M University, College Station

Click here to view the slide show that accompanied this presentation.

Introduction

Oil and gas exploration and development is extending into deeper and deeper water in the Gulf of Mexico; for example, the newly established Tahiti field is located in 4,200 ft (1,280 m) of water (MMS 2005). The costs of deep water exploration and development efforts are substantially greater than in shallower waters, and require equipment and facilities capable of withstanding the rigors of deep water applications. In addition, yields from wells in deep water are limited by the forces required to lift product from the seafloor to a processing platform on the sea surface.

Two main factors limit production in deep waters, namely pressure and temperature. Firstly, pressures required to lift the product to the surface are substantially greater in deep water than in shallow waters. Typical wellhead pressures for wells in shallow waters are on the order of 100-200 psig, whereas deep sea wellhead pressures may be 1,000 to 2,000 psig (Devegowda and Scott 2003). Secondly, the significant changes in temperature between the seabed and sea surface may allow slugging and the formation of hydrates and waxes in the pipeline risers that may significantly impede flow in the risers (Det Norske Veritas 2004).

Movement of production facilities to the seafloor offers a number of advantages for deepwater production. Offloading production equipment is expected to dramatically cut upfront investment costs, enabling production from fields that today are considered marginal. Subsea processing is considered to have several benefits including:

- Reduction in development costs,
- Improved wellhead yields and flow rates, and
- Reduced need for chemical injection.

Project Objective

The objective of this project is to provide the Minerals Management Service (MMS) with an evaluation of the potential environmental effects of subsea processing technologies based on available literature and current understanding that can be used to evaluate the applicability of these technologies to the Gulf of Mexico and the need for additional regulations or further studies. Subsea processing incorporates new applications of existing and new technologies in deep water environments.

Approach

The project consists of five tasks:

Task 1. Technical Information Collection
Task 2. Environmental Information Collection: Subsea Processing
Task 3. Environmental Information Collection: Prospective Technologies
Task 4. Identify Additional Information Needs
Task 5. Analysis, Evaluation, and Report Writing

Tetra Tech has completed the majority of Tasks 1 through 3 and is currently synthesizing the available information. Data collection activities included a review of peer-reviewed and grey literature, input from technical experts, and input from industry. A key component of this process was a MMS sponsored workshop held on 27 November 2006, in Houston, Texas, that was attended by over 30 people representing the MMS, U.S. Environmental Protection Agency, and the oil and gas industry.

Preliminary Findings

Deep Sea Environment

The deep sea environment in the Gulf of Mexico can be characterized by nearly constant low temperatures, the absence of light, and limited food availability. Benthic communities show a general decrease in abundance, biomass, and organism size with increasing depth. However, species richness is high. These patterns are related to the decline in food availability in offshore areas. However, the presence of methane hydrates and hydrocarbon seeps between 300 and 2,000 m (984 and 6,560 ft) depth have resulted in the establishment of diverse, highly productive chemosynthetic communities immediately surrounding these sources. Considerable discussion concerning the sensitivity of these communities to oil and gas production activities is present in the literature. Existing regulations require that these communities be avoided when siting oil and gas operations.

Available Technology

Two primary technologies have been considered for application on the seafloor: subsea multiphase pumping (pressure boosting), and subsea separation (Det Norske Veritas 2004; Devegowda and Scott 2003). Subsea pumping technologies address problems associated with uneven flow and high backpressures on the wells thereby increasing the rate and uniformity of flows. Subsea separation technologies allow control of hydrate and wax formation by separating the oil from the gas and water components.

Pressure boosting technologies are the most highly developed component of subsea processing operations. Multiple technologies exist; however, they are broadly similar in potential effects and typically consist of the installation of an in-line pumping system on the seabed between the resource and surface processing facility. The pressure boosting technologies allow the introduction of chemicals, including hydrate and scale inhibitors, into the petroleum product stream. Due to increased number of connections and valves, the frequency of potential spills may be increased. Chemicals including methanol and glycols may be released into the environment via leaks or equipment malfunctions. The toxicity of these chemicals is considered to be relatively low. These systems are considered to represent a minimal change to existing shallow water operations and are unlikely to require significant changes to existing regulations. Industry representatives indicated that there would likely be a need to permit subsea pressure boosting systems in the foreseeable future (i.e., within a five- to ten-year time frame).

Subsea separation is the most advanced of the seabed processing technologies currently available. Separation technologies involve the separation of the gas, water, and petroleum fractions of the reservoir. Few subsea separation systems have been installed in the world's oceans. The most notable is Troll-C Pilot Plant in the North Sea. Byproducts of subsea separation include produced water and produced sands.

Industry representatives have indicated that the produced water is likely to be pumped to the surface for treatment prior to discharge as existing subsea separation technologies are unlikely to achieve current water quality standards for surface discharge and will not be suitable for reinjection. Produced sands are likely to be slurried with the produced water and pumped to the surface. Current regulations prohibit the discharge of produced sands from surface facilities to the marine environment. Additional regulations may be necessary if subsea disposal of produced water or sands is considered. However, this is considered unlikely within the foreseeable future.

Assuming that produced water and produced sands will be pumped to the surface for treatment and disposal according to current regulations; the most important potential new impacts from this technology are due to the accidental release of water and sands. Due to the increased complexity of the equipment and higher number of connections, the potential for leaks may increase. These accidental releases of petroleum are likely to be similar in nature and extent to current practices. The use of emulsion breaking chemicals associated with separation technologies would be new to the seafloor. The potential effects of this chemical on seafloor communities would need evaluation prior to use.

Ancillary Issues

Several ancillary issues were identified during the discussion of subsea processing technologies. These issues included the effects of electromagnetic fields associated with power cables and transformers, and the effects of temperature on local benthic and demersal organisms and communities. Existing shallow water petroleum wells typically operate at temperatures of approximately 200°F (95°C) required to maintain fluidity of the petroleum. Existing regulations do not address the effects of operational well temperatures on the surrounding environment and communities. Similarly, little data have been developed on the effects of electromagnetic fields on demersal organisms. It is known that several species, particularly sharks and rays, respond to and use electromagnetic fields. However, whether the magnitude of electromagnetic fields generated by power cables will be sufficient to adversely affect sensitive species is unknown.

A key uncertainty in this analysis is the sensitivity of deep sea benthic communities. It is known that the soft-sediment deep sea communities will respond to energy supplements, such as from leaks of petroleum products. However, their responses to chemicals released from subsea processing are unknown. The responses of chemosynthetic communities associated with methane hydrates and petroleum seeps are unknown. Current regulations require surveys to determine the presence of these communities prior to oil and gas activities, and specify specific offset distances from known locations.

References

Det Norske Veritas. 2004. Risk Comparison Subsea vs. Surface Processing. Prepared for U.S. Dept. of the Interior, Minerals Management Service. Project number 70003245. 55 pp.

Devegowda, D. and S.L. Scott. 2003. Assessment of subsea production systems. Paper presented at the SPE ATCE, Denver, CO, 5–8 October 2003; 2004. SPE Journal of Petroleum Technology 56(8):56-57.

Minerals Management Service (MMS). 2005. Tahiti field development. MMS Ocean Science 2(6): 5.

Thomas M. Grieb has worked at Tetra Tech for 30 years where he is currently Vice-President and Director of the Research and Development Division located in the San Francisco Bay Area (Lafayette, California). For the past ten years, he has worked with the oil & gas industry in the Gulf of Thailand on the environmental effects associated with mercury in produced water, the development of Whole Effluent Toxicity testing methods, and the environmental effects of exploration and production operations. His primary research interests include the behavior of mercury in the aquatic environment and the application of statistical methods to characterize uncertainty in estimates of human health and ecological risks. Dr. Grieb has a Ph.D. in environmental health science from the University of California, Berkeley, an M.A. in biostatistics from the University of California, Berkeley, an M.A. in marine biology from San Francisco State University, and an A.B in zoology from the University of California, Berkeley.

DEVELOPMENT AND APPROVAL OF HIGH INTEGRITY PRESSURE PROTECTION SYSTEMS (HIPPS) FOR APPLICATION IN THE GULF OF MEXICO

Christopher Lindsey-Curran, BP

Click here to view the slide show that accompanied this presentation.

Introduction

The installation of High Integrity Pressure Protection Systems (HIPPS) has been limited to the North Sea for subsea applications. As exploration and drilling have moved into deeper water in the Gulf of Mexico, discoveries have increased in pressure and also temperature resulting in an increased need to address the application of HIPPS technology in this region. Although there are a number of subsea systems operating successfully in the North Sea, it has not been possible to transfer this experience directly to the Gulf of Mexico without a significant amount of ground work.

During a gap analysis for extreme high pressure high temperature (XHPHT) systems completed in 2004, BP indicated that HIPPS technology would be a key enabler to develop the new prospects. This was also based on the experiences at Thunder Horse, which was fully rated and with a shut-in pressure of less than 15,000 psi. Thunder Horse has shown the many challenges of trying to develop equipment for high-pressure systems resulting in some equipment being de-rated to less than 15,000 psi to reduce the challenge and hence the risk. Also, other HPHT projects have been seen to experience cost and schedule impacts.

Where systems are fully rated to the wellhead pressure, there is also the potential for this pressure to be present on the surface facility. By moving to a subsea specification break with the adoption of HIPPS, the topside pressures can be reduced.

HIPPS Overview

General Description

HIPPS are Safety Instrumented Systems (SIS) that isolate downstream facilities from an overpressure, upset condition developing upstream. Therefore, downstream flowlines, risers, etc. can be rated for a lower pressure than the full shut-in pressure (SIP) of the upstream well.

HIPPS generally are comprised of initiators (pressure transducers), controllers 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 SIL3 in the Gulf of Mexico. 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.

Benefits of HIPPS

The benefit of utilizing subsea HIPPS include:

- Reduce topside pressures;
- Reduce flowline and riser wall thickness;
- Reduced offshore welding time;
- Reduced temperature-induced axial force due to reduced wall thickness, leading to less onerous buckling behavior. An additional small effect is the reduction in pressure-induced axial force due to the reduction in design pressure;
- Improved riser design; and
- Potential to use existing, lower pressure flowlines and risers.

Codes and Standards

It was important to consider how the move to the Gulf of Mexico would affect application of standards used elsewhere. The Gulf of Mexico region is used to proscriptive standards and it was not clear how a risk-based approach to safety instrumented systems would adapt to the regulatory environment.

IEC 61508 and 61511 are the international standards which give the requirements for the specification, design, installation, operation and maintenance of a safety instrumented system, so that the system can be confidently entrusted to place and/or maintain the process in a safe state. IEC 61511 has been developed as a process sector implementation of IEC 61508.

API 14C is a high-level document that describes the requirements for safety systems to be used on offshore facilities. The requirements apply to the overall safety system design rather than requirements on the components within the system; there is no formal requirement to consider and meet SIL level requirements. However, certain requirements on the safety architecture should be noted.

Under API 14C, the design of safety systems is to be based on the philosophy that the safety system should be completely separate from the control system and that there should be two diverse safety devices (systems) to protect against an undesirable event i.e. the HIPPS system would form one of these two diverse systems.

A detailed comparison between the two approaches has been well documented and concludes:

“It is proposed that the best of both approaches will use API RP 14C, or better ISO 10418, as the basis for initial design with IEC 61511 used for subsequent analysis of integrity requirements allowing some proposed safety instrumented functions to be eliminated. This requires greater effort both during the design and operations phases compared with using only API RP 14C but results in 1) SIS safety integrity matched to the magnitude of risks they are protecting against, 2) optimization of maintenance effort spent on testing during their operational life, and 3) reduced production losses.”

Regulatory Issues

HIPPS is a new technology for the Gulf of Mexico in the subsea environment. Already a number of prospects have been considered for the application of HIPPS in the Gulf of Mexico, although these have not gone ahead. They have largely been for the tie-in of new wells to existing infrastructure, where the infrastructure is not fully rated for the well shut-in pressure. Even when it would have been commercially more attractive to use HIPPS over a conventional fully rated system, the conventional system has been chosen due to uncertainties over the approval process for HIPPS by the regulatory authorities in the Gulf of Mexico.

To overcome the uncertainty, DeepStar has through its regulatory group been in dialogue with the Minerals Management Service (MMS) to clarify the position. This group has been jointly chaired by Christopher Lindsey-Curran (BP) and John Allen (Vetco).

As part of the process of approving HIPPS, the MMS has requested BP to submit a New Technology Application (NTA). The NTA will use a worked field example to follow the design process as much as possible at the early stages of a field development. Due to the early status of the field development, there is a considerable amount of uncertainty around the reservoir information. This work included a HAZID and independent risk assessment to determine the integrity level required. The NTA was submitted to the MMS in March, 2006 and approved in July 2006.

Conclusions

The issues concerning specification of HIPPS for application in the Gulf of Mexico are now clearer than they were three years ago. With the work that has been undertaken by the MMS, companies and DeepStar, application of HIPPS in the Gulf of Mexico can be expected in the not-too-distant future.

Christopher Lindsey-Curran is a Senior Subsea Engineer with BP's Gulf of Mexico Deep Water Operations Group, where he focuses on subsea controls support to existing projects and tie-backs, as well as development of High Integrity Pressure Protection Systems (HIPPS) systems for the GOM. He has 28 years' experience of subsea systems, concentrating primarily on subsea production control systems. Experience includes shallow water and deepwater systems for around the world including North Sea, Asia, Australia, West Africa 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. He is a Fellow of the Society for Underwater Technology and a chartered engineer.

DEEPWATER OPERATIONS: A COAST GUARD PERSPECTIVE

LCDR Jeff L. Wolfe,
Chief, Offshore Compliance, 8th Coast Guard District

Click here to view the slide show that accompanied this presentation.

Deepwater challenges for the U.S. Coast Guard (USCG) were discussed during this presentation. The USCG will work with the MMS and industry to ensure regulatory schemes for new technology, and operations in the Gulf of Mexico (GOM) are in place and appropriate. Manned facilities have moved further offshore with each successive year. New ultra-deepwater reservoirs are being discovered that are very distant from helicopter shore bases. The growth in the offshore workforce was noted. This growth brings new workers with relatively little offshore experience. The injury and fatality rate from 1997 to 2006 was discussed. A lengthy discussion was provided on observations from post-hurricane overflights. Of primary concern is rig detachment and subsequent movement during the storms endangering the GOM's infrastructure.

The USCG will merge the OCS functions of New Orleans and Morgan City to Houma, Louisiana. The OCS functions of Galveston, Texas, will move to Port Arthur. The Corpus Christi, Texas, activities will remain unchanged. Concerns were offered regarding travel to far offshore facilities for USCG inspections. Finally, a path forward was provided to meet the upcoming challenges facing the USCG in the GOM.

LCDR Jeff Wolfe enlisted in the U.S. Coast Guard in June 1981. He was promoted through the ranks to E-7 and then commissioned as a Chief Warrant Officer in 1992. In 2000, he was awarded a direct commission to the grade of Lieutenant and received his current rank in April of this year. Since transitioning his career from a civil engineering background to maritime safety & security, he has been working with the offshore oil and gas industry since 1997. He completed two back-to-back tours of duty as Chief, Offshore Compliance, Marine Safety Office New Orleans and assumed his current role as Chief, Offshore Compliance 8th Coast Guard District in July 2004. His current role at the 8th Coast Guard District encompasses oversight of all Outer Continental Shelf related CG Safety and Security regulatory activities throughout the Gulf of Mexico.

SESSION 3D

COASTAL WETLANDS AND OFFSHORE ECOLOGY II

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

Co-Chair: **Margaret Metcalf, Minerals Management Service**

LONG-TERM REEF MONITORING AT THE FLOWER GARDEN BANKS: PAST, PRESENT AND FUTURE

R. B. Aronson, Dauphin Island Sea Lab

W. F. Precht and M. L. Robbart, PBS&J

K. J. P. Deslarzes, Geo-Marine, Inc.

L. S. Kaufman, Biology Department, Boston University

Click here to view the slide show that accompanied this presentation.

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 Bank and the other on the West Bank. MMS has been monitoring these sites on a long-term basis to detect any changes caused by oil and gas activities.

The current monitoring effort, which has been in place since 2002, represents a whole-ecosystem approach to assessing these sensitive and valuable coral-reef resources. Included in the monitoring program are: (1) assessments of water quality; (2) fish and sea-urchin surveys; (3) benthic surveys from videotapes of randomly located, 10-m transects; (4) surveys of coral populations in repetitively photographed, 8-m^2 quadrats; (5) quantification of lateral growth of individual colonies of the brain coral *Diploria strigosa*; and (6) sclerochronology of cores taken from colonies of *Montastraea faveolata*. These measures provide an integrated picture of stability and incipient change at the FGB. The salient results presented here help explain, largely by counterexample, the rampant degradation of reef ecosystems observed in the wider Caribbean region over the last few decades.

The randomly placed, videographic transects revealed high coral cover at both banks, consistent with previous results. Coral cover was 57%, averaged over the East and West Banks for 2004–05, showing no decline since coral cover was first monitored at the FGB in 1978–82. Macroalgal cover was 20% at both banks in both years but high at the East Bank in 2005, resulting in a significant site x year interaction. The benthic category CTB, which is a combination of crustose coralline algae, fine turf and bare rock, averaged 18% for 2004 and 2005. The cover of CTB was low at the East Bank in 2005, so again there was a significant site x year interaction. These complementary fluctuations were probably generated by differences in the time of sampling in 2004 (fall) as compared to 2005 (spring). Sea urchins occurred at low densities as in the past, and herbivorous fishes continued at high densities compared to Caribbean reefs that are heavily fished.

Monitored colonies of *D. strigosa* continued growing laterally as in previous years, and *Montastraea* spp. showed overall positive, lateral growth in the 8-m^2 repetitively photographed quadrats. There were few signs of coral disease or bleaching during the monitoring period. Subsequent to the monitoring period (which ended in June 2005), a bleaching event (in fall of 2005), Hurricane Rita (also in fall of 2005), and an elevated incidence of coral disease (in February 2005) have raised concerns about the potential for a sudden increase in coral mortality at the FGB. Sclerochronology of *M. faveolata* detected an interruption in the growth of colonies as a result of the worldwide coral bleaching event during the El Niño of 1997–98. Thus, there may be some precedent for pulsed coral mortality—or at least partial colony mortality—at the FGB.

The tight, reciprocal relationship between macroalgae and CTB at the FGB, in the absence of any complementary fluctuation in coral cover, highlights the control that coral cover exerts on the cover of other benthic components. The balance of coral growth, recruitment and mortality determines the availability of space for algal growth. At the FGB, continuing low levels of coral mortality result in persistently high coral cover. Short-term fluctuations in the balance between macroalgae and CTB are secondarily driven by seasonal changes in water temperature, and possibly also by transient fluctuations in herbivory and other factors. In the wider Caribbean, catastrophic coral mortality over the past three decades has opened enormous quantities of space, overwhelming the capacity of herbivores to respond, either behaviorally or numerically, to algal recruitment and growth. New threats to coral populations at the FGB from bleaching, hurricanes and disease could drive those reefs in the direction of lower coral cover and higher macroalgal cover, which would make them increasingly similar to Caribbean reefs.

None of these threats appears to be driven by or exacerbated by oil and gas activities in the area of the FGB. The only potential threat from oil and gas activities is that drilling platforms may serve as vectors for the spread to the FGB of the invasive, ahermatypic coral *Tubastraea coccinea*.

The scientific team will continue monitoring at least through 2008. With multiple disturbances in 2005 causing a recent spike in coral mortality, this hypothesis-driven study is sure to yield fresh insights about the reefs of the FGB in particular and the structure and function of coral reefs in general.

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.

CRISIS ON THE FLOWER GARDEN BANKS: THE ROLE OF HURRICANES, CORAL BLEACHING AND DISEASE IN 2005

K. J. P. Deslarzes, Geo-Marine, Inc.

W. F. Precht, M. L. Robbart, and B. Zimmer, PBS&J

E. Hickerson., G. P. Schmahl, Flower Garden Banks National Marine Sanctuary

R. B. Aronson, Dauphin Island Sea Lab

Click here to view the slide show that accompanied this presentation.

The impact of hurricanes and other natural disturbances to sensitive habitats in the Gulf of Mexico (GOMEX) is crucial to the mission of the MMS to protect both the marine and human environment. There are at least 16 significant topographic features located throughout the northern GOMEX and these comprise a network of sensitive habitats that make up a complex ecosystem that supports coral reef organisms and other critical hard-bottom benthic communities. These protected topographic features comprise much of the designated offshore Essential Fish Habitat throughout the GOMEX. Because of this, MMS and NOAA need the ability to distinguish natural impacts from potential oil and gas impacts in order to continue to make informed, scientifically-based, management decisions to protect these ecosystems.

As Aronson et al. (2005) noted "The high coral cover of reefs at the FGB contrasts markedly with the degraded state of reefs throughout the southern Gulf of Mexico, Florida, the Bahamas and the Caribbean." However, in that same paper it was noted that "due to … the recent occurrence of hurricanes and bleaching events, these coral reef ecosystems could change in the future." To our shock and dismay these words would come to life that very same year.

While there have been a number of small hurricanes to pass within 100 miles of these topographic features in recent years, Hurricane Rita was the first major hurricane (Category 3 or larger) to pass over (within 80 kilometers [km]) the reefs of the Flower Garden Banks (FGB) since the passage of Hurricane Allen in 1980. Hurricane Allen, a Category 5 storm, is known to have caused localized physical impacts such as displacing Volkswagen-size reef substrate and coral heads (up to two tons in weight) on the reef cap of the FGB. Unfortunately, the continuous, long-term monitoring effort of MMS and NOAA at the FGB was not ongoing at the time, so most of the reports of reef damage from that storm are purely anecdotal.

Because of Hurricane Rita, the potential for unanticipated oil and gas impacts, as well as physical injury from storm waves was a strong possibility. Waves were projected to be as high as 18 meters (m) in advance of the storm for the FGB, and sustained wave heights of 5 to 6 m for almost 24 hours were recorded at the closest monitoring buoy some 153 km due west of the West

Bank (and well west of the storm track). Hurricane Rita was a Category 5 hurricane on the Saffir-Simpson Scale with sustained winds of 140 mph prior to approaching the GOMEX shelf break on Friday, 23 September 2005. Hurricane Rita made landfall on the Texas/Louisiana coast on 24 September 2005. The storm's track took the eye to within 48 km of the East Flower Garden Bank. Wave heights of over 9 m were unofficially reported well west of the banks.

Sanctuary personnel made it out to the reefs approximately two weeks after the passing of the hurricane to document the effects of the storm. Large colonies of coral and pieces of reef rock with many corals had been plucked out the reef, overturned, and tossed around. The wave energy must have been quite significant as about meter of sand had been scoured out from the sand flats. Large barrel sponges had been "topped," and those that were close to sand patches and survived the storm were filled with sand.

During the early months of 2005, researchers were alarmed to find widespread plague-like coral disease affecting multiple colonies and multiple species, reef wide. This was the first time on record of such an occurrence of this magnitude at this site. It was an unusual event, as typically, coral disease strikes during the warmer, summer months whereas this outbreak occurred during the winter months. As the summer of 2005 progressed and water temperatures increased, the corals started to expel their zooxanthellae, which are symbiotic algae that live in the coral tissues and provide the coral with nutrition through the process of photosynthesis. By October, approximately 45% of the colonies of the corals on the coral cap, down to a 29 m water depth, or so, were affected by bleaching to some extent. This was the worst coral bleaching event on record at the FGB. Initial observations in mid-October 2005, indicated between 35% and 40% of the colonies were bleached to some extent—partially or fully. The bleaching appeared to be affecting 100% of the fire coral (Millepora alcicornis) and great star coral (Montastraea cavernosa), and affecting at least eleven other species to varying degrees. In follow-up surveys conducted in March 2006, approximately 4% to 5% of the coral colonies still exhibited various levels of bleaching. By June 2006 the bleaching event was over. Analysis is ongoing to document the level of coral mortality associated with this event.

Despite the hardships placed on the coral reef over the past year, the corals mostly recovered from the 2005 disease event, although a second event was documented during the winter months of 2006. As the waters warmed, the progress of the disease slowed down. The reef recovered from the severe bleaching event, although it is suspected that a substantial amount of fire coral was lost. In August and September 2006, as testament to the resiliency of the reef, two spectacular spawning events took place—new life begins. Unfortunately, future disease, bleaching, and hurricane events may not be so easily overcome and survived.

To document the long-term effects of Hurricane Rita and coral bleaching on the EFGB, Sonnier Bank, and Geyer Bank, and possibly other banks (McGrail, Bright, WFGB, and Stetson) as appropriate and as schedule, weather, and logistics allow. A remotely operated vehicle (ROV) will be used to investigate deeper portions of the banks where assessment with SCUBA is not feasible (>43 m water depth). This study when completed will promote a better understanding of hurricane impacts, characterize the general condition of these banks, enhance the ability to distinguish natural from anthropogenic impacts, all while supporting NOAA and MMS' decision-making capability as a resource trustee.

Reference

Aronson, R.B., W.F. Precht, T.J.T. Murdoch, and M.L. Robbart. 2005. Long-term persistence of coral assemblages on the Flower Garden Banks, Northwestern Gulf of Mexico: Implications for science and management. Gulf of Mexico Science 23(1):84–94.

Dr. Ken J.P. Deslarzes is Project Manager, Senior Marine Ecologist. Ken is currently a Co-PI of the long-term monitoring of coral reefs at the Flower Garden Banks, which is jointly funded by the MMS and NOAA. He began his studies of coral reefs at the Flower Gardens in 1989 as a Ph.D. student at Texas A&M University's Department of Oceanography. He was part of the original monitoring team led by Steve Gittings from 1989 to 1991. Beyond his graduate studies, Ken kept close ties with coral reef studies and conservation at the Flower Gardens. Following a relatively brief stay in the Caribbean, Ken developed many opportunities to continue his research interests at the FGB. Before his current position with Geo-Marine, Inc. in Plano, Texas, he worked as research coordinator for the Flower Garden Banks National Marine Sanctuary and then as a NEPA analyst for the MMS Gulf of Mexico Region with a special emphasis on topographic features. Ken is particularly interested in the study of the environment that supports the FGB coral reefs.

Ken has a multidisciplinary graduate scientific foundation (oceanography, zoology, botany, and ecology) and specializes in coral reef science. Since 1987, Ken has been a project manager, principal investigator, co-principal investigator, and/or participant in over 30 marine and terrestrial ecological research projects conducted in the United States (Gulf of Mexico outer continental shelf, Florida Keys, Oahu); Caribbean nations (Saba, Puerto Rico, St. Croix), and the British Indian Ocean Territory (Diego Garcia). He has more than 14 years of experience in managing and contributing to natural science research projects, National Environmental Policy Act (NEPA) documentation, and marine resource documentation for federal, academic, private, and non-governmental organizations. While at Geo-Marine, Inc., Ken developed his technical expertise and project management in the following areas: baseline coral reef assessments and coral reef monitoring; essential fish habitat assessment; mitigation and restoration: submerged aquatic vegetation; damage assessment; marine resource assessments; integrated natural resource management plans; and natural resource characterization

BACK TO THE FUTURE: ELKHORN CORAL RETURNS TO TEXAS REEFS AFTER 6,000-YEAR HIATUS

William F. Precht, Battelle Memorial Institute

Richard B. Aronson, Dauphin Island Sea Lab

Ken J.P. Deslarzes, Geo-Marine, Inc.

Click here to view the slide show that accompanied this presentation.

Elkhorn coral, *Acropora palmata*, was the most important shallow reef-framework builder in the Caribbean region during the Quaternary Period, but following a quarter-century of catastrophic population decline this species was listed as "threatened" under the U.S. Endangered Species Act in 2006. Caribbean acroporids generally do not grow where sea temperatures drop below 18^{o}C in the winter, including the reefs of Bermuda, the Florida Peninsula north of Miami, and the Flower Garden Banks (FGBs) in the northern Gulf of Mexico. Here we report that *A. palmata* inhabited the FGBs before 6,000 years ago, during the Holocene Thermal Optimum, and use that result to explain the species' recent reinvasion of the FGBs in light of current climatic warming.

The FGBs, which are located 175 km off the coast of Texas, support robust reef-coral assemblages consisting primarily of massive species. The coverage of living corals has remained stable at 40–60% since the 1970s. Living colonies of *A. palmata* were first observed on the West FGB in 2003 and on the East FGB in 2005. Those discoveries, coupled with a known history of bank-flooding and submergence since the Last Glacial Maximum, led us to predict that *Acropora*-dominated reefs underlie and form the structural foundation of the living reef communities. In June 2006, while scuba diving on the southeast corner of the East FGB (27°54.49'N, 93°35.81'W), we examined an open cave at 21 m depth, which exposed a 3-m vertical section of the reef framework just beneath the living community. Within that exposure we found branches and trunks of *A. palmata* >1 m in height in growth position. Additional *A. palmata* blades were admixed in the subsurface reef sediments as rubble. Radiocarbon dating of a branch from the top of the section yielded a conventional (isotopically corrected) date of 6330 ± 60 ^{14}Cyr (radiocarbon years before 1950), corresponding to a calibrated age of 6780 calbp (calendar years before present; range 6930 to 6650 calbp).

The discovery of fossil *Acropora* illuminates the history of reef development at the FGBs. The banks supported a shallow, warm-water reef-coral assemblage before 6,000 years ago. The reef community then lagged behind rapidly rising sea level in the middle Holocene. As sea temperatures cooled in the late Holocene, the reef community was capped by a deeper-water assemblage dominated by massive, eurythermal corals, which persists to this day. The recent return of *A. palmata* to the FGBs coincides with increased subtropical sea temperatures.

Reefs living in thermally reactive, subtropical areas are more likely than tropical reefs to change in species composition as the climate warms. As in the Gulf of Mexico, acroporids are presently expanding their ranges northward along the Florida Peninsula, where again they had not been dominant reef-framework constructors for more than 6,000 years. The swift biogeographic response of Caribbean acroporids to past and present climate change suggests that their framework-building activity could resume in marginal environments in the near future.

William F. Precht is a carbonate sedimentologist by training, studying coral reefs since 1978. He was first introduced to coral reefs at Discovery Bay Marine Lab in Jamaica as an undergraduate student and has been working there ever since. His current research areas include the Bahamas, Belize, Florida, Jamaica, Mexico, Puerto Rico, and the U.S. Virgin Islands. 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 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 2002 he has been the Chief Scientist of the Long-Term Coral Reef Monitoring Study at the Flower Garden Banks. This work is co-funded by MMS and NOAA-FGBNMS.

Since completing his graduate degree in marine geology and geophysics from the University of Miami’s Rosenstiel School of Marine and Atmospheric Science, William Precht has worked as an environmental scientist specializing in the restoration and rehabilitation of various coastal resources, especially coral reef, seagrass, and mangrove systems. In addition to these duties, Mr. Precht maintains status as a Visiting Research Scientist with the Smithsonian Institution’s Caribbean Coral Reef Ecosystem Program in Belize and as an adjunct faculty member with Northeastern University’s East/West Marine Science Program, where he teaches a course in coral reef ecology and geology every winter quarter. To date, he has published over 155 peer reviewed scientific journal articles and abstracts and has presented over 100 invited lectures to universities, professional societies, and organizations. He recently completed his first book entitled *Coral Reef Restoration Handbook* which was published by CRC Press of Florida in May 2006.

VERTICAL DISTRIBUTION OF ICHTHYOPLANKTON IN THE NORTHERN GULF OF MEXICO: RELEVANT TO LNG INTAKE AND DISCHARGE DEPTHS

Richard F. Shaw, Department of Oceanography and Coastal Sciences, School of the Coast & Environment, Louisiana State University

Click here to view the slide show that accompanied this presentation.

INTRODUCTION

To date, most of the pelagic environmental concerns in the northern Gulf of Mexico (GOM) have focused on continental shelf platforms, whether for oil and gas extraction or pumping facilities for offloading oil tankers, i.e., Louisiana's Offshore Oil Port (LOOP). These concerns have mostly focused on surface water issues related to authorized discharges and/or spills of buoyant materials or the discharge of drilling muds at depth. These concerns continue to evolve as advances in drilling and production technologies have expanded exploration beyond the shelf slope and into the deepwater pelagic zones of the GOM. In addition, recently there have been several applications to the U.S. Coast Guard for Deepwater Port Licenses for proposed offshore Liquid Natural Gas (LNG) terminals in the northcentral GOM. As presently proposed, the "open-loop" (flow-through) version of these offshore "platforms"/port facilities will need very large volumes of seawater to warm and re-gasify the LNG. These chlorinated and subsequently chilled waters ($-\Delta T$ = approx. 10–20°F or 6–12°C) will then have to be discharged back into the marine environment, probably through a turbulent diffuser system at depth. Volume estimates for these processed waters vary by facility, but range from 76 to 176 million gallons of water/day (287–666 million liters/day). The various regulatory agencies involved have expressed concerns about possible environmental/ecological effects associated with open-loop technology, namely, that the accumulated impacts of impingement on intake screens and entrainment within the system's chlorinated and chilled processed waters may result in significant adverse effects on the early life history stages of fish and decapods and their subsequent adult populations, especially for managed species.

Unfortunately, one factor exacerbates these concerns: as we move from estuaries and coastal waters across the continental shelf into the open GOM, our knowledge and understanding of the vertical distribution, spatio-temporal patterns, and structure and function of biological communities is inversely related to water depth in terms of both the water column (Lindquist et al. 2005) and distance from shore (Benfield et al. 2005). This lack of empirical data, therefore, often necessitates the reliance upon syntheses of the literature with the hope that patterns seen elsewhere will be germane to the ecosystem of concern. This general depth-related knowledge gap in across-shelf vertical distribution is especially true for continental shelf and oceanic ichthyoplankton research in the northern GOM.

The vast majority of ichthyoplankton research in the northern GOM has been of short duration, site specific, and/or conducted within territorial waters. There is, however, a relatively small body of literature that addresses across-shelf and along-shelf geographical patterns and spatio-temporal distributional abundances either in response to oceanographic features such as river plumes/fronts, the Louisiana-Texas coastal boundary layer, the LOOP Current, or other oceanographically complex regions such as Mississippi Sound and the adjacent offshore regions of the Louisiana-Mississippi-Alabama barrier islands or the western Florida shelf. Additional across- and along-shelf information has also been derived from analyses of larval fish collections from NOAA/NMFS's Southeast Monitoring and Assessment Program (SEAMAP) gulfwide surveys. Virtually all of the above studies, however, have historically utilized depth-averaged plankton tows taken obliquely throughout the upper 200 m of the water column, or have relied upon horizontal surface tows only. Even so, such studies provide us with some very useful generalized trends in across-shelf fish communities with respect to abundances and diversity.

GOM studies have shown larval fish abundances to be generally greatest within estuarine or coastal waters, and to decrease in the seaward direction across the shelf and down slope. The number of larval fish species, i.e., species richness, is, however, relatively low in estuarine and coastal waters and peaks at the inner to mid-shelf and decreases further offshore. Inshore waters are usually dominated by a few, highly abundant taxa. This low estuarine/coastal diversity is usually attributable to the highly fluctuating temperature and salinity environment which leads to a lack of physiological specialization (Nybakken 1988). The relatively low species richness on the outer shelf is generally believed to be due to the homogeneity of the bottom substrate (Bond 1996) and the more oligotrophic water conditions.

In general, the vertical distribution of ichthyoplankton is influenced by a combination of physical and biological factors. They include: dissolved oxygen/hypoxia; light intensity; hydrographic structure of the water column; feeding related responses; ontogenetic stage; and behavioral responses to diurnal and/or tidal rhythms.

When systematic, large-scale shelf/oceanic studies of ichthyoplankton vertical distribution have been conducted, they have shown most larval fish (in terms of abundance and number of families) to occupy the seasonally mixed layer above the permanent thermocline, if one is present. A few such representative studies from around the world included Boehlert and Mundy (1994 – Pacific oceanic islands/seamounts); Loeb (1979 – North Pacific central gyre); Boehlert et al. (1985 – off Oregon); Ahlstrom (1959 – California coast and off Baja); Kendall and Naplin (1981 – Mid-Atlantic Bight); Southward and Bary (1980) and Southward and Barrett (1983 – off Plymouth, England and the Celtic Sea); and Coombs et al. (1981 – eastern North Atlantic and the North Sea). However, within the northern GOM, ichthyoplankton vertical distribution data are relatively rare.

METHODS

An on-line search was conducted of potentially-relevant databases and then the pertinent literature, i.e., peer-reviewed and non-peer-reviewed literature or the "grey literature" (e.g., government documents, conference proceedings, major technical reports, etc.) relevant to the marine ichthyoplankton communities within the GOM was compiled and reviewed.

This compilation of literature was prepared with the assistance of several electronic databases subscribed to by Louisiana State University, Baton Rouge, Louisiana. The databases were searched electronically using the Cambridge Scientific Abstracts Internet Database Service (CSA), the U.S. Government Printing Office Access service (GPO), the Scholarly J. Archive (JSTOR), the Institute for Scientific Information (ISI), and Ovid Technologies database services. The following databases were searched: Academic Search Premier; Aquaculture Abstracts (ASFA); Aquatic Pollution and Environmental Quality (ASFA); Biological Abstracts; Biological Sciences (CSA); Biological Sciences and Living Resources (CSA); Catalog of US Government Publications; Conference Papers Index; Dissertation Abstracts; Effects of Offshore Oil and Gas Development; Electronic Collections Online (ECO); Energy Citations Database (Gov); GEOBASE; Grey Literature; JSTOR (Ecology); Marine Biotechnology Abstracts; National Technical Information Service; Oceanic Abstracts; Science.gov; Toxnet; and Zoological Record.

The search strategy included preparation of initial keyword and database lists. All data bases available for searching in the library at Louisiana State University and relevant to aquatic biology were queried to search article titles, abstracts, keyword lists, and any other available text in the databases using the list of key words. Nine key words or phrases, root forms, and logical operators (i.e., ichthyoplankton OR larval fish OR early life history stages of fish, AND vertical OR depth AND distribution OR preference, AND continental shelf OR across-shelf distribution, AND Gulf of Mexico) were used to develop the literature compilation. This search captured documents from 1964 to May 2006.

RESULTS

Formal results from the literature review described above will be reported to Minerals Management Service in the form of a manuscript ready to be submitted to a scientific journal (Shaw, In Prep.). That review will also include a synopsis of recent findings from a manuscript that analyzed the vertical distribution of ichthyoplankton and commercially-important decapod densities from the LOOP data set (Kupchik and Shaw, In Prep.).

REFERENCES

Ahlstrom, E.H. 1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. U.S. Fish. Wildl. Serv., Fish. Bull. 60:107–146.

Benfield, M.C., R.F. Shaw, and E. Burroughs Loden. 2005. Potential spatial and temporal vulnerability of pelagic fish assemblages in the Gulf of Mexico to surface oil spills associated with deepwater petroleum development. Prepared by the Coastal Fisheries Institute, Louisiana State University, Baton Rouge. Draft Final Report to U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2005-012. 153 pp.

Boehlert, G.W. and B.C. Mundy. 1994. Vertical and onshore-offshore distributional patterns of tuna larvae in relation to physical habitat features. Mar. Ecol. Prog. Ser. 107(1–2):1–13.

Boehlert, G.W., D.M. Gadomski, and B.C. Mundy. 1985. Vertical distribution of ichthyoplankton off the Oregon coast in spring and summer months. Fish. Bull. U.S. 83:611–621.

Bond, C.E. 1996. Biology of fishes. Orlando, FL: Saunders College Publishing,.

Coombs, S.H., R.K. Pipe, and C.E. Mitchell. 1981. The vertical distribution of eggs and larvae of blue whiting (*Micromesistius poutassou*) and mackerel (*Scomber scombrus*) in the eastern North Atlantic and North Sea. Rapp. R.-v. Reun. Consl. Int. Explor. Mer. 178:188–195.

Kendall, A.W., Jr. and N.A. Naplin. 1981. Diel-depth distribution of summer ichthyoplankton in the Middle Atlantic Bight. Fish. Bull. U.S. 79:705–726.

Kupchik, M.J., and R.F. Shaw. In prep. Vertical distribution and day/night ratios of ichthyoplankton and commercially-important decapods in Louisiana continental shelf waters. Dept. Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA.

Lindquist, D.C. R.F. Shaw, and F.J. Hernandez, Jr. 2005. Distributional patterns of larval and juvenile fishes at offshore petroleum platforms in the northcentral Gulf of Mexico. Estu. Coastal Shelf Sci. 62(4):655–665.

Loeb, V.J. 1979. Vertical distribution and development of larval fishes in the North Pacific central gyre during summer. Fish. Bull. U.S. 77:777–793.

Nybakken, J.W. 1988. Marine Biology: An ecological approach. New York: Harper and Row.

Shaw, R.F. In prep. Vertical distribution of ichthyoplankton in the northcentral Gulf of Mexico: A review. To be submitted to Bull. Mar. Sci.

Southward, A.J. and R.L. Barrett. 1983. Observations on the vertical distribution of zooplankton, including teleosts, off Plymouth in the presence of a thermocline and a chlorophyll-dense layer. J. Plankton Res. 5:599–618.

Southward, A.J. and B.M. Bary. 1980. Observations on the vertical distribution of eggs and larvae of mackerel and other teleosts in the Celtic Sea and on the sampling performance of different nets in relation to stock evaluation. J. Mar. Biol. Assoc. U.K. 60:295–311.

Richard F. Shaw has been the Director of LSU=s Coastal Fisheries Institute since 1989 and is a professor within the Department of Oceanography and Coastal Sciences. Dr. Shaw has over 25 years of experience conducting ichthyoplankton research on the continental shelf and within

estuaries of the northern Gulf of Mexico. He has published extensively on the temporal and spatial distribution of larval fish as well as on the role offshore oil and gas platforms may play as nursery grounds for the early life history stages of fish.

CHARACTERISTICS OF PRODUCED WATER DISCHARGED TO THE GULF OF MEXICO HYPOXIC ZONE

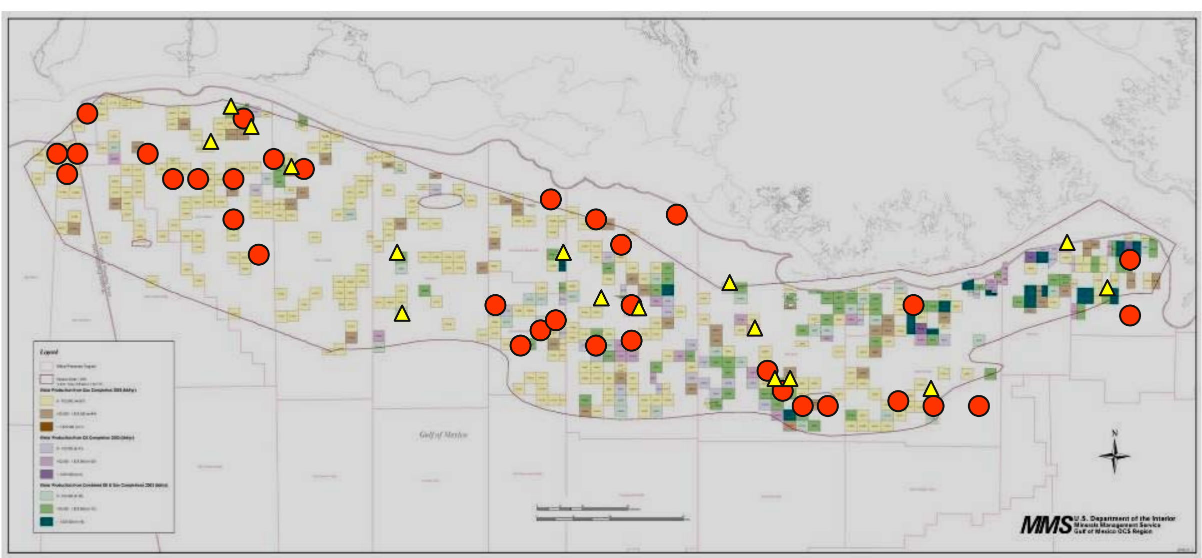
John A. Veil, Argonne National Laboratory

Click here to view the slide show that accompanied this presentation.

Introduction

The October 2004 general discharge permit for the western Gulf of Mexico Outer Continental Shelf (EPA Region 6) required that offshore oil and gas operators provide monitoring data for pollutants not normally tested in produced water (e.g., oxygen-demanding parameters). The permit required submittal of the data by August 2005. Argonne National Laboratory coordinated a study of sampled produced water from 50 offshore platforms. The study involved the EPA, DOE, MMS, API, Offshore Operators Committee, numerous oil and gas companies, and two different analytical laboratories.

Sixteen platforms were sampled three times each at approximately one-month intervals for an estimate of temporal variability. An additional 34 platforms were sampled once. The 50 sampled platforms were located throughout the hypoxic zone to give an estimate of spatial variability. The hypoxic zone and the locations of the sampled platforms are shown on Figure 3D.1.



Platforms sampled one time and selected at random

Platforms sampled three times and selected based on discharge volume and type of hydrocarbon produced

Figure 3D.1. Location of hypoxic zone and platforms sampled during the study.

Each platform was sampled for biochemical oxygen demand (BOD), total organic carbon (TOC), nitrogen (ammonia, nitrate, nitrite, and total Kjeldahl nitrogen [TKN]), and phosphorus (total phosphorus and orthophosphate). In addition to these parameters, each sample was monitored for pH, conductivity, salinity, and temperature. The field sampling and laboratory analytical efforts were conducted under a stringent Quality Assurance/Quality Control (QA/QC) program.

Results

The sampling provided average platform concentrations for each parameter. Table 3D.1 shows the mean, median, maximum, and minimum for the sampled parameters.

Table 3D.1

Summary of Data from Produced Water Characterization Study (Veil et al. 2005)

Parameter*	Mean	Median	Maximum	Minimum
BOD, mg/L	957	583	11,108	80
Dissolved BOD, mg/L	498	432	1,128	132
Suspended BOD, mg/L	76	57	146	16
TOC, mg/L	564	261	4,880	26
Dissolved TOC, mg/L	216	147	620	67
Suspended TOC, mg/L	32	13	127	5
Nitrate, mg/L	2.15	1.15	15.80	0.60
Nitrite, mg/L	0.05	0.05	0.06	0.05
Ammonia, mg/L	74	74	246	14
TKN, mg/L	83	81	216	17
Orthophosphate, mg/L	0.43	0.14	6.60	0.10
Total phosphorus, mg/L	0.71	0.28	7.90	0.10
Conductivity, μmhos/cm	87,452	86,480	165,000	360
Salinity, ppt	100	84	251	0
Temperature, °C	38	32	80	20
pH, SU	6.29	6.50	7.25	1.77

* BOD = biochemical oxygen demand; ppt = parts per thousand; SU = Standard Units; TKN = total Kjeldahl nitrogen; TOC = total organic carbon.

For some of the parameters, the mean is considerably larger than the median, suggesting that one or a few data points are much higher than the other points (outliers). For example, Figure 3D.2 shows the BOD concentration for all 50 platforms in bar-chart format. Two of the platforms have concentrations that are significantly higher than the others.

A primary goal of this study was to estimate the mass loading (lb/day) of each of the oxygen-demanding pollutants from the 50 platforms sampled in the study. Loading was calculated by multiplying concentrations by the discharge volume. The loadings calculated in this study of 50 platforms represent a produced water discharge volume of approximately 176,000 bbl/day (Note: a bbl is a barrel, equal to 42 U.S. gallons). The total amount of produced water generated in the hypoxic zone during the year 2003 was estimated as 508,000 bbl/day. This volume, based on

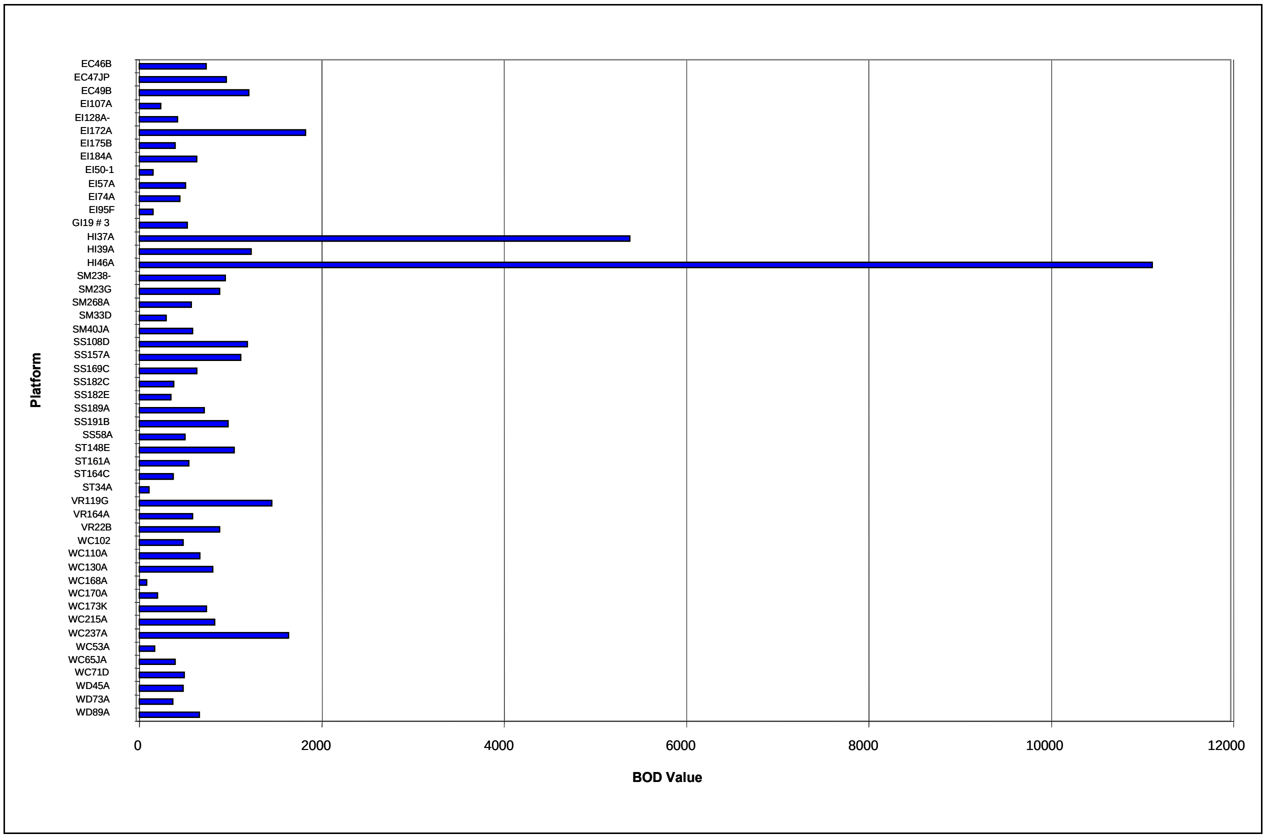


Figure 3D.2. BOD concentrations for 50 platforms (Veil et al. 2005).

operators' annual reports to the MMS, reflects the volume of produced water that is generated from each lease, not the volume that is discharged from each platform. The mass loadings from offshore oil and gas discharges to the entire hypoxic zone were estimated by multiplying the 50-platform loadings by the ratio of total water generated to the 50-platform discharge volume. The loadings estimated for the 50 platforms and for the entire hypoxic zone are shown in Table 3D.2.

Table 3D.2

Loading Estimates for 50 Platforms and Entire Hypoxic Zone (Veil et al. 2005)

Parameter	Loading from Sampled Platforms (lb/day)	Estimated Loading for Entire Hypoxic Zone (lb/day)
BOD	36,000	104,000
TOC	14,100	40,700
Nitrate	68.3	197
Nitrite	3.07	9
Ammonia	4,770	13,800
TKN	5,140	14,900
Orthophosphate	22.6	65
Total phosphorus	37.6	109

These estimates and the sampling data from 50 platforms represent the most complete and comprehensive effort ever undertaken to characterize the amount and potential sources of the oxygen demand in offshore oil and gas produced water discharges.

Although these numbers appear large, they should be considered in the context of all the oxygen demanding pollutant contributions to the hypoxic zone. Table 3D.3 shows a comparison of the produced water discharge mass loadings to the mass loading of key pollutants from the Mississippi and Atchafalaya Rivers. The last column of Table 3D.3 shows that the produced water discharge loadings estimated for the entire hypoxic zone are several orders of magnitude smaller than those entering the Gulf of Mexico from these rivers. The total nitrogen loading is about 0.16%, and the total phosphorus loading is about 0.013% of the nutrient loading coming from the Mississippi and Atchafalaya Rivers.

Table 3D.3

Comparison of Nutrient Loadings from Produced Water Discharges and Riverine Inputs

Nutrient	Mean Flux (lb/yr) from Mississippi and Atchafalaya Rivers from Reference (Goolsby et al. 1999)	Estimated Annual Mass Loading (lb/yr) from Produced Water Discharges to Hypoxic Zone (Veil et al. 2005)	Ratio of Produced Water Loading to Riverine Loading*
Ammonia	68,355,000	5,030,000	–
Organic nitrogen	1,278,900,000	389,000 (calculated as TKN—ammonia)	–
Nitrate	2,100,000,000	71,900	–
Nitrite	0	3,285	–
Total nitrogen	3,460,000,000	5,500,000	0.00159
Orthophosphate	92,100,000	23,700	–
Particulate phosphate	209,000,000	0	
Total phosphorus	301,000,000	39,800	0.00013

* The key ratios are total nitrogen and total phosphorus. Ratios for the other component comparisons are not shown.

Data Interpretation

The Argonne report (Veil et al. 2005) was submitted to EPA in August 2005. EPA contracted with three expert water quality modelers who used the Argonne results as model inputs. As part of their preparation, the modelers contacted Argonne to assist them in estimating the uncertainty of the data set so that sensitivity analysis could be conducted. Argonne used a box-and-whiskers plot technique to screen for outlier data values. Following that analysis, Argonne calculated the 95% confidence interval for the data. The range of values used by the modelers for the sensitivity analysis was the flow-weighted mean concentration plus and minus the 95% confidence interval.

The three modelers presented their findings to the EPA during May 2006 (Bierman 2006). EPA will assess the Argonne report and the modeling report to determine whether significant new requirements will be put into place after the current permit expires in 2007. The presentation that follows this one discusses EPA's actions and decisions.

Acknowledgments

Argonne's work on this project is funded by the U.S. Department of Energy's Office of Fossil Energy and National Energy Technology Laboratory, under contract DE-AC02-06CH11357.

References

Bierman, V.J. 2006. Predicted impacts from produced water discharges on hypoxia in the northern Gulf of Mexico. Greensboro, NC: Limno-Tech, Inc.

Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, B.T. Aulenbach, R.P. Hooper, D.R. Keeney, and G.J. Stensland. 1999. Flux and sources of nutrients in the Mississippi–Atchafalaya River Basin: Topic 3. Report for the integrated assessment on hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program, Silver Spring, MD. NOAA Coastal Ocean Program Decision Analysis Series No. 17. 130 pp.

Veil, J.A., T.A. Kimmell, and A.C. Rechner. 2005. Characteristics of produced water discharged to the Gulf of Mexico hypoxic zone. Prepared for U.S. Dept. of Energy, National Energy Technology Laboratory, August. ANL/EAD/05-03.
Available at http://www.ead.anl.gov/pub/dsp_detail.cfm?PubID=1874. Accessed 5 Dec. 2006.

John Veil is the manager of the Water Policy Program for Argonne National Laboratory in Washington, D.C., where he holds the rank of senior scientist. He analyzes a variety of energy industry water and waste issues for the Department of Energy and is a frequent speaker and author. Mr. Veil has a B.A. in earth and planetary science from Johns Hopkins University and two M.S. degrees—in zoology and civil engineering—from the University of Maryland. Before joining Argonne, Mr. Veil managed the Industrial Discharge Program for the State of Maryland government, where he had statewide responsibility for industrial water pollution control permitting through the National Pollutant Discharge Elimination System (NPDES), Underground Injection Control (UIC), and oil control programs. He also served as a faculty member of the University of Maryland, Department of Zoology for several years.

AN EXAMINATION OF THE POTENTIAL FOR PRODUCED-WATER DISCHARGES TO CONTRIBUTE TO THE NORTHERN GULF OF MEXICO HYPOXIA

Scott Wilson, United States Environmental Protection Agency, Region 6

Click here to view the slide show that accompanied this presentation.

Background

EPA is required to ensure that Ocean Discharge Criteria are met when National Pollutant Discharge Elimination System (NPDES) permits for discharges to marine waters are issued. The criteria, found in section 403(c) of the Clean Water Act, require that permitted discharges do not cause unreasonable degradation of the marine environment.

The Western Gulf of Mexico Outer Continental Shelf general permit authorizes discharges from approximately 250 platforms presently discharging produced water to the hypoxic zone in the northern Gulf of Mexico. Those discharges contain high concentrations of oxygen demanding pollutants and nutrients, which could potentially contribute to the hypoxia. When EPA was preparing a new permit for re-issuance in 2003, it was determined that there was not sufficient information to determine whether authorized discharges contributed to the hypoxia and thus degradation of the marine environment. EPA issued the general permit in 2004 for a three-year term rather than the traditional five-year term so that potential issues regarding produced-water discharges to the hypoxic zone could be studied and if necessary, new requirements could be included in the permit in a timely manner.

Summary of Study

The produced-water hypoxia study consisted of three components. The first was a literature review to determine data gaps in existing studies and potential direction for future work. The second phase consisted of data collection on produce water discharges to the hypoxic zone. The third part consisted of a modeling study which utilized the produced-water data and examined the potential contribution to the hypoxia.

The modeling portion of the study consisted of analysis of the industry-collected data using three existing models with a goal of determining the potential for produced-water discharges to impact the size and degree of the hypoxia. Models used in the study were developed by Bierman et al. (1994), Justić et al. (1996, 2002), and Scavia et al. (2003). Each of the models utilizes a different approach for analyzing the hypoxia as follows. The Bierman model predicts the percentage of change in bottom-water dissolved oxygen concentration based on a three-dimensional steady-state food-web-nutrient oxygen dynamics analysis. A two-layer oxygen demand analysis is used by the Justic model at one location in the hypoxic zone to predict changes in bottom water dissolved oxygen concentrations (Bierman 2006). The Scavia model calculates the length and area of the hypoxia in response to changes in nitrogen load. Comparisons of the models' attributes and variables follow in Tables 3D.4 and 3D.5.

Table 3D.4

Principal Attributes of Gulf of Mexico Hypoxia Models (Bierman 2006)

Attribute	MODEL		
	Bierman	**Justić**	**Scavia**
General Description	Moderately complex mechanistic eutrophication model	Simple two-layer dissolved oxygen model	Simple dissolved oxygen model for bottom waters
Spatial Scale	3D with 21 spatial segments in hypoxic zone	1D vertical at Station C6 in core of hypoxic zone	1D horizontal in subpycnocline downstream of river inputs
Temporal Scale	Summer Steady-State	Monthly Time-Variable	Summer Steady-State
Nutrients	Phosphorus, nitrogen and silicon	Nitrogen	Nitrogen
Hypoxia Characterization	3D structure of summer-average dissolved oxygen concentrations in hypoxic zone	Seasonal dynamics of dissolved oxygen concentrations in core of hypoxic zone	Interannual variability in hypoxic zone length and area
Calibration Time Periods	1985, 1988 and 1990	1985–1993	1985–2002

Table 3D.5

Model State Variables for Gulf of Mexico Hypoxia Models (Bierman 2006)

State Variables	MODEL		
	Bierman	**Justić**	**Scavia**
Dissolved Oxygen	X	X	X
Biochemical Oxygen Demand (BOD)	X		X
Sediment Organic Carbon		X	
Salinity	X		
Algal Carbon	X		
Phosphate Phosphorus	X		
Organic Phosphorus	X		
Ammonium Nitrogen	X		
Nitrate/Nitrite Nitrogen	X		
Organic Nitrogen	X		

Study Results

In all three cases, model results predicted an impact to the hypoxia as a result of produced-water discharge. That predicted impact was, however, small and within the margin of error of both the measurement of bottom-water dissolved oxygen and the inherent uncertainty of the models.

The Scavia model only predicted an increase in the size of the hypoxia for three of the 18 years examined when produced-water loading was entered at the mouths of the Mississippi and Atchafalaya Rivers. When produced-water loading was input along the spine of the hypoxia, the size was predicted to increase in only two of the eighteen years. For those two scenarios, the scale of the increased size of the hypoxia was predicted to be 4.5% and 3.1%, respectively (Bierman 2006).

The hypoxia was examined with the Bierman model for both settling and non-settling biochemical oxygen demand (BOD). Summer average bottom-water dissolved oxygen concentrations were predicted to decrease 0.11 to 0.201 percent for the settling produced-water BOD scenario and 0.118 to 0.143 percent for the non-settling scenario. Those predicted decreases are consistent with produced-water nitrogen loading relative to that contributed by the Mississippi River (0.16%) (Bierman 2006).

The Justic model predicted a decrease in the dissolved oxygen concentration of 0.0023% when produced-water loading was delivered at the Mississippi River delta. That decrease is relatively consistent with the percentage of nitrate nitrogen loading contributed to the hypoxia from produced-water discharges (0.003%) (Bierman 2006).

EPA has evaluated the hypoxia model predictions to determine the need to include any new restrictions or monitoring requirements in oil and gas permits. EPA continues to place a high priority on reducing the size and impact from hypoxia in the northern Gulf of Mexico. However, the study results indicate that any new controls on produced-water discharge would have an insignificant effect on the hypoxia. No new conditions to address the hypoxia are planned to be included in the general permit for the western Gulf of Mexico at this time.

References

Bierman, V.J. 2006. Predicted impacts from produced water discharges on hypoxia in the northern Gulf of Mexico. Greensboro, NC: Limno-Tech, Inc.

Bierman, V.J., Jr., S.C. Hinz, D. Zhu, W.J. Wiseman, Jr., N.N. Rabalais, and R.E. Turner. 1994. A preliminary mass balance model of primary productivity and dissolved oxygen in the Mississippi River plume/inner Gulf Shelf region. Estuaries 17:886–99.

Justić, D., N.N. Rabalais, and R.E. Turner. 1996. Effects of climate change on hypoxia in coastal waters: A doubled CO_2 scenario for the northern Gulf of Mexico. Limnol. Oceanogr. 41:992–1003.

Justić, D. N.N. Rabalais, and R.E. Turner. 2002. Modeling the impacts of decadal changes in riverine nutrient fluxes on coastal eutrophication near the Mississippi River delta. Ecological Modelling 152:33–46.

Scavia, D., N.N. Rabalais, R.E. Turner, D. Justić, and W.J. Wiseman 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. Limnol. Oceanogr. 48:951–956.

Scott Wilson is EPA Senior Environmental Scientist for Region 6 in charge of oil and gas permitting. He holds a M.S. in environmental science, with a specialization in water quality modeling, and has worked for the EPA since 1988. Mr. Wilson has played an integral role in developing EPA's waste water discharge regulations for many industries, including all oil and gas regulations since 1990. He has implemented those regulations in the Gulf of Mexico, as well as coastal and onshore areas, and continues to provide technical assistance for oil and gas permits in Alaska.

SESSION 3E

SPERM WHALE SEISMIC STUDY (SWSS)

Chair: Carol Roden, Minerals Management Service

Co-Chair: Deborah Epperson, Minerals Management Service

OVERVIEW OF THE SPERM WHALE SEISMIC STUDY IN THE GULF OF MEXICO

A. E. Jochens and D.C. Biggs,
Department of Oceanography, Texas A&M University

Click here to view the slide show that accompanied this presentation.

The Sperm Whale Seismic Study (SWSS) was a cooperative study of sperm whales in the Gulf of Mexico, their habitat, and their response to man-made noise. SWSS was 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), with additional support provided by the National Fish and Wildlife Foundation (NFWF). The study was 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), University of South Florida (USF), Woods Hole Oceanographic Institution (WHOI), and Ecologic Ltd. A Science Review Board was established to provide review and comment on the Summary Report for 2002–2004 and the project's final Synthesis Report. This board consisted 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 were performed under the terms of valid permits from NOAA Fisheries.

In 1991, MMS began a series of environmental studies to investigate cetaceans in the Gulf of Mexico. 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 Gulf of Mexico. This study, as well as earlier survey results, indicated that sperm whales tend to be most likely observed near the 1000-m isobath.

As oil and gas activities in the deepwater Gulf of Mexico 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 Gulf of Mexico. 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 of four summers of field research, 2002–2005, followed by analysis and synthesis. The study area was primarily the northern Gulf of Mexico, with focus on the region immediately off the Mississippi River Delta (Figure 3E.1). In year four, some work was done in the northwest Gulf to provide information for comparison with the main study area.

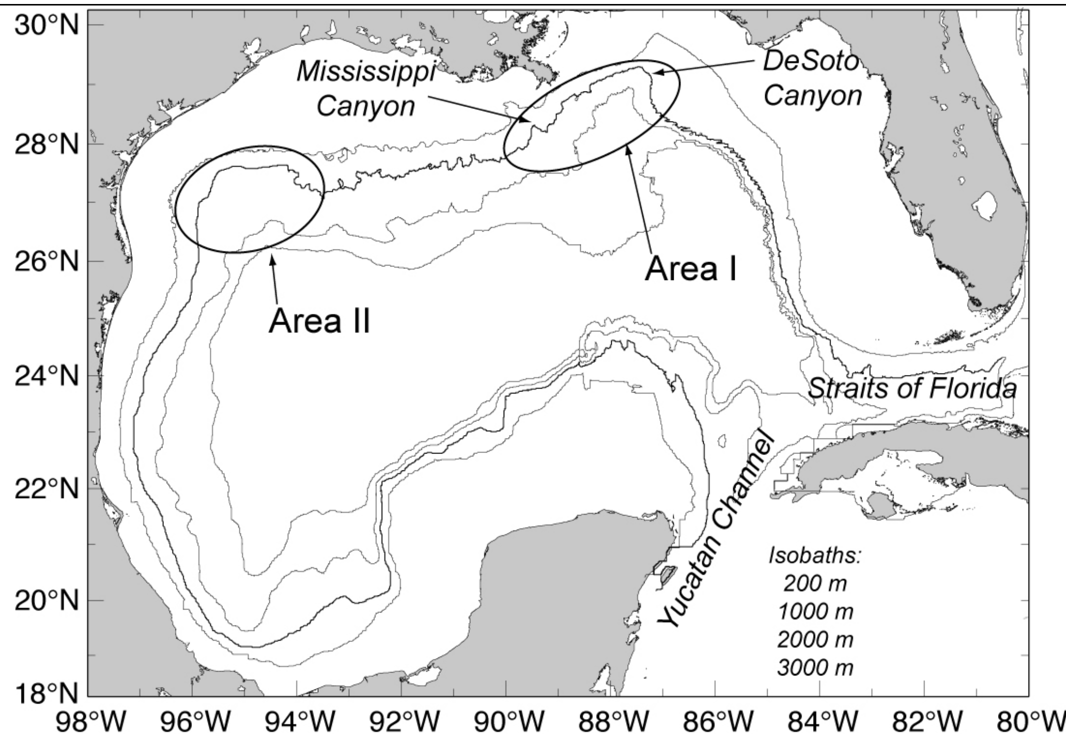


Figure 3E.1. SWSS study area in the Gulf of Mexico. Area I was the focus for SWSS cruises in summers 2002–2004 and for the MPS cruise in summer 2005. Area II was the focus area for the 2005 SWSS S-tag cruise. Several cruises also conducted brief surveys along the 1000-m isobath between the two areas. Shown are the 200-m, 1000-m (thick line), 2000-m, and 3000-m isobaths.

The objectives of SWSS were three-fold:

1. establish the "normal" behavior of sperm whales in the northern Gulf of Mexico,
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, OSU, and USF), and passive acoustics research (SIO). MMS provided fiscal support, project oversight, and cruise participants under the Cooperative Agreement. ONR provided funding for development of both the S-tags and D-tags used in this study. IRFC provided 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 in field year three, and purchase and support of the 3-D passive acoustic tracking array in field years three and four. NSF provided 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. NFWF provided funds to support the charter and operation of the motor sailor used in the MPS cruise in field year three.

The S-tag component was designed to monitor seasonal changes in distribution of sperm whales in the Gulf of Mexico and to identify behaviors, summer and other seasonal habitats, and, in coordination with the habitat characterization task, associations with oceanographic features. The D-tag component was designed to quantify diving behavior and vocalizations in Gulf sperm whales on short time scales (hours) and to conduct controlled exposure experiments to measure reactions of these whales to controlled airgun sounds. The Mesoscale Population Study used photo-identification, photogrammetry, and passive acoustics to study sperm whale group behavior and coda analyses; in years three and four this work was conducted aboard a quiet sailboat so that specific whale groups could be studied over several days. The genetic analyses component allowed study of groups of sperm whales in terms of relatedness through DNA analyses of skin/tissue samples, including comparisons with populations sampled outside the Gulf of Mexico. The habitat characterization component merged 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 were conducted to estimate 3-D whale locations underwater from their sounds.

During SWSS 2002–2005, there were four 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 two mesoscale population study cruises aboard a 46' Hunter sailboat. In Table 3E.1 are given the cruise type, ship name, and cruises dates for all four years.

Annual Reports summarizing data collection activities on the cruises have been completed (Jochens and Biggs 2003, 2004, and 2006). A Summary Report was completed in 2006; it presents the results of the individual program components based on field work from 2002-2004 (Jochens et al. 2006). All four reports are available from MMS at the following location: http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html. The Synthesis Report for SWSS was in preparation at the time of this Information Transfer Meeting; it should become available in late summer or early fall 2007. Planning is proceeding among the scientists and sponsors to extend the SWSS Cooperative Agreement to allow limited field work in summer 2005 and 2006 with additional analysis and synthesis. The Synthesis Report from such work would be 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.

Table 3E.1

2002–2005 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
2005		
R/V *Gyre*	S-tag	06/02/2005 – 06/20/2005
Summer Breeze	MPS[2]	06/13/2005 – 08/03/2005

[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

Acknowledgment

SWSS is supported by the U.S. Minerals Management Service under Cooperative Agreement Number 1435-01-02-CA-85186. Additional support was provided by the International Association of Geophysical Contractors, Industry Research Funders Coalition, National Science Foundation, and National Fish and Wildlife Fund. Finally, tag development supported by the Office of Naval Research enable the tagging activities of SWSS to occur. SWSS scientists thank all these entities for their support.

References

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.

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.

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.

Jochens, A.E. and D.C. Biggs, eds. 2006. Sperm Whale Seismic Study in the Gulf of Mexico; Annual report: Years 3 and 4. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2006-067. 111 pp.

Jochens, A., D. Biggs, D. Engelhaupt, J. Gordon, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, J. Wormuth, and B. Würsig. 2006. Sperm Whale Seismic Study in the Gulf of Mexico: Summary report, 2002–2004. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2006-034. 352 pp.

McKay, M., J. Nides, W. Lang, and D. Vigil. 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.

Dr. Ann E. Jochens is a Research Scientist in the Department of Oceanography at Texas A&M University. She came to physical oceanography as a mathematician and attorney with extensive experience in environmental, safety, and permitting in the oil and gas and minerals industries. Her J.D., with a background specialty in ocean law, is from the University of Oregon (1977) and her M.S. and Ph.D. are in oceanography from Texas A&M University (1989 and 1997, respectively). For over 15 years, Dr. Jochens has been a Principal Investigator on studies of the circulation and water properties over the Texas, Louisiana, Mississippi, Alabama, and Florida shelves and in the deep waters of the Gulf of Mexico. On each of these studies, she also served as Program Manager or Deputy Program Manager. Presently, Dr. Jochens is the Principal Investigator and Program Manager for a multi-disciplinary, multi-institutional study of Gulf of Mexico sperm whales, their habitat, and their response to anthropogenic noise. She also is the Regional Coordinator for the Gulf of Mexico Coastal Ocean Observing System Regional Association. Dr. Jochens has participated in over 10 oceanographic expeditions, has over 60 publications, reports, and abstracts, and has served on 11 graduate student committees. Her research interests are processes at the boundary of coastal and open oceans; Gulf of Mexico physical oceanography; meso- and large-scale ocean circulation and property distributions, with emphasis on shelf and slope regions; ocean law and policy; and research planning and management.

TRADITIONAL STUDIES OF SPERM WHALES IN THE NORTHERN GULF OF MEXICO: POPULATION SIZE, DISTRIBUTIONS, MOVEMENTS AND FORAGING

Jonathan Gordon, Gatty Marine Laboratory, School of Biology, University of St. Andrews and Ecologic

Christoph Richter, Department of Biology, Queen's University

Nathalie Jaquet, Provincetown Center for Coastal Studies

Bernd Würsig, Department of Marine Biology, Texas A&M University-Galveston

Click here to view the slide show that accompanied this presentation.

Introduction

One component of SWSS, which became known as "Mesoscale Population Study (MPS)," applied what must now be considered the classic approach to studying sperm whales (Rendell and Whitehead 2003) to investigate basic aspects of their biology in the Northern Gulf of Mexico, especially those aspects relevant to management and population assessment and monitoring. This background knowledge is necessary to assess the biological impact of observed anthropogenic activities. Fundamental to this approach are 1) passive acoustic monitoring and directionalisation via a combination of towed and directional hydrophones to find and follow sperm whale groups (often for a few days at a time) and 2) careful observation, photo-ID, and photogrammetry to identify, measure and characterize individual whales. In addition, acoustic recordings can be analysed to measure the length of individuals (Gordon 1991) and to explore culturally based population structure; genetic analysis (see Ortega et al. in these proceedings) and photography provides information on the gender and reproductive conditions of individuals. In contrast to, and complementing SWSS telemetry studies, this approach provides a moderate level of data from a large number of individuals, in some cases over extended periods of time. With sperm whales this approach was first developed and has usually been applied using modest sized motor sailors as research platforms (Whitehead and Gordon 1986). On SWSS we have been able to apply this approach working both from a large vessel, the *Gyre*, in 2002 and 2003 and from a chartered 46' motor sailor in 2004 and 2005. Because it was more manoeuvrable, quieter for acoustic monitoring, and more stable as a platform for photography and careful visual observation, the motor sailor has proven more effective. It is also a cost effective way of doing research in the open ocean; such vessels could provide a cost effective long-term monitoring project for this population.

Photo-identification studies with sperm whales started in the early 1980s (Whitehead and Gordon 1986). Recent advances such as digital photography, automated matching programs (Huele et al. 2000), and sophisticated analysis programs (such as Hal Whitehead's Socprog) have greatly expanded the scope and power of photo-identification research with whales. As part of this project we collated all available images for the Gulf of Mexico into one coordinated, quality-controlled catalogue. Figure 3E.2 shows the locations of photo-identification images taken in the Northern Gulf of Mexico between 1994 and 2005. Table 3E.2 shows the number of fluke sequences collected in various studies.

Here, we can only provide short summaries and preliminary results of some of the main findings of these studies.

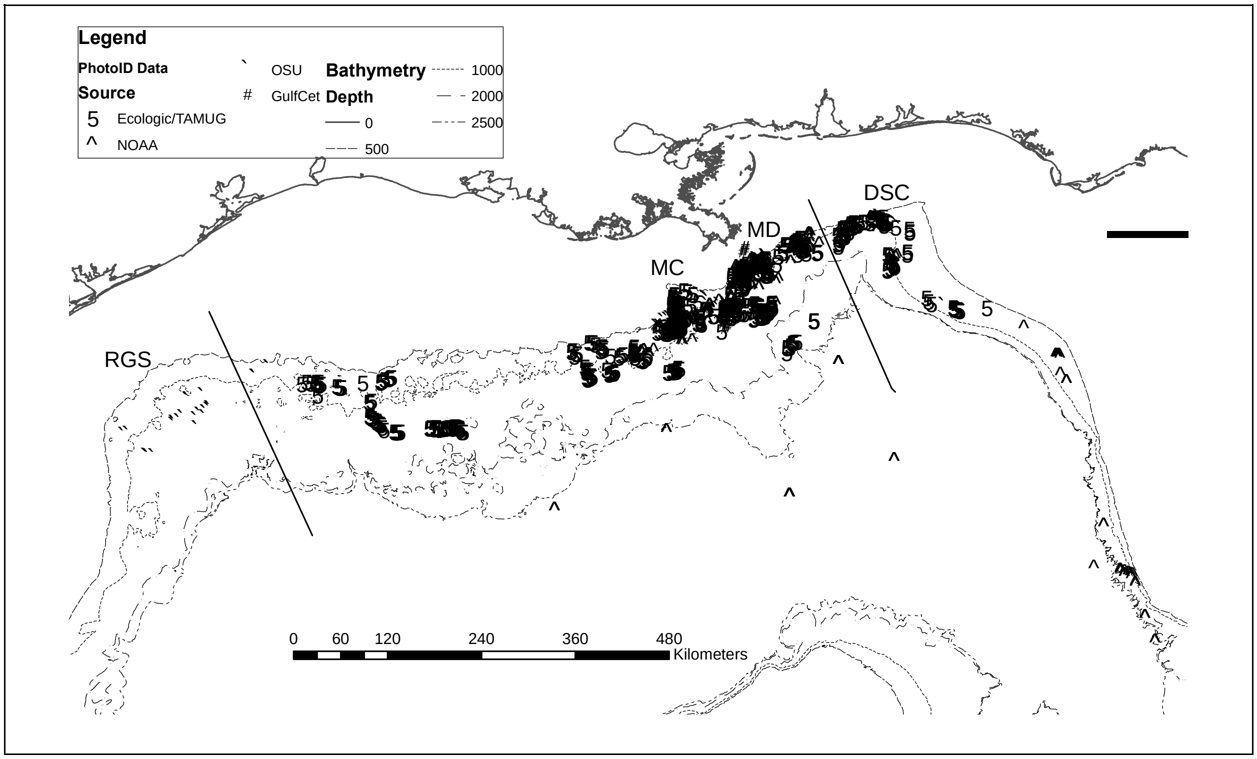


Figure 3E.2. Locations of photo-identification images taken in the Northern Gulf of Mexico between 1994 and 2005 and available for this analysis. Symbol type indicates the organizations that collected the images. Locations of main study areas are indicated: RGS=Rio Grande Slope, MC=Mississippi Canyon, MD= Mississippi River Delta, DSC=De Soto Canyon. Lines show demarcation used to determine the core area for some analyses.

Body Size

Body size has been measured using both a photographic measurement of fluke span developed on this project (Jaquet 2006) and a method based on acoustic analysis of sperm whale clicks (Gordon 1991). Whales in the Gulf of Mexico were found to be particularly small; in fact, body length is the shortest yet reported from any sperm whale population. Jaquet (2006) compared lengths (derived with the same fluke span method) measured in the Gulf of Mexico during this project and the Gulf of California. GOM whale modal lengths are some 2m less than those of the GOC. Its not known why GOM whales are so small, whether they were this small in the past and whether this should be a cause for concern now.

Table 3E.2

Total Number of Fluke Sequences and Those of Sufficient Quality for Long-term matching (in Parentheses) Collected by Different Groups in the Gulf of Mexico between 1994 and 2005

	1994	1996		2000	2001	2002	2003	2004	2005
GulfCet	33 (9)	21 (12)							
NOAA				54 (39)	92 (67)	20 (12)	57 (35)	18 (15)	
SWSS-OSU						29 (21)	30 (21)	19 (9)	23 (15)
SWSS Ecologic/TAMUG						64 (39)	167 (110)	324 (169)	191 (101)

Work is continuing to determine the most reliable methods for measuring body length acoustically from the time interval between sound pulses in clicks. Acoustic length estimates agree well with photogrammetric ones and will allow the measurement of animals with damaged or missing fluke tips. They could also provide measures with sufficient precision to measure the growth of individuals (Pavan et al. 1998).

Movements

Re-identification of individual whales provides information on the whale dive patterns and movements. The modal value of inter-fluke intervals in our data were 55 min providing an estimate for complete dive cycle length that agrees well with measures from other locations (Gordon and Steiner 1992), and from the very precise measures from a small number of animals provided by the SWSS D-tag data.

Within the SWSS project, photo-ID data on movements complements the high precision but short duration 3D data from D-tags and the lower precision data over periods of days to a year from S-tags. Photo-ID provides a significant amount of data on scales from an hour to a few days with a reduced but continuing dataset extending over lags of several years. The data show that averaged over periods of a dive cycle (around an hour) sperm whales in the Gulf move with a mean speed of around 3.2kms per hour. This is similar to, though slightly lower than, values reported from other areas. The whale's heading at the time of fluke up was shown to be a very good predictor of its net movement in its subsequent dive: whale tended to move parallel to isobaths. The mean displacement of groups tracked for hours to several days showed a range of patterns with displacement beginning to decrease again after periods of tens of hours as groups reversed direction and began to track back along the shelf edge. Maximum likelihood estimates of displacement using the methods of Whitehead (2001) showed that root mean square displacement levelled off after lags of about 100 days at value of ~220km, which might be taken as an indication of the home range of whales re-sighted within the Gulf. Some whales are seen repeatedly between years within the Northern Gulf study area with some of the whales identified off the Mississippi during GulfCet in 1994/6 (Weller et al. 2000) being sighted there a decade later. Detailed analysis of distances between years re-sightings in our photo-ID record shows that even with the Northern Gulf study area individuals appear to have preferred locations.

Calving Rates

The rate at which calves are produced could be a sensitive indicator of the health of whale population and so an important parameter to measure. To do this we assessed the number of calves and adults in tracked groups that we thought were "mixed groups" of females and immature males. Calving rates varied between years but the overall percentage of calves, 11%, was very close to the predicted annual calving rate for mixed groups in an unexploited population based on the IWC sperm whale model. However, we caution that while uncertainties remain about the length of time calves continue to suckle and about the timing of the breeding season, this may not be a reliable indication of the yearly calf production.

Foraging

Foraging rates and success are a short term indicator of factors that might affect population well-being in the longer term. As sperm whales feed deep in the water column (see Miller et al. in these proceedings) its not possible to observe foraging directly. We have measured defecation rate as a proxy. When sperm whales defecate at the surface, they do so during fluke up. Signs of defecation (reddish brown coloration) allow us to score the proportion of fluke ups adequately observed. We found that these observations could only be made reliably from the more stable platform offered by the sailing vessel. Twenty-one percent of the fluke ups adequately observed during 2004/5 showed signs of defecation, a rate that is among the highest observed by researchers using similar methods in other locations (Whitehead 2003). We take this as an indication that whales here are foraging adequately.

Distributions and Habitat Preferences

We have made comparisons between a variety of predictor variables—bathymetry, slope, bottom type, sea-surface height, chlorophyll, etc.—in locations where whales were not detected during surveys and the locations in which they were observed: fluke up locations. These data provide detailed information on habitat preference though they also present some challenges (such as pseudo-replication and autocorrelation) for statistical analysis. Using a GAMs framework we are able to show significant preferences for certain values of parameters such as bathymetry and sea-surface height and combine these to develop predictive surfaces or relative density maps. These should be useful for mangers in determining the number of animals likely to be affected by activities occurring in different regions and different times.

Population Size

We are using mark recapture techniques to determine the size of sperm whale populations in the Northern Gulf of Mexico. Photo-ID data and the results of SWSS S-tag tracking (see Mate and Ortega in these proceedings) strongly suggest that our Northern Gulf of Mexico study area closely overlaps the main distribution of a "core population" which seems to consist of mixed groups of mature females and immature males. We have identified animals that seem to belong to this and calculated MR population size for these and for the wider population (which includes maturing males) separately. A number of different population models provided in the SocProg analysis program were fitted using maximum likelihood methods. The best fit was with a model that included mortality and population trend. This predicted a population size (and 95% confidence intervals) of 281 (202–434) for the extended population and 140 (103–200) for the "core population." In both cases there was a positive trend of .35 and a mortality of ~.2. If the core population was made up of mixed groups with the same composition as found in other areas, then it would be expected to contain some 88 mature females producing 15–20 calves per year. These results should be treated as preliminary at this stage.

2005 Anomaly

Conditions encountered in the central and eastern parts of the Northern Gulf of Mexico by the mesoscale team in 2005 were very different from the pattern observed in other years, which seemed to have held back to the GulfCet cruises in the mid 1990s. Very few mixed groups were found in the traditional "hotspots" off the Mississippi and most of the whales encountered there were probable males. None of the "core population" of whales that had been resighted in this area repeatedly back to the mid 1990s were identified. Unfortunately, this was the last year of field work so we are left not knowing the cause of this changed distribution, nor what has happened to our "missing" population of whales. We do not know whether this was a short anomaly or sign of a permanent change and a new "regime" in the Gulf.

References

Gordon, J.C.D. 1991. Evaluation of a method for determining the length of sperm whales (*Physeter catodon*) from their vocalizations. Journal of Zoology 224(2):301–314.

Gordon, J.C.D. and L. Steiner. 1992. Ventilation and dive patterns in sperm whales, *Physeter macrocephalus*, in the Azores. Rep. Int. Whal. Commn. 42:561–565.

Huele, R., H.A. Udode Haes, J.N. Ciano, and J. Gordon. 2000. Finding similar trailing edges in large collections of photographs of sperm whales. J. Cetacean Res. Manage. 2(3):173–176.

Jaquet, N. 2006. A simple photogrammetric technique to measure sperm whales at sea. Mar. Mamm. Sci. 22(4):862–879.

Pavan, G., C. Fossati, M. Manghi, and M. Priano. 1998. Acoustic measure of body growth in a photo-identified sperm whale. European Research on Cetaceans 12: 254–258.

Rendell, L.E. and H. Whitehead. 2003. Vocal clans in sperm whales (*Physeter macrocephalus*). Proc. R. Soc. Lond. Ser. B-Biol. Sci. 270(1512):225–231.

Weller, D.W., B. Würsig, S.K. Lynn, and A.J. Schiro. 2000. Preliminary findings on the occurrence and site fidelity of photo-identified sperm whales (*Physeter macrocephalus*) in the northern Gulf of Mexico. Gulf of Mexico Science 18(1):35–39.

Whitehead, H. 2001. Analysis of animal movement using opportunistic individual identifications: Application to sperm whales. Ecology 82(5):1417–1432.

Whitehead, H. 2003. Sperm whales: Social evolution in the ocean. Chicago: University of Chicago Press. 456 pp.

Whitehead, H. and J.C.D. Gordon. 1986. Methods of obtaining data for assessing and modelling sperm whale populations which do not depend on catches. Rep. Int. Whal .Commn. Spec. Issue 8:149–165.

Jonathan Gordon has been studying sperm whales since his Ph.D. research some twenty years ago. That work involved using techniques such as passive acoustic monitoring, photo-id and photogrammetry from small vessels working offshore. He has continued to use and develop these approaches with sperm whales and other species in many different parts of the world, including the Gulf of Mexico. The extensive use of passive acoustics in this work fostered an interest in the potential effects of noise on marine mammals. He is based at the University of St. Andrews Sea Mammal Research Unit in Scotland.

SOCIAL STRUCTURE OF SPERM WHALES IN THE GULF OF MEXICO BASED ON PHOTO-IDENTIFICATION AND CODA USAGE

Christoph Richter, Department of Biology, Queen's University

Jonathan Gordon, Ecologic and Gatty Marine Laboratory, School of Biology, University of St. Andrews

Nathalie Jaquet, Provincetown Center for Coastal Studies

Ricardo Antunes and Luke Rendell, Gatty Marine Laboratory, School of Biology, University of St. Andrews

Introduction

The description of the basic biology of a species necessarily includes the characteristics of its social system and behavior. The type and degree of sociality influences many aspects of a species' general behavior, life history and population parameters, and is therefore a crucial piece of information for management decisions with this, the most social of the great whales.

The sperm whales' social organization has been studied in other areas for several decades and has yielded increasingly detailed knowledge. We now know that groups encountered at the surface usually consist of two or more social units and that membership of these units is stable for years or decades. Most of our current understanding is based on research in the South Pacific (Whitehead 2003). After four field seasons of photo-identification work and passive acoustic monitoring in the Gulf of Mexico (GOM), we are able to present some preliminary descriptions of the social structure of sperm whales here.

Methods

During four field seasons in 2002–2005, we used standard techniques to identify sperm whales using photos of the trailing edges of their flukes, and passive acoustic monitoring of their vocalizations. For the acoustic analysis, we focused on the usage of coda types. Analysis of social structure based on photo-identification was carried out with SOCPROG (H. Whitehead, available from http://myweb.dal.ca/hwhitehe/social.htm). Data from non-SWSS field seasons (1994–2003) were also included. Coda repertories from identified groups in the Gulf of Mexico were also compared with other groups from the GOM and from the Azores and Caribbean. The timing of clicks within codas was measured using the Rainbow Click program and similarity of codas and repertoires was calculated using the techniques described in (Rendell and Whitehead 2003).

Results

For the analysis of social structure, we limited the dataset to good-quality photographs and excluded individuals scored as males. From 741 photographs, we identified 186 individuals. Sperm whales in the GOM live in long-term social units consisting of 6.7 individuals. Groups encountered at the surface contained and average of 14.5 individuals, and they disassociated at a rate of 0.005/day.

The coda analysis was based on 3129 codas from the GOM and 5756 codas from the Azores, Caribbean and Mediterranean. Repertoires from groups in the GOM were generally more similar to each other than to those from groups in other areas forming a distinct cluster. This indicates that sperm whales in the GOM can be considered a single and distinct acoustic clan. Interestingly, coda characteristics from two GOM groups were more similar to non-GOM codas. One of these "anomalous groupings" was recorded in the Western GOM. The other was a group of likely males.

Discussion

In general, sperm whale social organization in the GOM is comparable to that described in other areas, showing evidence of stable social units that associate for periods of years, while forming temporary larger groupings. However, it appears that unit and group sizes are smaller in the GOM than in other areas. Results of our analysis have to be interpreted carefully though, since sample sizes are still very small for applying this type of analysis.

Coda characteristics indicate that sperm whales in the GOM form a single clan distinct from sperm whales in the Atlantic and Caribbean. There is an intriguing suggestion too for a western sub-population in the GOM, but more data are required to confirm this possibility.

Social structure within the GOM, and the fact that this population appears to be distinct (and potentially consists of two sub-populations) will be important considerations for some management decisions. Social units are assumed to be the functional units within which cultural information is passed from individual to individual (Whitehead 2003). Such cultural information may include adaptive behavioral patterns including those related to anthropogenic activities.

References

Rendell, L.E. and H. Whitehead. 2003. Comparing repertoires of sperm whale codas: A multiple methods approach. Bioacoustics: The International Journal of Animal Sound and Its Recording 14(1):61–81.

Whitehead, H. 2003. Sperm whales: Social evolution in the ocean. Chicago: University of Chicago Press. 456 pp.

Christoph Richter has been studying the influence of various anthropogenic activities on cetaceans for over 10 years. Most recently, he investigated the impacts of whale-watching activities on sperm whales and their social behavior in New Zealand. Since 2002, he has been involved in the annual SWSS cruises as visual observer, RHIB driver and photo-ID person. He currently holds an assistant adjunct professorship at the Department of Biology at Queen's University in Kingston, Canada, where he teaches statistics, animal behavior, and vertebrate evolution. He also instructs a marine mammalogy course at the College of the Atlantic in Maine and serves as a marine mammal guide on Arctic cruises.

ANNUAL MOVEMENTS AND HOME RANGE OF SPERM WHALES IN THE GULF OF MEXICO

Bruce Mate and Joel Ortega-Ortiz,
Hatfield Marine Science Center, Oregon State University

Click here to view the slide show that accompanied this presentation.

Although whaling data shows that sperm whales have inhabited the Gulf of Mexico (GOM) since the 1700s and more recent aerial and shipboard surveys have confirmed year-round occupancy, there has been debate about the stock status of this population. We have used implantable satellite-monitored Argos radio tags to track seasonal movements and home range to contribute significant new information to better inform managers concerned about anthropogenic impacts on local or Gulf-wide populations.

From 2001 through 2005 we tagged 57 sperm whales (33 females, 6 males, 18 of undetermined sex) and obtained data from 52 whales for periods up to 620 days. Whales were tagged during summers off the Mississippi River Delta (MRD) from 2001 through 2004 and in the western Gulf in 2005. Changes in the tag application technique in 2002 from crossbow to air powered applicators resulted in dramatically better initial tag deployment and longer tracking periods. After applying screening criteria to the resultant locations, 76% were retained, and half of these provided location qualities of 1 km or less error. Of the 52 tags sending data, 21 (40%) lasted >200 days, 12 (23%) lasted >300 days, and 8 (15%) transmitted for more than one year. The males transmitted for an average of 328.2 days while the females transmitted an average of 186.8 days.

Nine whales were resighted between 213 and 350 days after tagging, which included whales that had lost their tags, those with tags still transmitting, and some which continued to transmit after their last sighting. Only one whale showed any visible effect related to tag attachment at its last sighting, and this consisted of modest localized swelling. All whales appeared healthy and their behavior appeared normal.

We tracked whales for a minimum aggregate distance of 155,613 km between retained locations (35,598 km for males, 92,202 km for females). Based on a very few locations/week (under-estimated distances traveled), conservative speed estimates averaged 1.35 km/h with a small but significant difference between females and (faster) males.

Females inhabited the upper continental slope, mostly along the 1000 m contour, and usually ranged approximately 200 km around their tagging location with occasional round trips up to 778 km away from the tagging site and infrequently into deeper water. A group of five females tagged together in 2002 off the Mississippi River Canyon (MC), traveled together about 680 km west along the 1000 m depth contour, and returned to the tagging location by November. During the same period, a male and a female whale tagged at the same location remained within 200 km of the tagging site. Thus, the synchrony of some female movements may indicate a social bond rather than a population-wide seasonal migration.

Males were more varied and wide ranging in their movements, in waters over 3000 m. Their travels took them from 190–2100 km from their tagging sites, and their average maximum displacement was 2.5 times that of females. Displacement analysis identified no clear general seasonal movement pattern. In examining the interannual variation of three whales whose tags transmitted for more than 450 days, two (a male and a female) each showed some repeat patterns in the summer/fall, but another male had its only consistent seasonal movement during winter/spring. The latter was the farthest ranging whale and the longest duration track. It traveled out of the Gulf, passing the Dry Tortugas, into the North Atlantic for over two months, reaching as far north as South Carolina. In returning to the GOM, it spent time off the NW coast of Cuba. The whale spent two consecutive summers, presumably foraging, in different parts of the northern Gulf slope (MRD in 2002 and the Rio Grande Slope in 2003). In both subsequent winters, the animal spent time in the Gulf of Campeche.

The individual home range (95% utility distribution probability) of whales varied from 1463 km^2 to 1,131,365 km^2. Evaluating whales with more than 30 locations, the mean home range for females was 44,717 km^2, and for males was 392,764 km^2. Despite this large difference, no statistical comparisons were made due to the small sample size for males. The composite home range for all whales was 1,131,365 km^2. It comprised nearly the entire GOM in waters deeper than 500 m and a small portion of the N Atlantic coast off the SE US. Of that area, 86% was shared by 1–3 whales, 3% by 4–6 whales 1.9% by 7–9 whales, 1.5% by 7–10 whales, and only 7.8% by >12 individuals.

Core areas (50% UD probability area), the areas of highest utilization, ranged from 324 km^2 to 101,600 km^2. The average core area was 8,258 km^2 for females, and 41,285 km^2 for males. All core areas were found on the upper continental slope. The composite core area for all tagged whales occupied 12,691 km^2 along the northern slope, with the area shared by the highest number of whales concentrated in the MC, the MRD, and to a lesser extent, the RGS. Of the entire core area, 96% was shared by 1–3 whales, while only 1.8% was used by >12 whales.

The composite home range for the six males was identical to that of all whales, showing the enormous influence of their long term and wide ranging movements. The most widely ranging individual accounted for 66% of the range, and <1% of the home range was shared by all six whales. The composite core area accounted for just 2.8% of the home range, with primary concentration around the MRD and DeSoto Canyon (DSC), in water 500–3000 m deep, and secondarily on the RGS off the US/Mexico border between 500–2000 m. No portion of the northern slope between these two areas was included in the core area, suggesting its use by males was for transiting only.

The composite home range for females tagged in 2002–2004, was 140,407 km^2, just 12.4% of the composite home range of all whales, and extended along the northern slope on the

Texas/Mexico border along the DSC, in waters 500–2000 m deep. The highest-use area was from the MC to DSC in 500–1500 m deep, with shallower parts of the entire northern slope well used in pockets along the 1000 m contour. The core area was a narrower swath of 2150 km^2 along most of the northern 1000 m isobaths, with highest use in the MC to the MRD. The home range for all 2005 tagged whales was 104,362 km^2, and included the tagging area and the RGS in waters 500–2000 m deep and extending east along 1000 m contour to the MC. Like the female whales tagged in the eastern Gulf, the home ranges of the 2005-tagged females were small and tended to concentrate in the area of tagging. The home ranges of some females tagged in the north central Gulf and tagged in the NW gulf overlap; however, core areas of females tagged in the two locations did not. We consider the similar site-centric patterns observed for the female whales tagged in these two locations to be indicative of modal behavior for such groups. The high site affinity of female sperm whales for specific locations indicates enough food is consistently availability to support their constant presence in these areas. We would anticipate seeing similar patterns for females at other GOM upper slope regions.

The home range of two males included both female core areas in the central and western Gulf. Core areas identified from tracking generally overlapped with areas where whales were tagged, especially for females. Therefore, distribution and home range conclusions derived from tagging data may be greatly influenced by tagging location in other studies as well. Future single-site tagging studies could generate a significantly biased basin-wide picture of distribution and movements. Although we spotted mothers with calves nearshore, females we tracked in this study only briefly visited water deeper than 2000 m, where groups of sperm whales with calves have also been observed. Therefore, our data suggest that sperm whales sighted farther offshore may constitute a separate stock or a gradation between near-shore and offshore groups may occur. Our sample size for males was limited and more data are needed to generally characterize their movements.

The tag performance in this study is unprecedented in duration and location quality, providing more detailed information on the seasonal movements and home range than any previous large whale study. These data will provide the basis for the first ever multi-year analysis of natural variability in seasonal movements, habitat characterization, and social aggregation for any large whale species.

Acknowledgments

We thank the Minerals Management Service and Office of Naval Research for collaborative funding, as well as the ship crews and scientific parties of the R/V *Gyre* and *Gordon Gunter*. This work was conducted under NMFS permit #369-1440-02 and an Oregon State University IACUC review.

Bruce Mate is an endowed professor of wildlife and director of the recently established OSU Marine Mammal Institute. He has conducted marine mammal research since 1967, obtaining a

Ph.D. from the University of Oregon (sea lion migrations) and studying heavy metals and organo-chlorines as a NIH post-doc in biochemistry. Pinniped research has included population assessment, marine mammal/fishery conflicts, acoustic deterrents, and VHF telemetry. He pioneered the development of satellite-monitored radio tags for manatees and cetaceans. His cetacean research identifies the migration routes and seasonal habitats of endangered whales (gray, right, bowhead, humpback, sperm, fin, and blue whales), which can be used to reduce conflicts with human activities.

SOCIAL STRUCTURE AND GENETIC RELATEDNESS OF SPERM WHALES IN THE GULF OF MEXICO

Joel G. Ortega-Ortiz, and Bruce R. Mate,
Hatfield Marine Science Center, Oregon State University

Daniel Engelhaupt, Department of Biological Sciences,
Molecular Ecology Group, University of Durham

Click here to view the slide show that accompanied this presentation.

Social structure of satellite-tracked sperm whales in the Gulf of Mexico was compared to genetic relatedness between individuals. Satellite-determined locations of 51 sperm whales tracked from 2002 through 2005 were used to analyze social structure. Distance between contemporary locations (i.e. locations less than 2.5 hours apart) was estimated and association events, defined as whales within a distance of 8.3 km from each other, were identified. Association data were used to calculate simple ratio association index between individuals. Location data obtained for whales tagged in 2004 was not enough to conduct the association analysis. Skin biopsy samples were available for 39 of the whales and genetic analyses were conducted to determine sex of the individuals and relatedness among them. For the whales with genetic data and at least 10 contemporary locations we tested for significant correlation between genetic relatedness and association between individuals tagged on the same year.

This study showed that satellite-tracking (S-tag) data are usable for social structure analysis of sperm whales. Our location data provided good temporal and spatial coverage but the association analysis is, obviously, limited to tagged individuals. Although S-tag data may not reflect short-term social structures, such as "clusters" and "aggregations," long-term "social units" can be identified. Social structure of tagged whales coincides with reports from other areas: long-term (months) associations between females but no significant long-term association between males. Genetic relatedness between members of social units was variable in different years. No significant correlation was observed for whales tagged in 2002. Significant correlation was observed in 2003 and 2005 but only the last year was significant after permutation tests. This is consistent with previous studies which indicate that sperm whales do not form strictly matrilineal societies.

Joel Ortega is a research associate at the Oregon State University Marine Mammal Institute. He received his Ph.D. from Texas A&M University. His research interests include cetacean habitat preferences, movement patterns and behavioral ecology.

DIVING BEHAVIOR OF A SPERM WHALE (*PHYSETER MACROCEPHALUS*) IN THE WESTERN GULF OF MEXICO

Ladd Irvine and Bruce Mate
Hatfield Marine Science Center, Oregon State University

Click here to view the slide show that accompanied this presentation.

Introduction

The diving behavior of sperm whales (*Physeter macrocephalus*) has been documented by multiple studies which found that whales commonly dive for 40–50 minutes to depths between 400–1200m (Watwood et al. 2006, Drouot et al. 2004, Amano and Yoshioka 2003, Zimmer et al. 2003). The techniques used to identify these dive characteristics have produced a wealth of information about sperm whale diving behavior, but they are limited by short duration (3–4 days maximum) deployments, or the inability to monitor individuals for extended periods of time.

Satellite tags have been used to monitor the movements of whales at time scales of weeks to months (Krutzikowski and Mate 2000, Lagerquist et al. 2000, Mate et al. 1997, 1998, 1999, 2000), but with a few exceptions (Krutzikowski and Mate 2000, Lagerquist et al. 2000) were not equipped to report detailed dive-depth information. This study used a recently developed satellite tag with a pressure sensor to record the diving behavior of a sperm whale continuously for weeks.

Methods

An Argos monitored depth-of-dive tag was attached to a sperm whale (8m long) in the western Gulf of Mexico on 15 June 2005. Details about tag design and deployment can be found in Mate et al. (2007).

Dives were monitored by a salt water conductivity switch. Any submergence longer than seven seconds was recorded as a dive. The tags continuously recorded data from a pressure transducer during each dive, summarizing it in four six-hour summary periods: Period 1 (00:00-06:00), period 2 (06:00–12:00), period 3 (12:00–18:00), period 4 (18:00–00:00) all times local. Percent time spent in eight depth ranges (bins: 0–10m, 10–100m, 100–400m, 400–700m, 700–1000m, 1000–1300m, 1300–1600m, 1600+) was recorded for each period, as well as the total number of dives (Dive Count) and the duration of the longest dive (Max Dive Duration). Percent time spent at the surface and average dive depth were calculated for each summary period from the binned data.

A series of one way ANOVAs were used to test for differences between summary periods.

Results

Information from 66 summary periods was received for the dates 15–18 June and 1–7 July. The initial four days of data were excluded from the general analysis because of the small data set and to avoid any potential post-tagging influence. The whale remained within a 110km diameter area for the duration of the tag life. Mean water depth was 1146m (SD = 286).

The sperm whale spent the largest portion of its time at the surface and in the 400–700m depth range (Figure 3E.3). Time spent in the other depth ranges down to 700–1000m was approximately equal.

Mean values during summary period 2 were significantly different than other summary periods for Percent Time at the Surface ($p = 0.0019$, Figure 3E.4A), average dive depth ($p = 0.00054$, Figure 3E.4B), and maximum dive duration ($p = 0.0018$, Figure 3E.4C). No further significant variation was observed between the other three summary periods ($p = 0.25$, 0.97, 0.54 respectively). The whale spent more than 1.5 times as much time at the surface during summary period 2 (mean = 41.5% SD = 15.5) than the rest of the day (mean = 26.9%, SD = 12.9). Mean average dive depth of summary period 2 (231.3m, SD = 209.9) was 200.6m less than the mean of the other summary periods (431.9m, SD = 149.7). Maximum dive duration of summary period 2 was an average of 14.3 min shorter (mean = 39.4, SD = 15.4) than the other summary periods (53.7 min, SD = 12.5). There were no significant differences in total number of dives made between periods (mean = 40.3 dives, SD = 32.1).

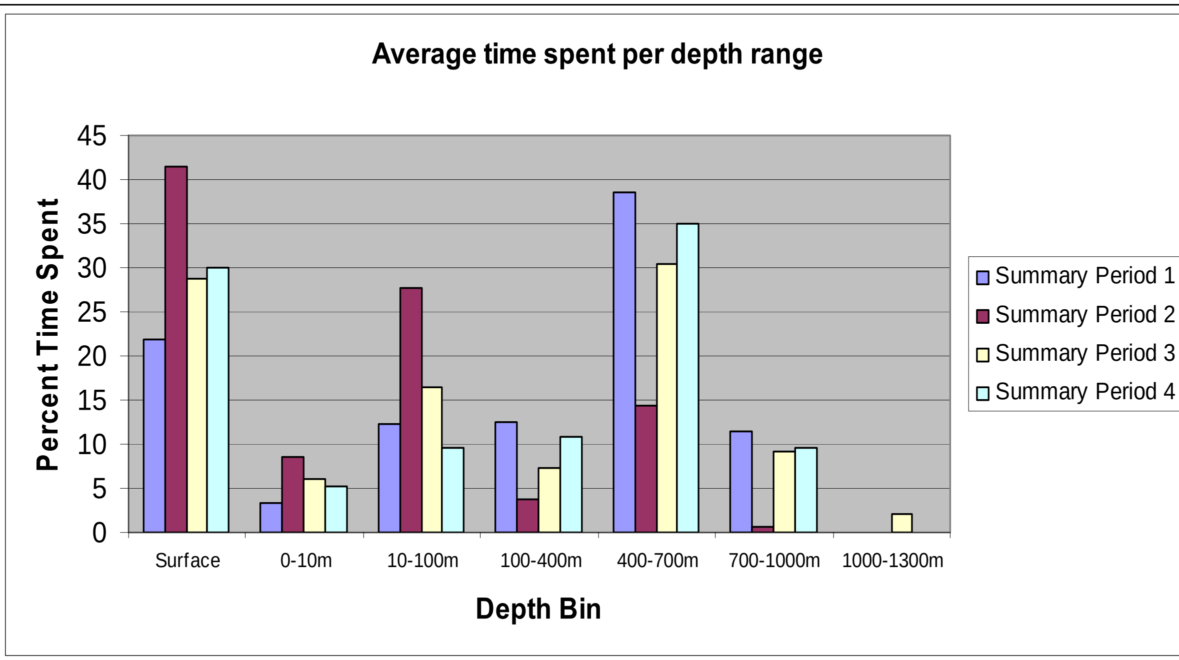


Figure 3E.3. Percent time spent by tagged whale in each depth range, 1–17 July 2005 (Time Periods 1 and 4 = Night, 2 and 3 = Day).

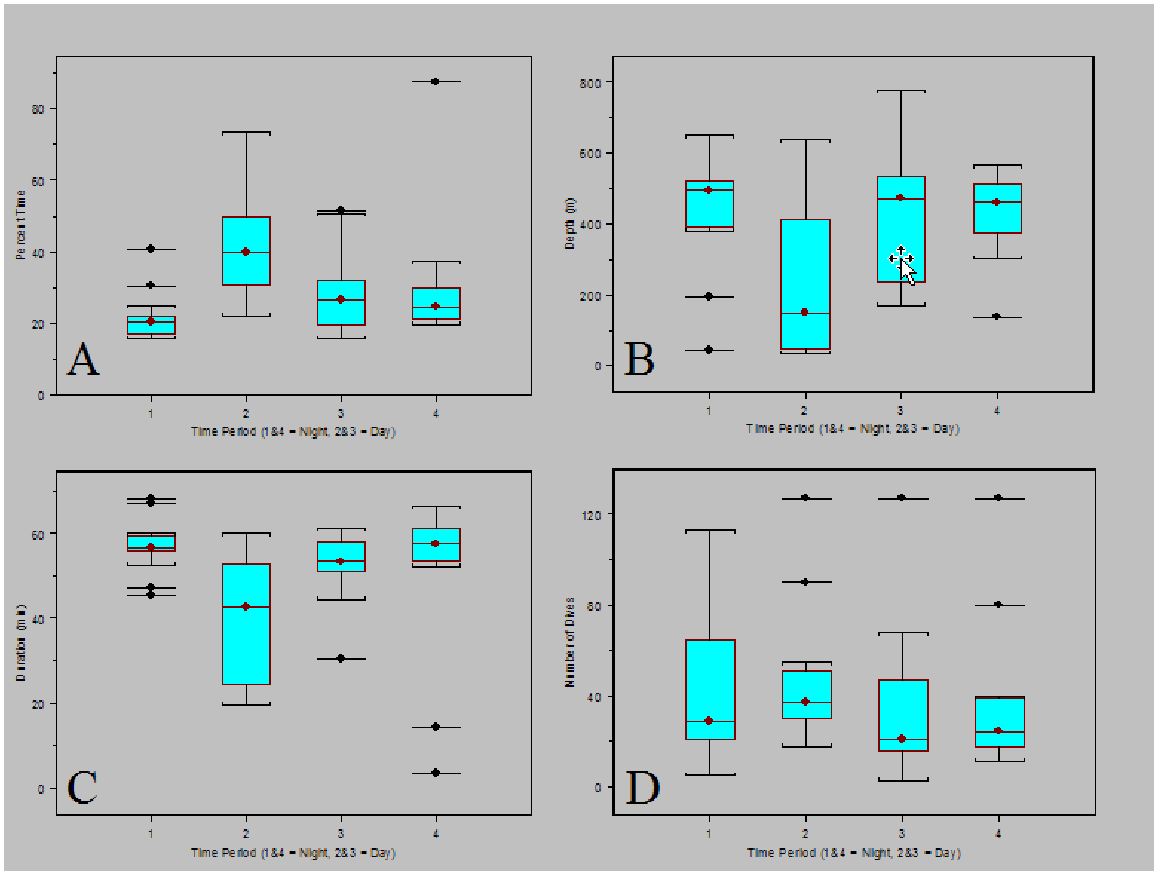


Figure 3E.4. Dive parameters plotted by summary period (A = Percent time at the surface; B = Average dive depth; C = Maximum dive duration; D = Total number of dives).

Discussion

This study describes the longest continuous monitoring of a sperm whale's dive behavior to date. With the exception of summary period 2, the data generally agree with results observed in other studies (Watwood et al. 2006, Drouot et al. 2004, Amano and Yoshioka 2003, Watkins et al. 2002, Watkins et al. 1993).

Our data suggest that the whale's behavior was consistent for most of the day and night, then changed during summary period 2 (06:00 to 12:00 local). As Average Dive Depth and Maximum Dive Duration decreased, Percent Time at the Surface increased, suggesting that the whale was less active or regularly engaged in resting behavior for at least part of the summary period.

We hypothesize that the change in behavior during morning daylight hours may represent a period of rest after prey has migrated to deeper waters for the daytime. It would be energetically beneficial for the whale to maximize its foraging intake when food is closer to the surface and rest/socialize when foraging requires more effort.

The satellite monitored depth-of-dive tag used in this study allowed us to collect the longest duration data set on the diving behavior of a sperm whale to date. The data supported the findings of previous studies and also raised the possibility of a regular period of rest or socializing in the morning daylight hours. Given the success of this tag, future studies of individual and geographic variability in diving behavior are now possible through the tagging of multiple individuals.

Acknowledgments

We thank the tagging crew: Joel Ortega, Craig Hayslip, Dan Engelhaupt, and Andy Szabo, the SWSS 2005 cruise participants and crew of the R/V *Gyre*. Funding was provided by the IRFC and a MMS grant #FO292A .

References

Amano, M. and M. Yoshioka. 2003. Sperm whale diving behavior monitored using a suction-cup-attached TDR tag. Mar. Ecol. Prog. Ser. 258:291–295.

Drouot, V., A. Gannier, and J.C. Goold. 2004. Diving and feeding behavior of sperm whales (*Physeter macrocephalus*) in the Northwestern Mediterranean Sea. Aquat. Mam. 30:419–426.

Krutzikowsky, G.K., and B.R. Mate 2000. Dive and surfacing characteristics of bowhead whales (*Balaena mysticetus*) in the Beaufort and Chukchi seas. Can. J. Zool. 78(7):1182–1198.

Lagerquist, B.A., K.M. Stafford, and B.R. Mate. 2000. Dive characteristics of satellite monitored blue whales (*Balaenoptera musculus*) off the central California coast. Mar. Mam. Sci. 16(2):375–391.

Mate, B.R., B.A. Lagerquist, and J. Calambokidis. 1999. The movements of North Pacific blue whales off Southern California and their southern fall migration. Mar. Mam. Sci. 15(4):1246–1257.

Mate, B.R., G.K. Krutzikowsky, and M.H. Winsor. 2000. Satellite-monitored movements of radio-tagged bowhead whales in the Beaufort and Chukchi seas during the late-summer feeding season and fall migration. Can. J. Zool. 78:1168–1181.

Mate, B.R., R. Gisiner, and J. Mobley. 1998. Local and migratory movements of Hawaiian humpback whales tracked by satellite telemetry. Can. J. Zool. 76:863–868.

Mate, B., R. Mesecar, and B. Lagerquist. 2007. The evolution of large whale radio tags: One laboratory's experience. Deep Sea Research Part II: Topical Studies in Oceanography 54:224–247.

Mate, B.R., S.L. Nieukirk, and S.D. Kraus. 1997. Satellite-monitored movements of the northern right whale. J. Wildlife Manage. 61(4):1393–1405.

Watkins, W.A., M.A. Daher, K.M. Fristrup, T.J. Howald, and G.N. DiSciara. 1993. Sperm whales tagged with transponders and tracked underwater by sonar. Mar. Mam. Sci. 9(1):55–67.

Watkins, W.A., M.A. Daher, N.A. DiMarzio, A. Samuels, D. Wartzok, K.M. Fristrup, D.P. Gannon, P.W. Howey, and R.R. Maiefski. 1999. Sperm whale surface activity from tracking by radio and satellite tags. Mar. Mam. Sci. 15(4):1158–1180.

Watkins, W.A., M.A. Daher, N.A. DiMarzio, A. Samuels, D. Wartzok, K.M. Fristrup, P.W. Howey, and R.R. Maiefski. 2002. Sperm whale dives tracked by radio tag telemetry. Mar. Mam. Sci. 18(1):55–68.

Watwood, S.L., P.J.O. Miller, M. Johnson, P.T. Madsen, and P.L. Tyack. 2006. Deep-diving foraging behavior of sperm whales (*Physeter macrocephalus*). J. Anim. Ecol. 75:814–825.

Zimmer, W.M.X., M.P. Johnson, A. D'Amico, and P.L. Tyack. 2003. Combining data from a multisensor tag and passive sonar to determine the diving behavior of a sperm whale (*Physeter macrocephalus*). IEEE J. Oceanic Eng. 28(1):13–28.

Ladd Irvine graduated in 1998 with a B.S. in biology from the University of Puget Sound and since then has worked at Oregon State University with Bruce Mate's Marine Mammal Program. As a research technician, Ladd does video editing, data entry, tag building, field logistics, and boat driving and maintenance. Two years ago, he entered graduate school at Oregon State University and he is currently finishing a Master's degree studying the dive habits and habitat preferences of blue whales off the California coast.

DIVING BEHAVIOR OF SPERM WHALES IN RELATION TO OCEANOGRAPHIC CHARACTERISTICS

Patrick Miller, University of St. Andrews

Doug Biggs, Ann Jochens, and Leila Belabbassi, Department of Oceanography, Texas A&M University

Click here to view the slide show that accompanied this presentation.

The SWSS program is a collaboration among multiple research teams, each with important new results. Here we present a synthesis of results that integrate aspects of sperm whale foraging behavior with oceanographic habitat parameters that were measured at sea and remotely sensed by satellites in earth orbit.

In summer 2003, 11 sperm whales were tagged with suction-cup attached archival tags (D-tags). They were encountered in water depths that averaged 850 m, in the region south and east of the Mississippi River delta where low salinity, high chlorophyll continental shelf water was entrained into the flow confluence produced by a deepwater cyclone-anticyclone eddy pair. Off-margin surface flow created by the counter-rotating eddies transported this primary production south and east, to feed planktonic assemblages in deepwater. Biggs et al. (2005) reported that sperm whales in the northern Gulf of Mexico are generally more abundant near such "jets" and "squirts" of planktonic primary production than they are over the adjacent slope. However, the trophic cascade through which surface productivity reaches the deep-living prey of sperm whales is unclear and likely quite complex.

Figure 3E.5 shows the locations where sperm whales were D-tagged in summer 2003, relative to the approximate core location of a dynamic squirt of primary production into deepwater (shown for the first week of the cruise by the red "+" symbol in Figure 3E.5A, and for the second week of the cruise by the black "+" symbol in Figure 3E.5B). On average, animals D-tagged in summer 2003 were found within 150–200 km of the shifting core location of this off-margin flow. Eleven additional whales D-tagged in summers 2001 and 19 other whales D-tagged 2002 were located on average 66–87 km and 51–92 km, respectively, from the core locations of off-margin flows of high primary production in summers 2001 and 2002. Whales encountered in water depths of 800–1200 m over the continental slope were seldom encountered at distances of > 250 km from such off-margin flows (Biggs et al. 2005).

Tags were attached to the whales using a 12 m cantilevered pole from a small boat. Reactions to tagging are minor, and tagging does not appear to affect dive depth—the depth of the first recorded dive does not differ from that of subsequent dives. After a D-tag detaches from the whale, it is recovered using VHF radio signals from its antenna. The archived data are then

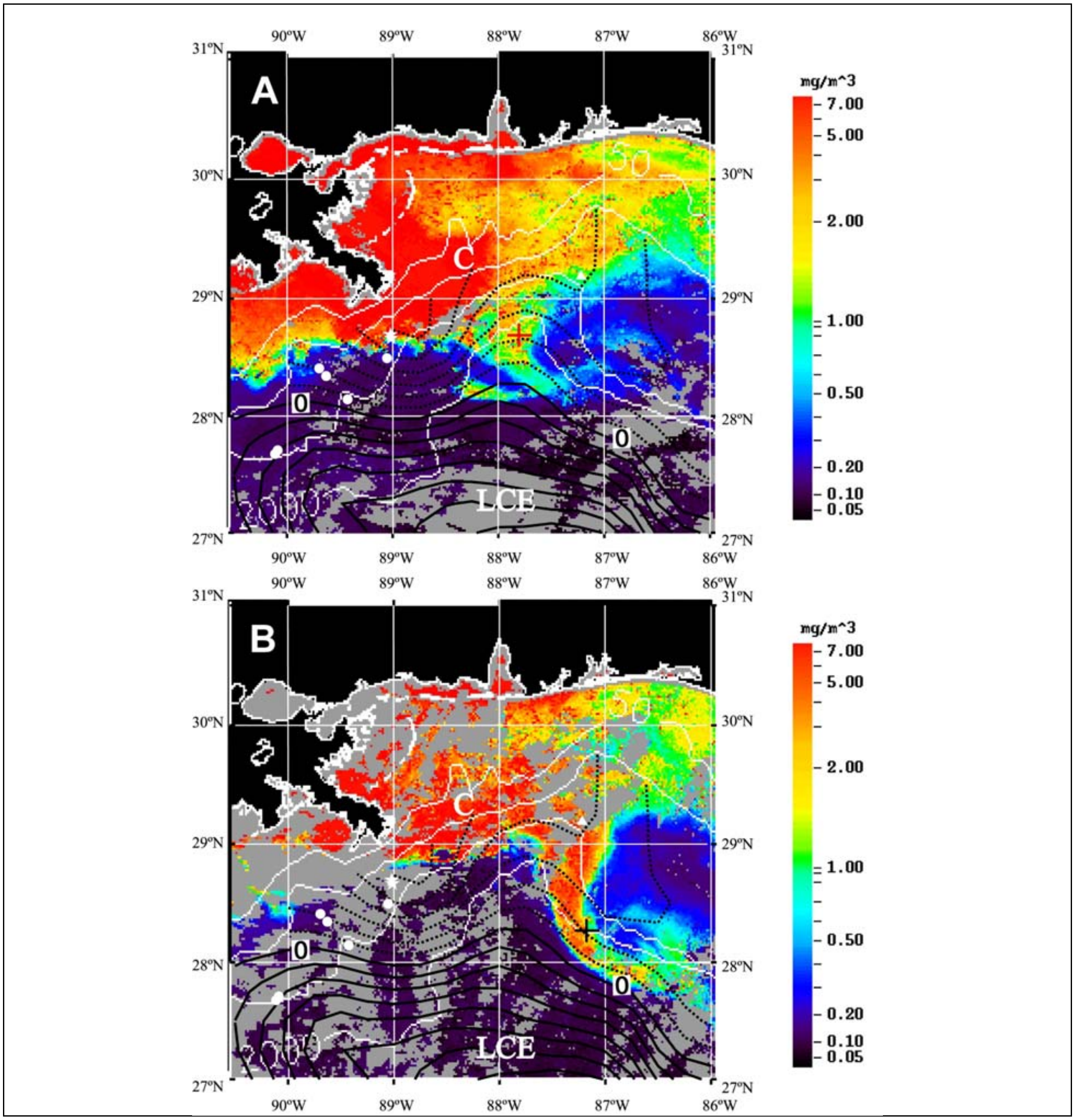


Figure 3E.5. Seven-day composites of SeaWiFS ocean color centered A) 7 June and B) 14 June 2003. Contours of sea surface height are overlaid as dark black lines. Solid lines are positive SSH; dashed lines are negative SSH; SSH contour intervals are 5 cm. The white triangle shows the location of a sperm whale tagged on the 2003 D-tag cruise during the time period of 4–10 June 2003. The white circles show the locations of sperm whales tagged during the time period 11–17 June 2003. The white stars show the locations of sperm whales tagged during the time period 18-24 June 2003. "LCE" denotes anticyclonic Loop Current Eddy, "C" denotes a cylonic eddy north of LC Eddy C, and "+" flags the core location of high chlorophyll entrainment for great-circle distance calculations of how close to this off-margin flow the sperm whales were tagged.

downloaded for analysis. The D-tag has multiple sensors, but for this presentation our focus is on dive depth and on the click and "creak" (buzz) sounds that are produced by diving whales.

We now know that click sounds are tightly linked to the dive cycle of sperm whales, with social coda and rubbing sounds occurring when whales are relatively near the surface, and regular clicks and "creak" (buzzes) occurring during the deep foraging phase (Miller et al. 2004). We have analyzed the diving behavior of sperm whales in relation to these "creak" buzzes very closely. At the 23rd ITM, Watwood summarized that sperm whales produce buzzes during the deeper parts of their dives, and that they increase their maneuvering during buzzes (Watwood et al. 2005). These behaviors combined with the acoustic structure of buzzes strongly support the theory that buzzes are produced by sperm whales during prey encounter and capture. While buzzes do not reveal the size of a prey target, nor whether a capture attempt was successful, we used buzzes here to track where and how often sperm whales attempted to catch prey.

For this ITM presentation, we analyzed in detail a total of 26 D-tag attachments on diving sperm whales during summers 2001, 2002, and 2003. At least one entire dive was recorded from these 26 sperm whales using D-tags, with a total of 144 deep foraging dives recorded. For these records, the depth of dives and buzz production were tracked versus time of day.

Figure 3E.6 gives a synopsis of the depths of dives and buzz production versus local time of day for all of the sperm whales tagged on the 2003 D-tag cruise. Sunset is shown as the transition between light and dark backgrounds. This simple way of presenting the D-tag data reveals three groups of foraging depths. Some whales foraged at the 400-600 m depth of the main deep-scattering layer (DSL), which could be imaged by the relative acoustic backscatter intensity data collected by a hull-mounted 38 kHz acoustic Doppler current meter (ADCP). Figure 3.7 shows this DSL contains migratory zooplankton and micronekton, visible as sunset ascending and sunrise descending bands of locally higher backscatter, as well as non-migratory animals (note that some DSL backscatter remains at depths of 400–600 m, even after sunset). Figure 3E.6 shows that the shallowest foraging depth of whales moved upwards in the water column just prior to sunset, suggesting that the whales were tracking the diel movements of the DSL. After sunset, most of the foraging occurred deeper than the main DSL.

Both day and night, some whales foraged just below this main DSL, in the 600–750 m depth range where Figure 3E.7 shows there are patchy acoustic backscatter returns. On certain days, particularly over slope water bottom depths of 800–1200 m, these substantial but patchy acoustic backscatter returns were detected deeper than the main DSL. We hypothesize that such returns represent local aggregations of squid, or of prey of squid, that live below the daytime depth of the main DSL.

Finally, we observed that some whales foraged on or near the seafloor, including the two largest males that we D-tagged. These whales also buzzed and so foraged in the mid-water column during dive transit to and from the seafloor. The buzz patterns observed in 2003 were observed in the other summers, as well. Foraging in all three depths layers was observed in 2001, though

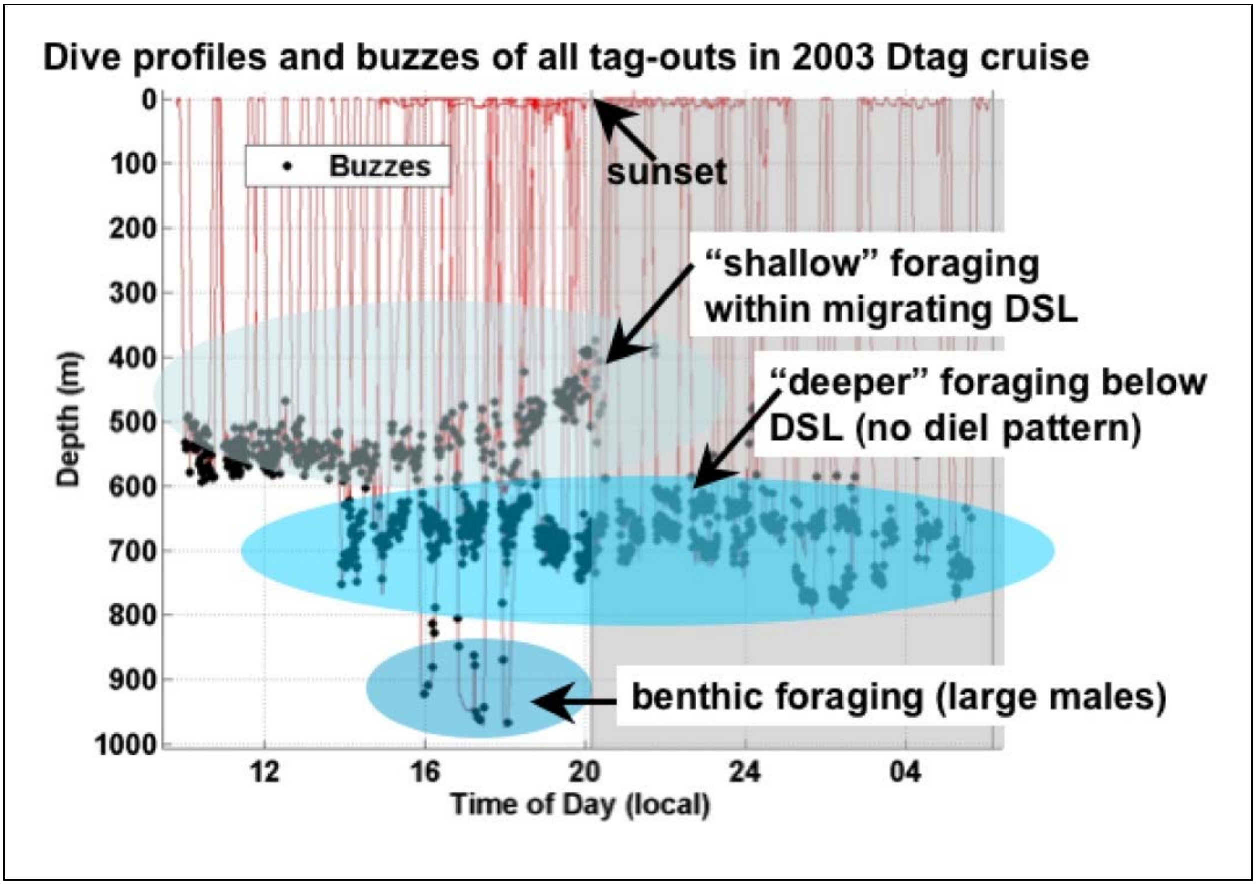


Figure 3E.6. Sperm whale dive profiles and buzzes (also known as "creaks") versus local time of day, for all 11 sperm whales D-tagged in summer 2003.

in that summer no tagged whales dove just prior to sunset. In 2002, we observed diel movements in several whales just before sunset.

A striking find is that prey capture attempt rates, scored as buzz rates, were higher in tag records when foraging occurred at great depths. This pattern of increased buzz rates with depth may indicate that prey fields deeper than the main DSL can be of different types or higher quality to sperm whales than those within the main DSL. If so, the presence of these deeper patches of acoustic backscatter may be a useful predictor of sperm whale presence. John Wormuth's group trawled in midwater in and below the main DSL in summer 2003 (see Wormuth 2005), but it is evident that more research is needed to describe the individual prey items living within these depth layers.

To conclude, we found that sperm whales diving and foraging in the northern Gulf of Mexico targeted prey at various depth layers. The choice by sperm whales of which depth to exploit is likely to be dynamic, depending on their real-time assessment of the prey field. However, we have not found any effect of surface oceanographic conditions (Figure 3E.5) on the diving depth

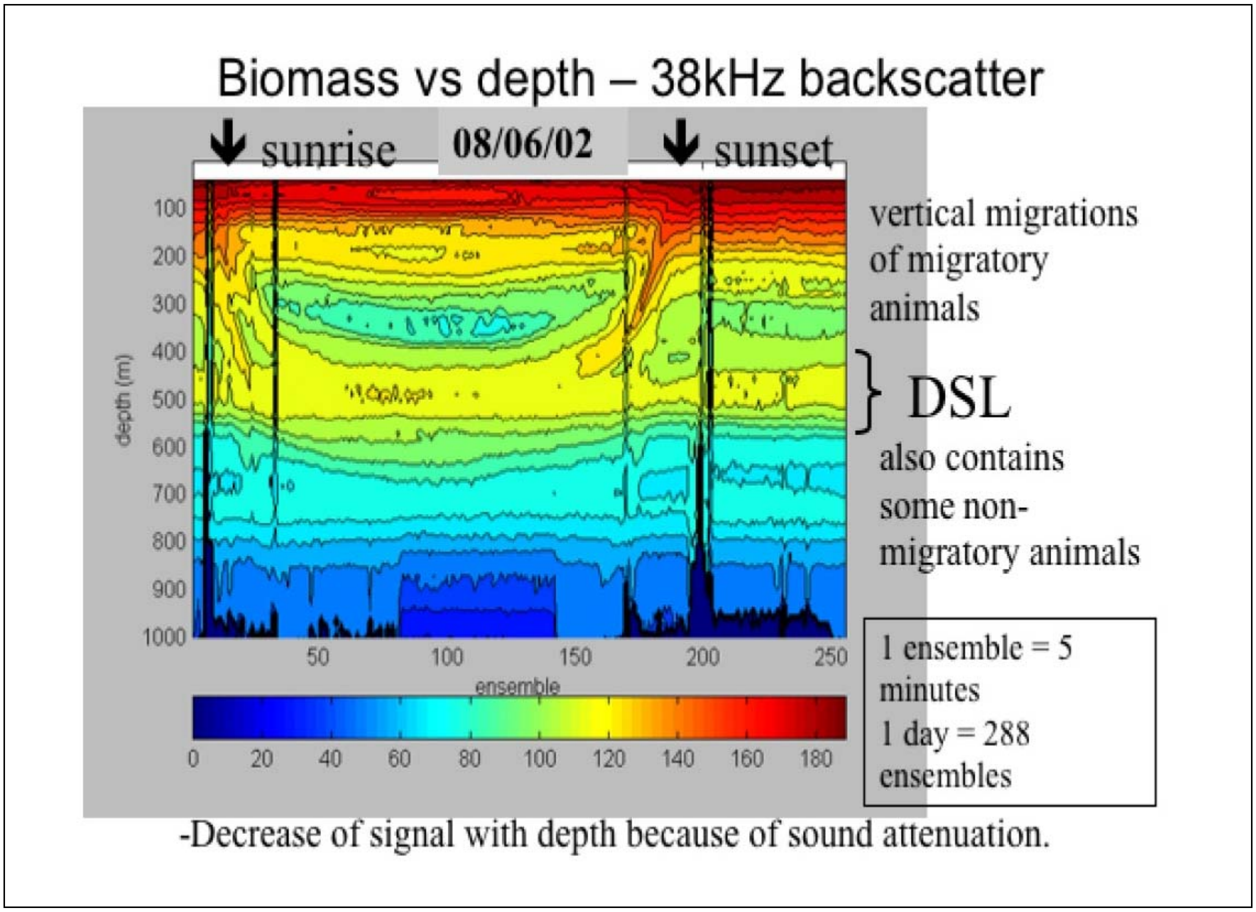


Figure 3E.7. Relative acoustic backscatter intensity (our proxy for nekton and micronekton biomass) was measured by a hull-mounted acoustic Doppler current profiler (ADCP) concurrent with D-tag fieldwork in summer 2003. After Kaltenberg (2004).

of sperm whales in our data set. While we will continue our analysis of exiting data, we recommend additional research to obtain real-time information on prey at depth during future tag deployments. One first step was the use of a ship-mounted Simrad fishery echosounder during the S-tag cruise in summer 2005, along with the 38 kHz ADCP, to allow higher resolution of acoustic backscatter at depths of 400–1000 m (see summary report by Benoit-Bird and Ortega 2008 in these proceedings).

References

Benoit-Bird, K.J., and J.G. Ortega. 2008. Acoustic assessment of sperm whale distribution, habitat, and habitat use. In: McKay, M. and J. Nides, eds. Proceedings: Twenty-fourth information transfer meeting, January 2007. U.S. Dept. of the Interior, Minerals Management Service Gulf of Mexico Region, New Orleans, LA. OCS Study MMS 2008-012. Pp. 425–426.

Biggs, D.C., A.E. Jochens, M.K. Howard, S.F. DiMarco, K.D. Mullin, R.R. Leben, F.E. Muller-Karger, and C. Hu. 2005. Eddy forced variations in on- 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: Circulation in the Gulf of Mexico: Observations and Models. Geophys. Monograph Series 161, Amer. Geophys. Union, 10.1029/161GM06. Pp. 71–85

Kaltenberg, A.M. 2004. 38 kHz ADCP investigation of deep scattering layers in sperm whale habitats in the northern Gulf of Mexico. M.S. thesis, Texas A&M University. 92 pp.

Miller, P.J.O., M.P. Johnson, and P.L. Tyack. 2004. Sperm whale behavior indicates the use of rapid echolocation click buzzes creaks in prey capture. Proceedings Royal Society of London B 271:2239–2247.

Watwood, S.L., M.P. Johnson, P.T. Madsen, P.L. Tyack, and P.J.O. Miller, 2005. Diving, foraging, and vocal behavior of sperm whales. In: McKay, M. and J. Nides, eds. 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. Pp. 274–276.

Wormuth, J.H. 2005. Analysis of the mesopelagic community in areas of feeding and non-feeding by sperm whales in the northern Gulf of Mexico. In: McKay, M. and J. Nides, eds. 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. Pp. 403–408.

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., he 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. Dr. Miller 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.

ACOUSTIC ASSESSMENT OF SPERM WHALE DISTRIBUTION, HABITAT, AND HABITAT USE

Kelly J. Benoit-Bird, College of Oceanic and Atmospheric Sciences, Oregon State University

Joel G. Ortega-Ortiz, Marine Mammal Program, Hatfield Marine Science Center, Oregon State University

Click here to view the slide show that accompanied this presentation.

The objective of this work is to assess the distribution in space and time as well as the availability of potential prey for sperm whales in the Gulf of Mexico. Prey assessment was done in conjunction with measures of whale distribution, diving behavior, and vocalizations. A two-frequency split-beam echosounder (Simrad EK60 at 38, and 70 kHz) aboard the R/V Gyre was used to measure the distribution of midwater sound-scatterers in the Gulf of Mexico during 3–29 June 2005. Scattering layers in the Gulf of Mexico during the study period were extensive. Even averaging over the entire study period, distinct layers in volume scattering are evident. Layers ranged in vertical extent from 1 m to over 100 m. Layers were most often less than 5 m in vertical extent. A comparison of the acoustic backscatter data from the echosounders with the visual observations for sperm whales showed that volume scattering in the upper 100 m of the water column was significantly higher when whales were detected. It was also possible to identify sperm whales within the echosounder data as extremely large, strong scatterers. A comparison of the detection rate of whales from the echosounder and the sightings of whales made by the visual observers showed a strong, linear correlation, supporting the identification of these targets as sperm whales. Looking at the overall pattern in the relationship between whale detection rate and volume scattering, revealed significant relationships at 5, 10, and 25 km scales, fewer show relationships at 1 km and 50 km and even fewer at the 100 km scale. This suggests that sperm whales are detecting changes in the habitat at horizontal scales of tens of kilometers, not one or hundreds. Whales were found to correlate with very small scales (1 m) of scattering in the vertical dimension. This study represents the first calibrated acoustic data of the distribution in space and time of animals that occupy trophic levels relevant as food resources to sperm whales in the Gulf of Mexico. This approach provides a powerful tool to obtain high-resolution information on the distribution of potential prey while simultaneously observing diving sperm whales and provides important information for designing future studies of sperm whale foraging and habitat use.

Kelly Benoit-Bird is an Assistant Professor in the College of Oceanic and Atmospheric Sciences at Oregon State University. She received her Ph.D. in zoology from the University of Hawaii at Manoa and a B.A. in ecology from Brown University. Her research uses state-of-the-art acoustic

approaches to understand the ecology of pelagic environments. Her research focuses on the spatial and temporal dynamics of marine animals ranging from zooplankton to whales. She was recently awarded the Presidential Early Career Award for Scientists and Engineers and the 2005 Office of Naval Research Young Investigator Award.

THREE-DIMENSIONAL UNDERWATER TRACKING OF SPERM WHALE DIVE PROFILES USING A PASSIVE ACOUSTIC TOWED ARRAY

Aaron Thode, Marine Physical Laboratory, Scripps Institution of Oceanography

Tom Norris, Science Applications International Corporation

Alyson Azzara, Department of Oceanography, Texas A&M University

Click here to view the slide show that accompanied this presentation.

Abstract

Sperm whale clicks generate enough energy to reverberate, or echo, off the ocean surface and bottom. These echoes can be used to track a sperm whale in range and depth using a set of hydrophones towed behind a monitoring vessel. This technique has been used to measure sperm whale dive profiles and foraging depths in the Gulf of Mexico. If the hydrophones can be deployed with sufficient horizontal separation, a 3-D dive track can be derived using only a single surface-reflected echo. Automated systems using this method are currently being developed as part of the Sperm Whale Seismic Study (SWSS) effort, where potential correlations between sperm whale foraging depths and acoustic backscattering measurements are also being investigated. These techniques are currently being incorporated into standard acoustic tracking software.

Sperm whales are a vocally active species, and detecting their signals, or "clicks," using towed passive acoustic arrays has become a standard procedure for detecting, locating and monitoring these animals (Gillespie 1997; Gillespie and Leaper 1997; Barlow and Taylor 1998). Since 2003 the US Minerals Management Service (MMS) and the Industry Research Funding Coalition (IRFC) has, through the Sperm Whale Seismic Study (SWSS), supported the development of a three-dimensional passive acoustic tracking system for sperm whales, by exploiting surface-reflected acoustic arrivals to create a virtual planar array out of a large-aperture array towed behind a ship (Figures 3E.8 and 3E.9; Thode et al. 2002; Thode 2004). This array has been deployed behind the R/V Gyre during cruises in 2004 and 2005 as part of SWSS "S-tag" cruises to satellite-tag sperm whales. Data were primarily collected at night or during rough weather days.

The key behind the technique is that sperm whale sounds are loud enough to produce echoes off the ocean surface and bottom (Figure 3E.8), but short enough in duration to permit these echoes to be separated in time from the sound arriving directly (direct path) from the animal (Figure 3E.10). If two widely-separated hydrophones record the direct path and surface-reflected echoes from a sperm whale click, and if the depths of the hydrophones are independently known, the range and depth of the whale can be determined by measuring the relative arrival times of the echoes relative to the direct arrivals. If the horizontal separation between the hydrophones can be

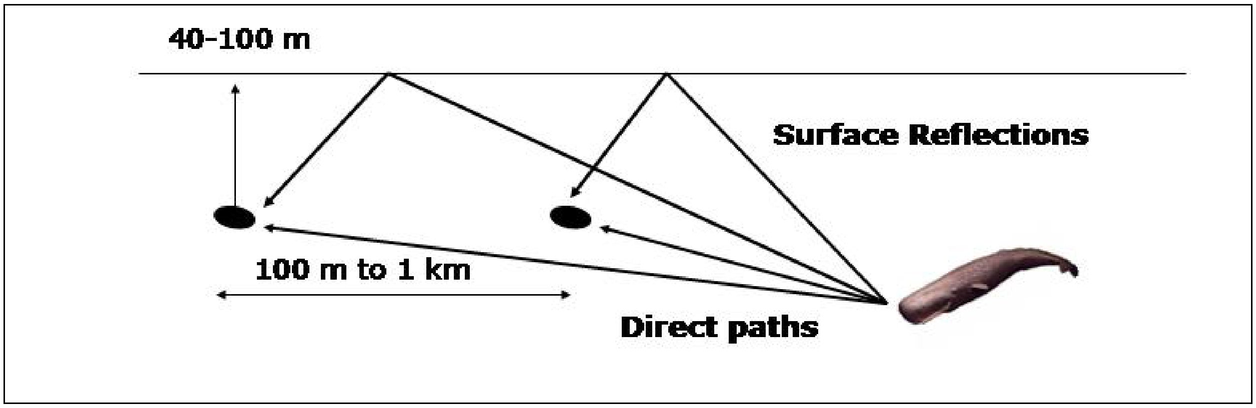


Figure 3E.8. Illustration of how sperm whale sounds reflect off the ocean surface. If these surface echoes can be detected they provide information about the whale's range and depth.

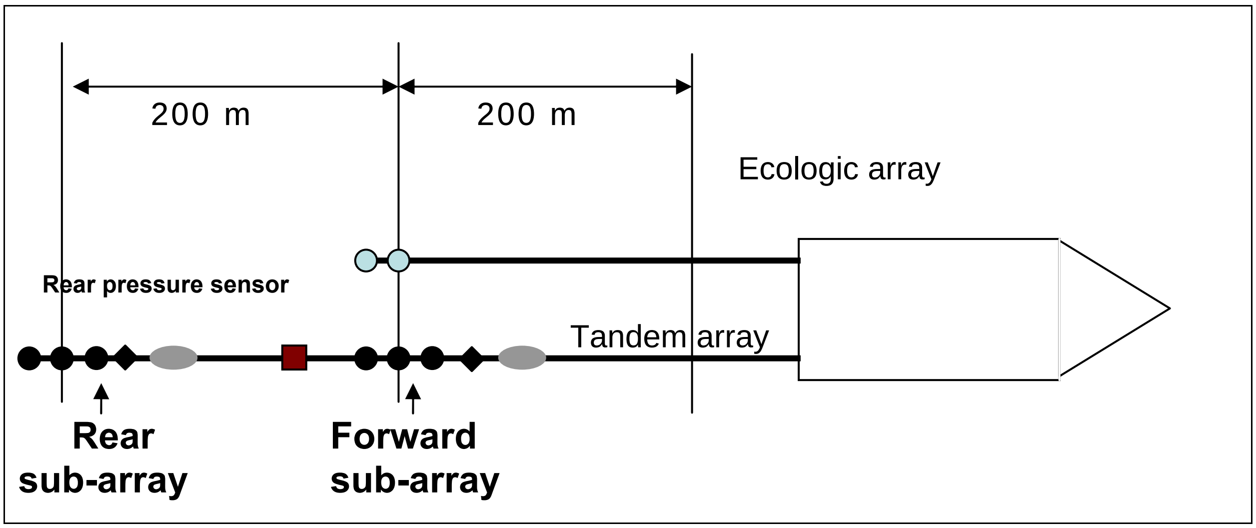


Figure 3E.9. Towed array deployment from research vessel, viewed from above. The tandem array is divided into forward and rear sub-arrays.

measured, then the animal's azimuth can be determined, providing a 3-D position fix, but with a port/starboard ambiguity (Thode 2004). If the horizontal separation between two widely-spaced hydrophones is at least 200 m, range/depth estimates can be obtained out to 1 km horizontal range. These techniques can be automated, and an example of the resulting trajectories are shown in Figure 3E.11. An overlay of some tracks with acoustic backscatter measurements is shown in Figure 3E.12. To date the dive depths obtained are consistent with those obtained via active sonar and tagging efforts through SWSS.

This program is being continued in 2007 with a focus on implementing real-time tracking software and a new array configuration with an expanded array aperture.

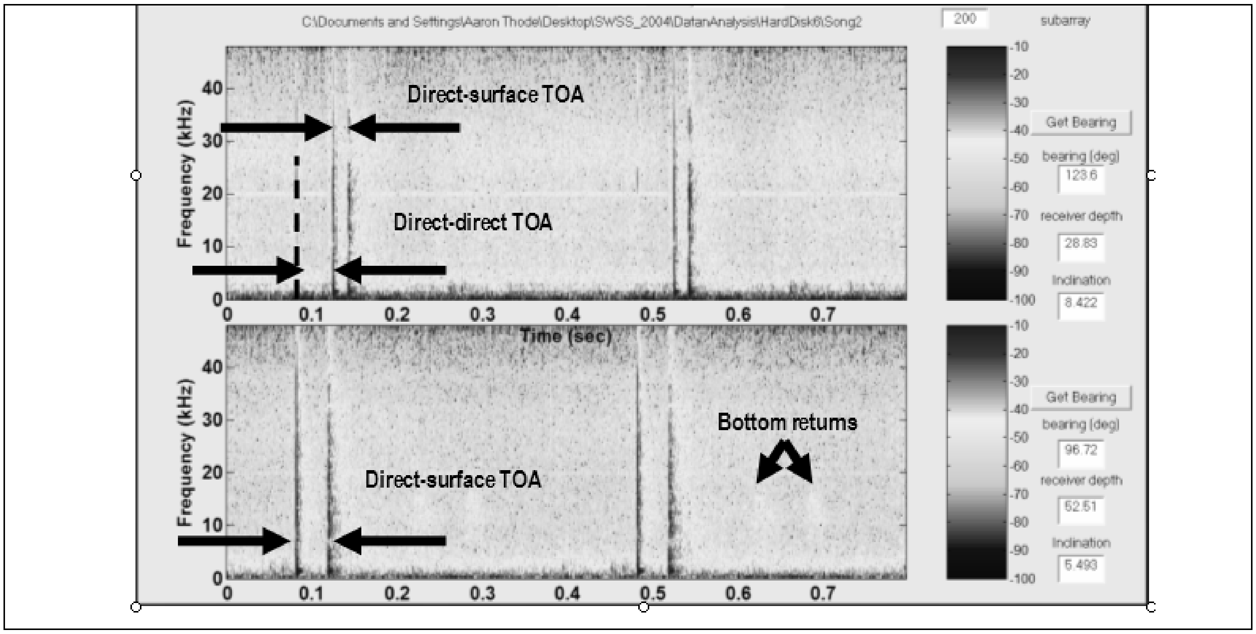


Figure 3E.10. Visual representation of sounds detected on equipment shown in Figure 3E.9. The top spectrogram represents data from the forward sub-array, and the bottom represents data from the rear sub-array. By measuring the three relative arrival times shown by solid arrow pairs, a range-depth position fix can be obtained. The interval between successive sounds made by the animal is called the "inter-click interval (ICI)," which is used during automated processing to identify the same sound on different hydrophones.

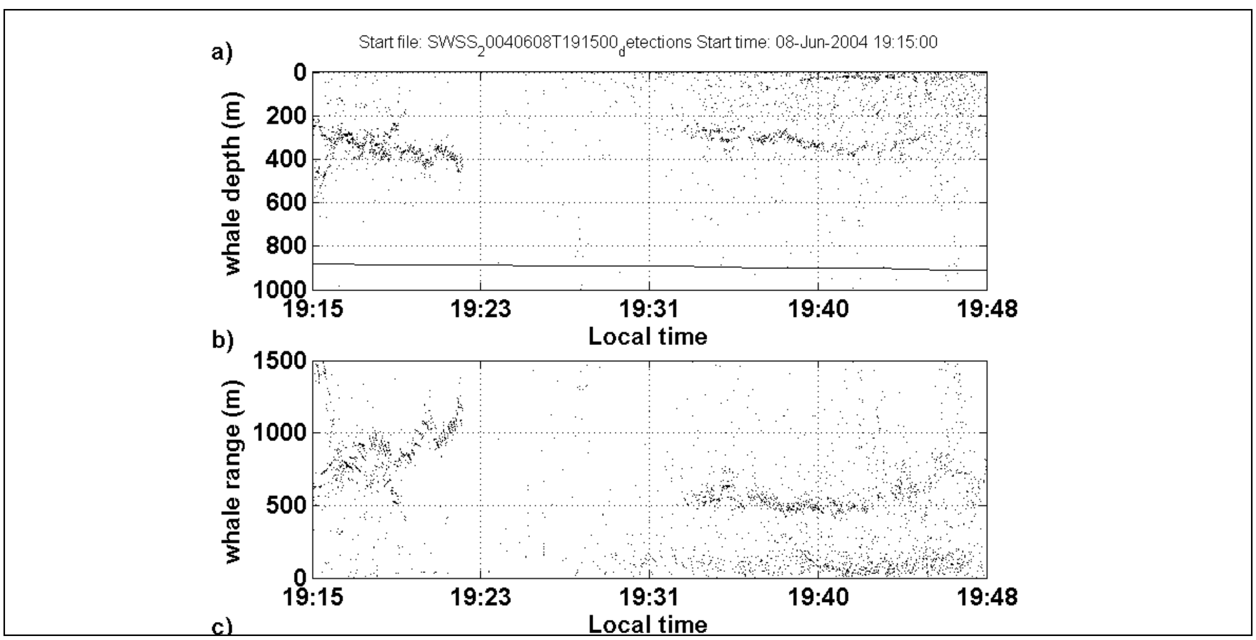


Figure 3E.11. Example range-depth tracks of three animals in the Gulf of Mexico.

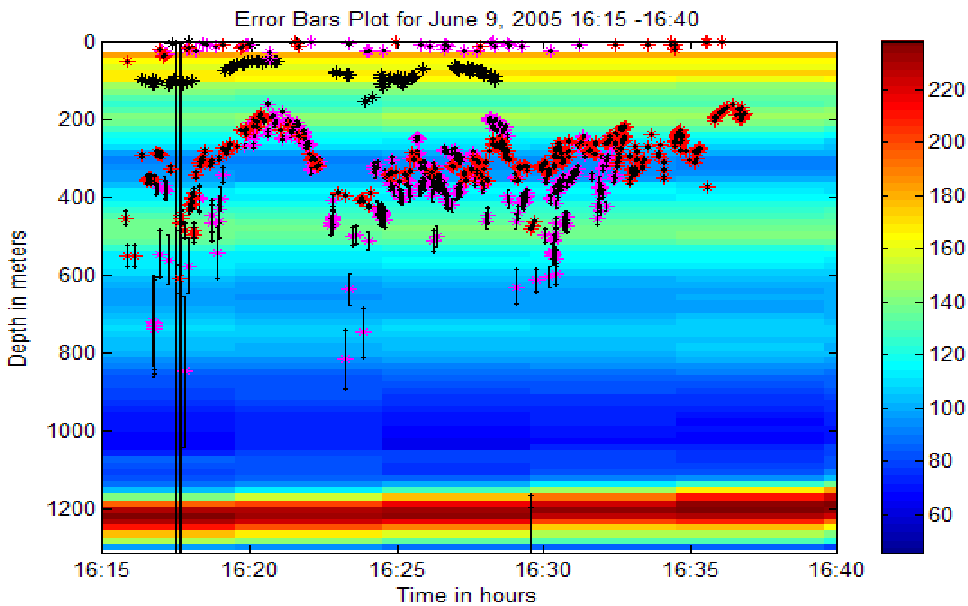


Figure 3E.12. Overlay of three dive profiles with backscatter from an Acoustic Doppler Current Profiler (ADCP), showing association of whale local dive extrema with regions of strong acoustic backscatter.

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. Int. Whal. Comm. Cambridge SC/50/CAWS 20.

Gillespie, D. 1997. An acoustic survey for sperm whales in the Southern Ocean Sanctuary conducted from the RSV Aurora Australis. Rep. Int. Whal. Commn. 47.

Gillespie, D. and R. Leaper. 1997. Detection of sperm whales (*Physeter macrocephalus*) clicks, and discrimination of individual vocalisations. Res. Cetaceans 10:87–91.

Thode, A. 2004. Tracking sperm whale (*Physeter macrocephalus*) dive profiles using a towed passive acoustic array. J. Acoust. Soc. Am. 116:245–253.

Thode, A., D.K. Mellinger, S. Stienessen, A. Martinez, and K. Mullin. 2002. Depth-dependent acoustic features of diving sperm whales (*Physeter macrocephalus*) in the Gulf of Mexico. J Acoust. Soc. Am. 112:308–321.

Aaron Thode earned his Ph.D. at the Scripps Institution of Oceanography at the University of California, San Diego, 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.” Currently he is an associate research scientist at Scripps.

SEISMIC SURVEY ACTIVITY AND THE PROXIMITY OF SATELLITE TAGGED SPERM WHALES

Martha H. Winsor and Bruce R. Mate,
Hatfield Marine Science Center, Oregon State University

Click here to view the slide show that accompanied this presentation.

Sperm whales (*Physeter macrocephalus*) frequent the lower continental slope (>1000m) off the Mississippi River Delta, which is an area also of interest to offshore oil industries and is extensively surveyed by seismic vessels. Because sperm whales are highly acoustically-oriented animals, there have been concerns about possible changes in behavior when they are subjected to airgun noise from seismic vessels.

During the summers of 2002–2006, 53 sperm whales in the Gulf of Mexico (GOM) were tagged with satellite-monitored radio tags (S-tags) as part of SWSS. One objective was to determine possible changes in the behavior of sperm whales when they are subjected to man-made noise produced by airguns during seismic surveys. Though the S-tag study was designed principally to describe long-term (months to seasonal) movements and distributions of sperm whales, the proximity of seismic vessel activity near S-tag locations provided an opportunity to explore any possible behavioral response.

The Argos Data Location and Collection System was used to obtain position data from the S-tags. High quality (Argos location class 1-3) whale locations from the S-tags (N= 1559 locations) were compared to positions of active seismic vessels with vessel information provided by the International Association of Geophysical Contractor (IAGC) members. IAGC data consisted of the start and end times and locations of central shot point of the airgun array for 9958 seismic lines from January 2002 through October 2006 (Figure 3E.13).

When a whale location occurred between the start and end time of a seismic line, the position of the central shot point of the airgun array, at the time of the whale location, was interpolated from the line's start and end locations. The distance between the whale and central shot point location was then calculated. Vessels' tracks bearings and bearings from shot point to the whale were calculated using the interpolated shot point location. Only locations within 100 km of active airguns were considered in this analysis under the assumption that exposure to sound from closer distances would be of more interest in whale behavior research. Additionally, vessel speeds and headings were assumed to be constant so that interpolated positions for central shot points were accurate.

Locations from 34 S-tags were within 100 km of active airguns (number of locations for each whale varied from 1 to 40). Forty locations were within 100 km of two active vessels and three

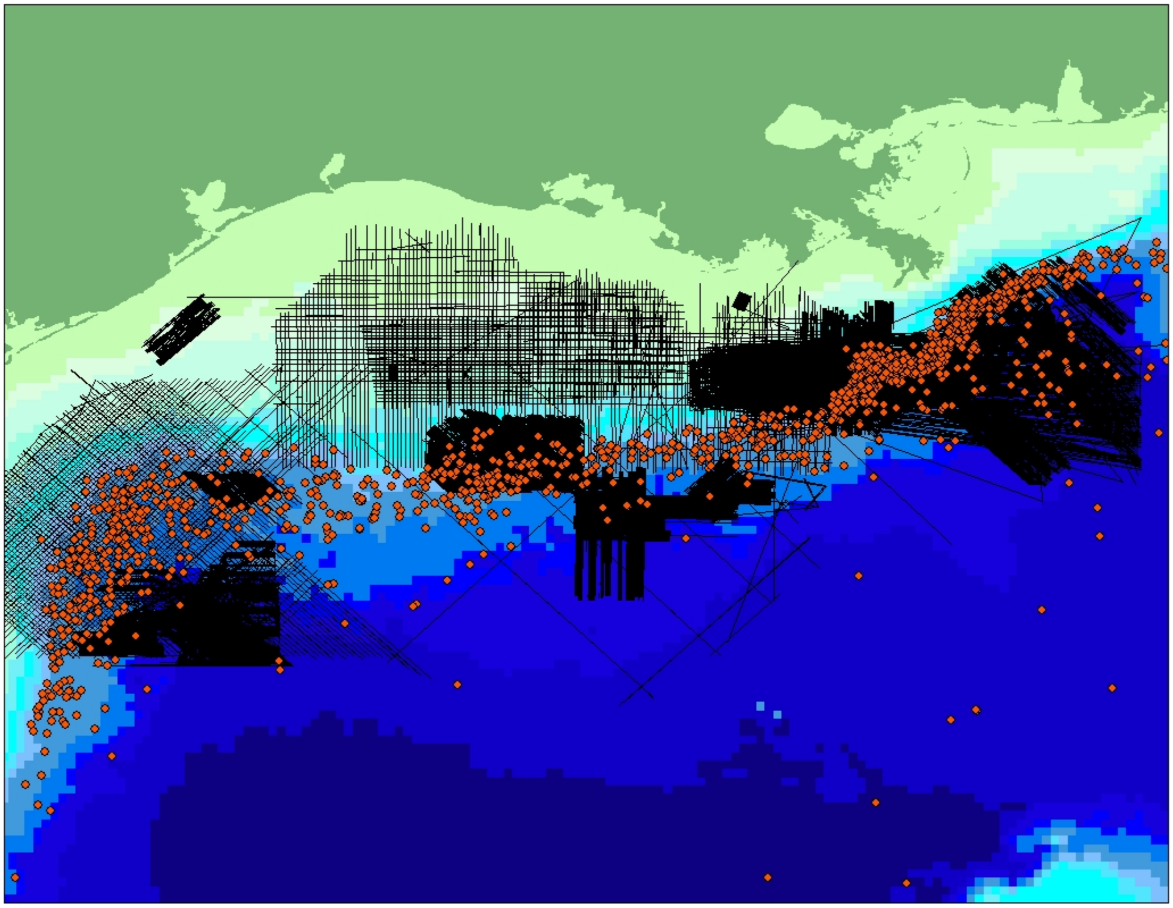


Figure 3E.13. Map of all seismic lines provided by IAGC members from January 2002 through October 2006 (black lines) and high-quality (Argos LC1, LC2, and LC3) locations (red dots) from S-tagged sperm whales from July 2002 through October 2006.

were within 100 km of three active vessels simultaneously (N=334 location/seismic line temporal matches). The minimum distance of any animal was 5.01 km and the total weighted (by individual sample size) mean was 66.3 km (S.D.14.7). Individuals that had more than seven locations fitting the criteria (N=15) had an average minimum of 16.5 km (S.D.=7.3 km) with a range of 5.01 to 27.4 km.

Distances to shot points for each individual animal were compiled and compared to determine whether there were significant (p=.05) differences between individuals and/or sex. Using data only from the 15 whales with more than seven locations (providing sufficient sample sizes for comparisons), showed significant differences between several individuals' mean distances (ANOVA; p-value 0.009) but no significant difference between sexes (ANOVA; p-value = 0.26, four males, seven females, four unknowns or p-value=.08 comparing just males and females).

The relative bearing of the 15 whales to the vessel's track was also calculated and categorized into one of three bearing classes: Class A – in front of the sound source (60° to either side); Class

B – to the side of the source (60°–120° and 240°–300°); and Class C – to the rear of the source (120°– 240°) providing equal coverage in the three categories (Figure 3E.14). Bearing classes were compared to determine whether whales were equally distributed in the three classes or whether there was an orientation to the sound source track occurring more frequently than others. There was no relationship between distance and bearing class or significant difference of bearing class (GLM; p=0.32).

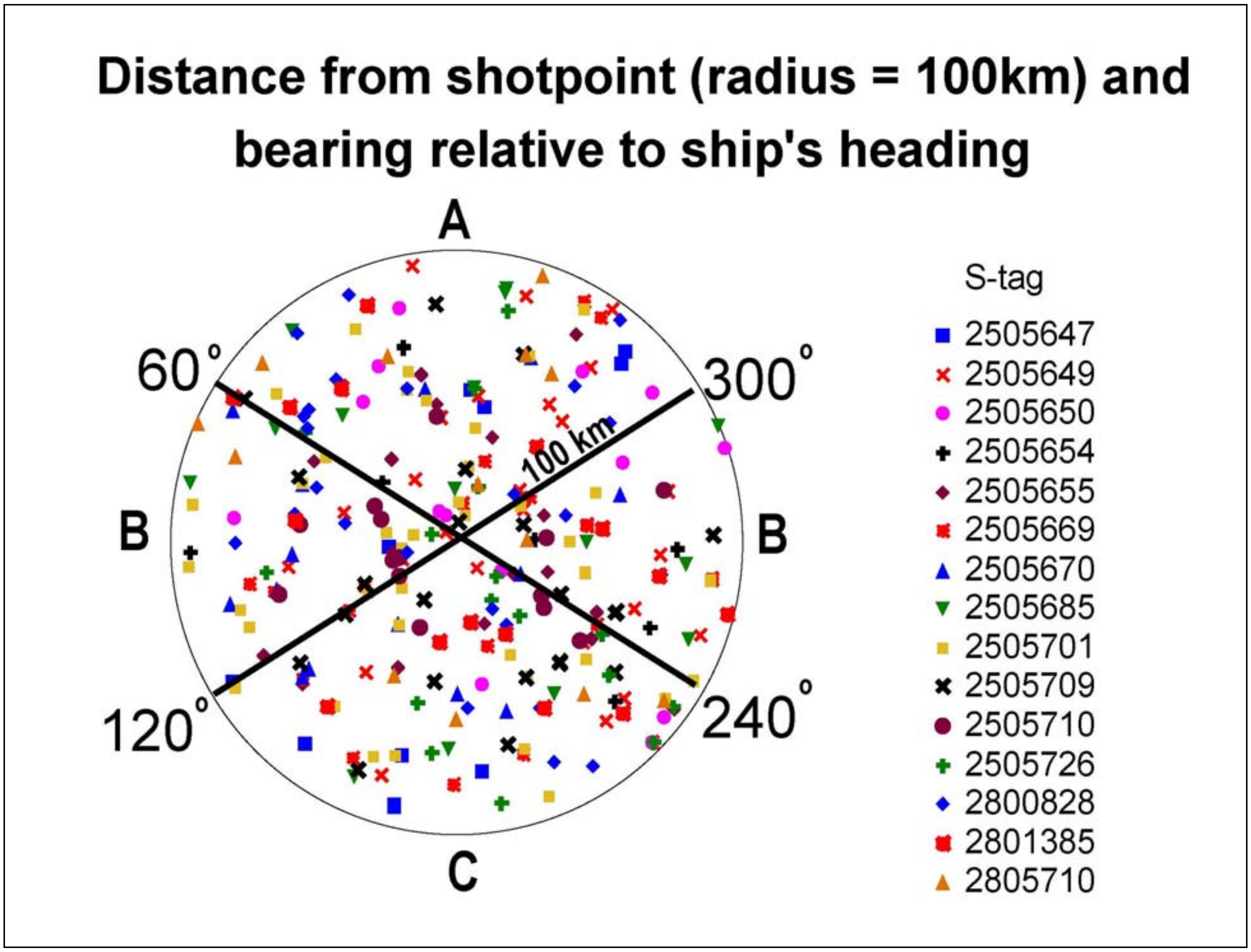


Figure 3E.14. Relative bearings of whale locations to vessels' track using data from S-tags with more than 9 locations within 100 km of an active seismic vessel. S-tag locations were partitioned into 3 orientation categories: A = in front of; B = to either side of; and C = behind the sound source.

A subset of the data, consisting of locations within 25 km of the central shot point was further analyzed to determine if locations were randomly distributed closer to the sound source. We hypothesize that if there is no evidence of avoidance to active airgun noise, 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 airgun noise.

Assuming a random distribution, the expected number of locations in each 5 km class was calculated by normalizing to the proportion of area the class represented in a 25 km radius circle. 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.

Because of the relatively small sample size available, 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. 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. 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.

Distances and bearings between whales and the central shot point of an active seismic vessel appear to be randomly distributed. From a distance greater than 5 km, there were no apparent patterns in the distances and bearings from the whale locations to the central shot that suggested a movement response to the presence of an active seismic vessel. These results, however, cannot totally refute a possible behavioral response at distances less than 25 km because of a lack of sufficient sample size. The number of individuals would need to be doubled (N=25) to have the power to detect a non-random distribution from 5 km out to 25 km. A much larger sample size (N=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.

Martha Winsor has been a research assistant for the Marine Mammal Program of Oregon State University for 20 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 for two years. Her education includes a Sc.B. in aquatic biology from Brown University and an M.S. in applied statistics from Oregon State University.

MODELING SPERM WHALE RESPONSES TO AIRGUN SIGNALS

Stacy L. DeRuiter, Woods Hole Oceanographic Institution/MIT Joint Program

Andy Solow, Woods Hole Oceanographic Institution

Patrick J. O. Miller, University of St. Andrews

Peter L. Tyack, Woods Hole Oceanographic Institution/MIT Joint Program

Click here to view the slide show that accompanied this presentation.

Introduction

We have developed several statistical methods to analyze data from the 2002 and 2003 SWSS experiments in which sperm whales were tagged with D-tags and exposed to airgun signals. This work has allowed us to assess the effects of airgun exposure on sperm whale foraging rates. Ultimately, we plan to use a similar statistical approach to quantify the relationship between noise exposure level and change in foraging rate. Once that relationship has been established, we will use literature data and established modeling methods to relate changes in whale foraging rate to changes in reproductive success, and finally to relate individual reproductive success rates to population growth rates. Such modeling will facilitate a noise-management approach in which managers can regulate noise exposure levels based on the predicted effects of noise level on population growth rate.

Methods

Data Collection

The data analyzed in this study were collected during controlled exposure experiments (CEEs) conducted on the 2002 and 2003 SWSS cruises. During the experiments, eight sperm whales were tagged with D-tags, which recorded sound and movement data. The tags recorded data for approximately 4–17 hours per whale, including 1–2 hours of airgun exposure. The distance between the tagged whales and the airgun source vessels varied from about 1–13 km, and the received levels of airgun signals recorded on the D-tags ranged from <131-164 dB re 1 μPa peak-peak (many airgun arrivals were so quiet that it was impossible to quantify their received level above background noise). Data from seven of the eight whales were analyzed in this study, since one whale did not forage at all during airgun exposure. More detailed information on the experimental methods and the quantification of received sound levels is available in the SWSS 2002 and 2003 cruise reports (Jochens and Biggs 2003, 2004) and in Madsen et al. (2006).

For all statistical analyses, we used the rate of echolocation buzzes recorded on the D-tags (which indicate attempted or successful prey capture events) as a proxy for foraging rate (Miller et al. 2004).

Statistical Analyses – Parametric Test

We assumed that buzz production is a Poisson process. Under that assumption, the number of buzzes during the control period (N_c) should have a negative exponential distribution. Our null hypothesis was that the foraging rate is constant for each whale; our alternate was that foraging rate is reduced during airgun exposure. Conditioning on n (the total number of buzzes produced during the experiment), N_c will have a binomial distribution. The p-value of the test is the probability of getting the observed number of control buzzes, N_c, from the appropriate binomial distribution. We used Fisher's method to account for multiple statistical tests and obtain a combined p-value indicating whether at least one of the seven whales showed a statistically significant reduction in foraging rate during airgun exposure (Fisher 1948). We also tested the hypothesis that all seven whales showed a concerted reduction in foraging rate in response to the airgun exposure. Assuming a normal approximation to the binomial distribution, the sum of all seven whales' N_c values ($N_{c,all}$) will have a normal distribution. The p-value of the test is the probability of obtaining the observed value of $N_{c,all}$ from the appropriate normal distribution. We calculated a method-of-moments estimate of the reduction in foraging rate during airgun exposure, and we estimated the power of the parametric tests using synthetic datasets.

Statistical Analyses – Nonparametric Rotation Test

We also developed a nonparametric method to test the null hypothesis that an individual whale maintains a constant buzz rate through control and airgun conditions. The test statistic was again the observed number of buzzes during control conditions (N_c). To get a distribution for the test statistic, we used a "rotation test" method to resample the data. For each rotation of the dataset, we kept the time-series of buzzes intact and held the duration of the airgun exposure constant but randomly shifted the nominal start time of the exposure to any time within the experiment. We then calculated $N_{c,rotated}$ for the rearranged dataset. We repeated the process 10,000 times to construct a distribution of $N_{c,rotated}$ and to calculate the p-value of the test (the probability of $N_{c,rotated}$ being at least as large as the N_c value observed in the data). We again used Fisher's method to obtain a combined p-value for all seven whales. We also tested the hypothesis that all seven whales showed a concerted reduction in foraging rate during airgun exposure; for that test we used the sum of N_c (for all whales) as our test statistic and again determined its distribution with a rotation test.

Results

Table 3E.3 shows the p-values of all statistical tests, along with estimates of the percent changes in foraging rates during airgun conditions. Applying Fisher's method to either the parametric or rotation test results indicated that at least one of the seven whales reduced its foraging rate by about 60% during airgun exposure, and that reduction was statistically significant at the p=0.05 level. However, we found no evidence for a concerted reduction in foraging rate during airgun exposure by all seven whales (p=0.19, rotation test). Figure 3E.15 shows the power of the parametric test to detect changes in foraging rate in response to airgun exposure. The test has more power to detect a concerted change by seven whales that to detect a change by a single whale, and it does not have sufficient power to detect small changes in foraging rate (power > 0.8 only for >15% reduction by all seven whales or >40% reduction by a single whale).

Table 3E.3

Results of Statistical Analyses

Whale	p-value (parametric test)	p-value (rotation test)	Change in foraging rate (%)
1	0.78	0.70	31%
2	0.54	0.54	4%
3	1.40e-4	0.069	-59%
4	5.20e-5	0.0021	-60%
5	0.93	0.92	40%
6	0.88	0.72	5%
7	0.13	0.13	-13%
Group of 7 whales			-9%
Fisher's method	0.0001	0.036	
Concerted change	0.083	0.19	

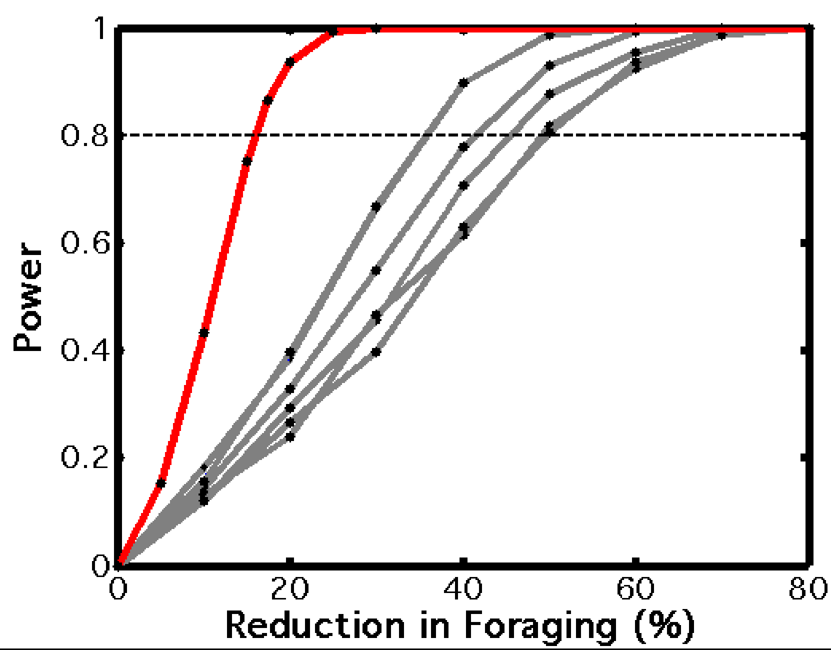


Figure 3E.15. Power of the parametric test to detect reductions in foraging rate at the p = 0.05 level. Red line: power to detect concerted change by a group of 7 whales; gray lines: power to detect change by an individual whale.

Conclusions

Results of the parametric and rotation tests are in relatively good agreement, although the rotation test gives slightly larger p-values in some cases. We believe that the rotation test method of statistical analysis is superior to the parametric method, which depends on the assumption that buzz production is a Poisson process. That assumption is probably invalid, since buzz production rate will vary if a whale's food is patchy in either space or time and since inter-buzz intervals do not fit a negative exponential distribution (as would be expected for a Poisson process).

Our data seem to indicate that airgun exposure—even at the low exposure levels observed in this experiment—can result in large reductions in foraging rate for some individual sperm whales. The ability of our method to statistically analyze the response of each individual whale is well suited to our long term goal of interpreting the effect of changes in foraging on population parameters. If the reduction in foraging tends to occur in reproductive females, this could have a larger impact on reproduction than if it occurs among males. It is also reasonable to expect that different age/sex classes, and individual whales with different histories of exposure would have different patterns of behavioral response. Unfortunately, the power of our statistical tests to detect small reductions in foraging rate was quite low. In future experiments, increasing the duration of the experiment (both control and airgun exposure periods) and increasing the number of animals involved would increase the power to detect changes.

Acknowledgments

The authors wish to thank the crews and scientific staffs of the SWSS 2002 and 2003 cruises. Funding for this work was provided by the Office of Naval Research, the U.S. Department of the Interior Minerals Management Service Cooperative Agreements numbers 1435-01-02-CA-85186 and NA87RJ0445 and the Industry Research Funders Coalition.

References

Fisher, R.A. 1948. Combining independent tests of significance. American Statistician 2:30.

Jochens, A.E. and D.C. Biggs. 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. 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.

Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguilar de Soto, J. Lynch, and P.L. Tyack. 2006. Quantitative measures of air gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. Journal of the Acoustical Society of America 120(4): 2366–2379.

Miller, P.J.O., M.P. Johnson, P.L. Tyack. 2004. Sperm whale behaviour indicates the use of rapid echolocation click buzzes 'creaks' in prey capture. Proceedings of the Royal Society B 271:2239–2247.

Stacy DeRuiter is a graduate student in the MIT-Woods Hole Oceanographic Institution Joint Program, working with Peter Tyack. Her research interests include toothed-whale foraging behavior and development of analysis techniques for behavioral data.

SPERM WHALES IN THE GULF OF MEXICO: WHAT WE HAVE LEARNED

Bernd Würsig, Texas A&M University at Galveston

Jonathan Gordon, Ecologic and University of St. Andrews

Click here to view the slide show that accompanied this presentation.

Introduction: Progression of Studies

Progression of studies of sperm whales in the Gulf of Mexico (GOM) might best be divided into three major phases: the 1970s and 1980s, when general nearshore and offshore studies first began to describe occurrence patterns of marine mammals; the 1990s GulfCet studies that coupled visual with acoustic censuses of marine mammals, incorporated oceanographic data for habitat descriptions, and began photographic identification of sperm whales; and the post-GulfCet studies specifically targeting data on sperm whales, as SWSS and related work. This latter work was the focus of the recent ITM special session on sperm whale-related physical and biological oceanography, behavior, habitat use patterns, and ecology.

Physical and Biological Components of the Environment

During the GulfCet studies, it began to be appreciated that sperm whales are responsive to warm core/cold core eddy systems that change primary and therefore higher trophic level productivity. SWSS work has been able to verify this, with the logical indication that there is a lag time of several weeks or more between enhanced primary productivity and the apparent aggregation of food that increases sperm whale occurrence in a particular area. Furthermore, sperm whales of the north-central Gulf may be quite responsive to Mississippi River discharge patterns, with whale abundance much lower in 2005 than in 2004, correlated with decreased river outflow in 2005.

Acoustic backscatter results have mapped the deep scattering layer (DSL) in detail, and show backscatter returns deeper than the main DSL as well. From SWSS data, it is presently hypothesized that these returns are indicators of squid, fish, or crustacean prey of squid, living below the daytime depth of the DSL. Dive data obtained from both D-tag information and satellite tagged (S-tag) whales indicate that whales do not greatly change dive behavior based on time of day, and dive above, through, and below the DSL both day and night. While detailed D-tag data have revolutionized aspects of fine-scale underwater dive behavior, correlations between dives and on what sperm whales are feeding are still incomplete.

Attributes of Individual Whales and Population Composition

Pre-SWSS, it was believed that most sperm whales of the northern GOM appear to be smaller (perhaps young) animals, as estimated by eye by experienced naturalists. During SWSS and related studies, extensive photography and photogrammetry, or size measurements by calibrated photography, showed unequivocally that sperm whales of the GOM are indeed smaller than those measured in similar populations elsewhere. At this point, it is not known what to make of the data, as the size difference could be mediated by population-level genetic differences, prey differences, environmental stressors, or a combination of these.

Pre-SWSS, vessel and aerial surveys provided information for large management areas, such as the entire northern GOM. The SWSS and related studies have provided more detailed assessments for different components of the sperm whale population, and these details are especially relevant to burgeoning offshore industrial activities.

Photo-recognition information has shown from mark-recapture methodology that the population in the northern GOM may be approximately 281, with 95% confidence intervals of 202–434. The "core population" of number of animals present at any one time is closer to 140 (95% CI = 103–200), with an estimated 88 reproductive females in that core, and an expected annual calf production of about 15–20. Repeated identifications of some whales since 1994 are indicative of long-term residence. There are indications of preferred locations for individuals between years within the core range, and the social organization is overall quite dynamic, with some long-term companions but also many incidences of casual acquaintances.

Analysis of a building data set of acoustic recordings indicates a single acoustic clan within the core range of the northern GOM, and that this clan is distinct from that of the Caribbean and North Atlantic. It is possible that a different acoustic clan exists at the western end of the Gulf, but this assertion needs to be further investigated with analyses of existing acoustic recordings and more data to be gathered.

Photo-identification, acoustic clan, satellite tag, and genetic data integration promises to provide for a more complete description of sociality in GOM sperm whales. Especially acoustic clan descriptions may give insight into cultural (or learning passed on through generations) presence and relationships of sperm whales in and outside of the GOM.

Before SWSS, virtually nothing was known about patterns of movements, beyond the suggestion of at least some residency from a handful of repeat photo-identifications. Now, after SWSS, we have a substantial and coherent information base from satellite tags and photo-identifications, making the northern GOM sperm whales perhaps the best-studied sperm whale population from the movement perspective.

While there are many intra- and inter-year details of movement, we now know that there are no discernable seasonal migrations. However, there is basin-wide movement of whales along the slope of the northern GOM, site-specific tenacity by many individuals, and larger home ranges and use of deeper water habitats by males than by females. Slope-oriented animals may constitute a separate stock from offshore animals, and more work is needed on this point.

Sperm Whale Responses to Industrial Seismic

Pre-SWSS, there were anecdotal observations of sperm whales within range of loud seismic, as well as for the possibility of some avoidance or behavioral change in relation to seismic. Post-SWSS, we have a more detailed but still very incomplete picture, from digital tags, satellite tags, non-experimental observations, and overall distribution. It is still not clear to what extent sperm whales are "disturbed" by seismic activities, and there is probably much variance by past exposure and present exposure intensity. The record of industrial seismic lines and present co-occurrence of satellite tag locations indicates that the overall occurrence patterns of industrial seismic and whales overlap strongly, but details of potential effects, again, are unknown.

Some Management-Related Data Weaknesses or Unknowns

While much has been learned about sperm whales and their habitats in the GOM, especially in the past 5–6 years, it is not surprising that there are data weaknesses. Sperm whales are long-lived, slowly reproducing animals using large amounts of space, and such creatures need longer-term study for best understanding. Thus, for example, we still know very little about breeding system or season, calf productivity, and calf and overall mortality. We do not know the meaning of the small size of members of this population, and we need to consider all potential factors of genetics, food, and anthropogenic activity relative to this remarkable difference from other populations.

On the movement/occurrence level, we do not know how the core shelf edge whales interact with the more offshore potentially different population, nor with animals of other parts of the GOM. Although we have correlations of occurrence patterns with aspects of both physical and biological oceanographic patterns, we do not truly understand intra- and inter-year changes. The year 2005 was anomalous in sperm whale occurrence and numbers in the northern GOM, and unfortunately we have no data for 2006. We believe it to be very important that we obtain follow-up information to this last-recorded "poor year" as quickly as possible, to establish whether a pre-2005 situation has taken place, and to re-identify previously known animals before too many change fluke markings with time and are not as easily recognized.

Finally, we still have only a rudimentary understanding of potentially short- or long-term reactions to, and therefore effects of, industrial seismic and other anthropogenic activities. We can pat ourselves on our collective backs for jobs well done, but the overall job is not finished.

Bernd Würsig is a professor of marine biology at Texas A&M University at Galveston. His research focuses mainly on social strategies of dolphins and whales. He has carried out work on bowhead and gray whales in the arctic and on several species of dolphins. He was PI of the behavioral part of the 1990s GulfCet studies on Gulf of Mexico cetaceans and co-published the book *The Marine Mammals of the Gulf of Mexico*, Texas A&M University Press.

SWSS PANEL DISCUSSION: RECOMMENDATIONS FOR FUTURE STUDIES AND AUDIENCE QUESTIONS

***Moderator*: A. Jochens, TAMU**

***Panel*: K. Benoit-Bird, OSU; D. Biggs, TAMU;
J. Gordon, University of St. Andrews; B. Mate, OSU;
J. Ortega, OSU; C. Richter, Queen's University;
A. Thode, SIO; P. Tyack, WHOI**

Click here to view the slide show that accompanied this presentation.

The SWSS special session at the 24th ITM closed with a panel discussion of audience questions. To start the discussion, Jochens reminded the audience that, in addition to preparing the SWSS Synthesis Report, the SWSS science team is working on developing a set of recommendations based on the results of the SWSS study. Jochens briefly outlined a few areas that are under consideration; these are summarized below. The panel then took questions from the audience in a session that lasted over an hour.

SWSS has greatly advanced our knowledge of the sperm whale population in the northern Gulf of Mexico, as the diversity of papers from this and the 23rd MMS ITM SWSS sessions shows. Nonetheless, there are a number of areas for which recommendations can be made for further study. These focus on knowledge gaps in basic population information, enhancements to behavioral response studies, and improvements in equipment and methods for studying sperm whale populations to allow improved management and understanding of the biological significance of human activities.

Many gaps in basic population information remain. Our knowledge of sperm whale distributions through the entire Gulf is deficient because the SWSS study area was focused mainly along the 1000-m isobath in the region between the Mississippi Canyon and De Soto Canyon, while the sperm whale population is found from the Dry Tortugas off south Florida into the Bay of Campeche of Mexico, as well as out into the deepest waters of the Gulf. Further, the shipboard research was almost entirely confined to the summer months. There also is a need to better understand and quantify the natural variability of the population. Important basic biological information that is essential for understanding population dynamics include the population size, calving rates and mortality, breeding and calving seasonality and behavior, feeding/foraging success, and the trophic cascade of the sperm whale food web in the Gulf of Mexico. Very little quantitative information is available about the prey of the Gulf of Mexico sperm whales.

The behavioral studies of SWSS considerably advanced our knowledge of the response of the sperm whale population to activities of the seismic survey industry. Nevertheless, additional work remains to achieve the goal of a comprehensive understanding of the behavioral response of sperm whales to anthropogenic noises in the Gulf of Mexico. This work includes additional controlled exposure experiments and other behavioral response studies to increase the sample size available for analysis and to study responses at higher sound levels than were achieved in SWSS. It also includes consideration of populations that have not yet been exposed to certain anthropogenic noises, such as from seismic source airguns. It is an open question whether the population off the Mississippi River Delta is habituated to human activity in ways that may have impacted the SWSS results.

A final area for possible recommendations is improved technology and methods. Improvements to digitally recorded and satellite tracked tag types will enable more information to be collected at less cost. Development of methods to use opportunistic behavioral response data sets can augment the controlled tests. Enhancements to passive acoustic monitoring instrumentation, both shipboard and moored, hold promise for substantial data collection opportunities. Finally, carefully planned "traditional" surveys using motor-assisted sailing vessels to count and photograph sperm whales in the years to come may provide cost-effective ways to monitor populations over extended time periods.

Dr. Ann E. Jochens is a Research Scientist in the Department of Oceanography at Texas A&M University. She came to physical oceanography as a mathematician and attorney with extensive experience in environmental, safety, and permitting in the oil and gas and minerals industries. She received the J.D., with a background specialty in Ocean Law, from the University of Oregon (1977) and the M.S. and Ph.D. in Oceanography from Texas A&M University (1989 and 1997, respectively). For over 15 years, Dr. Jochens has been a Principal Investigator on studies of the circulation and water properties over the Texas, Louisiana, Mississippi, Alabama, and Florida shelves and in the deep waters of the Gulf of Mexico. On each of these studies, she also served as Program Manager or Deputy Program Manager. Presently, Dr. Jochens is the Principal Investigator and Program Manager for a multi-disciplinary, multi-institutional study of Gulf of Mexico sperm whales, their habitat, and their response to anthropogenic noise. She also is the Regional Coordinator for the Gulf of Mexico Coastal Ocean Observing System Regional Association. Dr. Jochens has participated in over 10 oceanographic expeditions, has over 60 publications, reports, and abstracts, and has served on 11 graduate student committees. Her research interests are processes at the boundary of coastal and open oceans; Gulf of Mexico physical oceanography; meso- and large-scale ocean circulation and property distributions, with emphasis on shelf and slope regions; ocean law and policy; and research planning and management.

SESSION 3F

CHEMO III

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

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

INVESTIGATIONS OF CHEMOSYNTHETIC COMMUNITIES ON THE LOWER CONTINENTAL SLOPE OF THE GULF OF MEXICO – AN OVERVIEW

James M. Brooks, TDI-Brooks International, Inc.

Click here to view the slide show that accompanied this presentation.

As the introduction to this session, a summary of activities to date for the MMS funded program "Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico" was presented. Future activities, schedules and goals were also discussed.

ITM Presentation Outline

- Dr. Harry H. Roberts – site selection and geology of key Chemo III sites
- Dr. Ian R. MacDonald – reconnaissance methods for a regional inventory of seep chemosynthetic communities
- Dr. Samantha B. Joye – patterns of microbial activity and distribution in sediments of the deep slope, northern Gulf of Mexico
- Dr. Erik C. Cordes – preliminary investigations of the hard-ground communities below 1000 meters in the northern Gulf of Mexico
- Dr. Robert S. Carney – trophic relations and interactions with background fauna

Objectives of Program

- Characterize known or newly discovered chemosynthetic communities below 1000 meters
- Characterize other hard bottom biological communities encountered regardless of association with active seepage and living chemosynthetic communities
- Determine the comparative degree of sensitivity of anthropogenic impacts as well as similarity/differences with their shallower water counterparts
- Develop successful assessment methodologies to develop predictive capability that can be used by MMS to avoid impacts to lower slope sensitive biological communities
- Contribute to assessing and explaining diversity distribution and abundance at depths below 1000 meters and understanding functional role of marine species in areas of active seepage

Principal Investigators

- Dr. James Brooks, TDI-Brooks, Program Manager
- Dr. Charles Fisher, Penn State, Biology Group Leader
- Dr. Harry Roberts, LSU, Geology/Geophysics Group Leader

- Dr. Robert Carney, LSU, Deep-Sea Ecology
- Dr. Ian MacDonald, TAMU-CC, Imaging and Remote Sensing
- Dr. Samantha Joye, University of Georgia, Microbiology and Geochem
- Dr. Erik Cordes, Harvard, Hardbottom and Ecology
- Ms. Liz Goehring, Penn State, Education Outreach
- Dr. Gary Wolff, TDI-Brooks, Data Management
- Dr. Bernie Bernard, TDI-Brooks, Business Management and HC Geochem
- Dr. Stephane Hourdez, France, Polychaete Group Leader

Scientific Review Group (Task I)

- Dr. James P. Barry, Monterey Bay Aquarium Research Institute
- Dr. William R. Schroeder, University of Alabama
- Dr. Daniel L. Orange, AOA Geophysics and UC-Santa Cruz

MMS Chemo I AND II Programs

A brief history of the first two chemosynthetic programs was presented. Chemo I and II MMS projects were directed toward earlier reconnaissance and process studies using the Johnson Sea-Link and NR-1 submersibles and were thus restricted to study of communities in water depths < 1000-meters.

Field Plan

- Heavy field concentration in first year
- First six months (September to February): Review historical (cores, SAR, AUV and 3-D seismic) and industrial data to select 20–40 sites (Dr. Roberts et al.)

Historical Review – Cores/Seismic

- The historical review consists of cores, SAR, AUV and 3-D seismic and industrial data to select 20–40 sites (Dr. Roberts et al.)

Reconnaissance (Site Confirmation) Cruise – Goals

- Determine new sites for ALVIN
- Characterize a larger number of sites for predicative capability
- Collect box cores and trawls for seep-background studies
- Site confirmation cruise – May 2006
- Survey 20+ sites from review of historical data

Reconnaissance Cruise – Summary

March survey period all objectives were accomplished including the following:

- Photoreconnaissance of 24 sites

- USBL tracking and positioning of photo sled over target sites worked well
- Collection of 10,922 photos
- Many observations in the photographs of brine, bacteria, mussels (131), tube worms (135), and coral
- Cruise was successfully in high grading sites for ALVIN dives in May
- Trawls collected at three sites and box cores obtained for isotopic analysis of faunal contents

2006 DSRV Alvin/Atlantis Cruise

Goal

- Discover and characterize the seafloor communities that live associated with HC seepage and on hard ground in the deep GOM. 23 dives

Activities

- Photography – videos and stills
- Push cores
- Animal collections using various tools
- Growth studies

2007 ROV Cruise R/V Ron Brown – Second Field Year

- 2007 ROV cruise (JASON-II) – 33 days
- Mobilization – 6 May, Ft. Lauderdale, Florida
- Demobilization – 9 July, St. Petersburg, Florida
- Additional – four AUV quarter block surveys

Meeting Schedule for Project

Post Award Meeting

- Fall 2005 – review remaining technical & management issues
- SRG attendance
- Summary of discussion and mutual decision due two weeks later

Interim Program Review – Jason planning session

- ~18 months after award – January 2007
- MMS Office – Key Personnel/Co-PIs/SRG
- Review ALVIN results and Jason plans for Year II summary of results distributed

Information Transfer Meetings (2007 and 2009)

Data Interpretation, Synthesis & Reporting (Task 6)

Two Narrative Interim (Draft, Final & Proof) Reports

- Draft due six months after each year's field work (February 2007 and 2008)
- Purpose – dissemination of results of field and initial findings

Final Report (Draft, Final & Proof) – 45 Months into Project

- Assessment of data collection
- Description of methods and analysis
- Interpretation, results and discussion
- Synthesis of findings

Technical Summary

- Concurrent with submission of the Final Report

Publications (2 publications minimum expected)

- Primary goal of PIs and Co-PIs
- Requires MMS review and approval

Recent Nigerian Chemo Discoveries

- Two sites – 1600 and 2200 m water depths
- 200 miles apart
- Box core sampling only

Recent Indian Chemo Discoveries – Bay of Bengal

Dr. Charles Fisher and colleagues observations

- Tube worms – new species related to ones off Papua, New Guinea
- Mussels – new species related to *B. childressi*; may be two species in collection
- Clams – two species of vesicomyid clams

Dr. James Brooks is President and CEO of TDI-Brooks International Inc., the primary contractor for the MMS program "Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico." He has been conducting research and oil industry-sponsored service projects in the Gulf of Mexico for the last thirty years. As part of his surface geochemical exploration (SGE) studies, which he developed for industry in the early 1980s, he has collected approximately 9000 cores in the Gulf, mostly in deep water. These SGE coring studies resulted and contributed to the discoveries of macro oil seepage, chemosynthetic communities, and gas hydrates in the Gulf of Mexico. He was a co-discoverer of oil seep and chemosynthetic communities in the deep water Gulf of Mexico in 1985. He made the first discoveries of thermogenic gas hydrates in the deep water Gulf of Mexico, published in *Science*, and participated in the initial discoveries of other oil-seep related phenomena, including oil-stained cores on the continental slope, widespread occurrence of shallow and outcropping gas hydrates, brine seepage, and visible oil seepage to the sea surface. His current SGE coring and satellite seep studies in the southern Gulf for PEMEX resulted in the recent publication in *Science* concerning the discovery of tar flows and chemosynthetic communities in the Campeche Knoll region offshore Mexico. Dr. Brooks also made the first discovery of chemosynthetic ecosystems in West Africa (Nigeria) north of the equator. He has over 210 peer-reviewed publications.

SITE SELECTION AND GEOLOGY OF KEY CHEMO III SAMPLE SITES

Harry H. Roberts, Coastal Studies Institute, Louisiana State University

Jesse Hunt, Jr., and W. W. Shedd,
Office of Resource Evaluation, Minerals Management Service

Click here to view the slide show that accompanied this presentation.

The northern Gulf of Mexico continental slope is well known for hydrocarbon seeps and fluid-gas expulsion geology. Early studies of the northern Gulf of Mexico continental slope demonstrated widespread seepage with associated chemosynthetic communities as well as gas-charged sediments, authigenic carbonates, and mud volcanoes. Since the 1984 discovery of chemosynthetic communities in the Gulf, studies have been concentrated mostly on the upper continental slope in water depths < 1000 m, the maximum depth of most available manned submersibles. The Gulf's chemosynthetic communities are the most intensively studied and best understood of any cold seep communities in today's ocean. Community structure, basic biology, and life histories of the dominant animals and biogeographic variations are now known. However, prior to the summer of 2006, only a few hydrocarbon seep sites had been visited and sampled on the middle and lower continental slope. Differences in geologic setting and species composition below water depths of 1000 m pose important scientific questions concerning cross-slope and along-slope biologic variability and possible controlling factors. Advancing our understanding of middle-to-deep slope hydrocarbon seep-vent environments and their biologic communities is the overall goal of the project reported here.

Between 7 May and 2 June, an international team of researchers (biologists, geochemists, and marine geologists) studied ten seep sites on the middle-to-lower continental slope using ALVIN. The dive sites ranged in water depth from 1070 m to 2775 m and were located from the eastern Gulf (N 27°38.8'; W 88°21.7') to the far western Gulf (N26°11.0'; W 94°37.4'), Figure 3F.1.

Success in finding chemosynthetic communities and deep coral sites can be attributed to a two-stage data collection program initiated prior to the ALVIN dives. In October 2005 project personnel in conjunction with MMS geoscientists reviewed extensive volumes of 3-D-seismic data using surface reflectivity, both strength, phase, and pattern of the surface reflector. In addition, fluid-gas migration pathways from the deep surface were identified in seismic profiles. The entire continental slope of the northern Gulf from DeSoto Canyon on the east to the Texas shelf to the west is covered with 3-D-seismic data, some areas with multiple generations of overlapping data. These data sets are housed at MMS and used for source evaluation critical to the leasing process for oil and gas exploration and production. Because MMS is a sponsor of this project, these proprietary data were made available for site selection. By January 2006, eighty sites of potential chemosynthetic community occurrence were selected to address both potential

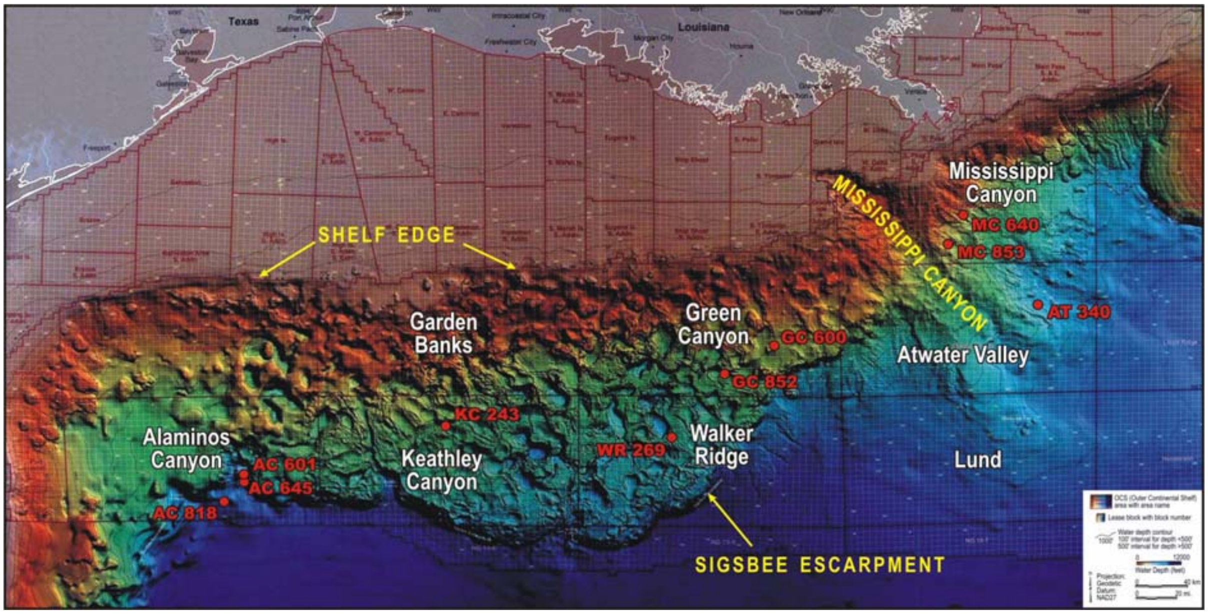


Figure 3F.1. This multibeam bathymetry image of the continental has been computer enhanced to apply 3-D relief shading. The ten hydrocarbon seepage sites visited by ALVIN in 2006 are superimposed on the slope map, which also shows major oil and gas leasing areas.

depth dependent and geographic-dependent variations in the fauna. These sites were further prioritized to twenty candidates by March 2006. Nineteen of the sites were imaged during 11–25 March 2006 with a drift camera system comprising a digital camera, CTD, and USBL navigation pinger. Based on both characteristics of the geophysical data and bottom photography, ten locations were selected as ALVIN dive sites for the May-June cruise. Consistent with project objectives, the final dive plan represented sites from a wide range of water depth and geographic locations.

The RV Atlantis II with ALVIN and a full complement of researchers, left Key West, Florida on the morning of 1 May for a 26-day cruise across the Gulf, arriving in Galveston on 2 June. At each of the ten dive sites, surface reflectivity maps and photographs taken during the drift camera cruise were used for dive planning. As a product of our dive site prioritization process, all sites had chemosynthetic communities. A minimum of dive time was spent traveling over featureless mud bottom.

This year's ALVIN cruise was the initial installment of a four-year study funded by NOAA's Ocean Exploration Program and Minerals Management Services (MMS). Twenty-four ALVIN dives were made at the ten different sites. Chemosynthetic communities were found at all sites. However, Atwater Valley Lease Area, Block 340 [(AT 340) N 27° 38.8'; W 88° 21.9'], Green Canyon Lease Area, Block 852 [(GC 852) N 27° 06.3'; W 91° 09.9'], Alaminos Canyon Lease Area, Block 601 [(AC 601) N 26° 23.5'; W 94° 30.9'], and Alaminos Canyon Lease Area, Block 818 [(AC 818) N 26° 10.7'; W 94° 37.3'] were the key sampling sites. These sites generally had the most flourishing and diverse communities as well as the most interesting sea floor geology. Multiple dives focused intense biological and geological/geochemical sampling at these sites.

Sampling opportunities for building a better understanding of the biology, geochemistry, and geology of deep slope hydrocarbon seep habitats were provided by our four key sampling locations (AT 340, GC 852, AC 601, and AC 818). The AT 340 and GC 852 sites were well-defined bathymetric highs supported by salt in the shallow subsurface. Both these sites were characterized by abundant authigenic carbonate blocks and pavements. Interspersed with these carbonates were well-developed and diverse chemosynthetic communities. In addition, the GC 852 site had both hard and soft corals seated on hard substrates composed of large blocks of authigenic carbonate. Characteristic of most thriving coral environments, currents were strong. Estimates of current speed made by ALVIN were in excess of 1 knot (> 50 cm/s).

The AC 601 site is geologically different from AT 340 and GC 825. Instead of the mound and ridge-like topography associated with those sites, AC 601 represents a breached anticlinal structure in the compressional regime of the lower slope. There is variable relief associated with AC 601 site. In the northwest part of the lease block a bathymetric low was found that was filled with brine (~90 ‰ salinity). This brine lake was ~4 m deep and ~180 m in diameter. A white precipitation floating in the brine and on the lake floor was found to be composed of barite. Dead organisms, including fish, were observed in the lake. Mussels, urchins, and holothurians were present on the "shore" around the lake. In contrast, the AC 818 site represents local leakage along a well-defined regional fault. Reducing sediment, clam beds, mussel beds, tube worms, and authigenic carbonates are localized along the fault. However, these communities, even though moderately complex, are rather limited in a real extent.

For ten years, Harry H. Roberts was 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.

CHEMO III PROGRAM: RECONNAISSANCE METHODS FOR A REGIONAL INVENTORY OF SEEP CHEMOSYNTHETIC COMMUNITIES

Ian R. MacDonald, Texas A&M University

Click here to view the slide show that accompanied this presentation.

The Continental Slope of the northern Gulf of Mexico hosts diverse chemosynthetic communities at oil and gas seeps. The CHEMO III program will extend knowledge of the Gulf of Mexico chemosynthetic ecosystem in the zones anticipated to receive energy exploration and production activities over the coming decades. A nested survey approach was developed to identify representative sampling sites within this vast offshore area. Potential sites where chemosynthetic community might occur were selected on the basis geophysical, geochemical, and satellite remote-sensing indicators. Harry Roberts and his colleagues reviewed the geophysical data archived by MMS to identify potential sites where communities might occur. A list of twenty high-priority targets was compiled from this review. Nineteen of these locations were surveyed during a reconnaissance cruise conducted on R/V GYRE from 11 to 25 March 2006 (Figure 3F.2). At each site, the seafloor was imaged using a drift camera system comprising a digital camera, CTD, and USBL navigation pinger (Figure 3F.3). Several previously unknown communities were discovered by this process and were targeted for follow-up sampling with submarine ALVIN. The ALVIN cruise was completed on R/V ATLANTIS during 6 May through 3 June 2006. Extensive collections were made at sites discovered during the reconnaissance cruise and at sites known from previous investigations.

The GYRE and ATLANTIS cruises produced approximately 15,000 geo-positioned images. A preliminary analysis of these data has been completed to identify substrates and faunal groups. Ongoing work will quantify density and diversity of chemosynthetic and associated species for comparison among study sites.

The CHEMO III program acquired over 60 RADARSAT SAR images from the northern Gulf of Mexico in cooperation with the Alaska Satellite Facility. The ship RV ATLANTIS was at sea during the acquisition and collected synoptic weather and oceanographic data. Texture recognition with use of a library of textons applied iteratively to the images was used to automate interpretation of the large image dataset. This treatment shows promise in distinguishing floating oil from false targets generated by rain fronts and other phenomena. One goal of the analysis is to delineate bounding boxes to quantify the ocean area covered by the thin oil layer. These data can be used to estimate the magnitude of discharge and the flow rates. A second goal is distinguish the ends of the slicks proximal to the seafloor sources. These results can be used to eventually to census the number of active seeps in the entire Gulf of Mexico basin. Finally, successful automation to map active seep locations and delineate slicks lays the foundation for a satellite-based monitoring system to detect oil pollution events throughout the Gulf.

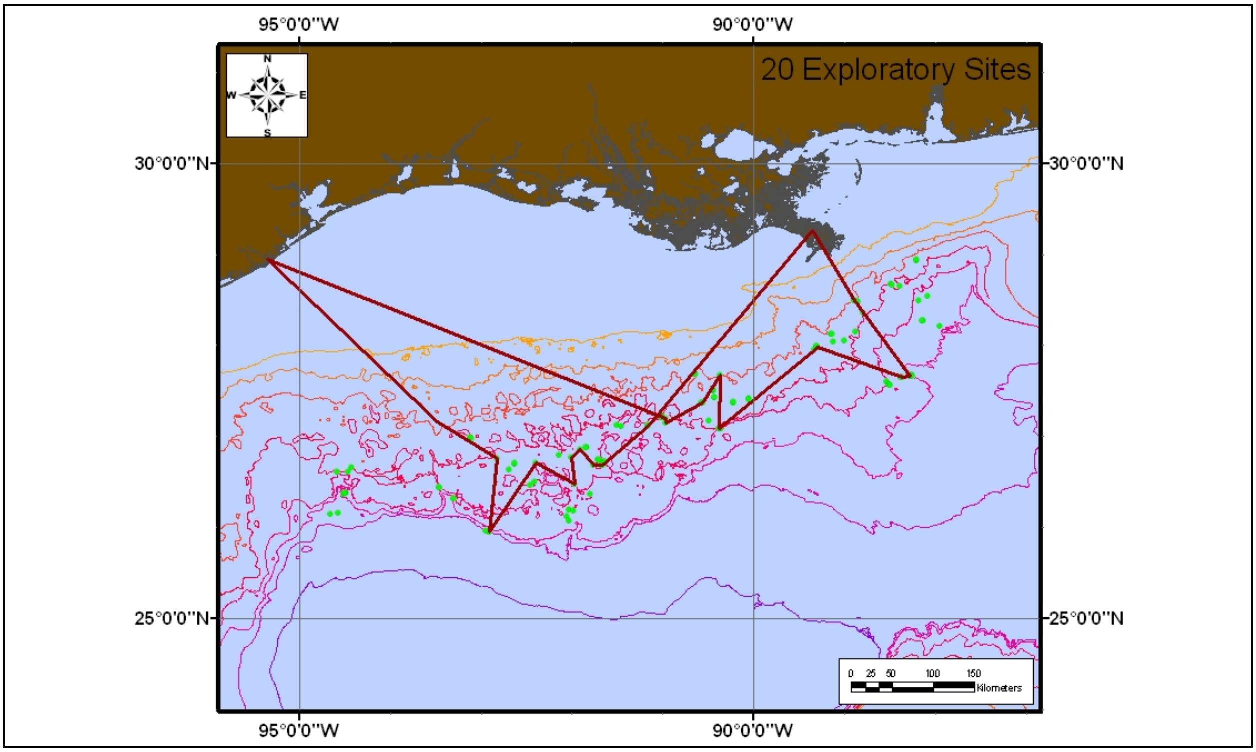


Figure 3F.2. The cruise track of RV GYRE (red line) visited 19 of the potential 180 sites identified in a review of geophysical data (green dots).

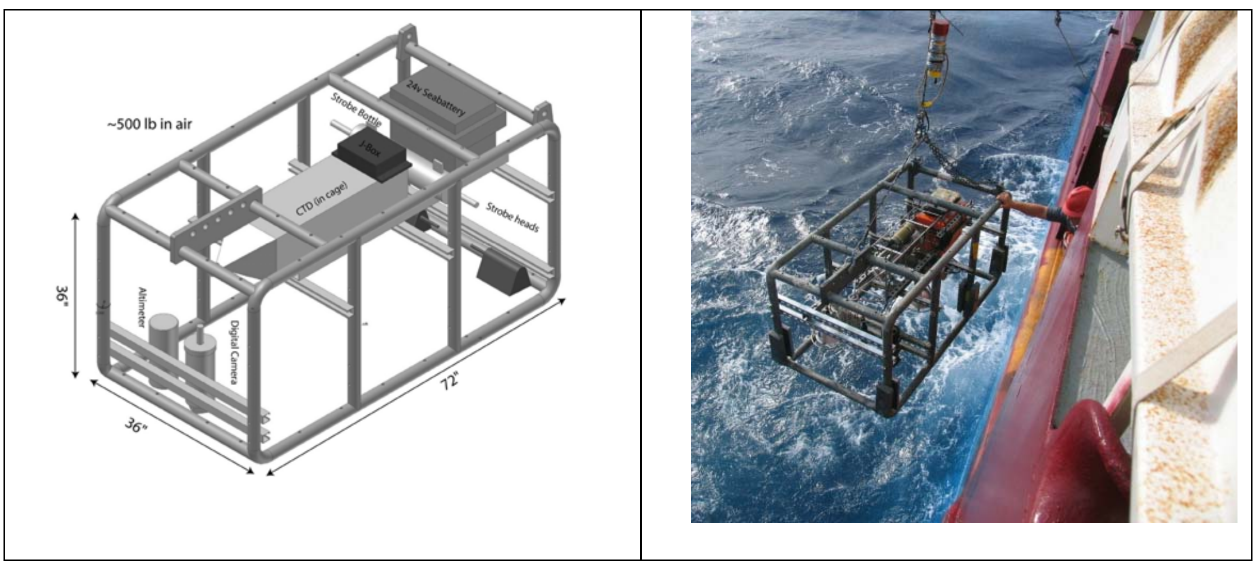


Figure 3F.3. The left panel shows a rendering of the drift camera system with components labeled. The drift camera is lowered with a 3-pt bridle and communicates to the surface. through a conducting cable. The right panel shows the DCS being deployed from GYRE during the survey cruise. The USBL navigation pinger can be seen attached to the sea cable above the bridle (arrow).

Ian R. MacDonald, Ph.D., is Professor of Environmental Science at Texas A&M University-Corpus Christi. Dr. MacDonald is an internationally recognized expert on the ecology and geology of natural marine hydrocarbon seeps and chemosynthetic communities. 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.

COLD SEEPS FROM THE DEEP CONTINENTAL SLOPE, GULF OF MEXICO AND A COMPARISON OF MICROBIAL ACTIVITY BETWEEN SHALLOW AND DEEP WATER HABITATS

S. B. Joye, M. W. Bowles, B. N. Orcutt , V. A. Samarkin,
Department of Marine Sciences, University of Georgia

J. M. Brooks, B. B. Bernard, TDI Brooks International

H. H. Roberts, Department of Oceanography and Coastal Sciences,
Louisiana State University

Click here to view the slide show that accompanied this presentation.

We examined sediment and brine fluid samples from brine, oil and gas seeps located along the deep continental slope between water depths of 1200m and 3300m in the Gulf of Mexico. Brine and oil stained sediments were abundant at all sites, as were dense chemosynthetic communities. While dense surface layers (mats) of sulfur oxidizing bacteria of the genus Beggiatoa and Thiomargarita are common at shallow slope seeps (water depth < 1000m), such mats were found at only the two most shallow deep slope sites. Depth integrated rates of sulfate reduction (SR), anaerobic oxidation of methane (AOM) and methanogenesis (MOG) in deep slope sediments were highest at brine-dominated cold seeps.

The highest rates of SR were observed at a brine lake located beneath 2300 m of water. The highest rates of AOM were associated with sediments from pogonophoran meadows. Rates of MOG were generally much lower than AOM rates and exhibited substantial variability between sites. Rates of SR were much lower in deep slope sediments than in shallow slope sediments, suggesting that the flux of reduced substrates fueling microbial activity is greater at shallow sites. Rates of AOM showed less variability between shallow and deep sites and methane concentrations were similar in cores from both locations, suggesting that pore water methane concentrations regulate AOM rates.

Samantha Joye received her Ph.D. in marine sciences, specializing in microbial biogeochemistry, from the University of North Carolina in Chapel Hill. She is presently a professor in the Department of Marine Sciences at the University of Georgia. Dr. Joye's research examines the microbiology and biogeochemistry of carbon and sulfur cycling in extreme environments, including sea floor oil, gas and brine seeps in the Gulf of Mexico and saline lakes in the Western U.S. as well as in the Dry Valleys of the Antarctic continent.

PRELIMINARY INVESTIGATIONS OF THE HARD-GROUND COMMUNITIES BELOW 1000 M IN THE NORTHERN GULF OF MEXICO

Erik E. Cordes, Erin L. Becker, Stephanie Lessard-Pilon, Stephane Hourdez, and Charles R. Fisher, Pennsylvania State University

Click here to view the slide show that accompanied this presentation.

As part of the joint Minerals Management Service and NOAA Office of Ocean Exploration study of the hard-grounds below 1000 m in the Gulf of Mexico, this portion of the study focused on the characterization of communities associated with tubeworms, mussels, and corals. These species form biogenic habitat that supports a variety of fauna at these sites. The goals of this portion of the study were to determine the bathymetric and biogeographic patterns in community structure, document sites of rare or unique species composition, and examine hypotheses derived from previous investigations of succession in upper slope seep communities. Specifically, the goals included: 1) a more precise determination of the depth of the shift in community structure known to occur somewhere between 800 and 1800 m; 2) the examination of the applicability of trends seen in the background communities to hard-grounds including declines in abundance and biomass with depth and a diversity maximum at mid-slope depths, and 3) a test of the upper slope succession model. This model describes a progression from mussel beds harboring a low diversity but high biomass community to young tubeworm aggregations with lower biomass but higher diversity as background species begin to colonize the seeps, to old tubeworm aggregations with a low biomass, low diversity community composed mainly of background species. There is also a general trend towards heavier stable isotope values in the associated community over time indicating a decline in relative importance of seep productivity.

Communities were sampled photographically for the construction of quantitative mosaics, and physically sampled using a variety of collection devices. Mosaics are still under construction at the time of this meeting (January 2007) and therefore will not be presented in any detail here. Quantitative physical samples were obtained using the Bushmaster collection device for tubeworm-associated communities, mussel pots for mussel-associated communities. Non-quantitative samples of a variety of habitats were collected with nets, push-cores, grabs of fauna or rock samples with the manipulator arm, and suction samples of mobile fauna. These samples were analyzed for the presence of taxa at sites and relative abundance, but the potential biases of these various devices (including escape of mobile fauna and under sampling of small fauna) precluded the use of quantitative analyses. Samples from the bushmaster and mussel pots were placed in containers upon retrieval of the submersible and the fauna retained on a 1 mm sieve were included in the community analyses. Subsamples for examination of fauna below 1 mm (meiofauna) were retained by collaborators. All tubeworms and mussels were measured and subsamples taken for genetic and stable isotope investigations. Macrofauna were sorted into morphospecies on board ship, or were preserved in higher taxonomic groups if identification was impractical (primarily small polychaete species). All macrofauna that could be reliably sorted into morphospecies on board ship were also sampled for isotopic and genetic analyses.

A total of 95 species were sampled in the 70 collections obtained on the first submersible cruise in May 2006. These species included at least six species of vestimentiferan tubeworms, bathymodiolin mussels, and vesicomyid clams. The tubeworms were *Escarpia laminata* (1410–3290 m), and a new species of *Lamellibrachia* (1175–2320 m). In addition, preliminary genetic analyses suggest that there may be a second species of *Lamellibrachia* present in the collections. The mussels collected include *Bathymodiolus brooksi* (1080–3290 m) which was found throughout the sampling range, *B. childressi* (525–2220 m), and *B. heckerae* (2180–3290 m). *B. childressi* was more common than *B. heckerae* in these collections, and these two species (both of which contain methanotrophic symbionts) were not observed to co-occur. A species of *Calyptogena*, now identified as *Calyptogena ponderosa* according to its mitochondrial COI sequence, was present in collections as deep as 2750 m, extending its known bathymetric range.

Overall, communities that were sampled from similar depths were the most similar. There were a few species known from the upper slope present in samples from MC 853 (1080 m) and GC 600 (1175 m) and rarely found in collections as deep as 2750 m, but these species never dominated the communities sampled. In these collections, the lower slope species *Alvinocaris muricola*, *Munidopsis* sp., and *Ophioctenella acies* were the most abundant. Previously reported bathymetric trends in background Gulf communities were not apparent in these collections when compared to similar collections from the upper slope of the northern Gulf. Density and biomass of fauna in the lower slope collections were within the range of those reported from the upper slope seeps, and a mid-slope diversity maximum was not apparent in these samples. This is likely due to the more significant influence of seep productivity and successional trends in determining these characteristics in the communities at hydrocarbon seeps.

In the quantitative samples collected, tubeworm aggregations and mussel beds hosted different associated communities. Although both communities were dominated in terms of biomass by *Alvinocaris muricola*, mussel beds contained higher abundances of *Ophioctenella acies*, and tubeworms contained high abundances of two species of capitellid polychaetes, *Heteromystides* sp. and *Protomystides* sp. *Heteromystides* sp. was found occupying and occasionally filling the tubes of dead tubeworms. *Protomystides* sp. was found forming small "caps" on the tops of *E. laminata* and occasionally *Lamellibrachia* sp. and their coelomic cavities were filled with blood, presumably from the tubeworms. Further investigations into the relationships of these two species to the tubeworms are underway.

Some successional trends were detected in the communities associated with both tubeworms and mussels. Comparisons between mussel bed samples indicated that community similarity was most closely related to the distance between collections and the average size of *B. brooksi* in the samples. In tubeworm aggregations, similar communities were found in collections from similar depths, although average size of *E. laminata* within an aggregation was also correlated to community similarity. These results suggest that within a given site community structure changes as tubeworms and mussels grow over time, providing a preliminary evidence for the successional progression of communities. However, additional replication within site is required to test this hypothesis.

Other seep-related communities sampled in this study include small "fields" of pogonophorans at Walker Ridge (WR269, 1950m) and urchin beds in Atwater Valley (AT340, 2220 m). The pogonophoran fields were inhabited by the holothurian *Chirodota heheva* as well as a small amphipod and a small gastropod normally found at the ends of the pogonophoran tubes. The urchins appeared to be plowing through surface bacterial mats, exposing dark seep sediments below. Photomosaics were obtained over the pogonophoran field and push cores were sampled within both habitats, though the analysis of these data is still underway.

Only one site, Green Canyon 852 (1410 m) contained hard-grounds extensively colonized by deep-water coral species. There were at least three species of scleractinians observed at this site, including *Enalopsammia rostrata*, *Madrepora oculata* (which was not collected and verified), and another morphotype of coral appearing in the photographic samples. There were also numerous species of gorgonian, antipatharian, and alcyonacean corals observed. A series of photographs were taken at this site and analysis of these samples in underway. Only a few physical samples of the corals at this site were possible due to the extremely rugged topography of the site and the strong currents in the area at the time of the submersible dives.

The data collected during the first field season of this study have provided a reasonable characterization of the hard-ground communities below 1000 m in the Gulf of Mexico. Some community types were observed and sampled for the first time, while tubeworm and mussel bed communities were sampled to the greatest extent. These communities were most similar to one another within a site and within a certain depth range. However, community structure was determined to a certain extent by the relative size of the foundation species sampled (tubeworms and mussels), hinting at some successional trends. Additional community samples along with time course studies and tubeworm growth rate determinations obtained in the second field season will allow a more thorough examination of these processes.

Erik Cordes is a post-doctoral fellow at Harvard University. As a visiting scientist at the Pennsylvania State University, Dr. Cordes is involved in the joint MMS-OE funded study of the deep-water (>1000 m) hard-grounds in the northern Gulf of Mexico, or Chemo III. His primary responsibilities are an analysis of the deep-water coral communities inhabiting the hard-grounds. He is also assisting in the oversight of the collection and processing of seep community samples, distribution of specimens to taxonomic collaborators, and data analysis. He was also involved in the MMS-funded *Lophelia* I study, and was responsible for the analysis of communities associated with *Lophelia pertusa* including biodiversity, biogeography, trophic relationships, and potential ties to seep productivity. Following his undergraduate degree at Southampton College, he studied soft coral and gorgonian age, growth, and reproduction at Moss Landing Marine Laboratories where he received his M.S. degree. His doctoral research at the Pennsylvania State University involved modeling the population dynamics and sulfide uptake of the tubeworms inhabiting the upper Louisiana slope seeps, and analyses of the communities associated with them. Over the course of his research, he has participated in 11 research expeditions and made 30 dives in the Johnson Sea-Link and Alvin submersibles and has published eight papers on the ecology of deep-water habitats in the Gulf of Mexico.

TROPHIC RELATIONS AND INTERACTIONS WITH BACKGROUND FAUNA

Robert Carney, Louisiana State University

Click here to view the slide show that accompanied this presentation.

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 (1976). 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.

LOOKING FORWARD: TIME SERIES ANALYSES AND PLANS FOR 2007 CHEMO III CRUISES

Charles Fisher, Pennsylvania State University

Click here to view the slide show that accompanied this presentation.

Two field operations are planned as part of CHEMO III for 2007, the second field year of this project. The first will be Hugin AUV surveys conducted by C & C Technologies. These surveys will cover approximately one-fourth of a lease block and be centered on our study sites in AT 340, GC 852, AC 601, and WR 269. These surveys will provide base maps of high-resolution bathymetry, side scan reflectivity, and sub-bottom profiles that will be used to further refine our plans for Jason II work at these sites and will also be used as navigational underlays during our ROV operations.

The second and major field operation for 2007 will be a research cruise using the NOAA Ship Ronald H. Brown, with the WHOI ROV Jason II. Our objectives for this cruise fall into four basic categories: collections for ongoing microbiology, geology, geochemistry, and macrobiological studies; continuing temporal studies designed to monitor activities of mobile fauna, growth of tubeworms, and changes in communities; acquisition of very high resolution multibeam and side-scan maps of central areas of each site; and detailed *in situ* characterizations of the chemistry among animal communities at each site.

Collections at our established study sites will supplement collections made in 2006 and will provide data that will allow robust comparison of community types, community compositions, and basic geochemical parameters among sites, and of potential biogeographical and depth-related variation in all parameters. Within this context we will be targeting similar habitats at each site for microbiological sampling and also full suites of collections from all un-sampled types of communities from each site. We will analyze communities of different apparent ages on the lower slope to test the generality of community succession hypotheses, which were formulated based on work on the upper slope. We will also specifically target discovery and sampling of sites between 800 and 1300 meters depth during this cruise to better document and understand the depth-related transition in species composition between the well known upper slope sites and the lower slope sites visited in 2006. To complete the sampling necessary to evaluate the trophic impact of the deep slope seeps on the surrounding background fauna, we will supplement the extensive off-site sampling of mobile fauna conducted in 2006 with on-site trapping and targeted collections of mobile fauna this year.

In 2006 we initiated three types of temporal studies that will be continued in 2007. A rotary time lapse camera system was deployed among seep fauna at the GC 852 site. It will be collected and the images analyzed to determine visitation rates by large mobile fauna to the site. This system and two sister systems will be deployed during the cruise for similar analyses for periods of up to one month. We will collect tubeworms stained in 2006 for determination of their yearly growth rate and development of growth models for the deeper living species. Finally we will revisit photo-mosaic sites established in 2006 and re-image these sites for analyses of changes between years. During the 2006 cruise we also were able to re-locate several tubeworms banded for growth studies in 1991 and areas mosaicked in 1991 at AC 645. These animals and sites will be re-located and imaged for additional growth and temporal change analyses.

Use of the precise navigational capabilities of Jason II, in conjunction with their high-quality mapping and imaging capabilities will not only provide base maps in which to nest all of our sampling and other activities, they will also allow better interpretation of the geological/geochemical features that drive the biological response features. In order to allow placement of all 2006 activities on the high-resolution multibeam and side-scan maps we will produce, we will re-occupy all markers deployed in 2006. We will conduct additional photo-transects and mosaics in precisely documented navigational space and also conduct *in situ* chemical surveys within these mosaics. During the 2007 Jason II cruise we will be using a new CONTROS Systems methane sensor and an *in situ* quadrapole mass spectrophotometer to measure environmental levels of methane, sulfide and oxygen on sub-decimeter scales to better understand the faunal distribution patterns both within and among sites.

CHEMO III is also among the first MMS projects to include a contractual and funded education and outreach component. During the 2006 Alvin cruise our education and outreach coordinator, Liz Goehring worked with a middle school teacher and the scientists on board to develop a prototype student laboratory exercise on oxidation at seeps and also collected data on seep mussels for the existing SEAS "classroom to sea" mussel lab (originally developed for hydrothermal vent mussels). Both are being pilot tested in a classroom setting this year. Ms Goehring was also the lead PI on a successful NSF/NASA GLOBE (www.globe.gov) proposal in 2006: FLEXE (From Local to Extreme Environments). The GLOBE partnership will facilitate distribution of the education materials developed to their international network that includes over 17,000 schools and 1,000,000 students in more than 100 countries. Education and outreach activities in 2007 will focus on integrating the classroom to sea activities into the FLEXE/GLOBE program and development of a two-day short-course for teachers to involve more educators from the Gulf Coast region.

Dr. Fisher is a professor of biology at the Pennsylvania State University. He has been actively researching the chemosynthetic communities in the Gulf of Mexico for 20 years and has authored over 50 peer-reviewed publications addressing various aspects of the biology of these communities.

INDEX TO AUTHORS

ATTENDEES

Adrian, Olivia F
MMS
381 Elden Street, MS 2100
Herndon, VA 20170
olivia.adrian@mms.gov

Ahlfeld, Thomas E
MMS
Environmental Sciences Branch (4041)
381 Elden Street
Herndon, VA 20170-4817
thomas.ahlfeld@mms.gov

Allee, Rebecca
Senior Scientist
NOAA Gulf Coast Services Center
c/o NDBC
Building 1100, Room 360
Stennis Space Center, MS 39529
becky.allee@noaa.gov

Allen, Dan
Ecologist
Chevron Texaco
935 Gravier St
Room 1454
New Orleans, LA 70112
dan.allen@chevrontexaco.com

Allen, James
400 N Galvez St #5
New Orleans, LA 70119-5716

Aronson, Richard B
Dauphin Island Sea Lab
101 Bienville Blvd
Dauphin Island, AL 36528
raronson@disl.org

Austin, Diane E
Researcher
University of Arizona
Bureau of Applied Research in Anthropology
Anthropology Building, Room 316
Tucson, AZ 85721
daustin@u.arizona.edu

Bacon, Leigh
Air Pollution Meteorologist
ADEM
1400 Coliseum Blvd
Montgomery, AL 36110
LBB@ADEM.STATE.AL.US

Badan, Antonio
CICESE
Departamento de Oceanografia Fisica
Apartado Postal 2732
Ensenada, BC 22860
MEXICO
abadan@cicese.mx

Baguley, Jeff
The University of Texas at Austin
Marine Science Institute
750 Channel View Drive
Port Aransas, TX 78373
jeffb@utmsi.utexas.edu

Baird, Bruce
MMS
1201 Elmwood Park Blvd, MS 5400
New Orleans, LA 70123
bruce.baird@mms.gov

Bankston, William
Professor of Sociology
LSU, 126 Stubbs Hall
Dept of Sociology
Baton Rouge, LA 70803
sobank@lsu.edu

Barber, Elizabeth
Consultant to MDMR
Barber and Mann, Inc
5939 Freret St
New Orleans, LA 70115
liz@barberandmann.com

Barkaszi, Mary Jo A
Director of Ecological Programs
GeoCet
One Sugar Creek Center Blvd, Suite 355
Sugar Land, TX 77478
maryjo@geocet.com

Barry, Carrie S
NOAA Fisheries
3209 Frederic Street
Pascagoula, MS 39567
carrie.barry@noaa.gov

Barry, Jim
MBARI
barry@mbari.org

Barwick, Kirk
Facilities Coordinator
Petrobras America Inc
2101 City West Blvd, Bldg 3, Suite 300
Houston, TX 77042
kbarwick.indep@petrobras-usa.com

Beasley, Jerry
Chief, Air Quality Planning Section
Mississippi Dept of Environment Quality
101 West Capitol Street
Brandon, MS 39042
jbeasley@deq.state.ms.us

Becker, Erin
Pennsylvania State University
208 Mueller Laboratory
University Park, PA 16802
elb209@psu.edu

Beggs, John J
LSU Dept of Sociology
126 Stubbs Hall
Baton Rouge, LA 70803
jbeggs@lsu.edu

Benner, Colleen S
National CIAP Coordinator
MMS
381 Elden Street, MS 4040
Springfield, VA 22150
lee.benner@mms.gov

Benoit-Bird, Kelly
Oregon State University

Bernard, Bernie B
Vice President
TDI Brooks International, Inc
1902 Pinon Drive
College Station, TX 77845
berniebernard@tdi-bi.com

Bhiwandiwalla, Dianna
MMS
381 Elden Street
Herndon, VA 20170
Dianna.Bhiwandiwalla@mms.gov

Bickerstaff, Elliott
Chief, Air Support Branch
Mississippi DEQ
101 W Capital
Jackson, MS 39201
elliott_bickerstaff@deq.state.ms.us

Biggs, Douglas C
Professor
Texas A&M University
Dept of Oceanography
TAMU Mail Stop 3146
College Station, TX 77843-3146
dbiggs@ocean.tamu.edu

Billings, Richard S
Eastern Research Group, Inc
1600 Perimeter Park Drive
ERG (Second Floor)
Morrisville, NC 27560
richard.billings@erg.com

Bjerstedt, Thomas W
Geoscientist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
tom.bjerstedt@mms.gov

Blanchard, Brian
Research Associate
LSU Coastal Studies Institute
Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
bblanc5@lsu.edu

Boland, Gregory S
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
gregory.boland@mms.gov

Boyer, Brian E
Vice President
COMM Engineering, Inc
1319 West Pinhook
Suite 400
Lafayette, LA 70503
brian@commengineering.com

Bradford, Vernessa J
Shell E&P Co
PO Box 61933, Suite 2900
New Orleans, LA 70131
vernessa.bradford@shell.com

Brantley, Will
State Lands Manager
Alabama Dept of Conservation & Natural Resources
64 North Union Street
Montgomery, AL 36130
will.brantley@dcnr.alabama.gov

Brass, Agaha Yure
Louisiana Dept of Natural Resources
617 North 3rd Street, PO Box 44027
Baton Rouge, LA 70804
agahab@dnr.state.la.us

Brewer, Gary D
Biologist
U.S. Geological Survey
11649 Leetown Road
Kearneysville, WV 25430
gbrewer@usgs.gov

Brinkman, Ron
Geophysicist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
ronald.brinkman@mms.gov

Brooke, Sandra
Florida Fish and Wildlife Institution
100 8th Avenue SE
Saint Petersburg, FL 33704
sandra.brooke@myfwc.com

Brooks, Jim
TDI - Brooks International Inc
3953 Cedar Ridge
College Station, TX 77845

Broussard, TJ
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
tommy.broussard@mms.gov

Brown, Harmon
LSU Coastal Fisheries Institute
2151 ECE Building
Baton Rouge, LA 70803
hbrow11@lsu.edu

Brown, Ralph B
Brigham Young University
PO Box 25400
Dept of Sociology
Provo, UT 84602
Ralph_Brown@byu.edu

Brown, Timothy
Research Assistant
Louisiana State University
126 Tubbs Hall
Baton Rouge, LA 70803
tbrown9@lsu.edu

Burger, Tracey
Senior Regulatory Specialist
Shell Oil Company
701 Poydras St
New Orleans, LA 70161
tracey.burger@shell.com

Cahoon, Donald R
U.S. Geological Survey
Patuxent Wildlife Research Center
c/o BARC-East, Building 308
10300 Baltimore Avenue
Beltsville, MD 20705
don_cahoon@usgs.gov

Cameron, Robert W
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
bob.cameron@mms.gov

Campbell, Jacob
Research Assistant
University of Arizona
BARA
PO Box 210030
Tucson, AZ 85721
jacob@email.arizona.edu

Carney, Robert S
LSU Coastal Ecology Institute
Coast, Energy & Environment Bldg
Baton Rouge, LA 70810
rcarne1@lsu.edu

Celata, Mike
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123

Chapman, Piers
CREST Program - LSU
153A Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
pchapman@lsu.edu

Charles, Colleen
Ecosystems Program
USGS
12201 Sunrise Valley Dr, MS 301
Reston, VA 20192
colleen_charles@usgs.gov

Chew, Dennis
Chief, NEPA/CZM Unit
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
dennis.chew@mms.gov

Christopher, Joe
Chief, Environmental Assessment Section
MMS
1201 Elmwood Park Blvd, MS 5400
New Orleans, LA 70123
joseph.christopher@mms.gov

Church, Robert A
Marine Archaeologist
C & C Technologies, Inc
730 E Kaliste Saloom Road
Lafayette, LA 70508
robert.church@cctechnol.com

Cimato, James
Oceanographer
MMS Environmental Services Branch
381 Elden Street, MS 4041
Herndon, VA 20170
james.cimato@mms.gov

Clement, Kirt
Louisiana Dept of Transportation and Development

Codina, Caron
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
codinac@mms.gov

Coholan, Patrice
Vice President Eddy Watch Operations
Horizon Marine, Inc
15 Creek Road
Marion, MA 02738
horizon@horizonmarine.com

Cole, Kelly
Texas A&M University
3146 TAMU
College Station, TX 77843
KellyLyne3@aol.com

Coleman, James M
Louisiana State University
667 CastleKirk
Baton Rouge, LA 70808
chanjc@lsu.edu

Conner, Mike
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
george.conner@mms.gov

Coomes, Carol
Evans-Hamilton, Inc
4608 Union Bay Pine
Seattle, WA 98105
carol@evanshamilton.com

Cordes, Erik
Postdoctoreal Fellow
Harvard University
3079 BioLabs
16 Divinity Ave
Cambridge, MA 02138
ecordes@oeb.harvard.edu
Cowen, James
LSU
Baton Rouge, LA 70803
jcowan@disl.org

Cowen, Mary

Cox, Jeffrey M
Evans-Hamilton, Inc
4608 Union Bay Pl NE
Seattle, WA 98105
jeff@evanshamilton.com

Crapo, Elizabeth
LT/NOAA
NOAA Ship Ronald H Brown
439 W York St
Norfolk, VA 23510
elizabeth.crapo@noaa.gov

Crout, Richard
Oceanographer
NOAA's National Data Buoy Center
1100 Balch Blvd
Stennis Space Center, MS 39529
richard.crout@noaa.gov

Current, Carole L
Physical Oceanographer
MMS
1201 Elmwood Park Blvd, MS 5433
New Orleans, LA 70123
carole.current@mms.gov

Dalthorp, Maggie
Texas A&M - Corpus Christi
PO Box 6349
Corpus Christi, TX 78466
mdalthorp@sbcglobal.net

Darby, Kristi R
LSU Center for Energy Studies
1069 Energy, Coast & Environment Bldg
Baton Rouge, LA 70803
kdarby@lsu.edu

Daughdrill, William
Environmental Scientist
Ecology & Environment Inc
220 West Garden Street, Suite 404
Pensacola, FL 32502
wdaughdrill@ene.com

Davis, Patti
Project Management Assistant
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
patricia.davis@mms.gov

Demopoulos, Amanda W
Research Ecologist
USGS Florida Integrated Science Center
c/o Scripps Institution of Oceanography
9500 Gilman Drive, 0218
La Jolla, CA 92093
amandad@ucsd.edu

DeRuiter, Stacy
Woods Hole Oceanographic Institution
Woods Hole Road 266, MS 50
Woods Hole, MA 02543
sderuiter@whoi.edu

Diaz, Janet
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
janet.diaz@mms.gov

Diaz, Robert
Virginia Institute of Marine Science
PO Box 1436
Route 1208 Greate Road
Gloucester Point, VA 23062-1346
diaz@vims.edu

DiMarco, Steven F
Associate Research Scientist
Texas A&M University
Dept of OCNG
3146 TAMU
College Station, TX 77843-3146
dimarco@tamu.edu

Dismukes, David
LSU/Center for Energy Studies
1069 Energy, Coast & Environment Bldg
Baton Rouge, LA 70803-0301
dismukes@lsu.edu

Donn, Ted
Tetra Tech, Inc
3746 Mt Diablo Blvd, Suite 300
Lafayette, CA 94549

Donohue, Kathleen A
Graduate School of Oceanography
University of Rhode Island
215 South Ferry Road
Narragansett, RI 02882
kdonohue@gso.uri.edu

Douglas, Sharon
Systems Applications International
Fairfax, VA 220311207

D’sa, Eurico J
Louisiana State University
Coastal Studies Institute
320 Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
ejdsa@lsu.edu

Eberharter, Hermann
UNO Conference Services
CERM 245, Lakefront Campus
New Orleans, LA 70148

Engelhardt, William
Biologist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
bill.engelhardt@mms.gov

Ensz, Holli
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
holli.ensz@mms.gov

Epperson, Deborah
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
Deborah.Epperson@mms.gov

Etnoyer, Peter
Texas A&M - Corpus Christi
Harte Research Institute
6300 Ocean Dr
Corpus Christi, TX 78412
peter.etnoyer@tamucc.edu

Evans, Donald P
Murphy Exploration & Production Co
131 South Robertson St
New Orleans, LA 70112
don_evans@murphyoilcorp.com

Fagot, Caryl
Staff Assistant
MMS
1201 Elmwood Park Blvd, MS 5000
New Orleans, LA 70123
caryl.fagot@mms.gov

Fahey, James T
Marine Measurements Sales Manager
Teledyne RD Instruments
14020 Stowe Drive
Poway, CA 92064
jfahey@teledyne.com

Farndon, Tom
MMS
381 Elden Street, MS 4050
Herndon, VA 20170
USA
thomas.farndon@mms.gov

Feeney, James W
Horizon Marine, Inc
15 Creek Road
Marion, MA 02738
horizon@horizonmarine.com

Fennel, Katja
Dalhousie University
1355 Oxford Street
Halifax, B3H4J1
CANADA
katja.fennel@dal.ca

Fernandes, Lincoln
Project Engineer
Petrobras America Inc
2101 City West Blvd
Building 3, Suite 300
Houston, TX 77042
lffernandes@petrobras-usa.com

Fertl, Dagmar
Biologist
Geo-Marine, Inc
550 East 15th Street
Plano, TX 75074
dfertl@geo-marine.com

Fisher, Charles R
Pennsylvania State University
Department of Biology
Office 219 Muller
State College, PA 16804
cfisher@psu.edu

Fitzpatrick, Pat
Associate Research Professor
Mississippi State University
Building 1103, Room 233
Stennis Space Center, MS 39529
fitz@gri.msstate.edu

Forristall, George
Forristall Ocean Engineering, Inc
101 Chestnut
Camden, ME 04843
george@forocean.com

Forsyth, Craig
University of Louisiana at Lafayette
PO 41652
Lafayette, LA 70504
cjf5714@louisiana.edu

Frederick, James "Bubba"
Senior Environmental Specialist
Chevron/OOC
3901 Briarpark
Houston, TX 77042
jfred@chevron.com

Frick, Martin
University of New Orleans

Frickey, Stacey L
Shell E&P Company
701 Poydras St, Room 2944
New Orleans, LA 70160
stacey.frickey@shell.com

Fruge, David
Louisiana Dept of Natural Resources
Office of Costal Restoration &
Management
617 N 3rd St, La Salle Building
Baton Rouge, LA 70802
david.fruge@la.gov

Fry, Michael
Director, Pesticides & Birds
American Bird Conservancy
PO Box 249
The Plains, VA 20198
mfry@abcbirds.org

Fury, Sandi
Chevron USA Production Co
935 Gravier St, Room 1364
New Orleans, LA 70112
sfur@chevrontexaco.com

Gambino, Stephanie M
Senior Environmental Scientist
MMS
1201 Elmwood Park Blvd, MS 5412
New Orleans, LA 70123
stephanie.gambino@mms.gov

Garcia, Oscar
Texas A&M University - Corpus Christi
6533 Patti Drive
Apt 1601
Corpus Christi, TX 78414
oscar.garcia@tamucc.edu

Gasser, Markus

Gitschlag, Gregg
NOAA Fisheries
4700 Avenue U
Galveston, TX 77551
gregg.gitschlag@noaa.gov

Goeke, Gary D
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
gary.goeke@mms.gov

Gonzalez, Carlos
Shell E&P Company
3520 General Degaulle
Algiers, LA 70114
cgonzalez@petronyx.com

Gordon, Jonathan
University of St. Andrews
Sea Mammal Research Unit
3 Alma Terrace
Newport-on-Tay, Fife
Newport-on-Tay, DD6 8HZ, UK
jg20@st-andrews.ac.uk

Gould, Greg
MMS
381 Elden Street, MS 4040
Herndon, VA 20170
gregory.gould@mms.gov

Graham, William (Monty)
Dauphin Island Sea Lab
101 Bienville Blvd
Dauphin Island, AL 36258
mgraham@disl.org

Grandy, Greg
Louisiana Dept of Natural Resources
617 North 3rd Street
PO Box 44027
Baton Rouge, LA 70804
gregory.grandy@la.gov

Gregus, Janelle
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
janelle.gregus@mms.gov

Griffin, Lynn
Environmental Administrator
Florida Dept of Environmental Protection
3900 Commonwealth Blvd, MS 47
Tallahassee, FL 32399-3900
toni.r.clanton@dep.state.fl.us

Haag, Alaric
LSU Coastal Studies Institute
Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
haag@lsu.edu

Haedrich, Richard
Professor Emeritus
Memorial University of Newfoundland
4 Clark Place
St. John's, NL A1C 5S7, CANADA
haedrich@mun.ca

Hall, Callie
NASA Applied Sciences
EA41
Stennis Space Center, MS 395229
callie.m.hall@nasa.gov

Hall, Joan
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
joan.hall@mms.gov

Hamilton, Peter
SAIC
615 Oberlin Road, #100
Raleigh, NC 27605
peter.hamilton@saic.com

Haney, Jay
Systems Applications International
ICF Consuting
9300 Lee Highway
Fairfax, VA 22031-1207
JHaney@icfi.com

Harris, Courtney
Professor
Virginia Institute of Marine Sciences
Route 1208 Greate Road
Gloucester Point, VA 23062
ckharris@vims.edu

Harris, Jeff
Consistency Resources Coordinator
Louisiana Dept of Natural Resources
PO Box 44487
Baton Rouge, LA 70804
jeffh@dnr.state.la.us

Hart, Alan D
VP, Science Director
Continental Shelf Associates, Inc
759 Parkway Street
Jupiter, FL 33477
ahart@conshelf.com

Hartley, Steve
USGS/NWRC
700 Cajundome Blvd
Lafayette, LA 70506
steve_hartley@usgs.gov

Hartzog, Larry
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123

Heaton, Jeffrey
Senior Project Manager
Providence Engineering and
Environmental Group
1201 Main Street
Baton Rouge, LA 70809
jeffheaton@providenceeng.com

Heintz, Matt
Woods Hole Oceanographic Inst, MS 7
Woods Hole, MA 02543
mheintz@whoi.edu

Henton, Chris
Geospatial Analyst
Radiance Technology
Building 1103, Room 210
Stennis Space Center, MS 39529
chenton@radiancetech.com

Herkhof, Dirk
Meteorologist
MMS
381 Elden Street
Herndon, VA 20170
dirk_herkhof@mms.gov

Hetland, Robert
Associate Professor
Texas A&M University
3146 TAMU
College Station, TX 77843-3146
hetland@tamu.edu

Hill, Michaela
Staff Officer
Mississippi Dept of Marine Resources
1141 Bayview Avenue
Biloxi, MS 39530
michaela.hill@dmr.ms.gov

Holder, Sue
53 Havoleans St
Harahan, LA 70123

Holder, Tim
MMS
949 E 36th Ave, 3rd Floor
Anchorage, AK 99508
tim.holder@mms.gov

Hollingshead, Kenneth R
Fishery Biolgist
NOAA Fisheries, F/PR2-Room 13600
1315 East-West Highway
Silver Spring, MD 20640
ken.hollingshead@noaa.gov

Holmes, Charles
Geologist
U.S. Geological Survey
600 Fourth Street South
Saint Petersburg, FL 33701
cholmes@usgs.gov

Hopson, Chuck
Regulatory Specialist
Waring & Associates
1101 Dealers Ave
New Orleans, LA 70123
chopson@ocsbbs.com

Hsu, SA
Professor
LSU Coastal Studies Institute
308 Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
sahsu@lsu.edu

Huang, Chester
Meteorologist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
chester.huang@mms.gov

Hunt, Jesse
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
jesse.hunt@mms.gov

Hunter, Cheri C
MMS
381 Elden Street
Herndon, VA 20170
cheri.hunter@mms.gov

Iledare, Omowunmi
LSU Center for Energy Studies
1107 Energy, Coast & Environment Bldg
Baton Rouge, LA 70803
wumi@lsu.edu

Inoue, Masamichi
Associate Professor
LSU Coastal Studies Institute
331 Howe-Russell Geoscience Complex
Baton Rouge, LA 70803-7527
coiino@lsu.edu

Ioup, George
Professor
University of New Orleans
Dept of Physics
New Orleans, LA 70148
geioup@uno.edu

Irion, Jack B
Chief, Social Studies Unit
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
jack.irion@mms.gov

Irvine, Ladd
Oregon State University

Islam, Quazi
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123

Jarratt, Amy
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
elaine.jarratt@mms.gov

Jennings, Grant
Commercial Manager
Teledyne RD Instruments
14020 Stowe Drive
San Diego, CA 92127
gjennings@teledyne.com

Ji, Jeff
MMS
381 Elden Street
Herndon, VA 20170
jeff.ji@mms.gov

Jochens, Ann E
Texas A&M, Dept of Oceanography
3146 TAMU
College Station, TX 77843-3146
ajochens@tamu.edu

Johnson, Carliane
Senior Biologist
Ecology and Environment, Inc
4001 N Moore St
Suite 1610
Arlington, VA 22203
cjohnson@ene.com

Johnson, Cherie
Secretary for Environmental Affairs
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
cherie.johnson@mms.gov

Johnson, Walter
Oceanographer
MMS
381 Elden Street, MS 4041
Herndon, VA 20170
walter.johnson@mms.gov

Jones, Sonya
Regional Program Officer
U.S. Geological Survey
3850 Holcomb Bridge Road, Suite 160
Norcross, GA 30092
sajones@usgs.gov

Jones, Stephen C
Geologist
Geological Survey of Alabama
Box 869999
Tuscaloosa, AL 35486
sjones@gsa.state.al.us

Joye, Samantha
University of Georgia

Kaiser, Mark
Research Professor
LSU Center of Energy Studies
1 East Fraternity Circle
Baton Rouge, LA 70803-0301
mkaiser@lsu.edu

Kaplan, Maureen F
Manager
ERG, Inc
110 Hartwell Ave
Lexington, MA 02421
maureen.kaplan@erg.com

Keith, Matt
Tesla Offshore
36499 Perkins Road
Prairieville, LA 70769
keithm@teslaoffshore.com

Kellogg, Christina
Microbiologist
U.S. Geological Survey
600 Fourth St S
Saint Petersburg, FL 33701
ckellogg@usgs.gov

Kendall, James J
Chief, Environmental Sciences Section
MMS
381 Elden Street MS 4021
Herndon, VA 20170
james.kendall@mms.gov

Kenny, Jan L
DEMEX International, Inc
16222 Halpern Falls Lane
Cypress, TX 77429
jan@demex.us

Kenny, John
Business Developer
Boh Bros Construction LLC
1207 North Freeway, Suite 490
Houston, TX 77060
jkenny@bohbros.com

Killian, Sharon R
Freeport-McMoRan, LLC
1615 Poydras St
New Orleans, LA 70112
Sharon_Killian@fmi.com

Kim, Mi Ae
NOAA
1315 East-West Hwy, F/PR3
Silver Spring, MD 20910
mi.ae.kim@noaa.gov

Kozlowski, Gregory J
Environmental Protection Specialist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
greg.kozlowski@mms.gov

Kuehn, Robert
Staff Environmental Engineer
Shell E&P Co
701 Poydras Street
New Orleans, LA 70139
robert.kuehn@shell.com

Kumar, Anu
Geo-Marine, Inc
2713 Magruder Blvd, Suite D
Hampton, VA 23666-1572
akumar@geo-marine.com

La Borde Johnson, Bonnie
Environmental Scientist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
bonnie.johnson@mms.gov

Labak, Stanley
Senior Scientist
Marine Acoustics, Inc
4100 Fairfax Drive, Suite 730
Arlington, VA 22203
stan.labak@marineacoustics.com

Lai, Ronald
MMS
381 Elden Street, MS 4022
Herndon, VA 20170
ronald.lai@mms.gov

Landry, Connie
Environmental Studies Program Specialist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
connie.landry@mms.gov

Landry, Laura A
President, LA Landry & Associates
490 Pompano
Hitchcock, TX 77563
lalala1@cox.net

Lang, William H
NSFRE
4201 Wilson Blvd
Arlington, VA 22230
wlang@nsf.gov

Latusek, Jennifer N
SAIC
1140 Eglin Parkway
Shalimar, FL 32579
jennifer.n.latusek@saic.com

Lavoie, Dawn
Science Coordinator: Gulf Coast
USGS
2045 Lakeshore Dr
CERM 447/8
New Orleans, LA 70148

Leben, Robert
University of Colorado at Boulder
431 UCB
Boulder, CO 80309
leben@colorado.edu

Leedy, Herb
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
daniel.leedy@mms.gov

Lessard-Pilon, Stephanie
Pennsylvania State University
208 Mueller
University Park, PA 16802
sal275@psu.edu

Lester, Gary
Louisiana Dept of Wildlife & Fisheries
PO Box 98000
Natural Heritage Program Coordinator
Baton Rouge, LA 70898-9000
glester@wlf.louisiana.gov

Lewandowski, Jill
Protected Species Biologist
MMS
381 Elden Street
Herndon, VA 20170
Jill.Lewandowski@mms.gov

Li, C
LSU
cli@lsu.edu

Lindsey-Curran, Christopher
British Petroleum
lindc7@bp.com

Lirette, Angela K
Research Technician
LUMCON
8124 Hwy 56
Chauvin, LA 70344
alirette@lumcon.edu

Lugo-Fernandez, Alexis
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
alexis.lugo.fernandez@mms.gov

Lustig, Jay N
Scientific Solutions, Inc
99 Perimeter Road
Nashua, NH 03063
jlustig@scisol.com

Luthra, Asha D
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
asha.luthra@mms.gov

Lyons, Michael
LAMOGA
801 North Blvd, Suite 201
Baton Rouge, LA 70802
lyons@lmoga.com

MacCready, Tyler
AeroVironment, Inc
tyler@geologist.com

MacDonald, Ian R
Texas A&M University
727 Graham Road
College Station, TX 77845
ian@gerg.tamu.edu

Mair, Alexander
University of New Orleans

Marcks, Brian
Environmental Scientist
DNR/CMD-Louisiana
617 N 4th St
Baton Rouge, LA 70804
brianm@la.us

Martin, Kevin
Civil/Structural Engineering Manager
Albert-Garaudy Consulting Engineers
3500 North Causway Blvd, Suite 600
Metairie, LA 70002
kmartin@aga-engineers.com

Martin, Tim
Air Pollution Meterologist
ADEM
1400 Coliseum Blvd
Montgomery, AL 36110
TPM@ADEM.STATE.AL.US

Martison, Robert
Biologist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
robert.martinson@mms.gov

Mastrangelo, Carlos
FPU Facilities Manager
Petrobras America Inc
1330 Avenue of the Americas, 16th Floor
New York, NY 10019
mastrangelo@petrobras-usa.com

Mate, Bruce
Oregon State University Marine Science
Center
2030 SE Marine Science Drive
Newport, OR 97367
bruce.mate@oregonstate.edu

McDonough, Mike
LSU
Baton Rouge, LA 70803

McGee, Thomas M
Center for Marine Resources &
Environmental Technology
220 Old Chemistry Building
University, MS 38677
tmm@olemiss.edu

McGehee, Yvette
ECS III
LDEQ
602 North 5th Street
Baton Rouge, LA 70802
yvette.mcgehee@la.gov

McKone, Kevin
Copiah Lincoln Community College
1614 Enterprise Road SE
Bogue Chitto, MS 39629
kevin.mckone@colin.edu

McPhearson, Terry
terry.mcphearson@ssc.nasa.gov

McPherson, Terry
NASA Applied Sciences
Building 3226
Stennis Space Center, MS 39529
terry.r.mcpherson@nasa.gov

Merritt, Stacie
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
stacie.merritt@mms.gov

Metcalf, Margaret C
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
margaret.metcalf@mms.gov

Meyer, Richard
Shell E&P Co
PO Box 61933, Room 840
New Orleans, LA 70161-1933
rick.b.meyer@shell.com

Miles, Scott
LSU
Department of Environmental Studies
1285 Energy, Coast & Environment Bldg
Baton Rouge, LA 70803
msmiles@lsu.edu

Miller, Lillian
Mind's Eye Productions
200 Ziegler Avenue
Houma, LA 70360
llillian@sw.rr.com

Miller, Patrick
University of St. Andrews
Gatty Marine Lab
St. Andrews, Fife KY16 8LB, UK

Mink, Bob
Director
Geological Survey of Alabama
Box 869999, 420 Hackberry Lane
Tuscaloosa, AL 35486
bmink@gsa.state.al.us

Montagna, Paul
Texas A&M - Corpus Christi
6300 Ocean Drive
Corpus Christi, TX 78412
paul.montagna@tamucc.edu

Moran, Bob
Director, Government Affairs
Halliburton Energy Services
1150 18th Street, NW
Washington, DC 20036
bobmoran@halliburton.com

Moran, Dave
Environmental Scientist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
dave.moran@mms.gov

Moreau, Jim
Sales and Marketing
Tesla Offshore
36499 Perkins Road
Prairieville, LA 70769
moreauj@teslaoffshore.com

Moreno, Paula
Fisheries Biologist
IAP World Services
705 Convent Avenue
Pascagoula, MS 39567
Paula.Moreno@noaa.gov

Morey, Steven
Assistant Scholar/Scientist
Center for Ocean - Atmospheric Prediction Studies
The Florida State University
Tallahassee, FL 32306
morey@coaps.fsu.edu

Morrison, Cheryl
U.S. Geological Survey

Myers, Candice
Research Assistant
LSU
985 Laurie Lane
Saint Gabriel, LA 70776
cmyers6@lsu.edu

Norman, Will
Louisiana Dept of Natural Resources
617 North 3rd St
Baton Rouge, LA 70804
charlesn@dnr.state.la.us

Nunez, Arlette C
Shell E & P
701 Poydras St
New Orleans, LA 70139
arlette.nunez@shell.com

Obiol, Barry T
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
barry.obiol@mms.gov

Oey, Leo
Princeton University
AOS Program
14 Taunton Court
Princeton Junction, NJ 08550
lyo@princeton.edu

OHara, David
GeoCet
One Sugar Land Center Blvd, Suite 355
Sugar Land, TX 77478
davidohara@geocet.com

O'Hern, Julia E
Texas A&M
College Station, TX 77840
juliaohern@tamu.edu

O'Neil, Calvin
USGS Geospatial Liaison for Louisiana
USGS/Louisiana NSDI Partnership Office
700 Cajundome Blvd
Lafayette, LA 70506
pat_o'neil@usgs.gov

Ong, Mike
MMS
1201 Elmwood Park Blvd, MS 5210
New Orleans, LA 70123-2394
mike.ong@mms.gov

Orgeron, Jim
Environmental Scientist, Staff
Louisiana Dept of Environmental Quality
PO Box 82263
Baton Rouge, LA 70884
james.orgeron@la.gov

Ortega, Joel
Oregon State University
Hatfield Marine Science Center
2030 SE Marine Science Drive
Newport, OR 97365
joel.ortega@oregonstate.edu

Osborne, Karen
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
karen.osborne@mms.gov

Overton, Ed
LSU Coastal Marine Institute
Howe-Russell Geoscience Complex
Baton Rouge, LA 70776
ebovert@lsu.edu

Pakunpanya, Sirisak (Patrick)
Air Quality Modeling Coordinator
Louisiana Dept of Environmental Quality
602 N Fifth Street
Baton Rouge, LA 70802
patrick.pakunpanya@la.gov

Parker, Michael E
Environmental Advisor
Exxon Mobil Production Company
800 Bell St
Room 4289 EMB
Houston, TX 77252-2180
michael.e.parker@exxonmobil.com

Patel, Harshad
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
harsha.patel@mms.gov

Patterson, William
Assistant Professor
University of West Florida
11000 University Parkway
Pensacola, FL 32514
wpatterson@uwf.edu

Peggion, Germana
University of New Orleans
Building 1009C
Stennis Space Center, MS 39529
gpeggion@uno.edu

Peneguy, Kathleen
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123

Perez, Brian
USGS/National Wetlands Research Center
700 Cajundome Blvd
Lafayette, LA 70506

Peuter, Elizabeth A
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
elizabeth.peuter@mms.gov

Pilie', Clay M
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394

Piltz, Fred
MMS
770 Paseo Camarillo
Camarillo, CA 93010
fred.piltz@mms.gov

Potter, Jeremy
Operations Coordinator
NOAA Ocean Exploration
1315 East-West Highway
SSMC3 Room 10234
Silver Spring, MD 20910
jeremy.potter@noaa.gov

Pour Biazar, Arastoo
University of Alabama in Huntsville
320 Sparkman Drive
Huntsville, AL 35899
biazar@nsstc.uah.edu

Precht, William F
Chief Scientist
7310 Poinciana Court
Miami Lakes, FL 33014
reefresources@aol.com

Rabalais, Nancy N
LSU Marine Consortium
8124 Hwy 56
Chauvin, LA 70344
nrabalais@lumcon.edu

Ray, James P
Oceanic Environmental Solutions, LLC
16606 Aldenham Place
Spring, TX 77379
jray@houston.rr.com

Rex, Mike
University of Massachussetts

Rice, Kenneth
Section Leader
USGS Florida Integrated Science Center
3205 College Ave
Fort Lauderdale, FL 33314
ken_g_rice@usgs.gov

Rich, Mike
Assistant VP
Planning Systems, Inc
115 Christian Lane
Slidell, LA 70458
mrich@psislidell.com

Richardson, G Ed
MMS
139 Deerlake Drive
Asheville, NC 28803
ed.richardson@mms.gov

Richter, Christoph
Queen's University, Dept of Biology
116 Barrie Street
Kingston, ON K7L 3N6, CANADA
richterc@biology.queensu.ca

Robbart, Martha
Scientist
PBS & J
2001 NW 107th Avenue
Miami, FL 33172
mrobbart@pbsj.com

Roberts, Harry
LSU Coastal Studies Institute
335 Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
hrober3@lsu.edu

Roden, Carol L
MMS
1201 Elmwood Park Blvd, MS 5432
New Orleans, LA 70123
carol.roden@mms.gov

Root, Michelle
EEIT, MDEQ
101 W Capitol Street
Jackson, MS 39201
michelle_root@deq.state.ms.us

Rosa, Cathy
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
catherine.rosa@mms.gov

Ross, Steve
UNOC-W/USGS
Center for Marine Science
5600 Marvin Moss Lane
Wilmington, NC 28409
rosss@ucw.edu

Rouse, Lawrence J
Director
LSU Coastal Marine Institute
Howe-Russell Geoscience Complex
Baton Rouge, LA 70776
lrouse@lsu.edu

Rouse, Steve
Shell Inc
701 Poydras Street
New Orleans, LA 70161
steve.rouse@shell.com

Rowe, Casey J
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
casey.rowe@mms.gov

Rowe, Gil
Professor
Department of Oceanography
MS 3146 TAMU
College Station, TX 77843
growe@ocean.tamu.edu

Rueffert, Celeste H
MMS
381 Elden Street, MS 2100
Herndon, VA 20170
celeste.rueffert@mms.gov

Ruiz-Cooley, R Iliana
New Mexico State University
Biology Department MSC 3AF
Foster Hall - PO Box 30001
Las Cruces, NM 88003
riliana@nmsu.edu

Sammarco, Paul W
Professor, LUMCON
8124 Highway 56
Chauvin, LA 70344
psammarco@lumcon.edu

Sanders, Scott
BHP Billiton
1360 Post Oak Blvd, Suite 150
Houston, TX 77056-3020
scott.s.sanders@bhpbilliton.com

Schafer, Mark J
LSU
101 Agricultural Administration Bldg
Baton Rouge, LA 70803
mschaf1@lsu.edu

Schmahl, G P
NOAA/Flower Garden Banks NMS
4700 Avenue U, Building 216
Galveston, TX 77551
george.schmahn@noaa.gov

Schroeder, William
Professor Emeritus
University of Alabama
Dauphin Island Sea Lab
5000 CR 108
Salida, CO 81201
wschroeder@disl.org

Schweitzer, Peter
University of Alaska Fairbanks
Fairbanks, AK 99775
ffpps@uof.edu

Scott, Loren
LSU
Baton Rouge, LA 70803

Sears, Ashley P
Texas A&M
2001 Holleman, Apt 931
College Station, TX 77840
asears@tamu.edu

Seip, John
Environmental Specialist
Crescent Technology
1615 Poydras Street
New Orleans, LA 70112
john_seip@fmi.com

Shah, Arvind
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123-2394
arvind.shah@mms.gov

Shaw, Richard F
Director
LSU Coastal Fisheries Institute
CCEER Wetlands Building
Baton Rouge, LA 70803-7053
rshaw@lsu.edu

Shedd, William W
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
william.shedd@mms.gov

Shinn, Gene
University of South Florida
4727 Paradise Way Street
Saint Petersburg, FL 33705
eshinn@marine.usf.edu

Shirley, Thomas
Harte Research Institute, Texas A&M-CC
6300 Ocean Dr, Unit 5869
Corpus Christi, TX 78412
thomas.shirley@tamucc.edu

Shumate, Tina
Director
Misssissippi Dept of Natural Resources
1141 Bayview Avenue
Biloxi, MS 39532
tina.shumate@dmr.ms.us

Sinclair, James E
MMS
1201 Elmwood Park Blvd, MS 5432
New Orleans, LA 70123
james.sinclair@mms.gov

Singelmann, Joachim
Professor
LSU Dept of Sociology
126 Stubbs Hall
Baton Rouge, LA 70803
joachim@lsu.edu

Skrupky, Kimberly A
Marine Acoustics, Inc
4100 Farifax Dr, Suite 730
Arlington, VA 22203
kimberly.a.skrupky@marineacoustics.com

Slack, Tim
LSU
Baton Rouge, LA 70803

Slaski, Larry
MMS
381 Elden Street
Herndon, VA 20170
larry.slaski@mms.gov

Smartt, Kathy
Texas General Land Office
1700 N Congress Ave
Stephen F Austin Building
Austin, TX 78701
kathy.smartt@glo.state.tx.us

Smith, David
4940 Folse Drive
Metairie, LA 70006

Smith, David C
TAMU Oceanography
College Station, TX 77843
dcsiv@scylla.tamu.edu

Smith, Gregory J
USGS/National Wetlands Research Center
700 Cajundome Boulevard
Lafayette, LA 70506
gregory_smith@usgs.gov

Smith, Joseph P
ExxonMobil Upstream Research Co
PO Box 2189
Houston, TX 77252-2189
joe.p.smith@exxonmobil.com

St. Pe, Kerry M
Barataria-Terrbonne National Estuary Program
PO Box 2663
Thibodaux, LA 70301
kerry@btnep.org

Stallman, Cara
Natural Resource Planner
Alabama Dept of Conservation & Natural Resources
State Land Division
64 North Union Street
Montgomery, AL 36130
cara.stallman@dcnr.alabama.gov

Steyer, Gregory D
Wetlands Ecologist
USGS National Wetland Research Center
PO Box 25098
Baton Rouge, LA 70769
gsteyer@usgs.gov

Stradtner, Jason
GDIT/NCDDC
Building 1100, Room 101
Stennis Space Center, MS 39529
jason.stradtner@noaa.gov

Streever, Bill
British Petroleum
PO Box 196612
900 E Benson Blvd
Anchorage, AK 99519-6612
streevbj@bp.com

Strellec, Kristen L
MMS
1201 Elmwood Park Blvd, MS 5411
New Orleans, LA 70123
Kristen.Strellec@mms.gov

Sulak, Ken
Research Fish Biologist
USGS
Florida Caribbean Science Center
7920 NW 71st St
Gainesville, FL 32653
ksulak@usgs.gov

Sullivan, Jason
John Chance Land Surveys
200 Dulles Dr
Lafayette, LA 70506
jsullivan@jchance.com

Szabo, David
Woods Hole Group Institution
1640 W Sam Houston Parkway North
Houston, TX 77043
dszabo@whgrp.com

Tackett, Bruce A
ExxonMobil
3225 Gallows Road
Room 07D0427
Fairfax, VA 22037
bruce.a.tackett@exxonmobil.com

Teague, William J
Oceanographer
Naval Research Laboratory
Stennis Space Center
Code 7332
Stennis Space Center, MS 39529-5004
teague@nrlssc.navy.mil

Terrebonne, Bill
Regulatory Specialist
Shell E&P Company
701 Poydras St, Office 3410
PO Box 61933
New Orleans, LA 70161-1933
william.terrebonne@shell.com

Thode, Aaron
Scripps Institution of Oceanography
9500 Gilman Drive
MC 0213
La Jolla, CA 92093
thode@mpl.ucsd.edu

Thompson, Earl
Civil Engineer Technician
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
Earl.Thompson@mms.gov

Times, Wilfred W
MAU-Visual Information Specialist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
wilfred.times@mms.gov

Tsoflias, Sarah L
Vice President - Marine Environment
IAGC
PO Box 921
Lawrence, KS 66044
sarah.tsoflias@iagc.org

Tucker, Deborah
Department Environmental Protection
3900 Common Wealth Blvd, MS 47
Tallahassee, FL 32399-3000
toni.r.clanton@dep.state.fl.us

Tyack, Peter L
Woods Hole Oceanographic Institution
9 Maury Lane, MS 50
Woods Hole, MA 02543
ptyack@whoi.edu

Vasil, William
Air Quality Specialist
Ecology & Environment Inc
90 Broad St, Suite 1906
New York, NY 10004

Veil, John
Aragonne National Laboratory
955 L'Enfant Plaza SW, Suite 6000
Washington, DC 20024
jveil@anl.gov

Viada, Stephen
Senior Staff Scientist
Continental Shelf Associates, Inc
328 Aris Ave
Metairie, LA 70005
sviada@gs.net

Vigil, Debra
MMS
1201 Elmwood Park Blvd, MS 5431
New Orleans, LA 70123
debra.vigil@mms.gov

Volstad, Jon H
Principal Biometrician
Versar, Inc
9200 Rumsey Road
Columbia, MD 21045
jVolstad@versar.com

Voparil, Ian
Marine Scientist
Shell Global Solutions (US)
3333 Highway 6 South
EC - 135A
Houston, TX 77082
ian.voparil@shell.com

Waddell, Evans
SAIC
615 Oberlin Road
Suite 300
Raleigh, NC 27605
wwaddell@raleigh.saic.com

Walker, Nan
LSU Coastal Studies Institute
Dept of Oceanography
LSU Howe-Russell Geoscience Complex
Baton Rouge, LA 70803
nwalker@lsu.edu

Wallace, Barbara
MMS
381 Elden Street, MS 4041
Herndon, VA 20170
barbara.wallace@mms.gov

Wallace, Michael B
Environmental Protection Specialist
MMS
1201 Elmwood Park Blvd
New Orleans, LA 70123
michael.wallace@mms.gov

Wang, David
Research Scientist
Naval Research Lab
Building 1009
Stennis Space Center, MS 39529
dwang@nrlssc.navy.mil

Wang, Dong-Ping
Professor
Stony Brook University
Marine Sciences Research Center
Stony Brook, NY 11794
dong-ping.wang@sunysb.edu

Ward, Aaryn
LSU
126 Stubbs Hall
Baton Rouge, LA 70803
award11@lsu.edu

Wartzok, Douglas
Florida International University
University Park, PC 526
11200 SW 8th Street
Miami, FL 33199
wartzok@fiu.edu

Watts, Randolph
Professor
University of Rhode Island
Graduate School of Oceanography
215 South Ferry Road
Narragansett, RI 02882
rwatts@gso.uri.edu

Weber, Edward D
Senior Scientist
Versar, Inc
9200 Rumsey Road
Columbia, MD 21045
eweber@versar.com

Webster, Jill
Environmental Scientist
US Fish and Wildlife Service
7333 W Jefferson Avenue, Suite 375
Lakewood, CO 80235
Jill_Webster@fws.gov

Weil, Rick
Associate Professor
LSU Dept of Sociology
126 Stubbs Hall
Baton Rouge, LA 70803
fweil@lsu.edu

Wheeler, Neil JM
Sonoma Technology, Inc
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169
neil@sonomatech.com

Williams, Dee M
MMS
949 E 36th Ave, 3F
Anchorage, AK 99501
dee.williams@mms.gov

Wilson, Darcy
Program Manager
Eastern Research Group, Inc
1600 Perimeter Park Drive
Morrisville, NC 27560
darcy.wilson@erg.com

Wilson, Scott
Environmental Scientist
USEPA
1445 Ross Ave
Dallas, TX 75202
wilson.js@epa.gov

Winbush, Debra
Public Affairs Specialist
MMS
1201 Elmwood Park Blvd, MS 5000
New Orleans, LA 70123-2394
debra.winbush@mms.gov

Winsor, Martha
Research Assistant
Oregon State University
martha.winsor@oregonstate.edu

Wolfe, Jeff F
US Coast Guard
Coast Guard District Eight, Room 1341
500 Poydras
New Orleans, LA 70130-3396
jwolfe@d8.uscg.mil

Wrzyszczynski, Mark
Regulatory Engineer
Shell E&P Company
701 Poydras St
Room 3466
New Orleans, LA 70139
mark.wrzyszczynski@shell.com

Würsig, Bernd
Texas A&M University
MMR Program
4700 Avenue U, Building 303
Galveston, TX 77551-5932
wursigb@tamug.tamu.edu

Yetsko, Chris
Seadata Division Manager
Fugro GEOS
6100 Hillcroft
Houston, TX 77081
c.yetsko@geos.com

Young, John V
ExxonMobil Exploration Company
222 Benmar
Corp GP8-734
Houston, TX 77060
john.v.young@exxonmobil.com

Zambrano, Thomas
Senior Scientist, Energy & Environmental Technologies
AeroVironment, Inc
1960 Wlaker Ave
Monrovia, CA 91016
zambranot@avinc.com

Zapp, Michelle
Graduate Assistant
LSU Dept of Oceanography & Coastal Sciences
Baton Rouge, LA 70803
mzapp1@lsu.edu

Zhang, Xiaoqian
Texas A&M University
Dept of Oceanography
College Station, TX 77840
zhangxq@tamu.edu

Zielonka, Jeffrey
Penn State University
Science Park Court
State College, PA 16801
zielonka@meteo.psu.edu

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.