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Proceedings: Twenty-Second Annual Gulf of Mexico Information Transfer Meeting

January 2003

U.S. Department of the Interior
Minerals Management Service
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ACKNOWLEDGMENTS

The Minerals Management Service (MMS) thanks all Information Transfer Meeting participants. Recognition goes to the speakers whose timely individual and panel presentations stimulated discussions and exchange of information. We are grateful to the chairs and co-chairs for the many hours spent organizing and chairing the sessions and for spending time gathering presentation summaries. Joe Souhlas of the Multimedia and Internet Production Section of MMS Gulf of Mexico Region prepared a beautiful and informative exhibit. Preparation of the exhibit was coordinated by Susan Childs. The University of New Orleans, Office of Conference Services, was the contractor responsible for the meeting. The dedicated staff and subcontractors play an integral role in the execution of this meeting and the completion of the proceedings. Their tireless efforts are greatly appreciated. The staff of the Airport Hilton were personable and accommodating to our countless requests. Support funding is provided through the MMS Environmental Studies Program.

INTRODUCTION

This years Information Transfer Meeting (ITM) again brought together people from all over the country and the world to discuss the various topics funded by the Environmental Studies Program. As always, the ITM provides a forum where interchange on topics of current interest relative to environmental assessments of the offshore oil and gas industry can occur. The accomplishments of the MMS Environmental Studies Program for the Gulf of Mexico and of other research programs or study projects were presented. The ITM is a place to foster an exchange of information of regional interest among scientists, staff members, and decision-makers from MMS, other Federal or State governmental agencies, regionally important industries and academia. It is an opportunity for attendees to meet and nurture professional acquaintances and peer contacts.

The 22nd ITM focused on numerous topics from sperm whale research far offshore to studies of the coastal environment of Louisiana. Two sessions focused on air quality issues including the completion of offshore air emissions inventories. Presentations were given on the types of organisms that live on and around the numerous structures in the Gulf of Mexico including their biotechnology potential. Physical Oceanographers presented their most recent findings of the movement of currents in deepwater using various models. Benthic organisms from the deep Gulf of Mexico provided a lively discussion on taxonomy and sample analysis issues. The continuing expansion into deepwater with new technologies and issues were discussed.

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

SESSION 1A

RIG AND REEF ECOLOGY

Co-Chairs: Susan Childs, Minerals Management Service
Greg Boland, Minerals Management Service

Date: January 14, 2003

LONG-TERM REEF MONITORING OF THE EAST AND WEST FLOWER GARDEN BANKS: NEW DIRECTIONS

William F. Precht, Ecological Sciences Program, PBS&J
Richard B. Aronson, Dauphin Island Sea Lab
Ken J. P. Deslarzes, Marine Sciences Group, Geo-Marine Inc.

The coral reefs of the Flower Garden Banks (FGB) are the most sensitive biological habitats in federal waters of the Gulf of Mexico (GOM). Since 1973, Minerals Management Service (MMS; formerly Bureau of Land Management) has conducted a program of protective activities at those reefs. This program includes implementation of the Topographic Features Stipulation (No Activity Zone, 4-Mile Shunting Zone), and a long-term coral reef monitoring program in partnership with NOAA's National Marine Sanctuary Program. MMS mandates require monitoring of coral populations to detect incipient changes that may be caused by oil and gas activities. The goal of the program is to address concerns related to both gradual and punctuated degradation of these unique offshore ecosystems. These data are of value in assessing the impacts of industrial activities and in resource management.

The FGB monitoring program has been continuously funded since 1988 by MMS and NOAA. Two sites, each 100 m x 100 m and 18-25 m deep, have been monitored over that period: one on the East FGB and the other on the West FGB. The two sites remain in excellent condition. Their status contrasts with reports of reefs in crisis throughout the southern GOM, the western Atlantic, and the Caribbean region. Across the Caribbean, regional disease outbreaks have changed the structure and function of reefs over relatively short time scales, and while scientists observed the changes they still do not completely understand the causes. Probable reasons for the exceptional condition of the FGB include 1) the water depth of the reefs, which buffers them from the effects of storm waves and anomalously high sea temperatures; 2) the lack of acroporid corals, which have suffered catastrophic levels of mortalities throughout the Caribbean; 3) the remote, offshore location of these reefs, which provides a water column characterized by oligotrophic, oceanic water; and 4) protective federal regulations, which prevent hydrocarbon-related impacts, and impacts caused by fishing and recreational diving activities.

In the early 1980s, a water-borne pathogen killed almost all the *Diadema antillarum* in the western Atlantic-Caribbean region, including the reefs of the FGB. This echinoid species had been one of the most important reef herbivores, so its disappearance increased macroalgal abundance on reefs where coral mortality had previously opened large areas of space. Recovery of *D. antillarum* has begun at a few locations in the eastern Caribbean. At present, however, populations on the FGB remain depressed. Pre-1983 population densities on *D. antillarum* from the FGB were measured at >1.0 ind/m^2 (Gittings, personal communication). These are contrasted with present day populations of ~0.02 ind/m^2.

Beginning in the 1970s and continuing through today, diseases or disease-like syndromes have appeared in many coral species throughout the western Atlantic and Caribbean. Although coral diseases are present in the FGB, their prevalence is low compared to most other reefs that have been surveyed. The short- and long-term impacts of coral diseases on populations remain difficult to assess, but disease is clearly a factor in the mortality of some corals on the FGB. Specifically, plague-like syndromes were observed on a number of coral species including the *Montastraea annularis* species complex, *Montastraea cavernosa, Colpophyllia natans*, and *Diploria strigosa*. Environmental stressors such as pollution, nutrient loading, African dust, and elevated temperature could be associated with disease outbreaks and other types of stress, yet no firm connections have been established. In addition to disease, widespread coral bleaching in response to anomalously high summer-season temperatures has become more frequent since the early 1980s. Bleaching episodes on reefs in the western Atlantic-Caribbean region, including the FGB, have generally been followed by recovery of most of the affected coral colonies (Hageman and Gittings 1992; Aronson *et al.* 2002). Other causes of coral mortality on the FGB include concentrated spot-biting by parrotfish, resulting in large lesions on head corals, as well as the impacts of damselfish territories, which result in patchy areas of coral mortality and algal growth on affected colonies.

Remarkably, no significant long-term changes have been detected in coral reef populations, total coral cover, or coral species diversity at the FGB since quantitative surveys of the reefs began in 1988. Percent coral cover on these reefs is among the highest measured in the entire region. These reefs, therefore, are potentially excellent models for understanding future patterns on reefs throughout the region and their causes. We are using four different methods to calculate benthic community structure at the study sites. These techniques have resulted in similar results: corals are the dominant cover on both reefs, accounting for over 50% cover in both cases. A category comprising bare rock and turf-covered rock was the second-most prevalent at ~ 25%, followed by crustose coralline algae at ~15%. Macroalgae and filamentous algae were next in abundance at ~5%, followed by sponges, which accounted for ~1% of total cover.

What MMS has primarily gained from 10+ years of monitoring is the quantitative and temporal assessment of coral cover, diversity, growth, and condition (bleaching, diseases, etc.) within restricted areas and narrow depth ranges (0.5% of the East FGB reef cap surface, and 1.7% of the West FGB; 18-25 m). It is tempting to extrapolate the monitoring results of Gittings *et al.* (1992), CSA (1996), and Dokken *et al.* (1998) and conclude based on surveys of the two study plots that the coral reef ecosystems contained within the 15-48 m depth range on both banks are in excellent condition. Although these are important and valuable data, their generality is uncertain. Their value and utility will be increased by the current programmatic additions of increased survey area and hypothesis-driven monitoring.

William F. Precht is a carbonate sedimentologist by training and has been studying coral reefs since 1978. His research areas include the Bahamas, Belize, Florida, Jamaica, Mexico, Puerto Rico, U.S. Virgin Islands and most recently the Flower Garden Banks National Marine Sanctuary in the Gulf of Mexico. 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 novelty and ecological importance of many of the recent maladies affecting Caribbean coral reefs. He is now developing cutting-edge assessment and restoration strategies for reefs impacted by various, anthropogenic sources, especially ship-groundings. This work includes providing expert assistance to a wide array of both national and international clients. Since completing his graduate degree in marine geology and geophysics from the University of Miami's Rosenstiel School of Marine and Atmospheric Science, Mr. Precht has worked as an environmental scientist specializing in the assessment, restoration and rehabilitation, and long-term monitoring of various coastal resources, especially coral reef, seagrass, and mangrove systems. He serves as the Ecological Sciences Program Manager for the firm PBS&J in Miami, Florida. In addition to these duties, Bill maintains status as a Visiting Research Scientist with the Smithsonian Institution's Caribbean Coral Reef Ecosystem Program and as an Adjunct Faculty to Northeastern University's East/West Marine Science Program, where he teaches a course in coral reef geology and ecology every winter quarter. To date, he has published over 125 peer reviewed scientific journal articles and abstracts and has presented over 95 invited lectures to universities, professional societies, and organizations.

CORAL COMMUNITIES AND RECRUITMENT ON OFFSHORE DRILLING PLATFORMS IN THE NORTHERN GULF OF MEXICO: SUMMARY

Paul W. Sammarco, Louisiana Universities Marine Consortium (LUMCON) and
Department of Oceanography and Coastal Sciences, Louisiana State University
Amy D. Atchison, Department of Oceanography and Coastal Sciences, Louisiana
State University and Louisiana Universities Marine Consortium (LUMCON)

Approximately 4000 drilling platforms currently exist in the northern Gulf of Mexico (GOM). These platforms provide hard substratum which extend well into the euphotic zone, in a region where such has been historically rare or absent in recent geological time. The major exception to this pattern is those coral reefs called the Flower Garden Banks (FGB), 110 nm S-SE of Galveston, TX. These platforms have been found to harbor scleractinian corals and other reef organisms. The purpose of this study was to determine whether coral populations exist on these platforms, to quantify them, and to determine levels and patterns of coral settlement on the platforms. We also attempted to determine how these coral community parameters may relate to distance from the Flower Garden Banks, platform age, and depth.

Data collection was done through visual surveys performed by SCUBA diving teams on 13 drilling platforms. These platforms fell within an ellipse extending 15 km W, 45 km E, and 15 km N of the FGB. In addition, two coral settlement racks made of galvanized steel were implanted at depths of 11–16 m on horizontal support beams inside each platform jacket. Each rack housed four terracotta plates, mounted on stainless steel pins at an angle 45° to the horizontal, providing the preferred substratum angle for the coral larvae. Plates were processed with a dissecting microscope in the laboratory, and coral spat were identified to genus and species.

In no case was distance from the Flower Garden Banks found to be related to any of the coral community parameters measured. This included total coral abundance, as well as abundance of *Madracis decactis, Diploria strigosa,* and *Tubastrea coccinea*. No relationship between coral abundance and distance was evident in shallow water ($\leq$ 27 m), deepwater (> 27 m), or both depths combined. In addition, distance from the FGB was unrelated to total coral species diversity (S). On the other hand, the age of the drilling platform was found to be significantly related to a number of coral community variables. Total coral abundance increased significantly with increasing platform age, whether in shallow water, deepwater, or with both depths combined. This relationship was also found to occur between platform age and abundance of *Madracis decactis*. The same significant positive relationship was found to occur between platform age and coral species diversity (S). There was no significant relationship, however, between abundance of *Diploria strigosa* and platform age, nor was such evident in *Tubastrea coccinea*.

All corals were found to have a significantly non-uniform depth distribution on the platforms, with total coral abundance exhibiting peak abundances at 10 and 20 m depth. *Diploria strigosa* exhibited a similar pattern of peaks. *Madracis decactis,* however, exhibited peak abundances at $\geq$ 27 m. *Tubastrea coccinea* exhibited peaks at 15–18 m.

Coral recruitment was rare on the plates processed from the five platforms sampled thus far. Only nine spat were found, seven of which were *Tubastrea coccinea* and two were *Madracis decactis*. No pioneer species, such as *Agaricia* spp. or *Porites* spp., were found on the settlement plates. It is believed that this extraordinary result is at least partially due to the distance of the platforms from the FGB and the effect of diffusion on the larvae after their release from that area. Very few adult *Porites* were found on the platforms, and no *Agaricia*. This situation represents an unusual situation for both coral recruitment and the development of coral community structure when compared to patterns observed on the Flower Garden Banks and a variety of Caribbean reefs.

Paul W. Sammarco is a Professor at the Louisiana Universities Marine Consortium (LUMCON) in Chauvin, Louisiana, USA. He has been conducting research on coral reef ecology for 30 years, in the western Atlantic (Caribbean, Gulf of Mexico, and the Bahamas) and on the Great Barrier Reef, Australia. Dr. Sammarco has served an Assistant Professor at Clarkson University (NY), a Senior Research Scientist at the Australian Institute of Marine Science, and Executive Director and Research Professor at LUMCON. He also served as Director of Environmental Research for the Department of Prime Minister and Cabinet in Australia for several years.

Amy Atchison is currently conducting research toward her master's degree in the Department of Oceanography and Coastal Sciences at Louisiana State University in Baton Rouge, Louisiana. Under the supervision of Professor Paul W. Sammarco, she is studying community structure, recruitment, and the molecular genetics of corals on drilling platforms in the northern Gulf of Mexico. She received her B.Sc. in biology at Louisiana Tech University in Ruston, Louisiana, where she received numerous honors and awards. She has also served as a research intern and research technician at Louisiana Universities Marine Consortium, (LUMCON) and as a teaching assistant in LUMCON's Coral Reef Ecology course. Additionally, she has taught at LUMCON, Harbor Branch Oceanographic Institute, and the Mote Marine Laboratory Center for Tropical Research.

SONNIER BANK: REEF FISH POPULATIONS AND NATURAL AND ARTIFICIAL HABITAT

Charles A. Wilson and Mark W. Miller,
Coastal Fisheries Institute, Louisiana State University

There are more than 4000 oil and gas platforms in the northern Gulf of Mexico (GOM) and an estimated 2900 square kilometers of naturally occurring hard bottom of various types. The large number of platforms notwithstanding, they only account for < 2 % of the hard substrate; yet they appear to harbor much larger numbers of fish species and individuals than do natural hard substrates. To further study and compare the fish habitat value of oil and gas platforms to natural reefs, we recently conducted a hydroacoustic and video survey of fish populations on Sonnier Bank, a natural reef. The results of these surveys were compared to those of earlier fish surveys on the natural reefs at the West Flower Garden Bank (WFGB), two nearby artificial reefs (WC 617 and HI A355) and to an active oil and gas platform (HI A350) located just to the north of the WFGB. These study sites are all in the northern Gulf and offshore of the Texas/Louisiana border.

Sonnier Bank is made up of several small, steep pinnacles and covers an area of 20 square kilometers. The WFGB is the northernmost living coral reef in the GOM and covers 140 square kilometers. The two artificial reefs are retired oil platforms that have been converted to a reef configuration; WC 617 (5100 m^2 footprint) is an eight-pile structure that was toppled in place in 98 m water depth and HI A355 (2400 m^2 footprint), also an eight pile structure, was left standing in place in 90 m of water with only the upper 30 m of the jacket removed. HI A350, the operating platform, is at a water depth of 90 m and has a footprint of 2100 m^2.

Surveys were conducted with dual-beam hydroacoustics to determine the number, location, and size of fish and with a video camera-equipped remotely operated vehicle (ROV) to collect video images that allowed us to determine species composition. Four transducers were used at the standing platform, one on each side of the structure looking down through the water column. A single transducer towed in a grid pattern behind a vessel (mobile hydroacoustics) was used at the other sites of the study area.

Initial results from Sonnier Bank show a greater density of fish than those seen at WFGB and numbers of fishes approaching that observed at some operating oil and gas platforms. Species composition was not as diverse as at WFGB and creole-fish *Paranthias furcifer* composed the greatest percentage of individuals present. Red snapper *Lutjanus campechanus* was the second most abundant species, and it occurred on the deeper pinnacles of Sonnier Bank. Some of the pinnacles at Sonnier Bank rise from the seafloor to within 16 m of the surface. Because of the relatively small size and steeps side of these features, they closely resemble the shape of partially removed platforms sited as artificial reefs, especially those left standing with just the upper 30 m of the jacket removed.

The WFGB was formed by uplift of a salt dome and is divided into three terraces based on biotic zonation: upper (20–50 m), middle (50–80 m), lower (80–100 m). We found that the upper terrace had 35-100 times more fish than the middle and lower terraces with the largest fish located near the sea surface. However, total numbers of fishes were only a fraction of those found at oil and gas platforms. We estimated that there were 2.5 million fish associated with the WFGB. Based on ROV video, the most common species present were Bermuda chub *Kyphosus sectatrix* and creole-fish.

Both artificial reef sites had higher fish densities than the WFGB but slightly lower than Sonnier Bank. Species observed at the artificial reefs were different from those at the natural reefs and included greater amberjack *Seriola dumeril*, red snapper, almaco jack *Seriola rivoliana*, and scamp *Mycteroperca phenax* as the most abundant. As with the natural reefs, fish were most common directly above the structure or adjacent to it near the bottom.

The active platform, HI A350, had the greatest fish density of all the surveyed sites with densities 100 times greater than that observed at the natural reefs and 1000 times greater than the surrounding sand and mud bottoms. Species composition of this site most closely resembled the natural reefs with pelagic planktivores, primarily Bermuda chub, comprising 50% of the fish population. These fish were located within the upper 25 m of the water column; red snapper, creole-fish, and greater amberjack were most abundant at greater depths.

We determined that there were more fish at the active platform than at either the partially removed or toppled artificial reef sites. In fact, converting an active platform to an artificial reef displaced 50-80% of the total fish population, but the species lost were the pelagic species. The composition of the commercially valuable species such as grouper and snapper remained largely unchanged.

Charles A. Wilson is a Professor in the Coastal Fisheries Institute and the Department of Oceanography and Coastal Sciences at Louisiana State University. Dr. Wilson has authored over 100 publications and reports dealing with artificial reef ecology and development, fish life history, mariculture, and most recently the relationship between artificial reefs (oil and gas platforms), natural reefs and associated fish communities. In 1985 he helped establish the Louisiana Artificial Reef Initiative, which explored and led to the development of the Louisiana Artificial Reef Program (the Louisiana Fishing Enhancement Act of 1986). Over the past 17 years he has served on a number of state and federal advisory boards, panels, and committees concerned with fishery management and habitat issues in the northern Gulf of Mexico. He currently serves as Interim Vice Provost of Academic Affairs at LSU.

FEEDING HABITS OF ADULT BLUE RUNNER NEAR PLATFORMS IN THE NORTHERN GULF OF MEXICO: DIEL PATTERNS, PREY SHIFTS AND SIZE SELECTION

Sean F. Keenan and Mark C. Benfield,
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ABSTRACT

The feeding habits of adult blue runner, *Caranx crysos* (Carangidae), were evaluated near offshore platforms in the northern Gulf of Mexico (GOM). Fish were collected near two platforms (VK203A and MP140A) and in open waters during the summer months of 2000. Meso- and macro-zooplankton comprised a large proportion of the diets of platform-associated and open-water blue runner. Decapod crustaceans, hyperiid amphipods, and chaetognaths, as well as small fishes and cephalopods formed the majority of blue runner diets. Diel sampling indicated that blue runner fed mostly during dusk, pre-dawn and dawn hours. Feeding occurred at lower levels during the day. Blue runner consumed primarily fish, decapod crustaceans, and cephalopods during the nighttime and zooplankton during the day. Platform-associated blue runner appeared to select larger sized prey items at night versus the daytime. Platforms may be functioning as passive plankton accumulators through hydrodynamic and illumination effects, which provide blue runner with an enhanced feeding environment.

INTRODUCTION

The offshore petroleum platforms in the northern GOM have been described as the largest unplanned artificial reef complex in the world (Kasprzak 1998, Stanley and Wilson 1998). These structures have been estimated to provide roughly 5000 km^2 of hard substrate (Kasprzak 1998), thereby substantially increasing available reef-like habitat. The platform's underwater jacket structure extends from the seafloor into the photic zone providing a unique habitat for encrusting organisms as well as reef-associated fish species. In addition to the reef community, pelagic fish species (i.e. jacks, spadefish, mackerels, and tunas) are often associated with these structures (Seaman *et al.* 1989), and schools often reach many thousands of individuals (Stanley and Wilson 2000).

Understanding how these large numbers of fish are sustained is important in evaluating platforms as productive reef habitats. Artificial reefs and fish attraction devices (FADs) are hypothesized to increase productivity through trophic linkages through provision of additional food and/or increased feeding efficiency (Bohnsack 1989). Platforms may also function in a similar manner to other artificial structures. Few studies have investigated the feeding habits of the highly abundant species of fish around offshore platforms in the GOM.

The blue runner, *Caranx crysos*, is a pelagic species commonly found around platforms as well as in open waters of the GOM (Sonnier *et al.* 1976, Stanley and Wilson 2000). This medium-sized (approximately 200–400 mm fork length (FL)) carangid is often found in large schools and ranges from Nova Scotia to Brazil (McKenney *et al.* 1958). A limited commercial fishery exists in the U.S. and an artisanal fishery is present in South America (Cervigón *et al.* 1993). Recreational anglers near Louisiana platforms frequently use blue runner as baitfish because of their abundance, hardiness, and attractiveness to larger gamefish. Stanley and Wilson (2000) found that blue runner numerically constituted up to 94% of the fish assemblage found near a mid-shelf platform (GI94B) off Louisiana and school sizes commonly reached over 10,000 individuals.

We hypothesize that platforms may provide blue runner with an enhanced feeding environment. Blue runner are likely visual planktivores that naturally forage during daylight hours in ambient light. Platforms are well illuminated at night and this artificial light field may allow blue runner to forage throughout the day and night. In addition, these large, lighted structures potentially attract different prey taxa at night, and this may influence blue runner feeding intensity and/or prey selectivity over the course of the diel cycle. The objectives of this study were to (a) describe the feeding habits of platform-associated and open-water adult blue runner; (b) evaluate diel feeding periodicity and daily variation in blue runner feeding habits; and (c) examine variations in prey size selectivity over the course of the day.

METHODS

Blue runner were collected during a series of cruises in the northern GOM from June to August 2000. Cruises were made aboard an 11.3 m charter-fishing vessel. Two mid-shelf platforms served as primary sampling sites: Viosca Knoll 203A (VK203A) located approximately 70 km south of Dauphin Island, Alabama (29.7816°N, 88.3330°W) and Main Pass 140A (MP140A) located approximately 30 km east of Venice, Louisiana (29.2947°N, 88.8612°W). In addition, one cruise was dedicated to collecting blue runner from open water, which was defined as a distance greater than 2.40 km from the nearest platform. Blue runner were collected using hook and line angling with artificial lures. Upon capture, mass, length, sex and time of capture were recorded for each fish. Stomach contents were preserved in buffered formalin for 48 hours and then stored in 70% ethanol for subsequent examination and identification of contents.

Stomach contents were examined under a dissecting microscope and identified to the following taxonomic categories: hyperiid amphipods, larval and adult decapods and larval stomatopods (hereafter referred to as decapods/stomatopods), chaetognaths, cephalopods, fish, other invertebrates (e.g. thecosomate pteropods, copepods, polychaetes) and unidentified material. The number of prey for each category and the total wet mass per category were recorded to the nearest milligram to provide a numerical and mass-based contribution of each prey category. To examine prey size selection, the decapods/stomatopods and fish prey categories from blue runner collected during two cruises were measured using a digital camera/microscope system (Pixera VCS 1.2.3) and image processing software (NIH Image 6.12).

During one cruise to VK203A, continual sampling of blue runner allowed evaluation of feeding periodicity over a complete 24 h cycle. During this cruise, approximately ten fish were caught every two hours and the stomachs were removed following the above protocol. A stomach fullness value was computed by dividing the wet weight of all the prey taken from each stomach by the corresponding weight of the empty stomach (modified from Juanes and Conover 1994). A stomach fullness index was then computed by dividing the fullness value from each fish by the maximum fullness value observed during the sampling. To evaluate blue runner diet composition over the diel cycle, we pooled the weight of fish and cephalopods to represent nektonic prey and zooplankton prey weight (i.e. decapods/stomatopods, hyperiid amphipods, chaetognaths, other invertebrates) for planktonic prey. The wet weight contribution of the two prey groups (fish/cephalopods and zooplankton) was computed for each blue runner within every two-hour time block. A qualitative estimation of prey switching was determined by averaging weight contributions of these two categories for all blue runner within each time block.

RESULTS

A total of 205 blue runner were caught near platforms, while 14 were taken from open-water environments. Relatively few open-water blue runner were collected because high sea states made it difficult to locate surface schools during most trips and fish in surface schools that were located were generally difficult to catch, possibly because of avoidance reactions to the vessel. The majority of open-water blue runner (n=11) were taken from a single school encountered during the open-water cruise. Mean blue runner lengths were 282.0 mm FL (±2.8 mm SE) from platform waters and 301.8 mm FL (±7.4 mm SE) from open waters. At least 20 blue runner were collected during each cruise to platforms; however, the majority of fish (n=117) were collected during the diel sampling study at VK203A.

The majority of platform-associated and open-water blue runner diets consisted of zooplankton (i.e. decapods/stomatopods, hyperiid amphipods, chaetognaths, other invertebrates). Based on the stomach contents of blue runner collected during all cruises, zooplankton made up 81%, 90% and 97% of the numerical composition of blue runner diets at VK203A, MP140A and in open waters, respectively (Figure 1A.1). Percent composition by prey weight also indicated that zooplankton constituted a large portion of the diet. Excluding unidentified prey, zooplankton formed 43% of the weight of blue runner diets at VK203A and MP140A and 56% of the weight of the diets of the open-water fish. The majority of zooplankton prey weight consisted of decapods/stomatopods for both platform and open-water fish. Open-water blue runner had greater amounts of chaetognaths in their stomachs (20% by weight) than platform blue runner. Unidentified tissue, which could not be placed into a specific prey category, remained relatively consistent between platforms and open-water fish (approximately 30–40% of total prey weight).

Blue runner did not exhibit a statistically significant peak in feeding during the diel sampling trip (Figure 1A.2), however, the pattern of gut fullness values indicated elevated feeding intensity during early evening and pre-dawn hours. Gut fullness values during the 02:00–03:00 h (0.186 ± 0.096) and 04:00–05:00 h (0.139 ± 0.039) suggested that blue runner could feed at greater levels at night than during the day. The gut fullness value during 18:00–19:00 h (0.142 ± 0.084) also indicated that blue runner feed at dusk. Stomach fullness from the 11 fish caught during the open-water trip had comparable fullness values (0.105 ± 0.018) to blue runner caught during the same time of day (18:00–19:00 h) on the diel trip.

Stomachs of blue runner caught during the diel sampling study contained prey of nektonic (fish and cephalopods) and planktonic (zooplankton) forms, however, the gravimetric contribution of these two prey groups shifted over the course of 24 hours (Figure 1A.3). Zooplankton were more prevalent in the diet during daytime hours and a shift towards fish/cephalopod prey occurred at night. Blue runner from the open-water school (n = 11) contained similar gravimetric proportions of fish (4.7%) and zooplankton (55.9%) prey as blue runner collected during the same time of day (18:00–19:00 h) from the diel sampling study at VK203A.

Blue runner around platforms exhibited size selective feeding for intermediate sized decapods and smaller fish during the day. Blue runner selected for 8–12 mm decapods during the day and decapods greater than 17 mm at night (Figure 1A.4). Evaluation of size selection for different sized fish prey was constrained because fewer blue runner stomachs contained fish prey. During the day, blue runner selected primarily for larval fish ranging in size from 4 mm to 14 mm length (Figure 1A.5). At night blue runner fed almost exclusively on fish larger than 17 mm. These fish prey included larval and adult forms such as herrings and codlets.

DISCUSSION

Zooplankton appear to comprise a large proportion of the diets of blue runner near platforms and in open waters of the GOM during summer months. Dietary analysis supported previous observations of zooplanktivory by blue runner at other platforms in the northern GOM (Keenan *et al.* 2000). Blue runner collected from open waters appeared to forage mostly on zooplankton; however, the proportions of zooplankton taxa in the diet differed (e.g., dominance of chaetognaths) from platform-associated fish. The limited number of blue runner collected from open waters prevented definitive conclusions about the diets of these fish. It should be noted that the majority of open-water fish were taken from one school and, therefore, may not represent the feeding habits of other open-water schools.

Enrichment of food resources has been proposed as one hypothesis for increased numbers of fishes near structures like FADs, artificial reefs and offshore petroleum platforms (Gallaway 1981, Deudero 2001). In a study of the feeding habits of yellowfin tuna, *Thunnus albacares*, near FADs off Hawaii, Brock (1985) found that these fish exhibited a dietary shift to oplophorid shrimps when compared to non-FAD-associated tuna, which fed primarily on fish. Brock stated, however, that sonar surveys did not indicate that oplophorid shrimps aggregated beneath the FAD. Greater amberjack, *Seriola dumerili*, studied near artificial reefs in the GOM, were defined as “reef-associated open-water feeders” foraging primarily on schooling fishes and squid (Nelson and Bortone 1996). However, Gallaway (1980) noted that amberjack and almaco jack, *S. rivoliana*, near platforms off the Texas coast often consumed blennies, which are associated with the biofouling community of the structure. In our study, blue runner from both open waters and near platforms foraged primarily on decapods/stomatopods although chaetognaths, hyperiid amphipods and fish prey (including blennies) were also important in the diet. Offshore platforms are different from FADs and artificial reefs in that they possess a complex sub-surface architecture and powerful lights, which illuminate surrounding waters at night. These factors may influence prey distributions and facilitate blue runner foraging, especially at night.

Blue runner are likely visual predators; however, results indicated that they are capable of feeding throughout the night near platforms. Although a distinct peak in nocturnal feeding was not observed during the 24 h-sampling trip, gut fullness levels were greatest during dawn and pre-dawn hours, suggesting nocturnal foraging. Another peak in feeding during the diel sampling occurred near dusk, potentially indicating crepuscular feeding, which has been reported for other carangids. Popova and Sierra (1985) reported morning and evening peaks in feeding for young black jack, *Caranx ruber*, in Cuban waters. Open-water blue runner, collected during the late afternoon and early evening (18:00 to 19:00 h) had gut fullness values similar to fish collected at the same time of day near VK203A.

Blue runner collected during the diel sampling trip shifted their diets from large gravimetric proportions of zooplankton during the daytime to fish/cephalopods at night. The zooplankton consumed during the day were mostly decapods and larval stomatopods, hyperiid amphipods, and pteropods. During the night, blue runner foraged on many species of fishes, including herrings (Clupeidae), codlets (Bregmacerotidae), butterfish (Stromateidae), and flatfishes (Bothidae). While these fishes are not identified as platform-dependent (Hernandez 2001), the lights from platforms may attract these fish making them more susceptible to predation.

During the daytime, blue runner around platforms selected for small to intermediate sized decapods ranging in size from 8 mm to 12 mm in length. Fish prey consumed during the day ranged between 4–8 mm suggesting that blue runner were feeding on similar sized decapod/stomatopod and fish prey during the daytime. At night, prey from both categories were generally greater than 17 mm and some prey were considerably larger at > 40 mm. Similarly to the diel shift in prey, blue runner foraged on larger nektonic decapods and fish at night and predominately passively transported planktonic prey during daytime hours. Since the majority of open-water blue runner were collected from one school in the early evening, the nocturnal feeding habits of open-water blue runner remains unknown.

Blue runner displayed a shift in foraging from smaller zooplankton prey during the daytime to larger sized prey at night, which supports the visual predation hypothesis. The lights of the platform may influence the distribution of prey by attracting these smaller forage fishes and cephalopods. Alternatively, the lights may provide blue runner with enough illumination to extend foraging into the night. Thus, the platform structure provides an altered environment where blue runner are not restricted to feed only during the daytime as may be the case in open-water environments.

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A COMPARISON OF EPIFAUNAL COMMUNITIES ON DEEPWATER REEFS IN THE NORTHEAST GULF OF MEXICO

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The Coastal Ecology & Conservation Research Group has been studying hard-bottom areas on the northwest Florida shelf for the last three years. The research aims at providing an understanding of the key biological communities and critical habitats including examining their link to physical process. This study is an effort to help address MMS information needs in the northeast Gulf of Mexico (GOM). One specific objective of these efforts has been to determine the community structure of epifaunal assemblages on these hard bottom areas. Previously, two studies have been conducted which describe epifaunal assemblages on the west side of the DeSoto Canyon. The first study entitled the "Mississippi-Alabama Continental Shelf Ecosystem Study" (MAMES) was conducted by Texas A&M in 1992 and documents the influence of the Mississippi River upon the hard-bottom reef assemblages in that area. The second study was entitled the "Mississippi/Alabama Pinnacle Trend Ecosystem Monitoring Study" (MAPTEM) and was conducted by both Continental Shelf Associates, Inc. and Texas A&M University. The MAPTEM study was performed to relate large-scale habitat features (habitat relief, sedimentation) to community assemblage patterns. This presentation is a synthesis of the dominant epifaunal community found on the East side of the DeSoto Canyon. Emphasis was placed upon comparing how epifauanal assemblages on the northwest Florida shelf compare to the Pinnacles (Mississippi/Alabama shelf) region (Figure 1A.6). Data from the Madison-Swanson Northridge, Madison-Swanson Southridge, and Coral Trees reefs are presented in this study.

Two types of data were collected to determine the dominant epifaunal community. At each sampling location, an ROV was used to first determine the frequency of occurrence for each taxa. Using a multibeam and/or sidescan map of the bottom a random point on presumptive hard-bottom was selected prior to each ROV dive. The research vessel would then anchor at the location and the ROV was deployed. Once on the bottom, the ROV operator was given a random direction to follow and the ROV was piloted along that trajectory at a constant speed for two minutes. Twelve replicate transects were conducted per dive. The video was then reviewed and all epifauna were identified to lowest possible taxon and enumerated.

The second method of data collection was to quantify the percent cover of the dominant epifauna using a digital still camera. As with the transect method, the ROV operator was given a random direction to follow for a random amount of time (0–2 min).

A downward looking image of the bottom (0.25 m2)was then taken from a consistent distance above the bottom. On each dive, 20–30 photographs were taken for percent cover analysis. The pictures were then analyzed for percent cover using a random point intercept method (Point Count Program – EPA Coral Reef Monitoring Program).

A detailed summary of the results is presented in Table 1A.1. Overall, the frequency of encrusting algae, sponges, octocorals, and cup corals is greater on the northwest Florida shelf than in the Pinnacles area. Compared to the Pinnacles, the percent cover of encrusting algae and encrusting sponges is also greater on the northwest Florida shelf. Percent cover of cup corals and antipatharians, however, is greater in the Pinnacles area. Crinoids, which occur occasionally in the Pinnacles, are almost absent on the northwest Florida shelf.

Table 1A.1. A comparison of epifaunal assemblages on the northwest Florida shelf compared to the Pinnacles area.

Taxa	**NW FL Shelf Compared to Pinnacles (MAMES)**	**NW FL Shelf Compared to Pinnacles (MAPTEM)**
Encrusting Algae	Greater Frequency on the NW FL Shelf	Greater Percent Cover on the NW FL Shelf
Encrusting Sponge	Greater Frequency on the NW FL Shelf	Greater Percent Cover on the NW FL Shelf
Antipatharians	Similar Frequency on the NW FL Shelf	Decreased Percent Cover on the NW FL Shelf
Ocotocorals	Greater Frequency on the NW FL Shelf	Similar Percent Cover on the NW FL Shelf
Erect Sponges	Greater Frequency on the NW FL Shelf	Similar Percent Cover on the NW FL Shelf
Cup Corals	Greater Frequency on the NW FL Shelf	Decreased Percent Cover on the NW FL Shelf
Crinoids	Decreased Frequency on the NW FL Shelf	Decreased Percent Cover on the NW FL Shelf

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Robert Allen Brooks received a B.S. in biology from Ohio University in 1994, a M.S. in zoology from the University of South Florida in 1997, and a Ph.D. in biology from the University of South Florida in 2001. He was hired in March of 2002 as a Research Benthic Ecologist at the U.S. Geological Survey's Florida Integrated Science Center.

SESSION 1B

EXPLOSIVE REMOVALS OF OFFSHORE STRUCTURES (EROS) STUDIES

Co-Chairs: Jeff Childs, Minerals Management Service
Sarah L. Tsoflias, Minerals Management Service

Date: January 14, 2003

NON-EXPLOSIVE REMOVAL OF OFFSHORE STRUCTURES

Robert C. Byrd, Twachtman Snyder & Byrd, Inc.

This presentation summarizes the results of the MMS study on "Operational and SocioEconomic Impact of Non-Explosive Removal of Offshore Structure," which is being conducted by Twachtman Snyder & Byrd, Inc. (TSB) jointly with LSU's Center for Energy Studies (CES). Dr. Mark Kaiser of CES is co-principal investigator for the study. The presentation reviews the objectives of the study and the major conclusions.

The relative socio-economic impact of mechanical, water jet abrasive, and diamond-wire cutting technologies will be discussed in the context of offshore platform decommissioning. Socio-economic impact of particular removal techniques such as jacket "hopping"—or "shallowing-up"—was discussed, and the preliminary conclusions of the study were presented.

Robert Byrd is a Principal at Twachtman Snyder & Byrd, Inc., of Houston, Texas. He is a former Coast Guard officer and has over twenty years of experience in the offshore oil and gas industry. For the past nine years he has focused on offshore platform decommissioning and has been project manager for a number of projects in this area. He was project manager for the MMS Technology Assessment and Research (TA&R) Program project "State of the Art of Removing Large Platforms Located in Deep Water," which was completed in September 2000. Dr. Byrd is currently the co-principal investigator for the MMS study on "Operational and SocioEconomic Impact of Non-Explosive Removal of Offshore Structure," which is being conducted jointly with LSU's Center for Energy Studies.Dr. Byrd received his B.S. in marine engineering from the U.S. Coast Guard Academy, New London, Connecticut and his Ph.D. in engineering at the University of California, Berkeley, where he was a Hans Albert Einstein Fellow in Hydraulic and Ocean Engineering.

A BINARY CHOICE SEVERANCE SELECTION MODEL FOR THE REMOVAL OF OFFSHORE STRUCTURES IN THE GULF OF MEXICO

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ABSTRACT

The decision to use explosive versus nonexplosive severance techniques to decommission an offshore structure will depend on the outcome of a risk-based comparative assessment involving cost, safety, technical, environmental, operational and managerial considerations. This paper describes the factors involved in the decision to use explosive/nonexplosive severance methods, to quantify the probability that a structure will be removed with explosive technology, and to develop a predictive model of the decision to use explosive methods. An empirical analysis of oil and gas structures removed in the Gulf of Mexico between 1986–2001 provides the historic data required to compute the probability of an explosive removal and to estimate binary choice models for severance selection. Binomial logit and probit models of severance selection are constructed to establish the relationship between a set of attributes describing a structure and the probability that a particular severance technique will be employed. The limitations of quantitative modeling are summarized.

INTRODUCTION

There are currently around 4000 or so structures in the federally regulated offshore waters of the Gulf of Mexico (GOM) associated with oil and gas production. The structures vary widely according to function and configuration type and since 1947, when offshore production in the gulf first began, roughly 6000 structures have been installed in the federal offshore waters and 2000 structures have been removed. A few thousand structures have also been installed in state waters off the coast of Louisiana and Texas and more than 1000 of these structures have been removed.

Structures are installed to produce hydrocarbons; when the time arrives that the cost to operate a structure (maintenance, operating personnel, transportation, fuel, etc.) outstrips the income from the hydrocarbons under production, the structure exists as a liability instead of an asset. The economic lifetime of a structure can be extended if the operating cost can be reduced (say, by divestment) or hydrocarbon throughout increased (say, by investment). In some countries, tax/royalty concessions may be negotiated for mature fields and end-of-life properties, but this is not a frequent occurrence. In the GOM, federal regulations require that offshore structures be completely removed to a depth 15 feet below the seafloor within one year after production on the lease ceases.

Lessees/operators must submit for approval an application to the Minerals Management Service (MMS)—the federal agency responsible for oil and gas development, production, and decommissioning activities in federal waters—and provide information on the structure, removal technique to be employed, and the number and size of well conductors to be removed. All structure removals require an environmental assessment, and if explosives are to be used, an Endangered Species Section 7 Consultation is also required.

The decommissioning of offshore structures is a severing intensive operation. Cutting is often required throughout the structure above and below the waterline and mudline on braces, pipelines, risers, umbilicals, manifolds, templates, guideposts, chains, deck equipment and modules. More significant cutting operations are required on elements that are driven into the seafloor, such as multi-string conductors, piling, skirt piling, and stubs, which need to be cut at a minimum of 15 feet below the mudline, pulled, and removed from the seabed. Cutting piles and conductors is probably the most critical and important part of a decommissioning project since if the piles and conductors are not cut properly, a potentially dangerous condition could arise. The bottom cuts on anchor piles and conductors must be “clean” and “complete.” Incomplete cuts pose a serious danger to the stability of the vessel during lift.

A variety of technologies exist to perform severance operations. The most common cutting methods include abrasive water jet, diamond wire, diver torch, explosive charges, mechanical methods and sand cutters. For severing operations that occur above the waterline, the cutting technique selected is usually dictated by the potential for an explosion. Cold cut methods are used when the potential for an explosion exists; otherwise hot cuts are employed. Cutting in the air zone is conventional[1] since it involves methods which are regularly used for dismantling onshore industrial facilities. Below the waterline cutting is more specialized. In water depths that do not exceed 150 feet or so, divers perform cuts on simple elements such as braces and pipeline, and for shallow water structures such as caissons, diver torch is sometimes the preferred severance method. In water depths exceeding 150 feet, remotely operated vehicles (ROVs) deployed with abrasive, diamond wire and explosive charges are used for severance operations. Cutting operations required on conductors, piling, and stubs normally employ abrasive water jet, explosive charges and mechanical methods. Mechanical methods and explosive charges are primarily used for conductors, while abrasive cutters and explosive charges are mainly used for piling.

The decision to use explosive and/or nonexplosive methods will depend on the outcome of a risk-based comparative assessment involving cost, safety, technical, environmental, operational and managerial considerations. To perform a risk-based cost assessment for GOM decommissioning projects after the operation has occurred (post-job) is clearly an imposing (some would say impossible) task, and so we must rely on various proxy variables to estimate the probability that a particular severance technique will be applied. It is desirable from a methodological point of view to build a predictive model of the decision to use explosive methods to gain insight into the removal patterns that are expected to occur in the GOM in the future. The scope of this paper is motivated by the desire to predict the removal techniques expected to be deployed in the future. Since economic and technical considerations on a structure-by-structure basis are essentially unobservable, we will rely on a simplified decision model to gain insight to the processes involved in severance selection.

The purpose of this paper is to describe severance operations within the context of decommissioning and to identify the factors involved in the decision to use explosive/ nonexplosive methods, to

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[1] Conventional but not hazard-free. All decommissioning operations are potentially hazardous to human life.

quantify the probability that a structure will be removed with explosives, and to establish a relationship between a set of attributes describing a structure and the probability that a particular severance technique will be used. A more complete version of this article is available from the authors.

The outline of this paper is as follows. The next section provides background information on the offshore structures in the Gulf of Mexico and on the cutting activities typically performed in decommissioning is presented. Next, the factors involved in severance selection are described and the probability of an explosive removal is computed. Following that, binomial logit and probit models of severance selection are constructed and the limitations of the analysis are discussed. Finally, brief conclusions complete the paper.

BACKGROUND INFORMATION

Gulf of Mexico Infrastructure

The first infrastructure in the Gulf of Mexico (GOM) comprised caissons, well protectors, and fixed steel jacket platforms installed in shallow water. As development has shifted to deeper water, installation types have changed to larger steel structures, tension leg platforms, spars, and subsea completions.

If a reservoir is small or isolated, it will normally be completed with a “minimal” structure—a caisson, well protector, or subsea completion—with flowlines tied back to shore or an accompanying fixed platform. Platforms are classified as major and nonmajor fixed structures. A major structure is defined to include at least two pieces of production equipment or six completions and will normally include all braced caissons, conventional piled structures with wells, skirt platforms, special platforms, and floating structures. Conventional piled platforms without wells (quarters platform, flare pile, storage facility, pipeline junction, metering facilities), single-well caissons, and well protectors are considered nonmajor structures. Configuration type and water depth are important variables since the cost of decommissioning is dependent on the complexity of the structure and the water depth in which it is located. The number of slots available[2] on a platform is also a useful classifier since it provides an indirect indication of the size of the underlying field and the capacity of the accompanying structure.

Oil and gas structures in the GOM are presented in <u>Table 1B.1</u> according to configuration type, water depth, and number of slots available. Major and nonmajor fixed structures represent slightly more than half of all active GOM structures. Most structures removed to date have been simple structures such as caissons and well protectors in shallow waters, and roughly speaking, for every major structure decommissioned, two nonmajor structures have been removed. The number and type of structures removed can vary considerably from year to year. Over the past decade, the number

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[2] The number of slots available on a structure provides an upper bound on the number of conductors associated with production, while the number of slots used represents a "snapshot" of the number of conductors associated with the structure. Since each conductor normally surrounds one well, the number of slots used corresponds roughly to the number of wells associated with the structure, but the correspondence is not perfect since each conductor may hold more than one well and wells may also run down the legs of a structure which are not “counted” as a slot.

of structures removed has ranged from a low of 75 to a high of 179, and this range continues to serve as a good indicator on the bounds of future decommissioning activity.

Table 1B.1. Gulf of Mexico active and removed structures by configuration type, water depth, and number of slots (1947–2001).

Configuration Type	Water Depth (feet)	Number of Slots	Active	Removed
Caisson	0-80		1076	921
	80-200		117	112
	200+		5	1
Well Protector	0-80	0-6	271	193
		7-12	8	8
		12+	2	2
	80-200	0-6	97	74
		7-12	16	12
		12+	3	2
	200+	0-6	26	3
		7-12	2	2
		12+	1	3
Non-Major Fixed	0-80	0-6	291	85
		7-12	5	0
		12+	0	0
	80-200	0-6	155	23
		7-12	7	0
		12+	2	1
	200+	0-6	57	6
		7-12	9	0
		12+	3	0
Major Fixed	0-80	0-6	511	272
		7-12	132	58
		12+	85	13
	80-200	0-6	304	168
		7-12	228	80
		12+	178	33
	200+	0-6	95	33
		7-12	109	28
		12+	212	24
TOTAL			4007	2159

The most common structure in the GOM is the conventionally piled platform with wells. In a conventionally piled platform, the platform is pinned to the seabed by long steel tubes called piles which are passed through the legs of the structure and act like giant tent pegs. The jacket of the structure provides a protective layer around the conductors which pass from the seabed up to the topsides and serve as the conduit to the reservoir. The number of piles can vary from three to eight or more and typically range in diameter from 24 to 96 inches. Piling is sometimes grouted to the jacket leg near the mudline for additional stability and support. In many cases the jacket is installed over one or more exploratory wells with development wells then drilled through conductor slots in a central bay. There can be as few as one or two wells per structure or as many as sixty. Fixed platforms have been used in the GOM in water depths up to 1300 feet, but beyond this limit[3] floating production structures are required.

Decommissioning is a Severing Intensive Operation

The basic aim of a decommissioning project is to render all wells permanently safe and remove most, if not all, surface/seabed signs of production activity. A site should be returned to its "green field" state, but how completely the site should be returned remains a subject of discussion between government, operator, and the public. Cutting operations occur throughout each stage of decommissioning except the first (permitting) and last (site clearance and verification) stage. In general, the phase, timing, and selection of severance operations, and in particular, pile and conductor cutting, is planned to maximize the safety of workers and to minimize the time of the derrick barge on-site.

Well Plugging and Abandonment. A well abandonment program is carried out by injecting cement plugs downhole to seal the wellbore to secure it from future leakage while preserving the remaining natural resources. Techniques used to accomplish this process are based on industry experience, research, and conformance with regulatory standards and requirements.

A traditional approach begins by "killing" the well with drilling fluids heavy enough to contain any open formation pressures. The Christmas tree is then removed and replaced by a blowout preventer through which the production tubing is removed. Cement is placed across the open perforations and squeezed into the formation to seal off all production intervals and protect aquifers. The production casing is then cut and removed above the top of the cement and a cement plug positioned over the casing stub. The remaining casing strings are then cut and removed close to the surface and a cement plug set across the casing stubs.

Mechanical methods of cutting and sand cutters are primarily associated with well plugging and abandonment (P&A) activities. After wells are plugged and casing tubing cut and pulled, a sand cutter or mechanical cutting tool may be run downhole to cut the conductors, or depending on the preference of the operator/contractor and configuration of the platform, may subcontract for abrasive or explosive severance methods. In a typical mechanical operation, the tubing and production casing is first cut using a jet cutter—a small explosive blast that utilizes less than five pounds explosive—and then the strings are cut out from 7-5/8 or 13-5/8 inches using a mechanical cutter. The general philosophy during decommissioning is to get as much cutting done as possible off the

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[3] Shell's Bullwinkle platform in 1350 feet water depth stands 1617 feet tall and is one of the largest fixed structures in the world.

critical work path and before the arrival of the barge if the activity can be performed in a cost-effective manner.

All wellheads and casings are required to be removed to a depth of at least 15 feet below the mudline, or to a depth approved by the district supervisor. The requirement for removing subsea wellheads or other obstructions may be reduced or eliminated when, in the opinion of the district supervisor, the wellheads would not constitute a hazard to other users of the seafloor.

Topside Equipment and Deck Preparation. Topside preparation and deck removal are severing intensive. Cold cuts are generally made with pneumatic saws or drills, including diamond wire methods and abrasive techniques. Hot cuts—torch cutting and arc gouging—are used to cut steel when there is no risk of explosion. Arc gouging, essentially an arc welder, is used to remove seal welds between steel connections. Burning torches work on the same principle as the arc-gouge, where a burning rod, usually magnesium, is arced with the member to be cut. Diamond wire methods have also been employed in the GOM (although not frequently) to cut the deck from the jacket.

Jacket Preparation. Several severance techniques are used below the waterline. Small cuts made to the jacket bracing and trimming, flowlines, umbilicals, and manifolds are typically performed with divers using burning torches, or if the water depth exceeds the diver capability, ROVs with diver torch or abrasive technology are employed. Intermediate cuts may be required to separate the jacket into vertical sections if the piling extends up through the jacket structure.

Pipeline Abandonment. Federal regulations allow decommissioned OCS pipelines to be left in place when they do not constitute a hazard to navigation, commercial fishing, or other uses of the OCS. Pipelines will generally be removed offshore through the surf zone and capped. Onshore pipeline may be removed completely, or some sections may be abandoned in place if they transition through a sensitive environment. The pipeline end seaward of the surf zone is capped with a steel cap and jetted three feet below the mudline. Most pipelines in the GOM are abandoned in place after structural connections have been cleaned and cut.

The method for cutting a pipeline depends on how the pipeline is to be recovered. The protective coatings typical of most pipeline sections must first be removed to cut the pipe with an arc torch. If a pipeline crosses or is adjacent to an “active” pipeline, chances are it will not be disturbed due to the potential damage that would result if complications arose in the removal. Diamond wire methods, abrasive water jet, and pneumatic saws deployed with diver or ROV have been used to cut pipeline.

Pile and Conductor Severing. Pile and conductor severing is the most critical and typically the most expensive of all the severance operations required on the structure. Piles are steel tubes welded together and driven through the legs of the jacket and into the seabed to provide stability to the structure, while conductors conduct the oil and gas from the reservoir to the surface. At the time of decommissioning, the piles and conductors must be cut and removed a minimum of 15 feet below the mudline. The physical characteristics that describe piles and conductors are important since they determine the technical feasibility of severance options.

Conductors are cut and pulled, if possible, early in the decommissioning process to avoid delay when the barge is on-site. Conductors are configured in various diameters and wall thickness and are characterized by the number of inner casing strings, the location of the strings relative to the conductor (eccentric vs. concentric), and the application of grout within the annuli. Conductors are usually cut with mechanical methods or explosive charges. Grouted annuli are usually easier to cut than annuli with voids since voids dissipate the energy/focus of the abrasive and explosive cutting mechanisms. Eccentricity may also pose a problem for mechanical cutters. Mechanical methods are commonly applied to cut conductors during P&A activity, while if conductors are cut when the barge is on-site, then explosive charges will probably be employed.

To sever jacket legs and piles, abrasive cutters and explosive techniques are effective. In principle, mechanical cutting could be used to cut piling, but in practice it is rarely used because piles are only open when a barge is on-site (after removing the deck from the jacket), and with a barge on-site, mechanical cutting is not a cost-effective or efficient way to sever[4]. With a barge, on-site explosives are deployed down the piling and below the mudline while abrasive cutters can be deployed internally or mounted externally using divers and a track. Obstructions within the pile (such as hangers) will necessitate additional operation or deployment of an external cut. Internal cutting is usually the preferred approach with water jet technology since it does not require the use of divers to set up the system or jetting operations to access the required mudline depth.

SEVERANCE SELECTION MODELING FRAMEWORK

Factors Involved in Severance Selection

A large number of factors are potentially involved in selecting the severance technique for a specific job with cost, safety, risk of failure, and technical feasibility the primary factors that are considered when alternative options are available. Many different severance operations are required during decommissioning, and depending upon the job, more than one alternative may be available at each stage of the operation. In general, cutting techniques are expected to be reliable, flexible, adaptable, safe, cost effective and environmentally sensitive. If a cutting technique fails with respect to one or more of these factors, or if an operator has more than one "bad experience" with a particular method, then chances are that the technology will not gain in popularity or acceptance among GOM contractors.

Variables that drive the cost and risk associated with a specific severance technique are numerous and involve factors such as the location and nature of the site, sensitivity of the marine habitat, structural characteristics, the amount of pre-planning involved, salvage/reuse decisions of the operator, human safety, marine equipment availability, operator experience and preference, contractor experience and preference, the number of jobs the contractor is scheduled to perform and the schedule of the operation, market conditions, etc. Some of these variables are observable, but the degree of correlation between the observable variables and severance decision factors is

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[4] Redeployment of the barge is usually not an option.

expected to be weak, and so the extent to which cutting methods can be accurately predicted based on these factors is uncertain.

THE PROBABILITY OF AN EXPLOSIVE REMOVAL

The choice of which severance technique should be used to cut the piles and conductors of a structure depends primarily on unobservable or uncertain factors, and so it is clear that for a given structure we can only seek the probability that explosive methods will be applied. It is necessary to proxy the unobservable variables with factors that are accessible and are "reasonably" reflective of the offshore environment. Configuration type, water depth, and the structure age upon removal are available within the MMS master database, while the characteristics of the piles and conductors associated with each structure; e.g., number, size, application of grout, number of casing strings, etc. are not recorded. It would be preferable to perform the analysis at the lowest possible level of aggregation—which in this case is described through the characteristics of the structure—and then to "work up" through various aggregation strategies. Unfortunately, due to deficiencies in the historical database, it was not possible to explore the impact of aggregation schemes on the probability measures.

The manner in which data is reported also needs to be interpreted carefully since an "explosive removal" suggests that all the piles and conductors of a structure are explosively severed, while in fact as previously discussed, various severance techniques may be used throughout the structure to cut the tubular members. The diversity of the severance procedures is not captured through the MMS database, and this "information loss" restricts the degree (and ultimately limits the ability) to which a decision model can be constructed. If more than five pounds of explosive are used to cut any tubular element on the structure, the structure is classified as an explosive removal. The percentage values computed thus need to be interpreted as the number of structures in which explosives were used at least once during decommissioning. It would be better to compute the frequency of application of explosive severance as a function of the number and size and type of tubular elements that are cut, but due to deficiencies in historic records, this characterization is not possible.

Caissons are the most likely to be removed using nonexplosive methods. When well protectors and fixed platforms are removed with nonexplosive technology, the procedures are more commonly performed in shallow water (Table 1B.2). As water depth increases, the chance of using explosives increases across all configuration types. Note that the percentage values depicted in Table 1B.2 need to be interpreted relative to the size of the set, since a category may only contain a handful of data, and in such circumstances, one cannot assign much confidence to the percentage values as being "representative" of conditions in the region. This is particularly a problem for well protectors in the 61–200 m water depth category where only six structures have thus far been removed from the GOM. Refined partitions of the water depth data (using 3 m, 10 m, and 25 m increments) showed no discernable "trends," indicating that the application of water depth as a relevant factor is questionable.

Table 1B.2. Number of structures removed (R), structures removed by explosive technique (R_E) and the percentage of explosive removals p_E as a function of water depth and configuration type for the Gulf of Mexico (1983–2001).

Water Depth Range (m)	Caisson			Well Protector			Fixed			All		
	R	R_E	p_E	R	R_E	p_E	R	R_E	p_E	R	R_E	p_E
0-60	749	381	51	193	119	62	595	387	65	1537	887	58
61-200				6	5	83	81	61	75	87	66	76
200^+										2	1	50
Total	749	381	51	199	124	62	676	448	66	1626	954	59

The percentage of structures removed using explosive techniques is depicted in Table 1B.3 according to age upon removal, configuration type, and water depth. The use of nonexplosive methods is most common across all configuration types within the 0–10 year category when the structure has the greatest chance for re-use, and as the age and water depth of structures increase, roughly speaking, the probability of an explosive removal also increases.

Table 1B.3. Percentage of explosive removals by configuration type and age upon removal in the Gulf of Mexico (1986–2001).

Age upon Removal (Year)	Caisson		Well Protector		Fixed	
	0-60 m	61-200 m	0-60 m	61-200 m	0-60 m	61-200 m
0-10	39		52	100	55	76
11-30	55		64	67	71	76
30+	72		77	100	73	100

BINOMIAL LOGIT AND PROBIT MODELS OF SEVERANCE SELECTION

Model Development

A binary-choice severance selection model assumes that the operator is faced with a choice between two alternatives (explosive versus nonexplosive severance) and that the choice of which cutting method to select depends on identifiable characteristics. The requirements of the binary-choice model are thus quite strong, since as we have described previously, many important characteristics of the severance decision are not observable, and hence, not possible to incorporate within a model. It is nonetheless useful to explore the use of an econometric model since it quantifies the probability of an explosive cut and provides additional insight into the decision making process.

The purpose of a qualitative choice model is to determine the probability that a structure with a given set of attributes will realize a specific removal method. We will try to establish a relationship between a set of attributes describing a structure and the probability that the operator will make a given choice.

A binomial logit and probit model is constructed to model the probability that a structure will be explosively severed. Define the dummy variable

$$D = \begin{cases} 1, \text{ structure is removed with explosives} \\ 0, \text{ otherwise.} \end{cases}$$

If we collect a sample of structures that have been removed from the GOM, it is clear that the outcome D is a random variable that will only be known after the sample is drawn.

There are many relevant variables that impact the selection of the severance method, and some of the observable characteristics include the configuration type, ψ; age upon removal, α; and water depth of the structure, δ. The general model is thus written

$D = f(\psi, \alpha, \text{and } \delta)$,

where,

$$\psi = \begin{cases} 1, \text{ if the structure is a caisson} \\ 2, \text{ if the structure is a well protector} \\ 3, \text{ if the structure is a fixed platform,} \end{cases}$$

α = Age of the structure upon removal

δ = Water depth of the structure

The logit model is based on the use of a cumulative logistic probability function which is specified as

$$F(l) = P(L \le l) = \frac{1}{1+e^{-l}},$$

while the probit model is associated with the cumulative normal probability function which is written as

$$F(z) = P(Z \le z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{-.5u^2}\, du$$

If the probability of an explosive removal is related to the variables in a linear fashion, such as

$$\mathrm{E}(D) = \beta_0 + \beta_1\psi + \beta_2\alpha + \beta_3\delta + \varepsilon,$$

then the probability that the observed value *D* takes the value 1 in the logit model is given by

$$P(L \leq \beta_0 + \beta_1\psi + \beta_2\alpha + \beta_3\delta) = F(\beta_0 + \beta_1\psi + \beta_2\alpha + \beta_3\delta) = \frac{1}{1 + e^{-(\beta_0 + \beta_1\psi + \beta_2\alpha + \beta_3\delta)}}$$

while the probit model expresses the probability as

$$P(Z \leq \beta_0 + \beta_1\psi + \beta_2\alpha + \beta_3\delta) = F(\beta_0 + \beta_1\psi + \beta_2\alpha + \beta_3\delta)$$

By construction, the value of the probability in the logit and probit models will lie in the interval (0, 1) and represent the conditional probability that an event occurs given the values ψ, α, and δ.

Model Results

The expected signs for the coefficients of the regression model are straightforward, since as the complexity, age, and water depth of a structure increases, so does the probability that explosives will be used (see Tables 1B.2 and 1B.3). Hence, the coefficients of the regression models are expected to be positive.

The sample set is the universe of structures removed in the GOM between 1986–2002 and consists of over 1500 individual observations. The coefficients of the logit and probit model are then estimated using maximum likelihood, an iterative estimation technique useful for nonlinear equations.

The results of the estimation are shown in Table 1B.4. The estimated coefficients have the expected signs and two coefficients are significantly different from zero. The water depth does not appear to be a relevant factor, which is supported from earlier statistical analysis. The logit and probit model results are similar since they are both based on cumulative distribution functions. The value of R^2 cannot be relied on as a measure of the overall fit of the model with a dummy dependent variable, but one alternative is to compute R_p^2, the percentage of the observations that the estimated equation correctly explains. To use this approach, compute

$$R_p^2 = \frac{\text{number of observations “predicted” correctly}}{\text{total number of observations}}$$

R_p^2 is not used universally, but it is a convenient and easily interpreted measure. The R_p^2 indicates that the equation correctly “predicted” over 60% of the sample based on nothing but three variables.

Table 1B.4. Probit and logit model results.

Factor	Probit		Logit	
	Coefficient	**(Z-Statistic)**	**Coefficient**	**(Z-Statistic)**
Constant	0.1372	(1.02)	0.0815	(0.97)
Configuration type	0.0563	(3.21)	0.1121	(3.26)
Age upon removal	0.0051	(5.42)	0.0167	(5.49)
Water depth	0.0005	(0.10)	0.00001	(0.11)
R_p	0.65		0.63	

Limitations of the Analysis

The binomial logit and probit models are limited by several conditions:

- Ability to capture the relevant factors involved in decision making,
- Ability to adequately model the identified factors, and
- Ability to extract sufficient data to support the modeling effort.

Each of these issues plays a role in the construction and development of the qualitative choice model.

The large number of factors potentially involved in the selection of a severance method provides the first indication that the decisions involved in severance are complicated and difficult to model. The proliferation of factors is the first clue that simple models can not provide a complete reflection of the decision framework, and in fact, it is unlikely that any model of the decision process can incorporate all the relevant factors. Most certainly a simple model will not yield satisfactory results, but the modeling process itself is useful and provides some additional information on severance selection. Relevant company and site specific information (e.g., equipment available at the time of the removal, the amount of pre-planning involved in the removal, the contractor's preference and the operational scheduling, the terms of the contract, the quality of the structure blueprints, etc.) play an important role in the choice of removal method, but because these factors are unobservable, they cannot be statistically analyzed. It is thus clear that a significant portion of the decision making framework cannot be incorporated within the model.

The MMS tracks the number of structures removed, the manner of severance and the structure classification, and this data provides the basis for the model construction. The characteristics of the structure, including the number and size of the tubular members, the application of grout, and the manner of removal of each tubular element do not form part of the MMS data set, and thus also cannot be incorporated within the decision model. It is unlikely, but not certain, that the inclusion of more refined data at a lower level of aggregation will provide more useful information in the model, and so in principle, the limitations of the MMS database are not effectual.

CONCLUSIONS

Decommissioning activities in the GOM are driven by economics and technological requirements and governed by federal regulation. Decisions about when and how a structure is decommissioned involve complicated issues of environmental protection, safety, cost, and strategic opportunity, and the factors that influence the timing of removal as well as the manner in which a structure is removed are complicated and depend as much on the technical requirements and cost as on the preferences established by the operator and/or project management team overseeing the decommissioning project.

The purpose of this paper is to describe the issues involved in severance selection and the factors involved in the decision to use explosive/nonexplosive severance methods, to quantify the probability that a structure will be removed with explosives, and to establish a relationship between a set of attributes describing a structure and the probability that the operator will select a given severance technique. The limitations of modeling were also described.

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OIL PLATFORM REMOVAL USING ENGINEERED EXPLOSIVE CHARGE

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INTRODUCTION

When it is necessary to remove offshore oil platforms, four techniques are available: torch cut, mechanical cutting, abrasive cutting, and cutting using bulk explosive charges. Each of the techniques has its drawbacks either in terms of danger or costs: danger for the first three and costs to the environment for the fourth. SNC TEC Corporation, the American subsidiary of the SNC TEC, and its team proposed in a white paper to Minerals Management Service (MMS) to review the bulk explosive charge method and recommend improved ways to implement this method. Specifically, SNC TEC proposed to design and test engineered charges that would perform the cutting job with charges of 10 pounds or less. These engineered charges, compared to the standard 50-pound charges, would reduce the effect on the environment. A contract was awarded to SNC TEC Corporation by MMS in November 2001 to design the charges and test them, first on mock-up structure and then on actual targets. It is also planned, as an option to the contract, to make comparative blast measurements with the bulk charge. These data could then be used in a model to obtain the effect of these reduced charges on marine wildlife.

SNC TEC Corporation organization is responsible to manage the project, participate in the design and manufacture the charges. Defence Research and Development Canada (DRDC) Suffield in Alberta, Canada is responsible for charge design and preliminary testing at their site. Explosive Services International (ESI) from Clinton, Louisiana, will be responsible for full scale tests, permits, and co-ordination of the support. Finally, if the option is granted, Sonalyst of Waterford, Connecticut, will be responsible for measurements and blast effects comparison.

WORK PERFORMED

This section presents the system considered to perform the requirements, along with work done and the objectives.

System Considered

Our technical approach for removal of large platforms located in deepwater is to use a system to deliver the charges exactly where they are needed and to ensure that they are positioned optimally in the pipe to be severed. This planned approach overcomes two shortcomings inherent in the current practice of bulk shooting structures. First, currently the bulk charge must be smaller in diameter than the target zone's inside diameter (ID) as there are diametric restrictions that must be passed through on the way to the target zone. As the bulk charge is undersized in relation to the target zone ID, the space between the charge and the target is filled with water. Second, many of the piles on platforms are slant driven. This means that when the bulk charge is delivered to the target zone, it lays against the lower side of the target. This exacerbates the first problem; therefore, a charge of much higher explosive weight than should be necessary is required to overcome the fact that there is not intimate contact between the charge and the target.

The bulk explosive charge has the disadvantage of being multi-directional, so a lot of energy is lost with minimal effect on the severing performance. A larger quantity of explosive is therefore required compared to what would be used if the explosive energy could be concentrated to the severing task. This constitutes the basis for the development of engineered charges considered in the project.

The different parts of the system considered will be discussed below along with the work done on them so far.

Scorpion delivery system: The collapsible delivery system (Scorpion™ Tubular Severing Device) developed by ESI was selected to deliver the charge to the target zones of the structures. In the first step, the Scorpion is in a collapsed form, enabling it to position itself where required. The Scorpion is then expanded in diameter to hold the charges in intimate contact with the surface of the target.

Shaped charges: The shaped charge effect, also known as Von Foerster/Munroe effect, was discovered in 1890s. The principle is that the perforation/penetration in a target is deeper when there is cavity at the bottom of the explosive charge and that it could be increased if the cavity is lined with a ductile material. Another increase of performance can also be achieved by positioning the shaped charge at some distance from the target. This positioning is known as stand-off. This effect, which was mainly used for military purposes was not explained until the 1040s. While this work was done on axi-symmetric charges, the effect was also applicable to linear charges, which have been used for demolition purposes. Studies have defined optimal dimensions of the charges for obtaining optimal performances. These dimensions must be adjusted depending on the type of explosive considered, liner and charge confinement, or casing. The term “charge confinement” will be used here instead of the term “casing” to differentiate from the casing used to contain the charges and fix them on the Scorpion™.

Studies of demolition on underwater targets have shown that water in the shaped charge cavity and the stand-off can produce a major reduction of the penetration in the target. However, if there is water below the bottom of the charge stand-off and the target, the effect is not as important.

For this program, different types of explosives have been considered; criteria included availability and cost. Composition B is a melt-pour explosive currently available at low cost from the demilitarization of different military warheads and is used in civilian charges. RDX is currently used in commercial linear charges. It is easily available and performs well. The performances of these explosives are similar enough in the linear charge arrangement not to require a different test for each of them. SNC TEC will perform casting tests on Composition B to see whether it can be manufactured.

Using the data available at DRDC Suffield, computer hydrocode LS-DYNA™ and some preliminary tests, the optimal value of the charge dimensions were obtained. These data were compared with data on commercially available linear shaped charges with the goal of reducing cost. The conclusion was that the Y230-4000 linear shaped charge from Accurate Energetics had dimensions very close to the optimal ones and should be able to section the thickness of the 48" pipes and the casing thickness described below. Eight charges, each covering an angle of 45°, will cover the circumference. With such a charge arrangement, about 7.5 lbs of explosive including boosters and detonator should sever the pipe.

Casing

The shaped charges perform optimally if some conditions are encountered, such as the optimal stand-off and the absence of material, including water, between the liner and the bottom of the stand-off. It is also important that the casing be sturdy enough to withstand the pressure at 200 feet under water and small enough to fit in the Scorpion System.

Three arrangements have been considered for the casing. The first is a cylindrical rubber pipe of 3" diameter which would provide the adequate stand-off. This arrangement could be easily formed to the required curvature but lacks the sturdiness required during the system deployment and is difficult to waterproof. Mounting the linear charge on a C-channel of the required size was also considered. While this had the required sturdiness and could be bent to the required curvature, it was difficult to ensure waterproofing along the interface between the charge and the channel. The selected casing is a hollow structural steel (HSS) which has the required sturdiness, can provide the required stand-off and be easily waterproofed at the ends. The required HSS could be bent to fit the dimensions required for a 24" diameter pipe. The charge jet will have to penetrate the HSS thickness (1/8") in addition to the pipe thickness but the computer simulations showed that was not a problem.

Initiation System

The charge initiation system was also studied because it must be sturdy enough to withstand the system deployment in the pipe. It needed some redundancy. Some studies were also made to optimize the linear charge performance by using multiple initiation points. Different design will be tested, and the one which should combine the best the reliability and lower cost quality will be selected.

FUTURE WORK

The linear charges were produced by Accurate Energetics and sent to DRDC Suffield for preliminary tests aimed at proving their capabilities against steel pipes. The casings were also bent and the closing-ends design was tested for waterproofing. These will also be tested, along with the charge and initiation system, in February against mock-up targets in view of possible improvements before the tests to be performed in fall of 2003 on actual pipes in the Gulf of Mexico. The decision regarding measurements by Sonalyst should be taken following the preliminary tests. The measurements will be discussed to ensure that they could be implemented in a model to study the effect on marine wildlife of using the engineered charges.

CONCLUSION

In conclusion, it has been shown by simulation that a linear shaped charge available commercially could be used in a casing fitted for it and that such a charge of about 7.5 lbs including booster and initiation system should be sufficient to sever pipes of up to 48" diameter (1.5" thick) when mounted on the Scorpion™ delivery system.

Preliminary tests of the arrangement against mock-up structure will be performed in February to prove the modeling results. Depending on the tests results, a decision will be made on required modifications and adjustments leading to a final test in the fall of 2003.

Since his graduation from Laval University in Quebec City, Canada, as a chemical engineer in 1980, Pierre Pelletier has worked in the field of explosive formulation development and application to different military charges for both the Canadian government and SNC Technologies. He has been involved in different projects related to shaped charges development, filling method, and testing. He has also worked in the area of terminal ballistic and material behavior at high strain rate including testing and computer simulations with hydrocodes. He obtained master's degree in mechanical engineering in 1995 from Carleton University in Ottawa, Canada. Mr. Pelletier is currently Senior Scientific Advisor on Energetic Materials in the Development and Technology Department of SNC TEC in Montreal, Canada, where he has been working since 1987.

Denis Saint-Arnaud graduated in 1989 from Laval University in metallurgical engineering. Prior to this, he spent seven years as a metallurgical technologist for the Quebec Ministry of Transportation where he worked in the quality assurance area for bridges and superstructures. Following his graduation as an engineer, Mr. Saint-Arnaud worked for X-Per-X as failure analysis, quality assurance, and welding manager. He did case analysis and act as expert witness in court on failure or premature degradation. He also ensured that customers' needs were in accordance with quality assurance and quality controls requirements for the services and products. He was involved in projects such as the Logan International airport gateway project, conversion of the Spirit of Columbus oil platform to Petrobras-36 and embedded parts fabrication and coating for the La Grande-1 hydro-electric dam. He joined the Development and Technology Department of SNC TEC in 2001 and has been involved since in different projects where his material knowledge was put to contribution such problem solving, design, and computer simulation.

SHOCK WAVE/SOUND PROPAGATION MODELING RESULTS FOR CALCULATING MARINE PROTECTED SPECIES IMPACT ZONES DURING EXPLOSIVE REMOVAL OF OFFSHORE STRUCTURES

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INTRODUCTION

The removal of offshore structures by explosive methods impacts marine life. To assess that impact adequately, a methodology is needed that accurately models the shock effects caused by the detonation of an explosive charge below the mud line (typically 15 feet) inside a pile, leg, conduit or other structural element. Current methodologies do not take the effects of an explosive detonating below the mud line and the pile leg confinement into consideration when determining shock characteristics in the water at distances. This effort investigated the reduction of energy transmitted to the water due to the below-the-mud-line detonation inside a pile or leg. Near-field numerical simulations of the explosive, water, soil system were performed that quantified the energy partition and ultimately the amount of energy transmitted to the water. Based on these results, a method was developed that calculates the effectiveness of the explosive as a function of the pile diameter and wall thickness, and the weight of explosive used.

APPROACH

The approach was to numerically simulate the various pile, explosive, clay, and water conditions with the CTH shock propagation code to understand the phenomenology of explosive detonations below the sea floor and in offshore structural elements such as piles. From these studies, the effects of explosive burial and pile attributes on the coupling of explosive energy to the water were determined. The end result was that an explosive efficiency factor was defined for each case. For example, if a 50-lb. explosive below the mud line inside of the pile, coupled 40% of the energy as a 50-lb. explosive in free water, then the explosive efficiency factor would be 40%. Using the explosive efficiency factor, the user would use 40% of the explosive weight, in this case 20 lb., in calculating the peak pressure, impulse, and energy flux density using free-water equations or other methods.

RANGE OF PARAMETERS

The range of parameters for this study was developed based on the literature, and input from MMS staff, as well as Mr. Russell W. Wilcox of DEMEX Explosive Products & Services. These parameters were used as input for the numerical simulations of the near-field explosive effects and subsequent energy coupling to the water.

The major parameters for this study are:

Soil:	Soft clay and stiff Beaumont clay
Explosive Weight:	25, 50, and 100 lbs.

Explosive Type:	C-4 / Cyclotol
Explosive Shape:	Bulk and toroid
Detonation Point:	15 feet below mud line
Pile Material:	Steel
Pile Diameter:	24", 36", 48", and 72"
Pile Wall Thickness:	¾", 1 ½" and 2 ½"

CALCULATIONAL MATRIX

Seventeen numeric simulations were performed to quantify the effects of the pile/mud/explosive configuration on the water shock. This selected set of runs was chosen to cover a wide range of typical conditions to facilitate the model development while limiting the number of calculations because of the relatively short duration of this project. All simulations were computed using a C-4 explosive, which has nearly the same explosive performance as Cyclotol (their explosive release energies are within 2½% of each other). A 15-foot explosive burial depth was used for all numerical simulations.

All the numeric simulations were performed with the CTH Eulerian hydrocode which was developed at Sandia National Laboratories. This code handles complex one-, two-, and three-dimensional geometries for shock propagation problems and non-linear material properties. It is a first-principle finite difference code that uses conservation of mass, momentum, and energy along with equations-of-state and strength models for the various materials. The geometry and materials are modeled in a discretized grid. For these calculations, the two-dimensional cylindrical (i.e., axisymmetric) grid contained approximately 130,000 cells. The code uses an explicit solver, meaning that it solves the problem for a single time step (that is automatically determined based on shock properties of the simulation to ensure numeric stability) and marches forward in time until the specified end time is reached. The time step ranged from 3 to 8 microseconds, and the typical CTH numerical simulation took 3 to 8 hours on a 1-GHz Linux workstation.

Five numeric simulations were performed for free water or mud (i.e., no pile) as listed in Table 1B.5. The one soil only numerical simulation was performed to isolate the effect of the soil on the shock propagation into water.

Table 1B.5. Free water and soil simulations.

Medium	Explosive Weight, lbs.			
	12.5	25	50	100
Free water	X	X	X	X
Soil			X	

Table 1B.6 shows the twelve calculations that were done for the pile cases. This set of simulations were run to understand the effects of pile geometry and properties for the various charge weights.

Table 1B.6. Pile simulations (explosive weight indicated).

Pile Wall Thickness (inches)	Pile Diameter (inches)			
	24	36	48	72
¾	25 lb.			
1½ 1½ 1½	50 lb.	50, 100 lb. 50 lb. (water) 50 lb. (toroid)	100 lb.	100 lb.
2½		50, 100 lb.	100 lb.	100 lb.

To separate the effects of the soil and the pile, one calculation was done without a pile (50 lbs, Table 1B.5) and another calculation was done with a pile but without soil (50 lb., 36" diameter, 1½" wall thickness, Table 1B.6). One calculation was done with a toroidal charge instead of a bulk charge to investigate any differences in energy coupling to the water due to the explosive charge shape (50 lb., 36" diameter, 1½" wall thickness, Table 1B.6).

BASELINE NUMERICAL SIMULATIONS

The first four simulations were designated as baseline simulations whose objectives were to gain an understanding of the phenomena and isolate the factors that affect the amount of energy coupled into the water.

The four baseline calculations were:

1. 50-lb. explosive – free water
2. 50-lb. explosive – stiff clay (no pile)
3. 50-lb. explosive – pile and water (no clay)
4. 50-lb. explosive – pile in clay, and water

These near-field calculations extended from the explosive charge to approximately 30 m in each direction. The 30 m distance was chosen to be more than twice (2.3 X) the extent of the strong shock or nonlinear region. Each calculation was run out to a simulation time of 20 to 25 ms, which is the time it takes for the shock wave to propagate 30 to 37 m through water. The energy coupled to the water was monitored as well as the pressure, impulse, density, particle velocity, temperature, and other thermodynamic variables at various points in the grid. A typical calculational result is shown in Figure 1B.1 where the material plot is shown on the left and the pressure field is shown on the right at a particular time.

The explosive coupling efficiencies which were defined by dividing the kinetic energy coupled into the water for each simulation by the kinetic energy for the free water case for the four baseline calculations are shown in Table 1B.7 and plotted in Figure 1B.2. Interestingly enough, if the efficiency for the clay only case (79%) is multiplied by the efficiency of the pile in water only case (49%), one obtains the efficiency for this combined case of the pile in the clay (39%).

Table 1B.7. Explosive coupling efficiencies for the four baseline simulations—50 lb explosive weight.

Numerical Simulation	Explosive Coupling Efficiency
Free water	100%
Stiff clay (no pile)	79%
36" diameter, 1½" wall thickness in water (no clay)	49%
36" diameter, 1½" wall thickness in clay	39%

The pressure and impulse time histories at a range of 20 m are compared to the baseline calculations in Figure 1B.3 and Figure 1B.4, respectively. The pressure waveforms in Figure 1B.3 show that these calculations with confinement due to clay and/or pile have lower peak pressures than the free water case. More significantly, the pressure drops off faster as can be more dramatically seen in the impulse comparisons in Figure 1B.4. The clay-only calculation shows some reduction in impulse, while the pile in water and pile in clay cases show a very significant reduction in impulse. This drop in impulse is another indication of reduced energy coupling and lower effective explosive weight.

These simulations showed that a reduction of coupled energy into the water was dominated by pile confinement followed by soil confinement. Both pile and soil confinement offer inertial and strength effects which need to be over-driven by the explosive prior to explosive energy deposition into the water. The pile confinement has a much greater effect than the soil due to increased strength and density of the pile material. The numerical simulations also indicate that some energy loss is due to explosive energy propagating in the water in the pile core (typically less than 5%).

PARAMETRIC NUMERICAL SIMULATIONS

To further define the explosive coupling efficiency over a broader range of pile diameter, wall thickness and explosive weight, numerical simulations were performed for the conditions previously given in Table 1B.6. Note this was a parameter study and the explosive amount for a particular pile presented here is not necessarily the optimum or recommended value.

The results of these numerical simulations were analyzed in a similar way to the baseline calculations presented in the previous section. The energy coupling efficiency was calculated by dividing the coupled energy to the water by the appropriate free water value. The resulting energy coupling efficiencies are presented in the parametric variations in Table 1B.8. A 3% difference between the coupling efficiencies of a bulk charge to that of a toroidal charge for the same pile geometry is shown in Table 1B.8. This small difference is caused by the toroidal charge being closer to the pile wall; thus it can deliver more energy into the surrounding water.

The trend that is shown in Table 1B.8 is that more energy is coupled into water for thinner pile walls, larger pile diameters, and higher explosive weights. These findings will be quantified more fully in the analysis and modeling section, which follows.

Table 1B.8. Explosive coupling efficiencies for pile geometry in clay simulations.

Pile Wall Thickness (Inches)	**Explosive Weight (lb.)**	**Pile Diameter (Inches)**			
		24	**36**	**48**	**72**
¾	25	45%			
1½	50	44%	39%		
	50 (toroid)		41%		
	100		48%	51%	62%
2½	50		26%		
	100		35%	36%	53%

ANALYSIS AND MODEL DEVELOPMENT

The main result of the parametric numerical simulations was the determination of the amount of energy coupled to the water and hence, the explosive coupling efficiency for the various pile scenarios (Table 1B.8). The next step was to develop a model for the explosive coupling efficiency as a function of the pile attributes and the amount of explosive.

Based on thin-walled pressure vessel theory, in which the hoop stress is directly proportional to the internal pressure and radius (or diameter) and inversely proportional to wall thickness, we developed the pile parameter, p, as follows:

$$\text{Pile parameter, } p = \frac{w \cdot d}{t} \qquad (1)$$

where: w = explosive weight, lbs.
d = pile diameter, inches
t = wall thickness, inches

We then plotted the explosive coupling efficiency versus the pile parameter, *p*, as shown in Figure 1B.5. The data show that there is approximately a linear relationship for the three pile wall thicknesses that were studied. We fit a line to the points and came up with the following equation:

$$\text{Explosive coupling efficiency } (\%) = 34.37 + 0.005 \cdot p \text{, with } R^2 = 0.6638 \qquad (2)$$

There is some scatter in the results shown in Figure 1B.5. This scatter is also indicated by the coefficient of determination (R^2) indicating that 66.4% of the uncertainty has been explained by the linear fit. The reason for this scatter is that the piles were not severed to the same degree. Some walls were completely destroyed while others did not fail as catastrophically. The pile parameter that we chose was just one of many possible. However, the form makes sense physically. More energy is coupled with increasing charge weight (the strength of the pile is over matched), increasing pile diameter (increased forces that the pile must resist), and decreasing wall thickness (higher stresses). As a side note, when the 1½-inch pile wall thickness data is plotted alone, a much better linear fit is obtained ($R^2 = 0.9133$) than when all the data is plotted together. The 1½-inch wall thickness data is banded more tightly and offers less scatter than the data for 2½-inch wall thickness data.

The upper bound for the explosive coupling efficiency should be approximately 80% as that is the value for the clay only, no pile case (Table 1B.7).

Having established the energy coupling factor for a particular pile configuration, the next step is to multiply the actual explosive charge weight by the explosive coupling efficiency and use the resulting reduced explosive weight to calculate the water shock using free-water methods.

UNDERWATER CALCULATOR (UWC) SPREADSHEET EXAMPLES

This section presents examples using the UnderWater Calculator (UWC) spreadsheet which is based on the explosive coupling efficiency concept described previously and the similitude equations for shock propagation in water. One free water calculation will be presented and compared to REFMS results. Then UWC results will be given to demonstrate the differences in range to effect for peak pressure and energy flux density between the free water and pile cases.

The free water case is an open water 22.68 kg (50 lb) H-6 explosive charge. The receiver is 400 meters from the surface and at a slant range of 403.11 meters. Given this geometry, the receptor is 50 meters horizontally from the source. The geometry of the free water case is shown in Figure 1B.6. Table 1B.9 compares the UWC and REFMS results. The peak pressure, impulse and energy flux density are nearly the same for both methods.

Table 1B.9. Results of the free water case for the two methods.

Method	**Peak Pressure (MPa)**	**Impulse (kPa-s)**	**Energy Flux Density re 1μPa^{2}s (dB)**
REFMS	0.167	0.205	191.6
UWC	0.162	0.202	191.6

To demonstrate the difference in the shock propagation into the water between a free water and a pile case, the UWC spreadsheet was exercised. The piled case is similar to the free water case with the exception of the 36-inch diameter pile with a 1.5 inch wall thickness. The water depth was 200 meters and the receiver depth was 100 meters. We performed a series of calculations to determine the range for a given energy flux density (182 dB for any 1/3 octave band) and for a given peak pressure (12 psi). The results for the free water charge and the buried pile charge are shown in Table 1B.10 and Table 1B.11. As can be seen from these two tables the range to effect for the pile case is less than the free water case. This is an expected result because of the reduced energy coupling to the water for the pile configuration.

Table 1B.10. 50 lb H-6 charge, range to 182 db energy flux density.

Explosive Configuration	Range (m)	Peak Pressure (psi)	Total Energy Flux Density re 1μPa^{2}s (dB)	Max 1/3 Octave Band Energy Flux Density re 1μPa^{2}s (dB)
Free Water Charge	394	24.2	191.8	181.5
Buried Pile Charge	252	28.7	191.8	181.5

Table 1B.11. 50 lb H-6 charge, range to 12 psi peak pressure.

Explosive Configuration	Range (m)	Peak Pressure (psi)	Total Energy Flux Density re 1μPa^{2}s (dB)	Max 1/3 Octave Band Energy Flux Density re 1μPa^{2}s (dB)
Free Water Charge	710	11.98	186.5	177.0
Buried Pile Charge	525	11.98	185.1	175.9

SUMMARY

The objective of this work was to develop a method to determine the shock wave propagation into water caused by the removal of offshore structures by explosive methods. This was accomplished by performing numerical simulations of various explosive, pile, clay, water systems and by determining the amount of energy coupled to the water. The numerical simulations showed that less energy is coupled to the water for the pile cases than would be coupled for free water explosions. These simulations showed that a reduction of coupled energy into the water was dominated by pile confinement followed by soil confinement. Parametric numerical simulations were performed that covered a range of typical pile diameters, wall thicknesses, and explosive weight. From these results, a model was developed to predict the explosive efficiency factors for various pile scenarios. Lastly, the UnderWater Calculator spreadsheet was developed to predict peak pressure, impulse and energy flux density for both the free water and pile cases.

Peter Dzwilewski led the methodology development for this MMS-sponsored project that included the structure and soil effects in determining the water shock environment caused by underwater explosives. His experience includes oceanography, marine geotechnology (ocean soil mechanics), shock wave propagation, testing and modeling of materials, and modeling and numerical simulations. He received a M.S. degree in civil engineering, in the Marine Geotechnology Laboratory at Lehigh University. Currently, he is a principal engineer at Applied Research Associates, Inc., Littleton, Colorado, where he has worked for over twenty years.

THE APPLICATION OF THE ACOUSTIC INTEGRATION MODEL© (AIM) TO EROS AND SEISMIC ISSUES IN THE GULF OF MEXICO

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OBJECTIVE

The primary objective of this paper is to describe the Acoustic Integration Model (AIM) and its potential application to the regulatory issues arising from both the EROS and seismic operations in the Gulf of Mexico (GOM). The evolution of AIM is reviewed, including the development of the original concept as well as the wide range of applications where AIM is currently in use by various agencies of the government. Relevant references are also provided.

Three examples illustrating the utility of AIM for both EROS and seismic applications are discussed, including a graphic model run demonstration of a shallow water EROS event, and the resultant acoustic assessment for selected species of whales in the region of the survey.

AIM CONCEPT AND EVOLUTION

The original concept for AIM derived from the need for an assessment tool that took into account the spatial, spectral and temporal properties of both sound fields and the natural behavior of marine wildlife. Two previous research efforts gave rise to this project: a software algorithm developed in conjunction with modeling the spring migratory behavior of the bowhead whale (*Balaena mysticetus*) off of the coast of Barrow, Alaska (Sonntag *et al.* 1986) and an acoustic reverberation algorithm developed to describe the effect of large fields of pressure ridges on the sound field from a moving source (Bishop and Lellberg 1987). The former laid the groundwork for a practical, yet realistic model for simulating three-dimensional movement behaviors in a whale; the latter provided confidence that Monte Carlo techniques could be used for simulating large scale natural phenomena. In both instances, the models were validated by extensive comparison with observed data.

The first version of the AIM model was a FORTRAN program quite similar to the Ice Scattering model, particularly in its ability to integrate an acoustic propagation model with an incremental time sequencer that allowed for realistic transient acoustic analysis in a 3D environment (Ellison *et al.* 1999). Range and depth-dependent transmission loss (TL) was calculated with the Navy Standard PE 3.4 model. Animal movement, including diving behavior, was based on the extant literature as well as ongoing field research, especially those efforts using tagged animals to determine depth vs. time dive profiles. The model output desired could effectively be described as an acoustic dosimeter measurement for each virtual animal, recording the sound level each was exposed to every time the sound source "pinged." Dr. Robert Gisiner of the Office of Naval Research has sponsored continued research for AIM, both on a three-year 6.2 effort in ONR's EQ program, and most recently as a participant in ONR's Effect of Sound on the Marine Environment (ESME) program (Ellison 2000; Ellison and Frankel 2002; Frankel *et al.* 2002). The objective of the 6.2 program was to reformat the AIM program to be more user friendly and to allow its installation on a wide range of Operating

Systems. To this end, the program was adapted to JAVA, and a current version is now running on all current versions of WINDOWS.

CURRENT VERSION OF AIM

Figure 1B.7 portrays the essential elements of the current version of the AIM model as applied to the acoustic impact assessment problem:

- sound source is modeled in terms of its key characteristics, including sound level, frequency spectrum, 3-D motion over time and temporal properties of the acoustic output such as duration and repetition rate
- acoustic propagation model using database or *in situ* measured input for the seasonal environment (bathymetry, bottom loss, absorption, and sound velocity profile calculates the resultant three dimensional sound field over time
- animal seasonal behavior and distribution model distributes (animal regional as well as sub-regional density) and moves (directional and diving mobility) the animals within the relative range of the source sound field
- AIM integration engine evaluates the sound field at user-selected intervals (i.e., each ping of a sonar) and records the resultant sound level at each animal in a database suitable for post-run evaluation (e.g., EXCEL or MATLAB).

ANIMAL SEASONAL BEHAVIOR

This is the most difficult part of the virtual simulation as the required database does not exist in a machine accessible form at the level of behavioral detail required by AIM, i.e. seasonal movement and diving behavior. As a result, the site-specific input must be developed through literature review and expert assessment on a case by case basis. Once these data have been developed, however, the AIM model interface is very adaptable in its use. For example, animals could be distributed uniformly over an area, or they can be distributed within a depth stratum and by behavior. Thus, migrating blue whales off Southern California might be confined off the shelf with a narrow travel direction, and feeding animals could be restricted to near-shore waters (e.g., depth < 300 m). Each would have its own diving profiles. The feeders could have two different feeding strata, for example, with mean values of time spent at each depth and at the surface. The virtual result looks very much like a real whale feeding and moving over time. In essence, AIM is rule-based. If one can write down the rule, the model can be programmed to follow it. For example, temperature or prey abundance could be used to modify animal distribution. The relevant data must simply be available in a LAT/LON/DEPTH/TIME format. AIM can currently model an animal’s response (aversion or attraction) to a number of environmental factors, such as water depth and sound received level. With the planned introduction of GIS compatibility in FY 03, a wider range of associative effects can be displayed and made operative with AIM. Examples might include time and location-dependent water temperature, salinity, or even prey distribution.

Following this reasoning a host of other applications for AIM became viable, from pollution indices to ship strike potential, as well as the masking of animal vocalizations. Specifically, to what degree will the vocalizations of one animal be masked at any other animal’s location by a given noise?

RELATED STUDIES

Transition of the AIM product to greater capability and range of applications has occurred across a wide range of programs within the Department of Defense as well as other U.S. government programs, as discussed below:

- Under a Phase II SBIR Effort with the U.S. Air Force, the AIM model has been integrated with the U.S.A.F. SONIC BOOM acoustic model for the purpose of assessing the impact of sonic booms from U.S.A.F. flight activities on marine mammals that may lie in the path of such operations. These results are reported in "Advanced Analytical Sonic BOOM UNDERWATER PROPAGATION ANALYSIS," Marine Acoustics, Inc. Final Contract Report for U.S. Air Force under U.S.AF SBIR AF98-008 II, July 2002.
- Under a completed SBIR Phase I and Phase II (in process, MAI teamed with DSR, Inc. of Anaheim CA) SBIR Effort (N01-14) with NAVAIR (PMA 299) the AIM model is proposed for integration with the SH60 dipping sonar system as an environmental assessment tool. These results are reported in "Environmental Assessments and Mitigation of Naval Operations," Phase I Final Report for PMA 299, Contract Number N68335-01-C-0219, prepared by DSR and MAI, 06 October 2001.
- The AIM model was the centerpiece analytical acoustic impact assessment tool for the LFA SURTASS EIS, "Final Overseas Environmental Impact Statement and Environmental Impact Statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar," Department of the Navy, Chief of Naval Operations, June 2000.
- Under a Phase I STTR (N01-T002) Effort with ONR the AIM model is being integrated with other sensor models as a component of a multi-sensor approach to marine mammal acoustic mitigation. This effort was reported in "Integrated Marine Mammal Monitoring and Protection System: STTR Phase I," Final Report, ONR N00014-01-M-0205, January 2002.
- Under contract to NOAA/NMFS, an Acoustic Prediction Validation variant of the AIM\model is being produced with the capability of independently assessing acoustic propagation predictions.

AIM EXAMPLES

At the request of MMS, three scenarios were analyzed using AIM: two EROS examples and one seismic example. These examples are instructive as they highlight the types of information required by the AIM tool that are unique to these applications, as well as areas in which additional development is required in the various databases needed. Table 1B.12 summarizes the basic source/species/output parameters for each of the three.

Table 1B.13 provides the density of the modeled animals for each example, as well as the maximum dive depth. To expand the effective sampling rate, each example was run using an amplified population. Results in this approach provide a more uniformly varying probability density function (PDF), but are presented normalized back to a percentage basis. This percentage when multiplied times the actual population results in estimates for actual individuals in the affected population.

Table 1B.12. The basic source/species/output parameters for each of the three scenarios analyzed using AIM; two EROS examples and one seismic example.

AIM Application Examples

INPUT: SOURCE & Animal Distribution Parameters

#1. EROS: 6—75 lb charges in 69 m of water (28.35N/91.5W) Dolphins (*Tursiops, Stenella*)

#2. EROS: 1—90 lb charge in 1300 m of water (27N/93W)Whales: Brydes, Sperm, Beaked (*Mesoplodon, Ziphius*)

#3. Seismic: 2-week survey in vicinity of 28.5N/89W Whales: Brydes, Sperm, Beaked (*Mesoplodon, Ziphius*)
Source: Omni-directional airgun, towed at 5 m depth, 12 sec cycle

- 100 Hz @ 245 dB re 1μPa^2 <rms> at 1 m
- 200 Hz @ 239 dB re 1μPa^2 <rms> at 1 m
- 400 Hz @ 233 dB re 1μPa^2 <rms> at 1 m

OUTPUT: % Population vs. Exposure Levels

#1 & #2. Relative to 182 dB re 1μPa^2 sec, total acoustic energy
#3. Relative to 160 and 180 dB re 1μPa^2 <rms>

Table 1B.13. Density of the modeled animals for each example and maximum dive depth.

Species	Model Density (Ex 1 & 2/Ex 3) Animals/km^2	Real Density* (Animals/km^2)	Dive Depth
Bottlenose Dolphin	0.5	.086	To bottom (< 100 m)
Stenella	0.5	.148	To bottom (< 100 m)
Bryde's Whale	0.5/0.005	.00041	150 m
Sperm Whale	0.5/0.005	.00081	1400 m
Beaked Whales	0.5/0.005	.00115	1453 m

* Densities from Davis *et al*. 2000. MMS Study 2000-003

Figure 1B.8, a screen shot of the AIM modeling developed for Example #1, provides some insight into the analysis mechanisms used. The upper left hand box lists the population folders for each of the modeled species. Opening each folder lists each animal, identifiable by a sequential number as well as an icon on the geo-display to the right. In this instance we have highlighted *Stenella* #14 with the control cursor. This action has simultaneously produced three results:

1) The detailed data box just to the right of the listing showing the animal's location and depth as well as its calculated received level of sound of 188.4dB.
2) *Stenella* #14's icon in the chart view (LAT/LON & depth color gradient) to the right has been highlighted by a black box.
3) *Stenella* #14's icon in the side view (Range vs. Depth & transmission loss, TL, color gradient in the bottom right of the screen) has also been highlighted by a black box. Note that this view coincides with the direction of the red bearing cursor emanating from the source location and shows all animals within a selected arc (in this instance +/- 45 deg). The bearing cursor can be controlled by mouse, or by the curved arrow control buttons at the bottom of the side view display. Related control buttons allow manipulation of all the displays, including display of a wide range of other database values (e.g. water temperature or salinity) in either the chart or side view windows.

From the color chart the TL at *Stenella* #14 is approximately 50 to 52 dB. As the "effective" source level for the 75 lb charge was estimated at an equivalent of 240dB//1μPa^{2}sec at 1 m, this would imply a received level of 188 to 190 dB, as expected from the readout in the data box (Urick 1975).[1] Thus the graphical display provides the user with an accurate and quick overall view of the transmission field relative to the animals arrayed within the model zone. The source location is also shown in both views.

For illustration purposes, in this depiction the animal densities shown in the screen shot are those listed as real in the table above. The range circle overlaid is roughly 3 km in radius and only 7 animals total reside within, an indication of the real difficulty of visual observations at these ranges, even for animals as densely populated as *Stenella*. In this example the animals are allowed to dive freely in this shallow water from the surface to the bottom. This snapshot therefore catches these virtual divers distributed fairly uniformly in depth, as arrayed by the distribution algorithm. If one allowed the model to run in time (see the "play" toolbar above the chart view), both the chart view and the side view would show the actual motion of the various animats depicted, providing the viewer with a graphical understanding of the interaction of the sound field and diving animals over time. The 3 km range is also the approximate range at which animals would be expected to be taken at the 182 dB//μPa^{2}sec threshold. The take algorithm used adds an additional 3.9dB to the RL calculated by the model to accommodate the 6 sequential explosions by an extrapolation factor [5Log(N)] commonly used to account for the amplification associated with non-simultaneous but closely spaced acoustic events. It is interesting that the number of animals located within the 3 km radius (5 *Stenella* and 2 *Tursiops*) in this "real" distribution snapshot compare closely with the takes (5.1 and 2.9, respectively) estimated using the amplified sample size approach.

This particular example points out an animal distribution feature of AIM currently in development, i.e. the introduction of pods for animals that exhibit this characteristic. Thus, in this example, both *Stenella* and *Tursiops* would be more accurately represented in a pod relationship than as

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[1] The equation for total acoustic energy in dB//μPa^{2}sec on p. 86 has been used here. The "effective" SL was calculated for the BELLHOP TL model to match Urick's Total Acoustic Energy results at ranges greater than 500 m.

individuals. Again the statistical parameters for such an approach must be worked out, but the concept is sound, and would provide more meaningful results when implemented.

This example also points out the need for two specific investigations with regard to the explosive/acoustic modeling used in AIM. The first is the need for a more detailed and accurate explosive model such as the new model developed for MMS by ARA, Inc. and described elsewhere in this volume (Dzwilewski 2003). The second is the need to conduct detailed field measurements to validate any propagation models used. In many instances the calibration factor needed to bring the observed and predicted results into agreement, is the adjustment of bottom loss parameters. This is especially true in virtually all locations where the sound path from the source interacts in any way with the bottom. Finally, all models should err on the side of environmental conservatism, but in a realistic and justifiable manner.

Analysis of the other two examples was carried out using the AIM model in a manner similar to that just described for Example #1. The end results are summarized in the Table 1B.14.

Table 1B.14. Summary of analysis carried out using the AIM model.

Species	**Ex #1: EROS Shallow (69 m)**	**Ex #2: EROS Deep (1300 m)**	**Ex #3: Seismic (600 to 1400 m)**
Stenella	5.1 takes at RL>182 dB//μPa^{2}sec	Not modeled	Not modeled
Tursiops	2.9 takes at RL>182 dB//μPa^{2}sec	Not modeled	Not modeled
Bryde's Whale	Not modeled	.028 takes at RL>182 dB//μPa^{2}sec	9.8 takes at RL>160 dB//μPa^2 <rms> 0.2 takes at RL>180 dB//μPa^2 <rms>
Sperm Whale	Not modeled	.057 takes at RL>182 dB//μPa^{2}sec	9.8 takes at RL>160 dB//μPa^2 <rms> 4.0 takes at RL>180 dB//μPa^2 <rms>
Beaked Whale	Not modeled	.069 takes at RL>182 dB//μPa^{2}sec	9.8 takes at RL>160 dB//μPa^2 <rms> 2.3 takes at RL>180 dB//μPa^2 <rms>

One can bring some simple extrapolation to bear on these results. For example, the species used in the second EROS example have a distribution roughly 1/100th of those in Example #1. It is not surprising then that the ratio of takes between the two examples follow this same proportion. In the seismic example one expects a greater number of takes due to the fact that both the source and the animals are moving, and thus opportunity for closer encounters will grow over time. Further, the seismic source is transmitting every 12 seconds over a 20-hour period in this example. Also the take threshold of 180dB is less than that used for the explosive, and in this example a source level of 245 dB for the seismic was used, 5 dB higher than the “effective” source level of the explosive.

As with the explosive source model discussion, a more accurate model for seismic propagation is needed. In particular, a model is needed that accounts for array dimensions, phased steering, the spectral and spatial properties of the radiated field. The use of an omni-directional model (as has been used here) with a source level equal to the effective beamformed level of the array is clearly overly conservative in estimating its impact. As with the explosive model any new analytical model for seismic must also undergo extensive review versus actual measured results.

ONGOING DEVELOPMENT GOALS

The AIM model continues to be a developing project with expanded applications gained through new tools and databases as well as refinement of the basic software and screen tools. Areas in which work is in progress are briefly listed below:

- Additional environmental databases including directional ambient noise
- Simultaneous multiple source, multiple frequency capability
- GIS Compatibility
- Capability to:
  - Model joint acoustic/visual transect data
  - Model masking
  - In-Air Modeling (application to human as well as terrestrial and avian wildlife)
  - Pollution
- Related tool development, such as the NMFS APV tool, including non-acoustic and explosive model applications

SUMMARY

The AIM model presented here is a highly useful tool for a wide range of regulatory and scientific applications. It provides a graphical visualization of the interaction between sound producing activities and resident marine populations as well as the statistical assessment results needed for regulatory purposes.

It also has potential utility as a mission planning tool including parametric or “gaming” analysis of each key input parameter. An apt example in this regard is the concept of using multiple small explosive charges instead of a smaller number of large charges in EROS applications, with the intent to reduce the radiated peak pressure and acoustic field. AIM is uniquely suited to evaluating the net effect on “takes” in such an evaluation. AIM, as currently configured, has the capability to be quickly updated based on *in situ* measurements for any of the database inputs, with the change in results rapidly compared. Finally, it can be used as an event reconstruction tool.

Several new AIM applications, as highlighted above, will be available within CY 2003. The model is in continuous use on a variety of environmental issues, and the experience gained in each application continues to refine and improve the basic product.

William Ellison is CEO and Chief Scientist of Marine Acoustics, Inc. A graduate of the U.S. Naval Academy and the Massachusetts Institute of Technology, he has been active in underwater acoustical engineering, research, test and development for 40 years. He has been a principal scientific advisor for a number of major acoustical research programs for the Department of Defense and other government agencies. His involvement in marine mammal acoustical research commenced in 1983 with the development of the first field portable acoustic localization system designed for tracking vocalizing marine wildlife in the Arctic ice pack. Dr. Ellison has served on the U.S. Delegation to the Scientific Committee of the International Whaling Commission, and has served as an Expert Witness before the National Energy Board of Canada as well as other landmark environmental issues.

Dr. Adam Frankel is a whale researcher and bioacoustician at Marine Acoustics, Inc.

SESSION 1C

AIR QUALITY, PART I

Chair: Chester Huang, Minerals Management Service
Co-Chair: Richard Karp, Minerals Management Service

Date: January 14, 2003

CHARACTERISTICS OF OVERWATER VISIBILITY AND MIXING HEIGHT OVER THE GULF OF MEXICO

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

INTRODUCTION

Measurements of offshore visibility and other meteorological parameters began in November 2001 and are currently ongoing. Monthly data return has typically been greater than 95%, and a second station is planned for deployment. This data set, along with historical records from coastal stations and offshore buoys, will be analyzed for occurrences of reduced visibility, i.e., fog and haze. This presentation summarizes some of our preliminary findings, including improved techniques for estimation of marine atmospheric stability and mixing height.

OVERWATER VISIBILITY

The mixing height can be defined as the vertical distance between the earth's surface and the altitude to which wind can effectively disperse pollutants. This upper limit is usually a temperature inversion. The ventilation factor (VF) is the product of the wind speed and mixing height. Poor pollution dispersion prevails when the VF is less than 2000 m^2 s^{-1}. Low visibility occurs during fog or haze, most often under low ventilation conditions. Haze and fog are determined as follows: According to the User's Guide of the Automated Surface Observing System (ASOS) published by the National Weather Service, when visibility drops to below 7 statute miles, the "Obstructions to Vision (OTV) Algorithm" obtains the current dewpoint depression (DD) to distinguish between fog and haze. If the DD is less than or equal to 4°F (or approximately 2.2°C), then fog will be reported. If the DD is greater than 4°F and no present weather is reported by the Precipitation Identification and Freezing Rain sensors, then haze is reported by the OTV. When Present Weather is occurring, haze is not reported.

Funded jointly by CMI/MMS, visibility measurements have been made at an offshore station (CSI-3, located at 29°26.47' 92°03.68'). Along with other meteorological and oceanographic parameters, these measurements are available in near-real-time at the website http://wavcis.csi.lsu.edu/. The fog/haze definition described above is being applied to this data record to identify episodes of reduced visibility. An example of offshore haze/smoke is presented using pertinent meteorological and satellite information.

Because the dewpoint depression (DD) is a surrogate for low visibility such as fog or stratus, seasonal distribution of the frequency of the DD is also presented. For this analysis, the yearly records for three NDBC stations are employed; #42001, #42020, and #42007 representing the deep Gulf, shelf-break, and shallow water regions, respectively. It is shown that in January, low visibility (when the DD is less than 2°C) occurs most frequently over the shallow water (near 24%), and least over the deep Gulf. In April, nearly 40% of the time the DD was less than 2°C along the shelf break. However, in July, the DD values all are larger than 2°C (or no fog) for these three environments. In

October, the DD value below 2°C increases from less than 2% in July to a maximum of 16% along the shelf break.

STABILITY CLASS

Atmospheric stability in the surface boundary layer is generally classified into three categories. They are unstable when heat convection dominates, near-neutral when mechanical turbulence dominates, and stable when mechanical turbulence is damped by temperature stratification (e.g., Panofsky and Dutton 1984). A stability parameter widely used is z/L where z is the height and L is called the Monin-Obukhov stability length (see, e.g., Panofsky and Dutton 1984).

In the marine environment, Smith (1980, Eq. 17a) found that

$$\frac{\sigma_U}{U} = 0.101 - 0.12\frac{z}{L} \tag{1}$$

where $_U$ is the standard deviation of the horizontal wind speed (downwind direction) U; $_U$/U is termed the horizontal turbulence intensity. On the other hand, Hsu (2001) proposed that $_U$/U and the gust factor, G (defined as the ratio of peak to sustained wind speed), are related that

$$G = \frac{U_{gust}}{U} = 1 + 3\frac{\sigma_U}{U} \tag{2}$$

where U_{gust} is the peak gust. Substituting Eq. (1) into (2), we have

$$G = 1.30 - 0.36\frac{z}{L} \tag{3}$$

In order to determine the impact of offshore and onshore emissions for joint sources on the air quality of coastal regions, Hanna *et al.* (1985) proposed and evaluated their Offshore and Coastal Dispersion (OCD) Model. In that model, overwater stability classes are required. On the basis of this OCD model, which has been recommended for regulatory use by the U.S. Minerals Management Service, Hsu (1992) proposed and verified that when |z/L| is within 0.4, that stability class is neutral, or near-neutral (i.e., z/L = 0). In other words, mechanical turbulence will dominate the air-sea interaction. From Eq. (3), G = 1.30 when z/L = 0. A verification of this concept is provided in Hsu (2003). Now, substituting z/L = 0.4 into Eq. (3), G = 1.16, and for z/L = -0.4, G = 1.44. Hence, when the value of G is between 1.16 and 1.44, there is neutral stability, for G 1.45, unstable, and G 1.15, stable conditions.

Based on these criteria, it is shown that over 80% of the time during the year, the stability is neutral for the deep Gulf and shelf break and between 70 to 90% over the shallow water. However, more stable conditions are observed over the shallow water environment. This is in agreement with the greater frequency of low DD (less than 2 C), particularly from November through February.

For atmospheric dispersion modeling over the Gulf, improved formulas for the stability parameter are presented in the Appendix (for more detail, see Hsu and Blanchard 2003).

MIXING HEIGHT

Under near-neutral conditions, the mixing height is 125 times the DD value (see Hsu and Blanchard 2003). Since the mean DD value is between 5 and 6 C, the mixing height over the deep Gulf and along the shelf break is around 670 m with very little diurnal variation. However, in the shallow water environment the mixed height can be much lower as compared to further offshore due to the greater frequency of low DD.

Estimates of the mixing height under unstable and stable conditions over the Gulf have been provided in Hsu and Blanchard (2003).

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S. A. Hsu received his Ph.D. in meteorology from the University of Texas at Austin. He has been a Professor at Louisiana State University since 1969. His research interests are coastal and marine meteorology, air-sea interaction, and pollution transport physics. Dr. Hsu has published extensively, including a textbook entitled *Coastal Meteorology*.

Brian W. Blanchard was awarded his B.S. degree in Atmospheric Sciences from Northeast Louisiana University (now ULM) in 1983. He has been a Research Associate at Louisiana State University for nearly 20 years and has contributed to many meteorological studies ranging from sand transport to tropical storm forecasting. He is the co-author of several journal articles and technical reports.

APPENDIX

Improved estimation of z/L from the bulk Richardson number, Rb, using routine buoy measurements. (For more detail, see Hsu and Blanchard 2003).

$$L = -\frac{u_*^3 \rho C_p T}{\kappa g H \left(1 + \frac{0.07}{B}\right)}$$

$$\tau = \rho u_*^2 = \rho C_d U_{10}^2$$

$$H = \rho C_p C_T \left(T_{sea} - T_{air}\right) U_{10}$$

$$\frac{z}{L} = -\frac{\kappa g z C_T \left(T_{sea} - T_{air}\right)\left(1 + \frac{0.07}{B}\right)}{\left(T_{air} + 273.16\right) U_z^2 C_d^{3/2}}$$

$$B = 0.146\left(T_{sea} - T_{air}\right)^{0.49}$$

$$\frac{z}{L} = \kappa C_T C_d^{-3/2} R_b = A R_b$$

$$R_b = -\frac{g z \left(T_{sea} - T_{air}\right)\left(1 + \frac{0.07}{B}\right)}{\left(T_{air} + 273.16\right) U_z^2}$$

$$R_b = \frac{g z \left(T_{air} - T_{sea}\right)}{\left(T_{air} + 273.16\right) U_z^2}$$

BOUNDARY LAYER STUDY IN THE WESTERN AND CENTRAL GULF OF MEXICO

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Steven R. Hanna, Hanna Consultants

This four-year project began in late 1998. The study plan was approved in 1999 and the project is expected to be completed by August 2003. This paper presents an overview of the project, plus selected data analysis results.

PROJECT OBJECTIVES

The purpose of this study is to provide the U.S. Department of the Interior Minerals Management Service (MMS) with a description and analysis of the atmospheric boundary layer and to explain how its structure influences the dispersion and transport of pollutants in the western and central Gulf of Mexico (GOM). The results of this study will be used by the MMS to support techniques for evaluating the effects of oil and gas exploration, development, and production activities in the Outer Continental Shelf (OCS) on air quality over coastal areas. To complete this study we are conducting a number of technical tasks including the following:

- Producing a data inventory for synthesizing the characteristics of the Atmospheric Boundary Layer (ABL) and its dispersion properties in the western and central GOM, based on May 1998 through October 2001 observations and modeling results.
- Evaluating annual, seasonal, and diurnal variations in the ABL's structure.
- Describing the processes governing variations in the ABL's structure.
- Evaluating transport and mixing characteristics that govern pollutant dispersion over diurnal and multi-day scales.
- Providing a conceptual model summary of processes that influence the ABL's structure and variability and pollutant transport and dispersion.

BACKGROUND

Much uncertainty exists concerning the atmospheric boundary layer in the region due to space and time variations caused by variable underlying water temperatures and the effects of mesoscale atmospheric structures. To obtain boundary-layer observation measurements, the MMS instrumented two oil platforms with 915-MHz radar wind profilers (RWPs), 2-KHz Radio Acoustic Sounding Systems (RASS), and near-surface routine meteorological instruments. In addition, the Offshore Operators Committee (OOC) instrumented four sites (including three oil platforms) with RWPs, RASS, and surface monitors plus two platforms with surface monitors for the Breton Island Aerometric Project (BAMP). The two MMS-sponsored meteorological stations operated from May 1998 through October 2001 and the four OOC-sponsored meteorological stations operated from

October 2000 through October 2001. Figure 1C.1 shows a map of the GOM region and indicates the locations of the various observation sites.

The RWPs measure winds and RASS measure virtual temperatures between heights of about 100 m and a few kilometers. RWPs also provide reflectivity data that are being used to estimate the height of the atmospheric boundary layer on an hourly basis. The near-surface observations at the oil platforms include sea-skin temperature as well as wind speed, wind direction, air temperature, and mixing ratio at about 25 m. These new data, in addition to the traditional data collected by buoys and available from the National Climatic Data Center (NCDC), are being analyzed to investigate the overwater surface energy balance and boundary layer structure for both steady-state horizontally homogeneous conditions and for conditions variable in time and space. These three-dimensional, time-dependent meteorological fields are being used for analysis of transport and dispersion from overwater sources.

The new and routine data collected are being analyzed to investigate the following technical issues:

1. The over-water surface energy balance is being studied using the near-surface observations for both steady-state horizontally-homogeneous conditions and for conditions variable in time and space. A climatology of latent-heat and sensible-heat fluxes, and other boundary layer parameters are being developed for both situations using the COARE algorithm (Fairall *et al.* 1996). The COARE algorithm was designed to improve estimates of surface fluxes and scaling parameters over the deep ocean in tropical regions and has been modified in this project for the shallow waters of the GOM.

2. Given the surface energy balance components determined in part (1), the vertical profiles of wind and temperature are being studied to develop climatologies and parameterizations. In particular, it is desirable to be able to estimate the full vertical profiles of wind and temperature based only on near-surface measurements of air-water temperature differences and wind speeds.

3. The extensive virtual temperature profiles and RWP reflectivity data are being used to estimate the mixing depths and prepare empirical formulas to parameterize these observations.

4. The frequency of occurrence of very stable conditions near the surface and in layers aloft is being investigated due to the importance of these layers for defining worst-case conditions for air pollutants.

5. The horizontal spatial variability of wind speed and direction is being studied to identify the fraction of time that wind directions and speeds persist over several hours in the GOM, thus causing straight-line transport of pollutants towards the shoreline.

6. Estimates of the scaling velocity (u*) and scaling temperature (T*) have been created and are being studied. These scaling parameters are directly related to surface momentum and heat fluxes. Since turbulent velocities (important to dispersion) are directly proportional to

u*, it should be possible to derive improved parameterizations for the dispersion coefficients $_y$ and $_z$.

7. Synoptic (regional) classification schemes are being developed so that meteorological atmospheric boundary layer and pollutant transport and dispersion characteristics are being estimated by synoptic class.

8. Three-dimensional prediction fields of surface winds, heat and momentum fluxes, and wind profiles—from the National Center for Environmental Protection's (NCEP's) Eta Model—are available for the GOM and are being compared with the observations from the profilers and buoys. The Eta model predictions are being used in conjunction with observations in the preparation of three-dimensional estimates of boundary layer parameters and for creation of high horizontal resolution (4 km) gridded wind fields. The wind fields will be used to estimate transport for various meteorological conditions.

9. Conceptual models are being developed that summarize the physical processes that influence the ABL's structure and variability and pollutant transport and dispersion.

10. The various data sets described above are being collected, and quality assurance/quality control (QA/QC) procedures are being applied to produce a single user-friendly database. A user interface has been developed to view and analyze the data in the database.

SAMPLE RESULTS

- Upper-air synoptic patterns for the study period show an almost equal representation of both ridges and troughs. Other patterns (the post trough, flat, zonal, and tropical storm patterns) were observed less than 20% of the time.

- Onshore surface flow occurs 70% to 80% of the time when a ridge is present; it occurs 50% to 60% of the time for the other upper-air patterns.

- The average vertical wind profiles for the study period at South Marsh Island (SMI) and Vermillion (VRM) showed a general pattern of light winds (1–3 m/s), transitioning from southeasterly to easterly winds at the surface, through southerly winds at the mid-levels, to southwesterly winds above 1500–1700 m. Below 1400 m, pre-dawn winds had a prominent southeasterly component, especially at SMI. The surface winds generally matched the aloft winds at both sites, except from 1100 to 1500 CST at VRM, when the surface winds were easterly. With the exception of these slight discrepancies, the overall wind averages at the two sites coincide well with one another.

- The fluxes and scalar parameters calculated by the Coupled-Ocean Atmosphere Response Experiment (COARE) algorithm in the GOM are physically consistent with expectations and are similar to observations and COARE calculations for Tropical Ocean-Global Atmosphere (TOGA)-COARE, which took place in the warm western Pacific Ocean near the equator. Calculated monthly average sensible-heat fluxes in the GOM were about 5 to 30 W/m2, typical of other over-water areas. Similarly, calculated monthly average latent-heat fluxes were about 50 to 150 W/m2, also typical of other over-water areas. Both the latent- and sensible-heat fluxes were highest in the late fall and winter and lowest in the summer, although the yearly cycle in latent heat values is less pronounced than the seasonal cycle.

- The monthly average Eta model latent- and sensible-heat fluxes were generally in good agreement with the calculated fluxes. However, the model fluxes did not show as much variation between sites as the calculated fluxes. In addition, the model fluxes were about 20% greater than the calculated fluxes in the fall and early winter, but were very similar during the spring and summer. The COARE estimates of latent- and sensible-heat fluxes were made using observations at buoy 42040 or the VRM and SMI oil platforms (see Figure 1C.1).

- The COARE and Eta estimates of hourly-averaged friction velocity were compared for four case studies. On average, the Eta-predicted hourly-averaged friction velocity values were about 50% to a factor of two larger than the COARE hourly-averaged friction velocity values. Since the momentum flux or surface stress is proportional to friction velocity squared, the Eta momentum fluxes were a factor of two to four larger than the COARE estimates. This difference is difficult to understand from a boundary-layer perspective since overall average and maximum sensible- and latent-heat flux values estimated by COARE and Eta agreed fairly well. Because both sensible- and latent-heat fluxes are proportional to hourly-averaged friction velocity, we would expect the Eta-predicted sensible- and latent-heat flux values to also be 50% to a factor of two larger than the COARE estimates. This difference is being investigated.

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Clinton P. MacDonald, Manager of Meteorological and Air Quality Analysis Services at STI, has performed meteorological and air quality data analyses in coastal and inland environments throughout the United States. He has made extensive use of radar wind profiler and RASS virtual temperature upper-air meteorological data to understand the phenomena occurring in the atmospheric boundary layer. Mr. MacDonald has developed and implemented several computer software tools to process and interpret upper-air and surface meteorological data.

Paul T. Roberts, STI's Executive Vice President, designs and manages air quality field, data management, and data analysis projects. Most of these projects involve the use of field data and analysis methods to explain important meteorological and air quality phenomena, and to develop, apply, and evaluate meteorological and photochemical models. Specific projects headed by Dr. Roberts for which boundary-layer processes over water and shoreline environments were important components include Breton Aeromatic Monitoring Program (BAMP), the MMS-sponsored Gulf of

Mexico Air Quality Study (southeast Texas and Louisiana and offshore), the Southern California Air Quality Study (SCAQS) and several subsequent data analysis efforts in and around the South Coast Air Basin (SoCAB), the Lake Michigan Ozone Study, and the NARSTO-Northeast Air Quality Study (covering Virginia to Maine, including offshore).

Steven R. Hanna is a specialist in atmospheric turbulence and dispersion; in the analysis of meteorological and aerometric data; and in the development, evaluation, and application of air quality models. He is an AMS Certified Consulting Meteorologist with over 30 years of experience. He has led several research and development projects involving, for example, the statistical evaluations of hazardous gas dispersion models and regional ozone models; the development of models for the dispersion of emissions from tall power plant stacks and from offshore oil platforms; and the analysis of data from large regional field experiments in the Santa Barbara area, in the Lake Michigan region, in the GOM, and in the northeastern United States. He led the development of the OCD Model. Dr. Hanna was Chief Editor of the Journal of Applied Meteorology from 1988–1997 and has published over 100 articles in peer-reviewed journals, six chapters in books, and four books for which he is the primary author.

DATA QUALITY CONTROL AND EMISSIONS INVENTORIES OF OCS PLATFORM ACTIVITIES IN THE BRETON AREA OF THE GULF OF MEXICO

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INTRODUCTION

In this study, being conducted by Eastern Research Group, Inc. (ERG), quality assurance/quality control (QA/QC) is being performed on activity data collected by MMS for platforms adjacent to the Breton National Wildlife Refuge/Wilderness Area (BNWA), and an emission inventory is being developed. The inventory will cover 12 consecutive months from September 2000 through August 2001, for nitrogen oxides (NO_x) and sulfur dioxide (SO_2).

The objectives of this study are to QC and archive activity data from 600 platform sources located within 100 kilometers (km) of the BNWA. The activity data were collected with the Breton Offshore Activity Data System (BOADS) Visual Basic data collection software (developed under another project, and written in Access). The activity data will be used to develop monthly emission estimates of NO_x and SO_2, using a previously-developed Oracle database management system (DBMS). The DBMS is currently being updated, and will be used to calculate and archive emissions estimates using the most current emission factors, calculation methods, and activity data.

PROJECT IMPLEMENTATION

Initial QA/QC and Completeness Checks

The initial data collection phase using the BOADS software was to run from January 2000 through December 2000. The collection phase was then extended until September 2001. Data requested included Company ID, Structure and Complex ID, lease number, block and area number, and latitude/longitude. Equipment-specific activity data were requested for amine units, boilers/heaters/burners, diesel engines, drilling equipment, flares, glycol dehydrators, natural gas engines and turbines, and vents.

For each equipment type, the BOADS software has an equipment screen that contains fields for the parameters to be recorded. As an example, the boiler/heater/burner equipment screen requires operators to enter parameters such as hours operated, fuel type, fuel heating value, amount of fuel used, and equipment elevation.

We received the majority of the BOADS data sets in November 2001. All files received were logged unto a tracking sheet, and the original files were archived. Overall, data were provided by 54 companies for 599 platforms (combination of Complex and Structure IDs). At the current time, we have completed approximately 90% of QC activities.

Once MMS provided the data to ERG, we performed file integrity checks to verify that the file submitted could be opened. If we could not open the file, we contacted MMS for assistance. Our initial QA/QC tasks consisted of verifying and correcting the User, Complex, and Structure IDs as necessary. The MMS list of companies, leases, and platforms was retrieved from MMS. Additionally, the locational data (area, block, and latitude/longitude) provided was checked for each platform.

Forty-two platforms (8%) did not report any equipment records. These 42 platforms excluded cassions or platforms that have been dedicated only as living quarters and did not include emission sources. Nine of these identified platforms were flagged as inactive, leaving 33 platforms for which equipment records should have been provided, but were not. The possible explanations are that 1) equipment data were intentionally not submitted; or 2) the platforms were "inactive" during the entire period but were not flagged as such. ERG intends to contact the platforms to determine the reason why equipment records were not submitted and develop a plan to deal with the missing equipment data.

Approximately 69% of the platforms completed all 12 surveys. The remaining 184 platforms submitted between 1 and 11 surveys. These platforms were investigated to see why all monthly data were not reported. For 20 platforms, it was clear that there was a change of ownership—with months submitted under two different company IDs.

Equipment Completeness

Equipment information and activity-level data for 9 different types of equipment can be populated for each platform-survey combination. We have identified the fields in each equipment table that are necessary for developing emission estimates. Of these "key" fields, surrogate data may be available for any missing data.

QC procedures were programmed into the software in an effort to minimize the submittal of incomplete and erroneous activity data by the platform operators. The BOADS software automatically runs a series of QC checks on the data when it is saved. If the operator leaves a field blank, provides data that is out of range, or enters a value that is not consistent on a month-to-month basis, an error message will appear. The operator can either correct the problem, override the QC check (and provide a comment), or ignore the message and save the file anyway. When operators entered data that appeared in the QC results, ERG attempted to reconcile the missing, atypical, or suspect data by reviewing the comments, contacting the operators, or developing surrogate data. In general, we have encountered the following:

1. Required field blank;
2. No control efficiencies;
3. Structure diesel usage less than equipment sum;
4. Structure natural gas usage less than equipment sum;
5. Missing months for equipment; and
6. Value submitted is an outlier.

Every equipment survey with missing values was first checked against other surveys for the same equipment to determine if the operator may have mistakenly not populated the field. In this situation, we populated the missing data to match the other surveys if the equipment were flagged “active” for the missing month(s).

ERG then completed six types of data analysis:

1. Pre-processing of the data;
2. Equipment survey consistency;
3. Data range checks;
4. Stream analysis between certain equipment;
5. Applying surrogate values; and
6. Post-processing.

We have completed most of the QC/gap filling activities, and are in the process of contacting operators for details as needed.

Calculations

Using activity data and emission factors, the updated Breton Study DBMS will be used to calculate NO_x and SO_2 emissions from amine units, boilers, diesel engines, drilling equipment, flares, glycol dehydrators, natural gas engines and turbines, and vents. ERG has completed the following steps to update MMS’ Breton Study DBMS:

- Examined each calculation routine and corrected mathematical and typographical errors;
- Updated the emission factors using the latest information in EPA’s *AP-42* document (EPA 2002);
- Standardized the calculations to be consistent with the units of measure in *AP-42*;
- Compared the calculation methods to current Emission Inventory Improvement Program (EIIP) methods and updated ones where calculations did not agree with current methods; and
- Revised the DBMS so that the database users can query by pollutant, month, equipment type, or platform.

The DBMS is also populated with surrogates for values such as fuel sulfur content, fuel heating value, fuel density, and control efficiencies. The DBMS is currently being finalized. We will then batch-upload the final activity data files after QC is complete. We will not be working with 600 individual platform submittals. We will QA all of the uploaded input data and the resulting calculations, and prepare draft, proof, and final reports.

OTHER TASKS

Also included in this project was a review of the available non-platform inventory data for the BNWA. An inventory of non-platform sources is being developed by ERG for the entire Gulf, but only for the 2000 base year. We assessed the representativeness of the data for the time period of the Breton study (September 2000–August 2001) and provided recommendations to MMS on how to obtain the activity data needed to develop a non-platform inventory for the study area for January–August, 2001.

Richard Billings has a master's degree in environmental science and engineering and has worked with Eastern Research Group (ERG) for 10 years. The focus of most of his work has been the quantification of air emissions or water discharges to support regulatory decision making and development of control strategies. His work includes development of criteria pollutant and hazardous air pollutant emission factors and emission inventories for a variety of sources. Richard particularly specializes in the development of mobile source inventories.

Darcy Wilson is an environmental scientist with over 15 years of experience. Her expertise includes air pollutant emission factor and emission inventory development, technical writing, database development, and quality assurance/quality control. She has been serving as Program Manager for the MMS Gulfwide Study since its inception in 1999.

GULFWIDE EMISSIONS INVENTORY STUDY FOR THE REGIONAL HAZE AND OZONE MODELING EFFORTS

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INTRODUCTION

MMS is currently sponsoring several atmospheric sciences studies, including two air quality emission inventory projects that affect only platforms near the Breton National Wilderness Area in the Gulf of Mexico (GOM). The current study, the Gulfwide Emission Inventory Study, builds on these MMS studies with the goal of developing a base year 2000 inventory of criteria pollutant and greenhouse gas emissions for all oil and gas production-related sources in the GOM, including non-platform sources. To develop the inventory, ERG expanded the Breton Offshore Activities Data System (BOADS) program to create the Gulfwide Offshore Activities Data System (GOADS). For non-platform sources covered by the Gulfwide Emission Inventory Study, the 1995 "Gulf of Mexico Air Quality Study" was used as the starting point. Ultimately, state agencies will use the Gulfwide criteria pollutant and greenhouse gas emissions inventory to perform modeling for ozone and regional haze for use in their State Implementation Plans (SIPs).

COLLECTING PLATFORM ACTIVITY DATA

The BOADS software was used as the starting point for GOADS. In fact, GOADS was designed so operators can directly import monthly BOADS files for 2000. The primary differences between BOADS and GOADS are that GOADS covers additional equipment types and has an annual (not monthly) survey for fugitive sources. GOADS was used to collect activity data from platforms in the entire GOM, a total of nearly 3400 platforms, including the 600 platforms in the Breton Area studies. GOADS activity data are reported on a monthly basis, with additional activity data reported for mud degassing, pneumatic pumps, and pressure/level controllers. Another parameter, sales gas composition, was added to the Structure Screen for operators to report composition of gas processed and transferred off the structure.

ERG programmed automatic quality assurance (QA) procedures into the software in an effort to minimize the submittal of incomplete and erroneous activity data by the platform operators. ERG requested that operators submit a printout of their Quality Assurance Summary Form along with their monthly activity files. The QA Summary focuses on identification of critical data that the operators need to complete prior to submitting their data to MMS.

The software also automatically runs a series of quality control (QC) checks on the data when the operator saves it. If the operator leaves a field blank, provides data that is out of range, or enters a value that is not consistent on a month-to-month basis, an error message will appear. The operator can either correct the problem, override the QC check (and provide a comment), or ignore the message and save the file anyway. When operators entered data that appeared in the QC results or on the QA Summary Form, ERG attempted to reconcile the missing, atypical, or suspect data by reviewing the comments, contacting the operators, or developing surrogate data.

MMS sent 239 unique data files to ERG primarily on two compact disks (CDs) and all files were logged onto a tracking sheet. The first CD (CD-1) contained 81 files and the second (CD-2) contained 237 files (including 80 duplicate/replacement files for files on CD-1). An additional CD was sent containing a replacement GOADS submittal with 12 files, and a new submittal (1 file) was provided via file transfer protocol (FTP). All electronic data were in the prescribed Microsoft Access 2000 database that was created by the GOADS software.

Ninety-three companies submitted data for 3154 platforms (combination of complex ID and structure ID). Included in the submittal were 1150 survey records and 35,198 structure records.

ERG checked file integrity to verify that the files submitted could be opened, and that they matched the QA Summary Forms (same Company, Structure, and Complex IDs). ERG was able to open and review all of the files provided. Companies were also required to submit a hard copy of their QA Summary Form. Of the 239 files submitted, 222 were accompanied by a hard copy of their QA summary results (93%). For the submittals missing hard-copy QA summary forms, ERG was able to print the form for review.

Our initial QA/QC tasks consisted of verifying and correcting the User, Complex, and Structure IDs as necessary. Additionally, we checked the locational data (area, block, and latitude/longitude) provided for each platform.

ERG then completed six types of data analysis:

1. Pre-processing of the data;
2. Equipment survey consistency;
3. Data range checks;
4. Stream analysis between certain equipment;
5. Applying surrogate values; and
6. Post-processing.

We have completed most of the QC/gap filling activities and are in the process of uploading the activity data into the Oracle database management system (DBMS) where monthly emissions for each pollutant and equipment type are calculated by platform.

ORACLE DATABASE MODIFIED TO CALCULATE PLATFORM EMISSIONS

ERG modified the Breton Area Oracle DBMS to create the Gulfwide Oracle DBMS. The Gulfwide Oracle DBMS, with expanded equipment types and emission factors, imports the activity data and calculates monthly emissions of CO, SO_2, NO_x, PM_{10}, $PM_{2.5}$, VOC, CO_2, CH_4, N_2O, and total hydrocarbons. ERG:

- Updated and expanded the emission factors using the latest information in EPA's *AP-42* document (EPA 2002);
- Added calculation routines for mud degassing, pressure/level controllers, and pneumatic pumps;
- Standardized the calculations to be consistent with the units of measure in *AP-42*;
- Compared the calculation methods to current Emission Inventory Improvement Program (EIIP) methods and updated ones where calculations did not agree with current methods; and
- Revised the DBMS so that database users can query by pollutant, month, equipment type, or platform.

NON-PLATFORM EMISSION SOURCES IN THE GOM

In addition to compiling activity data from platform operators and developing an inventory of platform emissions, ERG compiled activity data from non-platform sources in the GOM, and developed emission estimates for each source category. Non-platform sources consist of:

- Survey Vessels;
- Drilling Rigs;
- Support Vessels;
- Support Helicopters;
- Pipe Laying Operations;
- The Louisiana Offshore Oil Platform (LOOP);
- Vessel Lightering;
- Commercial/Recreational Fishing;
- Military Vessel Operations;
- Commercial Marine Vessels; and
- Biogenic/Geogenic Sources.

We have compiled all of the base year 2000 activity data and developed the emission estimates for the above source categories. Updated diesel emission factors were obtained from EPA's Background Information Documents associated with the Marine Diesel Rule. Emission factors for residual oil-fueled vessels were derived from methods used in the 1999 National Emission Inventory (NEI) Commercial Marine Vessel Documentation. Helicopter emission factors were developed specifically for this inventory from available test data. Biogenic and geogenic emission estimates for the GOM were obtained from recently published studies.

Activity data for these non-platform sources were obtained from a variety of references. The basis for most of the compiled activity data was hours of operation. Data in geographic information system (GIS) format were preferred. This will facilitate development of spatially disaggregated emission estimates in the future.

Gulfwide emission estimates for each source category are summarized in Table 1C.1. The activity data and resulting emission estimates can be disaggregated in the future to MMS lease blocks or GIS data sets, depending on MMS's program needs.

Table 1C.1. Summary of non-platform emission estimates (tpy).

Category	PM-10	NOx	SO_2	CO	VOC	CO_2	N_2O
Survey Vessels	4.67	188.26	31.55	18.56	1.65	12,468.76	*
Drill Ships	676.92	27,270.17	4586.99	2862.27	263.13	1,812,575.83	*
Support Vessels	929.20	37,118.26	6351.91	5104.26	542.19	2,509,262.29	*
Support Helicopters	107.28	1437.82	177.12	6060.37	2285.23	*	*
Pipelaying Vessels	444.02	17,887.46	3008.77	1877.46	172.59	1,188,932.25	*
LOOP	159.94	5589.94	1033.07	2355.85	1137.95	406,481.11	*
Vessel Lightering	554.07	18,989.35	3530.57	8754.34	9526.65	1,390,920.91	*
Fishing	47.06	1898.59	318.21	187.13	16.66	125,749.05	*
Military Vessels	245.50	8747.19	1841.15	859.29	77.57	576,178.03	*
Commercial Marine Vessels	137.62	1550.92	1046.57	76.71	36.02	*	*
Biogenic/Geogenic Sources	NA	NA	NA	*	25,832.50	*	3710.00
Total (tpy)	3,306.28	120,677.95	21,925.91	28,156.24	39,892.14	8,022,568.23	3710.00

* Appropriate emission factors currently not available.
NA = Not applicable.

Darcy Wilson is an environmental scientist with over 15 years of experience. Her expertise includes air pollutant emission factor and emission inventory development, technical writing, database development, and quality assurance/quality control. She has been serving as Program Manager for the MMS Gulfwide Study since its inception in 1999.

Richard Billings has a master's degree in environmental science and engineering and has worked with Eastern Research Group, or ERG, for 10 years. The focus of most of his work has been the quantification of air emissions or water discharges to support regulatory decision making and development of control strategies. His work includes development of criteria pollutant and hazardous air pollutant emission factors and emission inventories for a variety of sources. Richard particularly specializes in the development of mobile source inventories.

PRELIMINARY REVIEW OF BRETON IMPROVE MONITOR AIR QUALITY AND METEOROLOGY DATA

Richard Karp, Minerals Management Service

INTRODUCTION

In July of 1999, the Environmental Protection Agency established regulations to address visibility impairment due to emission releases from various air pollutant sources across a broad geographic region. The Regional Haze Rule is intended to protect the visual air quality in 156 mandatory federal Class I areas. A monitoring network, commonly referred to as the Interagency Monitoring of Protected Visual Environments (IMPROVE), has been expanded to include 110 sites nationally. The data collected from these sites will be used to establish baseline conditions in each Class I area and to track the progress of the air quality goals set forth in each state's implementation plans.

The IMPROVE monitoring network for the BNWA was installed and began collecting data in Mid-August of 2000. However, due to initial start-up problems, there is considerable "missing data" through January of 2001. Further, the current availability of data is only through November of 2001. With such a limited data-set, the results of any analyses must be considered with some caution. However, analysis of even this limited set of data may be useful.

TECHNICAL ANALYSIS

The IMPROVE monitor collects 24-hour samples every third day (Table 1C.2). Therefore, in the 12-month period, 12/00 to 11/01, approximately 122 samples were collected and 20% would represent approximately 24 days. The 24 days constituting the 20% Worst Days do not show any particular seasonal predominance. With the exception of January and February, there is at least one "Worst Day" in each month.

Table 1C.2. Summary of extinction values for worst and best days: BNWA IMPROVE.

	Extinction Maximum Value	**Coefficient Average Value**	**Meter-1 Minimum Value**
20% Worst Days	225.5	135.0	109.8
10% Best Days	41.3	34.8	28.8

Back trajectory analyses have been used for various applications in the past to identify the role meteorological conditions play in the transport and dispersion of air pollutants. The results obtained from the trajectory analysis (Figure 1C.2) can provide essential information needed for development of conceptual models. The conceptual model in turn is used to identify the processes associated with the formation of regional haze.

The model used to calculate the back trajectories is the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model. It is a complete analytical system for calculating air parcel trajectories, dispersion and deposition simulations. This model was developed by the National Oceanic and Atmospheric Administration (NOAA).

Back trajectory analyses were conducted for the 20% Worst Days based upon extinction coefficient. To the extent possible the procedure developed by CenRAP was followed. This procedure consisted of running HYSPLIT for 72 hours, twice daily, i.e. 0900 CST and 2100 CST, and for three elevations: 200 meters, 500 meters & 1000 meters.

To obtain accurate back trajectory predictions, the most refined (i.e., spatially and temporally resolved) and readily available meteorological dataset, the EDAS, was proposed for use.

For a given day, comparison of the morning (i.e., 9:00am) and evening (9:00pm) may account for potential diurnal variations. Similarly, comparison of the different elevations may indicate any stratification.

Richard (Dick) Karp currently works in the Gulf of Mexico regional office of the MMS, where he is involved in reviewing potential air quality related impacts associated with exploration and development plans related to extraction of oil and gas. In this capacity, Dick works with onshore regulatory entities (e.g., EPA, states) to coordinate the air pollution requirements for both onshore and off-shore industry, as per the 1990 Federal Clean Air Act Amendments. Coordination activities Dick is involved with include a PSD increment assessment of the impact of OCS sources on the Breton National Wilderness Area, a federal Class I air quality area; potential OCS contribution to exceedances of the new 8-hour ozone standard along the Gulf Coast; and potential OCS contribution to visibility impairment associated with the EPA regional haze program. A major element in assessing potential OCS contributions to onshore air quality impairments is the quantification of air pollution emissions arising from OCS sources. Dick is involved in two such on-going contractual projects for OCS sources in the Gulf of Mexico, in one of which he is the contracting officer's technical representative (COTR), while for the other he provides technical support to the COTR.

SESSION 1D

MAPPING AND GROUND TRUTHING

Co-Chairs: Susan Childs, Minerals Management Service
Greg Boland, Minerals Management Service

Date: January 14, 2003

MULTIBEAM MAPPING AT THE HEAD OF THE DESOTO CANYON

James V. Gardner, U.S. Geological Survey

INTRODUCTION

A joint USGS/MMS multibeam mapping program was conducted in 2002 to complete the mapping of the outer continental shelf from immediately east of the Mississippi River delta to south of Panama City, Florida. (Figure 1D.1). Previous mapping in 2000 and 2001 left a large gap in the coverage that was deemed critical to the understanding of the geomorphology of the entire outer shelf. The objective of all three of the mapping surveys was to identify the locations and details of hardgrounds, pinnacles, “reefs,” and other features that might provide unique habitats for benthic biological communities. The mapping used a high-resolution multibeam system (MBES) that differs from the more traditional sidescan sonar and single-beam profiler systems in that a MBES produces geodetic-quality, tide-corrected, swath bathymetry as well as co-registered, calibrated acoustic backscatter. The 2002 mapping was concentrated on the western flank of the head of De Soto Canyon and covered the entire area between the 50-m and 130-m isobaths, mapping more than 1350 km^2.

DESCRIPTION OF THE AREA

The outer continental shelf in this area is composed of five large shelf extensions or platforms (Figure 1D.2) that have geomorphologies suggestive of delta lobes deposited during a lower stand of sea levels. The surfaces of the platforms occur at water depths that range from 50 to 110 m. Two of the platforms are composites of two platforms built one beside the other. The south sides of each platform, in about 100-m water depths, have extensive fields of asymmetric bedforms that fall in the range of very large subaqueous dunes (Ashley 1990). The lee sides of the dunes all face west, and the present water depth and size of the dunes suggest a westward-flowing current of several knots. The northwestern portions of the shallower platforms are covered with fields of large asymmetric bedforms that also classify as very large subaqueous dunes. The lee sides of these dunes face southwest.

The center of the southern-most platform is covered by hardgrounds and its shelf edge is rimmed with build-ups that resemble reefs (Figure 1D.3). Unusual, smooth mounds that strike perpendicular to the contours (Figure 1D.4) are found along the northeast-facing upper slope of this platform in water depths deeper than 100 m and may be Oculina lithoherms. About midway in the image of Figure 1D.2, along the southwestern rim of the shallow plateau, a striking 8.3 km long, slightly curved ridge occurs in water depths of 55 m. The ridge has 2 to 4 m of relief, is smooth and flat topped. The seaward facing slopes are less than 10° and the geomorphology resembles a barrier island (Figure 1D.5). Another curved ridge, this one 22 km long, can be seen in the northern-most part of Figure 1D.2. This ridge is similar in all respects to the one to the south and also occurs at 55 m. Both of them are strikingly similar to the present-day barrier island immediately south of Pensacola Bay.

Images and data for all three areas mapped are available for download at the following internet address: http://walrus.wr.usgs.gov/pacmaps.

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James V. Gardner received his B.S. in geology from San Diego State University and his Ph.D. in marine geology from Columbia University/Lamont-Doherty Earth Observatory. He is presently a Senior Research Geologist with the U.S. Geological Survey, where he has worked since 1975. Chief of USGS Pacific Seafloor Mapping in Menlo Park, California, he has carried out mapping in all oceans except the Antarctic. Dr. Gardner also serves as adjunct professor at the Center for Coastal & Ocean Mapping, University of New Hampshire.

MULTIBEAM MAPPING IN THE OUTER CONTINENTAL SHELF REGION OF THE NORTHWESTERN GULF OF MEXICO

James V. Gardner, U.S. Geological Survey

INTRODUCTION

It has been known since the 1930s that the outer continental shelf of the northwestern Gulf of Mexico has a series of banks that rise above the general surface (Shepard 1937). Although several of the banks have been "mapped" with sidescan sonar or single-beam echo sounders, none was mapped with a modern multibeam echosounder system (MBES) until 1998 (Gardner 1998). The MBES system used for the mapping differs from sidescan sonar and single-beam profiler systems in that a MBES produces geodetic-quality, tide-corrected, swath bathymetry as well as co-registered, calibrated acoustic backscatter. The success of the 1998 MBES mapping lead to a joint USGS/MMS/NOAA project to map 12 additional banks in 2002. The newly mapped banks include Alderdice Bank, Bouma Bank, Bright Bank, Geyer Bank, Jakkula Bank, McGrail Bank, MacNeil Bank, Rankin #1 and #2 Banks, Rezak Bank, Sider Bank, and Sonnier Bank (Figure 1D.6). Together, more than 1665 km^2 of seafloor was mapped at a spatial resolution of 4 m. The new data provide the first detailed view of the banks and their immediate surroundings.

DESCRIPTION OF THE BANKS

MacNeil Bank is a 1500-m diameter roughly circular bank that appears to be constructed on top of a salt dome. The bank stands 20 m above the surrounding seafloor. The summit of the bank, at 53-m water depth, is relatively smooth but with a 1-m high outer rim that surrounds the summit proper. The acoustic backscatter of the summit rim is about -24 dB, 3 dB higher than much of the summit surface, suggesting a different facies between the two areas. A large area to the south of MacNeil Bank was also mapped as part of this survey and discovered an unnamed bank

10 km south of MacNeil Bank. The unnamed bank rises only 25 m above the surrounding seafloor and appears to have been sliced by a NE-SW fault. The summit of the bank is smooth with a uniform acoustic backscatter of -23 dB compared to the -28 dB values of the surrounding seafloor. Although pockmarks are not found in the vicinity of MacNeil Bank, they are found surrounding the unnamed bank on all sides.

Rankin #1 and #2 Banks and Bright Bank were mapped as one survey. The shapes of the Rankin and Bright Banks suggest all are related to salt intrusion. The high acoustic backscatter that connects the banks (Figure 1D.7) suggests the surface of the salt is extensive and is not too far below the surface. The smooth summits of the banks occur at about 65-m depth for Rankin #1 Bank, 51 m for Rankin #2 Bank, and 50 m for Bright Bank. The area between the banks is littered with pinnacles, typically about 10 m high, and the area north of Bright Bank is covered with pockmarks.

Geyer Bank stands as a 140-m high, elongated, relatively flat, smooth feature that appears to be an amalgamation of two oval-shaped (in plan view) salt extrusions. The 60-m-deep surface is generally flat with only a few large (~50-m high) pinnacles on the northern end. A 20-m deep depression occurs on the western half of the southern oval that appears to be a dissolution feature. The acoustic backscatter of the summit region of Geyer Bank is ~14 dB higher than the uniformly smooth surrounding seafloor, suggesting very different lithologies for the two areas.

McGrail, Bouma, Rezak, and Sider Banks all occur in close proximity to one another, so they were mapped as one survey. Although Bouma Bank appears to be related to a salt intrusion, the other banks are not so obviously salt-dome related. Bouma Bank has a roughly circular 3-km shape with what appears to be a 20-m deep dissolution pool on its southeast side. McGrail, Rezak, and Sider Banks all have irregular and elongated shapes. The tops of the banks are all at around 60 m deep. All of the banks have acoustic backscatter 8 to 12 dB higher than the adjacent seafloor. The seafloor surrounding Bouma and McGrail Banks is covered with pockmarks but not the seafloor surrounding Rezak and Sider Banks.

Sonnier Bank is a roughly 3-km diameter circular feature located in about 60 m of water that appears related to a subsurface salt dome. The bank is generally about 2 m lower than the surrounding seafloor except for large pinnacles around the bank rim that rise as much as 35 m. The acoustic backscatter of the pinnacles is 5 to 6 dB higher than the surrounding area but the summit of the bank has a complex pattern of high and low backscatter, suggesting a variety of materials at the seafloor.

Alderdice Bank (Figure 1D.8) appears to have developed on the top of a near-surface salt dome along the 78-m isobath. The bank is oval in plan view with a long axis of about 4.5 km and a short axis of 2.8 km, and rises about 3 m above the surrounding seafloor. The surface of the bank is relatively rough, in sharp contrast to the smooth surfaces on many of the banks to the west. Three prominent high-acoustic-backscatter spires rise as much as 6 m above the bank surface, one of which is known to be composed of basalt (Rezak *et al.* 1985). The area surrounding Alderdice Bank is characterized by abundant pockmarks. An interesting 600-m wide, 1-m high step, down to the southwest, occurs on the southeast corner of the bank. The high acoustic backscatter of the bank continues in a broad band to the southeast, suggesting some connection of the bank to a larger feature not mapped.

Jakkula Bank is an irregularly shaped feature of about 2-km diameter with a central bank that appears related to salt intrusion but with elongated "wings" attached to the northwest and northeast sides that extend more than 6 km beyond the bank (Figure 1D.9). The similar high acoustic backscatter of the bank and the wings suggest some relationship of the features in the shallow subsurface. The central bank is surrounded by pinnacles and the NW wing is mantled by pinnacles. The summit of the central bank, at 90-m depth, is smooth with uniform acoustic backscatter of -22 to -23 dB.

Images and data for all of the areas mapped are available for download at the following internet address: http://walrus.wr.usgs.gov/pacmaps.

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James V. Gardner received his B.S. in geology from San Diego State University and his Ph.D. in marine geology from Columbia University/Lamont-Doherty Earth Observatory. He is presently a Senior Research Geologist with the U.S. Geological Survey, where he has worked since 1975. Chief of USGS Pacific Seafloor Mapping in Menlo Park, California, he has carried out mapping in all oceans except the Antarctic. Dr. Gardner also serves as adjunct professor at the Center for Coastal & Ocean Mapping, University of New Hampshire.

BIODIVERSITY ASSOCIATED WITH TOPOGRAPHIC FEATURES IN THE NORTHWESTERN GULF OF MEXICO

George P. Schmahl, Emma L. Hickerson, and Douglas C. Weaver,
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ABSTRACT

The Flower Garden Banks National Marine Sanctuary (FGBNMS) led the Sustainable Seas Expedition (SSE) to the northwestern Gulf of Mexico (GOM) during July–August 2002—a submersible effort culminating from a partnership between NOAA and the National Geographic Society's (NGS) Explorer-in-Residence, Sylvia Earle. Submersible dives focused on select topographic highs that have been identified as biological features warranting protection from oil and gas activities by the Minerals Management Service (MMS), including Alderdice, Sonnier, Jakkula, McGrail, Rezak, and Sidner Banks. Multibeam bathymetry maps were produced in June 2002 by James Gardner, USGS, through funds provided by NOAA's Office of Ocean Exploration, and Minerals Management Service (MMS). These base maps were instrumental in targeting dive sites during the SSE submersible operations. Detailed bathymetry maps were not previously available for features of the northwestern Gulf, with the exception of the East and West Flower Garden Banks, where these data have been crucial in Deep Water Habitat Characterization efforts. Previous investigations conducted on the features of interest (with the exceptions of Sonnier Banks, accessible by SCUBA) had not been conducted since the 1970s and 1980s. Data obtained during this project will contribute to the benthic habitat characterization and assessment of the associated fish communities on these unique geological features, and multibeam base maps and benthic habitat maps will also be used for all future ROV and submersible missions to investigate these features. The survey data has provided a base data layer for Geographic Information Systems (GIS) projects into which all future (and historical) data can be integrated and upon which future scientific investigations can be implemented.

INTRODUCTION

Submersible surveys of select topographic features were conducted during the 2002 Sustainable Seas Expedition (SSE) to the northern GOM, led by the Flower Garden Banks National Marine Sanctuary (FGBNMS) in conjunction with the National Geographic Society (NGS). Topographic highs associated with the surface expression of salt domes have been identified as unique biological features warranting protection by Minerals Management Service (MMS) from oil and gas activities, and are of interest to future biological and ecological investigations. The most recent investigations conducted on the shelf-edge features in the northwestern Gulf (with the exceptions of East and West Flower Garden and Sonnier Banks) were conducted during the 1970s and 1980s (Bright and Rezak 1976 and 1978a; Rezak and Bright 1981; Rezak *et al.* 1983 and 1985; Dennis 1985), without the use of high-resolution multibeam bathymetry.

The topographic features of the northwestern Gulf have been afforded some protection since the early 1970s. The MMS recognized early on that these sensitive areas should not be subjected to the direct impacts of offshore oil and gas development, and defined them as "no activity" zones. However, these features are subject to a variety of other potential impacts unrelated to offshore development, which may not be regulated sufficiently. These impacts include those of commercial shipping (predominantly anchoring), fishing, cultural resource recovery and recreational activities. There is recent emphasis on the increased use of marine protected areas (MPAs) in many ocean regions as a method to consolidate management under a coordinated mechanism. Accurately identifying the resources in the northwestern Gulf will contribute greatly to this effort.

In spite of the fact that the topographic features have been restricted from the direct impacts of oil and gas development for many years, details of the ecology of these areas are poorly known. Surprisingly, one of the healthiest coral reef systems in American waters is the Flower Garden Banks (Lang *et al.* 2001). It is well known that many of the other topographic features in this region also contain coral reef resources (e.g., McGrail, Sonnier, Geyer Banks) yet the extent of this has not been well documented. As interest continues to grow by the oil and gas industry, it will become more important to have accurate baseline information on biological resources associated with these features.

METHODS

Following the publication of the high-resolution multibeam images of the Flower Garden Banks area (Gardner *et al.* 1998), the office of Ocean Exploration (OE) and the MMS sponsored additional multibeam echosounder (MBES) surveys of shelf-edge banks in the northwestern Gulf (Gardner *et al.* this volume). Twelve banks were surveyed using MBES technology during June 2002 (images, data and detailed survey methodology can be found at: http://walrus.wr.usgs.gov/pacmaps).

Multibeam base maps were used to guide submersible operations as part of the SSE mission to the northern Gulf of Mexico during 24 July–6 August 2002. Submersible dives were conducted using the Deepworker 2000 and Deep Rover submersibles aboard the M/V OCEAN PROJECT. Bathymetry maps were geo-referenced in Arcview 3.2 GIS software, and used to plot waypoints for submersible transects. Submersible position was continuously logged during dives, and dive tracks were superimposed on bathymetry maps after each dive to identify location of video surveys. The objective of the SSE cruise was to visit all of the banks mapped with multibeam bathymetry; however, due to logistical problems, a total of 12 submersible dives were made on Alderdice, Sonnier, Jakkula, McGrail, Rezak, and Sidner Banks (Figure 1D.10).

SUBMERSIBLE SURVEYS

The use of multibeam bathymetry and submersibles has resulted in the discovery of previously unknown formations associated with these offshore banks. Alderdice bank is unique among the banks in that it bears outcrops of basalt associated with the underlying salt dome. Earlier bathymetric surveys of the area identified a single "spire" at Alderdice bank, although the multibeam data set resolved two distinct spires with associated talus fields. Submersible investigations revealed that the basalt spires provide high-profile structure that attracts large schools of creole-fish (*Paranthias furcifer*), vermilion snapper (*Rhomboplites aurorubens*), and several species of grouper, including the marbled grouper (*Dermatolepis inermis*).

Submersible surveys on McGrail Bank revealed extensive growth of a hard coral community dominated by the blushing star coral (*Stephanocoenia intercepta*), large brain corals (*Diploria strigosa*), the great star coral (*Montastrea cavernosa*, and a species of *Agaricia*. Estimated coral coverage reached 30% between depths of 45–60 m, while the base of the bank is approximately 85 m. McGrail Bank is one of the few banks in the northwestern Gulf of Mexico that has extensive growth of reef-building corals, in addition to East and West Flower Garden Banks.

Multibeam bathymetry of Sonnier Banks clearly resolved multiple peaks ranging in depth from 18 to 55 meters, and five of these peaks were surveyed during a submersible dive. Video transects revealed a diverse assemblage of fishes and invertebrates, from speciose reef fish and invertebrate assemblages on the *Millepora* sponge zones associated with the two shallowest banks, a high-diversity sponge assemblage on banks of intermediate depths, to drowned reef assemblages occurring on the smaller features within the region. Results of our surveys indicate unique biological assemblages associated with each of the banks at Sonnier, and are related to the depth of the bank crest and the extent of the Nepheloid Zone, which occurred over all surrounding soft-bottom areas during submersible surveys.

Submersible dives on Jakkula, Rezak and Sidner Banks revealed vast algal nodule fields near the crests of the features, and extensive areas of partly drowned and drowned reef communities in the surrounding deeper waters. Jakkula possesses a spectacular wall, 30 m in vertical profile, to the northwest of the central mound, where black coral, scamp grouper, masses of crinoids, basket stars, as well as a deep glass sponge were recorded by the pilots during the submersible dives.

DISCUSSION

The production of multibeam base maps has allowed us to accurately depict the seafloor of the northwestern Gulf of Mexico in unprecedented detail and to plan comprehensive surveys to develop habitat maps and faunal inventories of the shelf-edge reef communities. The multibeam data sets will be useful in a variety of applications in geological and biological investigations, and also provide the foundation for educational programs at FGBNMS. These geo-referenced data sets will be used to guide extensive ROV and submersible surveys to fully document the biological assemblages that occur on these unique geological features, including banks that were not visited during the 2002 SSE mission.

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George P. Schmahl has been the manager of the Flower Garden Banks National Marine Sanctuary since March 1999. Prior to that he served for eight years as the Lower Keys Regional Manager of the Florida Keys National Marine Sanctuary in Key West, Florida. As Sanctuary manager, he is involved with a broad array of marine protected area management issues including research, education and resource protection. Since obtaining a graduate degree in zoology from the University of Georgia, G.P. has held a variety of positions relating to marine research, coastal management, resource planning and environmental regulation. His primary interest is the ecology and management of coral reefs and associated ecosystems, and he has specific interest and expertise in the biology and ecology of marine sponges.

Emma L. Hickerson has held the position of Research Coordinator at the Flower Garden Banks National Marine Sanctuary since 1997. She conducted her master's thesis project at the Sanctuary where she studied the movements of loggerhead sea turtles using radio and satellite telemetry technology. She has focused her research efforts in the Gulf of Mexico since 1994, and has led and participated in over 50 cruises in this region. These include three submersible cruises during which she piloted a single person submersible, DeepWorker 2000. She has coordinated recent efforts to acquire high-resolution multibeam bathymetry of the topographic features of the Northwestern Gulf of Mexico. Her interests and strengths include marine biology and ecology, underwater photography/ videography, underwater exploration and technology, science interpretation through multimedia production, and SCUBA.

Douglas C. Weaver is a Research/GIS Specialist at the Flower Garden Banks National Marine Sanctuary and has conducted research of the Gulf of Mexico for 15 years. He has made over 600 SCUBA dives and participated in 28 research cruises, including four submersible cruises, in the Gulf of Mexico and Atlantic Ocean. He is a trained DeepWorker submersible pilot and research diver. His research interests include coral reef fish biology and ecology, and landscape ecology of shelf-edge hardbottom and coral reef communities.

MAPPING AREAS OF HARD BOTTOM AND OTHER IMPORTANT BOTTOM TYPES: OUTER CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE (NORTHERN GOM)

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Coastal Studies Institute and The Energy Center, Louisiana State University

As the petroleum industry moves into deeper and deeper water of the northern Gulf of Mexico continental slope, it is important to locate and map seafloor types and features like faults that may constitute risks to drilling, locating production platforms, laying pipelines, and related activities. With the recent trend toward subsalt drilling, new attention is also being focused on the continental shelf as technology advances continue to improve seismic imaging beneath salt masses. Because of continued success at finding hydrocarbons in deepwater using 3D-seismic and improved processing techniques, the northern Gulf of Mexico OCS is clearly one of the most actively expanding and productive deepwater oil and gas province in the world. For this reason, it is very important to locate and understand the risks associated with the spectrum of geohazards that occur within the OCS region.

This project has converted existing seafloor maps compiled from high resolution seismic profiles, side-scan sonar data, and bathymetry to MMS-approved GIS format for use in geohazards evaluations. The 182 OCS lease blocks of data were acquired in five areas in the outer shelf-upper slope region. Six mapping categories were used: 1) undisturbed seafloor, 2) seafloor erosion, 3) hard bottom areas (carbonate banks, bioherms, hardgrounds, and outcrops), 4) faults, 5) acoustic wipeout zones, and 6) mass movement features. The original maps produced at Coastal Studies Institute and funded through an industry consortium, have been converted to stratified digital files that are in the MMS-GIS format. Filling data gaps in the matrix of original data is being accomplished with 3D-seismic surface attribute data. All mapped data will be converted to MMS-GIS compatible products. Experience has clearly shown that understanding the processes that are associated with geohazards and the locations of potential "trouble spots" on the seafloor saves money and lives. This project will produce a set of seafloor maps that can be used for planning activities in five well-defined areas of the northern Gulf's the OCS region. Final products for this project will be ready by June 2003.

Harry Roberts, the Director of Coastal Studies Institute at LSU, currently conducts research on both deep-water and shallow-water environments of the Gulf of Mexico and teaches in the Department of Oceanography and Coastal Sciences. Dr. Roberts is LSU's most recent Boyd Professor and has had a research and teaching career at LSU that spans 33 years. During this entire period he has worked on various aspects of the Mississippi River delta complex. Currently his interest is focused or developing a better understanding of basic processes and depositional responses associated with the Atchafalaya-Wax Lake bayhead deltas and their downdrift counterparts along the chenier plain. Additional current research interests deal with the impacts of natural fluid and gas expulsion as a driver of geology and biology of northern Gulf's continental slope.

IMPROVING THE PREDICTIVE CAPABILITY OF 3D-SEISMIC SURFACE AMPLITUDE DATA FOR IDENTIFYING CHEMOSYNTHETIC COMMUNITIES SITES

Harry H. Roberts and James M. Coleman,
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Louisiana State University

A difficult task faced by MMS Gulf of Mexico regulatory personnel is determining, from remotely sensed seafloor data, the deep-water sites of lawfully protected chemosynthetic communities. These communities have been traditionally found and studied by direct observation and sampling techniques, but their unique set of seafloor features/conditions have yet to be convincingly identified on seismic and sidescan sonar records which are data sources used in the regulatory process. The actual observational data base on chemosynthetic communities is still quite small. In addition, the remotely sensed data bases (mostly high resolution seismic d side-scan sonar) which have been used as regulatory guides have not been uniform; a wide variety of instrumentation and data acquisition techniques have been used. Till recently, the only uniform; slope-wide database has been bathymetry (multibeam). Now, over 90% of the northern Gulf of Mexico slope is covered with high quality 3D-seismic. Employing the knowledge that chemosynthetic communities directly depend on delivery of hydrocarbons to the seafloor and that the delivery system is related to the geologic framework, the assumption is made that seafloor 3D-seismic surface amplitude patterns and intensities reflect these relationships. Therefore, the focus of this project has been to systematically "calibrate" 3D-seismic surface amplitude anomalies to direct field verification data in a matrix of known geologic configurations for developing criteria to be used for predicting the sites of chemosynthetic communities.

To date, numerous amplitude anomalies have been evaluated using 3D-seismic surface attribute data. From this large pool of prospective sites, nineteen have been selected for collection of field verification data using a manned submersible. In the selection process, wave form analysis helps focus areas of interest for establishing ground-truth data-collection transects. Transects are planned so that total spectrum of surface amplitudes or any given site is sampled. Results confirm that 3D-seismic surface amplitude data and results of seismic wave form analysis calibrated to field verification data constitute a powerful method for predicting seafloor types, including sites of chemosynthetic organisms. Although this approach is not without some uncertainty, there is no question that it has enormously improved our predictability of the modem seafloor. By the end of this next contract year when all data sets are summarized, criteria for predicting chemosynthetic community sites from remotely sensed acoustic data will be routinely available for MMS and broader scientific use.

Harry Roberts is the Director of Coastal Studies Institute at LSU, where he currently conducts research on both deep-water and shallow-water environments of the Gulf of Mexico and teaches in the Department of Oceanography and Coastal Sciences. Dr. Roberts is LSU's most recent Boyd Professor and has had a research and teaching career at LSU that spans 33 years. During this entire period he has worked on various aspects of the Mississippi River delta complex. Currently his interest is focused or developing a better understanding of basic processes and depositional responses associated with the Atchafalaya-Wax Lake bayhead deltas and their downdrift counterparts along the chenier plain. Additional current research interests deal with the impacts of natural fluid and gas expulsion as a driver of geology and biology of northern Gulf's continental slope.

GAS HYDRATE IN THE GULF OF MEXICO

Roger Sassen, Geochemical and Environmental Research Group

The Applied Gas Hydrate Research Program (AGHRP) focused on the study of gas hydrate as a potential energy resource, agent of global and climate change, and an important component in geochemical and ecological systems in the Gulf of Mexico (GOM). The major findings are summarized below.

1. Bottom water temperature on the GOM slope varies due to seasonal changes and the propagation of warm core Loop Current eddies across the slope. Large volumes of gas hydrate are concentrated in sediments near the seafloor of this region at water depths as shallow as 440–615 m. The results of modeling indicate that both seasonal and short-term variations of bottom water temperature may affect gas hydrate stability only in the upper 1–2 m of sediments. The zone where repetitive gas hydrate formation and decomposition occur because of bottom water temperature change is very extensive; however, encompassing much of the Gulf slope. Gas blowouts, oil ejection into water column, sediment slumps, and other geohazards triggered by gas hydrate decomposition could occur in this zone, and impact sub-sea operations.

2. Based on limited geological and geophysical data, the northwestern GOM sediments may hold ~10–14x1O^{12} m^3 of hydrate-bound gas. The specific gas hydrate accumulations may contain 10^8–10^{11} m^3 of gas at STP. These estimates indicate that gas hydrate may be a significant source of energy in the GOM, although the resource values are not as great as previously believed.

3. Only large structural gas hydrate accumulations in deep-water areas may provide quantitatively significant concentrated gas hydrate resources and have a potential to supply reserves.

4. Although based on assumptions, the results of 2D modeling of gas hydrate decomposition related to drops in sea level and bottom water temperature increases in the northwestern GOM are consistent with the suggestion that the role of gas hydrate in global change is likely to be overestimated. The minimum late Pleistocene-Holocene gas flux from a leaky petroleum system in the GOM is suggested to exceed the average rate at which gas might have been released from gas hydrate decomposition attributed to 100 m sea level drops and 4°C bottom water temperature increases. In addition. only a portion of hydrate-derived gas is likely to vent from sediments into the water column and atmosphere, and to impact climate change through the global carbon cycle. Recrystallization of gas hydrate, trapping of free gas below the gas hydrate layer, rapid oxidation of free gas by bacteria and archaea, and sequestration of hydrate-derived gas as authigenic carbonate rock in sediments are thought to retard loss of greenhouse gas from sediment. Additional models, and study of the molecular and isotopic properties of gas hydrate and associated sediment in natural settings

may improve model input, and thus constrain speculation concerning the significance of gas hydrate as an agent of global change.

5. Vent gas is the primary source material from which other carbon pools are derived, including gas hydrate and the free hydrocarbon gases in sediment. The bulk of ^{13}C-enriched hydrocarbon gas and CO_2 from the subsurface hydrocarbon system bypasses shallow sediment and exits by venting to the water column and to the atmosphere. Some fraction of the vent gas crystallizes as structure II gas hydrate with a diagnostic molecular distribution.

6. The occurrence of gas hydrate in chemosynthetic communities is thought to play a number of roles in community development and stability. Free gas is trapped beneath the gas hydrate, and the massive accumulation of gas hydrate serves as a buffer to maintain hydrocarbons in sediment even if hydrocarbon venting rates fluctuate over time for geologic reasons. Microbial methane oxidation, concomitant production of CO_2, reduction of CO_2, and precipitation of carbonate rock appear to occur continuously in sediment.

Several directions of future research are suggested:

1. Study specific gas hydrate accumulations that are assessed to have a high economic potential (e.g., the MC 852/853 site in the GOM). The study should utilize both direct (coring, drilling, and sampling) and indirect geophysical (seismic, well-logging, and others) and geochemical (the study of pore-water and gas composition) methods. The ultimate goal of such a study would be the visualization of a 3-D shape of the gas hydrate accumulations and the estimation of gas in place.

2. Develop models that describe the fate of gas released from dissociated gas hydrates at the base of the GHSZ attributed to sea level drop and water temperature increase. Several processes that lead to sequestration and consumption of gas in sediments and prevent gas flux into the water column should be considered.

3. Estimate modem regional gas flux from a deep subsurface petroleum system into the water column in the GOM based on direct measurements. Rough estimates indicate that “normal” gas flux from a leaky petroleum system might be of the same order of magnitude as a maximum possible gas flux due to catastrophic gas hydrate dissociation following a major water temperature increase. However, the role of thermogenic hydrocarbon gas leaking from subsurface in global climate change is still rarely addressed.

4. Continue to study geochemistry of gas hydrates. There is geochemical evidence that anaerobic microbial oxidation of the C_1-C_5 hydrocarbon gases may be a significant process in association with gas hydrate in chemosynthetic communities. Geochemical observations have, in the past, led to microbiologic investigation and support of hypothesized anaerobic methane oxidation, and it is important to test the hypothesis of possible anaerobic microbial oxidation of the C_2-C_5 hydrocarbons.

Roger Sassen is the Deputy Director of Resource Geosciences at the Geochemical & Environmental Research Group of Texas A&M University. Dr. Sassen is an organic geochemist with extensive experience in gas hydrate research.

SESSION 1E

EXPLOSIVE REMOVALS OF OFFSHORE STRUCTURES (EROS): EXPERIMENTAL MITIGATION MEASURES

Co-Chairs: Jeff Childs, Minerals Management Service
T. J. Broussard, Minerals Management Service

Date: January 14, 2003

ACOUSTICS AS A NEGATIVE STIMULI TO CETACEANS

Dave Potter, NOAA Fisheries
Jonathan Gordon, Ecologic

The goal of this exercise is to describe the potential use of sound as a negative stimulus to whales in the vicinity of deepwater drilling rigs to displace them approximately 1000 m while explosive demolition occurs.

BACKGROUND

Anthropogenetic sound in the ocean has become a concern to many scientists and environmentalists as we learn more and more about the natural history and behavior of cetaceans, pinnipeds, sea turtles, and other marine organisms. We know that many of these animals use sound to communicate with each other to some extent. Whether it is simply to locate potential mates, or 'call the kids to dinner' is not important. The important thing is that they evolved using sound to conduct their daily business, and that man-made sound may interfere with their acoustic behaviors.

We know that most odontocetes (toothed whales) use sound for echolocation. This is the ability to image their environment through the transmission of sound and receipt of short bursts primarily to detect prey, although imaging their environment for navigation and obstacle avoidance also occurs. Balenopterids (baleen whales) are not believed to use sound in quite this way, as we have no evidence that they can use echolocation. However, we do know that several species of great whales can communicate over vast distances using very low frequency sound. This has been of great concern to many with such things as ATOC or LFA being used.

- ATOC, (acoustic tomography) uses low-frequency sound over ocean basin scales to monitor global climate changes. (Walter Monk, Scripps early 1990s)
- LFA is a more recent development of military tactical sonars for submarine detection (U.S. Navy)

Both of these devices are extreme in the sound pressure levels of the source: LFA is capabile of around 240 dB (all references to decibel levels are re 1 micro Pascal/1 meter) although operational specifications refer to -220 dB. ATOC operates at 195 dB, and current variations on that technique operate at similar levels. A significant amount of work has been done and is ongoing to investigate long-term impacts of these activities.

What do we know about cetaceans' response to sound? We have had a number of well-planned scientific experiments to document cetacean responses to various sources of sound. The book *Marine Mammals and Noise* by Richardson *et al.*(1995) is a very good primer on the subject.

SOME EXPERIMENTAL RESULTS

– Tyack	grey whales	California playback experiments
– Greene-Richardson	Bowhead whales and drilling noise	
– Krause-Read	Harbor porpoise	Pinger experiment
– Kastelein	captive harbor porpoise	

BRIEFLY

Tyack (1995 and later) conducting playback experiments of the SURTASS LFA showed that migrating grey whales off the coast of California would alter their southward tracks slightly to avoid the waters around a vessel moored directly in their path. The positions of the whales were located as they traveled south using theodolites in periods with and without the playback in operation. Received levels were approximately 120dB at the point of avoidance. Interestingly, however, when this experiment was duplicated farther offshore, behavior was greatly reduced.

Greene (1985, 1987), and Wartzok (1989) surveyed for bowheads around Arctic drilling operations and found significant displacements from the area around the drilling operations. Although there was a wide variation on the displacement of animals, it appeared that the bowheads reacted to received levels between 94-118 dB. Wartzok's strongest avoidance response occurred when broadband transmissions were received at >120 dB. They suggest that the variability in the reaction distance may be a function of two things: 1) sensitivity variability between individuals as some react much earlier at lower received levels than others; and 2) habituation. The bowheads may react differently to the onset of industrial noise during a brief playback but habituate to the continuous sound coming from a fixed drillship. Richardson (1990) states that a typical summering bowhead does not react overtly unless the broadband received sound levels are 115 dB or approximately 20dB above ambient. This distance can be considerable, in fall migration studies LGL and Greeneridge (1987) and Hall (1994) noted that most bowheads avoided the area around a drilling operation in excess of 10 km and received levels of broadband noise at 114 dB.

Kraus and Read (1994) conducted a controlled, double blind, experiment with 425 experimental units and 423 control units in the sink gillnet fishery in the Gulf of Maine. The experimental nets had active 10 kHz Acoustic Deterrent Devices (pingers) attached. These devices operate at 132 dB, with a 300 msec pulse every 3 seconds. They demonstrated a 95% reduction in harbor porpoise bycatch between the control and experimental nets.

In a series of papers (Kastelein *et al.* 1997, Kastelein *et al.* 2000 and Kastelein *et al.* 2001) Kastelein and co-workers recorded the responses of captive porpoises when various models of pinger were introduced into their enclosures. In all cases, animals immediately moved away from the devices. Kastelein *et al.* (1997) found that they moved to ranges at which pinger sound levels were measured as being between 78 and 90 dB re 1 Pa. However, their flight was limited by the enclosure, and the distance they would have fled in the wild is undetermined.

However, these experiments are only presented as documentation that sound can measurably effect the distribution of cetaceans over various scales of time and space. More relevant studies, at least relevant to the task at hand, are found in work done by Peter Olesiuk from DFO in Canada, Morton, and Morton and Symonds, also in BC Canada.

Olesiak (2002) showed that the placement of Acoustic Harassment Devices (AHDs, which operate at approximately 195 dB at 10 kHz, although some harmonics occur and the sound source degrades over time through biofouling) in pristine (acoustically) sounds in British Columbia displaced harbor porpoises from the source. Surveys were done before and during periods of transmission. Animal abundance was reduced by 90% within 3.5 km following the onset of the AHDs. The concern, of course, was that the use of these AHDs on salmon aquaculture pens, to prevent seal depredation, would displace porpoise from several square kilometers of natural habitat; with dozens of these pens in some areas, there could be large areas of natural habitat (potentially critical habitat) unavailable to the porpoise.

David Johnson (2001), currently a graduate student at Duke University, has shown similar displacements of harbor porpoise around an AHD located in Gulf of Maine waters as well. In his study, an AHD was placed within sight of Grand Manan Island in the Gulf of Maine and within well studied harbor porpoise habitat. Johnson's closest observed approach during transmission was 728 m vrs 13 m during inactive periods. The mean closest approach was 1248 meters vrs 304 m between active and non-active projectors.

Data on the occurrence of orca in areas where AHDs were introduced on fish farms are presented by Morton & Symonds (2002). Observations of orca occurrence were analyzed in this study. These observations were made around the Broughton Archipelago and in the mouth of Johnstone strait between 1985 and 2000 by two independent research groups using very similar approaches, Acoustic, as well as visual methods were used.

AHDs were introduced on fish farms in the Broughton Archipelago area during 1993, and four devices were deployed there until 1999. No AHD devices were operational in the Johnstone Strait area, which thus served as a control. In the Broughton Archipelago area the mean number of days per year on which whales were seen decreased by a factor of ~3 once AHDs were introduced and sighting rates recovered to near pre-exposure levels once the AHDs were removed. Further, there were no between-year differences in whale occurrence in the Johnstone Strait "control" area over the same period.

Although AHDs were active on the same farms for six years and photo-identification studies showed that the same relatively small population of whales were repeatedly exposed to them, there is no indication in these data of any habituation.

In summary, the main findings of Morton & Symonds (2002) were that

- use of a large area of habitat by orca decreased when local farms began using AHDs,
- there was no indication of habituation or waning in this response over the six years that AHDs were used in the area,
- encounter frequencies in a control area did not alter significantly over the same time,
- orca encounter rates returned to pre-exposure rates.

Morton also has indicative data for baleen whales, although these data are more anecdotal. Morton (1997) noted a decrease in the number of sightings of humpback, grey and minke whales in the Broughton Archipelago after local farmers started to use AHD devices. Sightings rates recovered substantially after the use of AHDs in the areas was discontinued in 1999.

During the summer of 1995 the NEFSC mapped the locations of each of the salmon pens along the coast of Maine and went to pen sites to measure the acoustic field surrounding these pens in an effort to evaluate the potential habitat loss to harbor porpoise along the coast. We found 130 separate lease sites along the coast and measured essentially spherical spreading of the sound in adjacent waters with a maximum source level of approximately 183dB. However, what was most interesting was that moments after arriving at our first site we observed two groups of porpoise swimming directly through a cluster of 15 pens while two AHD systems were fully functioning.

Where was the displacement seen in BC or in the Gulf of Maine? I believe the answer lies in habituation and a positive reward stimulus. The pen system I was on had been in operation for greater than two years and had their AHDs operating 24/7 during that time. Additionally, salmon farmers feed the raised fish pellet food slightly in excess of what they can actually consume to maximize their growth. Excess feed falls from the pen system and supports an unusually dense aggregation of small fish surrounding the pens. The combination of the continuous sound (it becomes the ambient standard) and the availability of quantities of food fish seem to overcome the negative aspect of the AHD to these porpoise.

These are but a small sample of the various studies of the effects of sounds on various marine species. These and other studies demonstrate that sound may be an effective mechanism to displace animals temporarily from an area. Depending on the species and the sound used (both frequency characteristics and sound pressure levels) the distance of displacement varies considerably. Additionally, as Richardson points out, there may be significant differences between different animals of the same species.

We believe that the key feature to this proposal is that in all cases shown to date this displacement is a temporary feature and that the cessation of insonification allows the return to pre-exposure behaviors and distribution almost immediately (actually, in several cases even if the sound sources were to continue, the animals often return to pre-exposure behaviors as a result of habituation). Therefore this may be a good candidate to temporarily displace animals from harm’s way during explosive removals without any lasting effects on animal distribution.

EXPERIMENT PROPOSAL

We believe that there is sufficient evidence of efficacy to propose an experiment using sound as a displacement tool to prepare deepwater rigs for explosive removal. Additionally, we believe that an experiment to demonstrate this capability would be fairly easy and inexpensive to carry out.

Due to uncertainties concerning animals' densities in and around these platforms, a pilot study of distribution and abundance of the species of concern would have to be undertaken prior to setting up a definitive experiment.

There are several possible sound sources that could be used to test our ability to temporally displace cetaceans from a kilometer radius of a chosen site. These could include airguns, explosives, existing sonar devices, etc. However, most of these have major drawbacks: airguns are expensive and technically complex to operate without skilled personnel; explosives eliminate the capability to ramp up a signal over time and continue a source for several hours or days; existing powerful sonars would need large vessels equipped with these expensive arrays on-site regularly. However, commercially available AHDs are relatively inexpensive. They are easily manipulated in terms of sound pressure levels and frequency, and they are relatively small and easily handled by a couple of people. Finally, they can operate independently for days if necessary.

We propose using AHD projectors surrounding an offshore site. The projectors would extend from the four corners of the site and potentially along the sides depending on the size of the structure. The AHDs would be operated, on a random basis, beginning with a 2-hour ramp up period (beginning source level at 100dB) to full power. Observations would begin 2 hours after the AHDs were operating at full power. Observations would be made by observers on the rig, on vessels conducting line transect surveys and by aerial platforms also conducting line transect surveys. These observation periods would be sufficiently long to adequately cover the area within 1000 meters of the rig. Hence, relatively short surveys by the rig observers and aerial surveys and longer surveys on board ship.

The AHDs would be secured (turned off) following the survey day or essentially by twilight. The following day another random draw will be made to determine whether the AHDs are in operation or control mode. This random operation would continue until a sufficient sample size of sightings occurs. It is difficult at this time, to determine how long it will take, as it depends on sighting rates. If the occurrence of animals is very low, it will take many more days to be able to say with any certainty that there is an effect from the source. If there are lots of animals seen daily in and around the site, it will take only a few days to have a definitive statement concerning displacement.

The experimenters would use a blind survey technique where observers on the rig, ship and aerial platforms would not know whether the projectors were in operation that day, and standard line transect techniques would be used to analyze the data for the ship and aerial teams. The rig team would use theodolites to determine range and bearing from the rig.

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David Potter graduated from the University of New Hampshire in 1973 in zoology, and he completed his graduate studies at the Virginia Institute of Marine Science in 1978. He has worked for the National Marine Fisheries Service since 1974 in various capacities. Most recently he supervised the Protected Species Branch with the responsibility of conducting abundance and bycatch studies on 34 species of marine mammals and turtles in the northwest Atlantic. Mr. Potter began using acoustics in 1995 to track harbor porpoise using their echolocation signals. He studied AHDs and their use on salmon aquaculture farms and worked on the development of an obstacle avoidance sonar to prevent collisions at sea. He is currently the Chief of the Fisheries Sampling Branch (read Observer Program) at the Woods Hole Massachusetts Laboratory.

Jonathan Gordon is a marine mammal biologist with a particular interest in under water acoustics and the effects of sound on marine mammals. He has conducted studies on the effects of airguns and oceanographic noise sources on cetaceans and was part of a team that developed a semi-automated passive acoustic monitoring system for detecting cetaceans for offshore mitigation purposes. As a consultant based in Scotland, Dr. Gordon has been involved in a variety of offshore mitigation work including projects involving the explosive removal of oil-related structures in the North Sea.

SHOCK WAVE SHAPING—SOUND ATTENUATION SYSTEMS (SAS^{TM})

Hal Dreyer, Gunderboom; Engineered Aquatic Filter Barrier Systems

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Hal Dreyer is President of Gunderboom, Inc., and its lead technical designer, a position he has held since 1995. He has been actively involved in the marine, environmental and communications industries for 32 years, working both in the private and government sectors. His career has focused on design, fabrication, problem resolution, and operations in the marine environment. His career started with construction, civil projects, submarine installations, vessel modifications and repair, security projects, docks, dredging, site development, survey and electrical installations for the Woods Hole Oceanographic Institute and peripheral support contractors. He has also performed tasks for the U.S. Navy, Coast Guard, NOAA, Corps of Engineers, National Marine Fisheries, and other similar organizations. Mr. Dreyer was founder, president and CEO of Underwater Construction, Inc., an Alaskan based Marine Contracting firm that undertook numerous projects in marine contracting, commercial diving, marine fabrication, salvage & emergency response and environmental contracting over an 18-year period.

ACTIVE SONAR DETECTION OF MARINE MAMMALS

Peter J. Stein, Scientific Solutions, Inc.

PROBLEM STATEMENT

Manmade underwater sounds of high enough intensity, and of certain characteristics (frequency, duration, etc.), can result in harm to marine mammals. These sources of sound include air gun operations, high-powered military sonars at mid and low frequencies, and the detonation of explosives. Mammals located very close to these sources, say, out to about 500–1000 yards, can have direct physiological damage from the acoustic pressure and/or hearing loss. Animals beyond 1000 yards might have an avoidance or behavioral response. The behavioral response alone might be enough to result in damage to the animal.

For these reasons, regulators are requiring, with ever-increasing restrictions, that areas around activities that produce intense underwater sounds be reliably scanned for marine mammals before operations begin. Further, these operations must be shut down if marine mammals are detected within a specified danger zone surrounding the operation. However, current mitigation techniques that include visual monitoring and passive detection (listening for vocalizations) are highly flawed.

Visual monitoring has a limited range and only works in good visibility and calm seas. Further, many marine mammals spend only a small portion of their time at the surface. Thus, relying on visual detection may either greatly restrict when operations can be conducted or result in undetected harm to a whale.

Passive detection only works when the marine mammal is vocalizing. But many marine mammals spend a large portion of the time silent, and a commonly observed reaction to loud sounds is to stop vocalizing. Again, relying solely on passive detection may result in harm to an animal.

ACTIVE SONAR DETECTION

At least for the region surrounding the source, in which direct acoustic injury is certain, a highly reliable means of detecting marine mammals is required. Generally active sonar, where a transmitted sound pulse is reflected off a target and then received, is the only reliable means for detection of quiet underwater objects. The feasibility of using active sonar to detect whales out to about 2 km is now well proven. There are measurements where depth sounders have been used to detect diving sperm whales and a few active sonar systems have been built specifically to detect whales. Here we discuss two systems built by Scientific Solutions, Inc. (SSI) to detect marine mammals. One is a relatively mature mechanically steered system called HF/M3 (High Frequency Marine Mammal Monitoring Sonar). This system is currently in use by the Navy for marine mammal monitoring. The other is a phased-array system that will eventually be integrated with passive monitoring and a control module that contains a statistical database of marine mammals. We have begun calling these systems “whalefinders” to distinguish them from other sonar systems.

The idea of using active sonar essentially to protect marine mammals from other active sonars or loud sound sources tends to be a point of confusion. However, what we are developing is a sonar that is “friendly” to marine mammals. These systems are much more like depth sounders and fish-finding sonars than military sonar. The frequency of these whalefinders is generally higher than 20 kHz, likely out of the hearing range of the baleen whales and larger odonocetes. The source level is also much lower than most military sonars, air guns, and explosion sounds. In general, the receive pressure level will never be higher than 180 dB re Pa farther than 100 yards from the whalefinding sonars. Due to the exponential increase in the absorption of underwater sound with increasing frequency, the signals from these whalefinders die away rapidly beyond about 2000–4000 yards.

Although smaller odonocetes, such as dolphins and porpoises are known to hear in the same frequency range of the whalefinders, there is ample scientific proof that the signals transmitted by these whalefinders will not pose any harm unless they are within about 30 m. The two systems developed by SSI use ramp-up procedures. When first turned on, the source level is gradually increased to the operational source level over roughly 10 minutes. Also, when used, there are always procedures in place to shut down the whalefinders if any animal comes within 100 yards. This ensures that no animal is exposed to levels above 180 dB re Pa.

HIGH FREQUENCY MARINE MAMMAL MONITORING SONAR SYSTEM (HF/M3)

The High Frequency Marine Mammal Monitoring Sonar (HF/M3) is the more mature of the two whalefinders developed by SSI. HF/M3 is what we refer to as a mechanically steered system. It has four parabolic transducers that produce narrow beams. They are mounted on a carousel at 90-degree intervals. The carousel is turned via a stepper motor to aim the parabolas in a particular direction. The system scans for marine mammals covering 360-degrees out to its maximum working detection range of 2500 yards in about 45 seconds. Actual detection range depends on the propagation conditions, clutter conditions, and size of the animal. The operational frequency of HF/M3 is 30–40 kHz, the maximum source level is 220 dB re Pa at 1 m, and the signal transmitted is a FM sweep usually 40 milliseconds long with a bandwidth of 3000 Hz.

The HF/M3 system began development in 1998 and has had several successful tests against artificial targets. There have been almost 75 probable detections of marine mammals and several confirmed detections of marine mammals.

HF/M3 is a relatively inexpensive system, as it has only four data channels. The in-water unit is about 3 feet in diameter and 3 feet tall. Total weight is about 200 lbs. Topside electronics consist of a small power amplifier, a PC, and two small custom power units. A version of HF/M3 has been built for the Marine Mammal Active Sonar Test (MAST), which is supposed to occur in January 2003 and is discussed below. We refer to this system as the MAST system.

The second system SSI has designed and built is called the Integrated Marine Mammal Monitoring and Protection System (IMAPS). IMAPS is a Phase II Small Buisiness Technology Transfer Program funded by the U.S. Navy. The development team consists of researchers from SSI, Cornell, and Marine Acoustics, Inc. (MAI). In its final form, IMAPS will consist of a single sonar head which contains both an active and passive system. The active component will give short-range, high probability of detection, while the passive component will provide less certain, but longer range detection. This sonar system will be coupled to a control module that will contain a database of marine mammals and routines for exposure prediction. It is envisioned that all three IMAPS components will be used in tandem to provide the best decision-making tool for proceeding with an operation and avoiding harm to marine mammals.

As of this time, the active sonar head has been designed and a prototype built. It is a phased array system consisting of a vertical line array source roughly 3 feet long and 60 line array receivers each roughly 12 inches long. The prototype center frequency is 25 kHz. The sonar head weighs 1200 lbs. Data is digitized in the sonar head and brought topside via a fiber optic link. Although the data acquisition and processing system is much more complex than HF/M3, it remains PC based. Topside electronics consist of a PC and a two custom power supply boxes. Since IMAPS is a phased array system, it will be able to scan 360 degrees approximately every 4 seconds instead of every 45 seconds. This will enable improved performance in high clutter environments such as very shallow water. However, the system is far more expensive then HF/M3.

IMAPS beam patterns and transmit levels have been verified at test facilities. However, it has not yet been tested against artificial targets or marine mammals. This was to be done during the Marine Mammal Active Sonar Test described below.

MARINE MAMMAL ACTIVE SONAR TEST

The Marine Mammal Active Sonar Test (MAST) was scheduled for 8 to 29 January 2003 off the central California coast, near Saint Luis Obispo. Both the MAST mechanical system and the IMAPS prototype were to be tested. The goals of the test are to 1) determine the effectiveness of the whalefinding sonars, 2) measure the target strength of a large baleen whale at whalefinding frequencies, and 3) determine whether the whales have any avoidance reaction to the whalefinding sonars.

The Scripps Institute of Oceanography research vessel R/V New Horizon was to be moored in the path of the Gray Whale migration with one of the two sonar systems deployed. Shore-based observers from the Woods Hole Oceanographic Institute would track the migrating whales to provide ground truth and to determine if there was any reaction to the whalefinding sonars.

On 8 January 2003 a Federal District judge put a temporary restraining order on the test due to concerns raised by environmentalists. This restraining order was issued despite a review of the test by many marine mammal biologists and the issuing of a permit by the National Marine Fisheries Service. At the time of this writing, a hearing is scheduled for 17 January to determine whether testing can be performed during the end of January.

LONG-TERM GOALS

Our long-term goal is to develop “whale friendly” marine mammal detection sonar systems. Two systems have been developed one of which is being actively used for marine mammal monitoring. These systems will be used to study marine mammals and more importantly to protect them from high-powered military sonar systems, seismic surveys (air guns), underwater explosions, underwater acoustic experimentation, and ship strikes. In the future they will be integrated with other means of detection, along with statistical models and databases to provide a complete mitigation tool for a variety of operations.

Peter Stein received his Ph.D. from the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution in 1986. Dr. Stein is currently the President of Scientific Solutions, Incorporated, a company he founded in 1992. Scientific Solutions specializes in the development of underwater acoustic systems. For the past several years they have been developing active sonar technology for the detection of marine mammals.

REMOVAL MITIGATION PLANNING AND IMPLEMENTATION: CALIFORNIA CASE STUDY

Peter C. Howorth, Marine Mammal Consulting Group, Inc.

INTRODUCTION

The Marine Mammal Consulting Group, Inc. (MMCG), is an independent firm that provides marine environmental consulting and mitigation to industrial, military, academic, and government clients. MMCG has been involved in numerous EROS (Explosive Removal of Offshore Structures) projects in California, together with other projects that involve impulse power, such as geophysical surveys, ship shock trials, pile-driving, and rocket launches. These projects required extensive environmental planning and mitigation, yet were carried out on time and on budget with no significant impacts to marine mammals, sea turtles or sea birds.

The Minerals Management Service posed several questions which will be answered in this paper:

1. Describe the types of structures removed and the explosive methods by which they are removed.
2. Explain the roles of the various governmental agencies involved in the structure removals, as well as other entities such as those from the commercial (e.g., Industry) and private sectors (e.g. environmental NGO’s).
3. What studies or preliminary analyses are performed prior to decommissioning offshore structures using explosives?
4. Identify the protected species of concern. Describe the pre- and post-blast mitigation and monitoring measures used on their behalf. This should include aspects such as the maximum charge size, physical parameters for setting explosives (e.g., 3 m below the mudline), timing, use of observers, and other survey methods, etc.
5. Were measurements made of the shock waves and acoustic energies released from the explosives used during the removals? If so, what data were gathered, and what did they indicate? If explosives were discharged below the mudline and/or within a structure, do the data demonstrate a dampening of the shock waves and acoustic energies and to what magnitude?
6. Explain the results and effectiveness of the mitigation and monitoring measures. What “takes” were documented? What “takes” may not have been detected? What recommendations do you offer for improving mitigation and monitoring measures for EROS actions?

STRUCTURES REMOVED

A number of structures and various demolition strategies were selected to provide a variety of examples.

Chevron 4H Decommissioning Project

Four production oil platforms were decommissioned off Santa Barbara, California, in 1996. These structures had been built from 1957 through 1962 and consisted of four platform legs with eight internal pilings in each leg. The pilings were severed five feet below the mudline with 45-pound, targeted charges. Detonations were staggered to avoid a buildup of sound pressure levels. One of the platforms had four steel-jacketed caissons beneath the platform legs. These caissons were 27 feet in diameter and 40 feet tall. These have yet to be removed.

Chevron Wellhead Removal

This project involved the removal of a wellhead off Ventura, California, using a single 35-pound charge ten feet below the mudline. The well had already been plugged and abandoned.

Riser Platform

This platform had been constructed to connect an offshore sewer discharge pipe, which was part of a joint U.S.-Mexico sewage treatment system off San Diego, California. Four pilings, each four feet in diameter, were severed 15 feet below the mudline with 4.6-pound charges.

Mobil Seacliff Pier Complex

This project involved the demolition of 21 steel-reinforced concrete caissons northwest of Ventura, California. The caissons extended from bedrock through the sediments to the sea floor, then through the water column to the surface. Tiers of staggered charges were used in holes drilled into the caissons. Charge weights varied from 37 pounds to less than one pound. Total charges used in each caisson weighed from 88 to 596 pounds.

San Francisco-Oakland Bay Bridge, East Span Replacement Project

State highway engineers planned to level a rocky undersea area with explosives to prepare the base for the main tower of the replacement span of the bridge. In addition, they planned to demolish the old piers at the base of the original bridge using explosives. To prepare the rock bench, they planned on detonating a series of charges placed in holes drilled in the rock. Total weight of charges to be detonated during this single event was 50,000 pounds. Even more explosives were planned to demolish some of the old piers.

As part of the environmental planning, MMCG modeled the underwater sound pressure levels generated by the explosives; as a result, the engineers revised their plans.

OTHER RELEVANT PROJECTS INVOLVING IMPULSE POWER

Several other projects involving impulse power are presented for comparison to projects in the Gulf of Mexico:

U.S. Navy Ship Shock Trials, Aegis Class Destroyer *U.S.S. John Paul Jones*

This project involved the detonation of single, 10,000-pound charges beneath the surface in the open ocean some 200 miles off San Diego, California. Such trials are conducted to test the integrity of the first ship in each new class by detonating charges progressively closer to the ship.

Geophysical Surveys

Exxon conducted a geophysical survey in the Santa Barbara Channel using airguns. Vertical seismic profiling was conducted on an existing well, followed by a geophysical survey around the well. Hydrophones were deployed to detect the presence of marine mammals and to test sound pressure levels from the geophysical operations.

In addition, geophysical testing was conducted in the Santa Barbara Channel by the U.S. Coast and Geologic Survey in an effort to detect submarine earthquake faults. Retrievable acoustic tags were placed on blue and humpback whales to measure received sound pressure levels and to determine the whales' reactions to such levels.

Pile-Driving

A pile-driving demonstration was conducted in San Francisco Bay to determine the capabilities of driving very large pilings into bay sediments. In another project, five small steel pilings were driven into bedrock in Carpinteria, California, within ten feet of the edge of a harbor seal rookery. Finally, pile-driving was conducted in a harbor in Iceland adjacent to a floating enclosure where Keiko, the killer whale made famous in the Free Willy movie, was kept. An acoustic model was prepared to determine a safe range at which to move the animal.

Rocket Launches

Rocket launch noise from Vandenberg Air Force Base, California, can disturb several nearby harbor seal rookeries. In addition, sonic booms from the launches have the potential to disturb literally tens of thousands of pinnipeds at San Miguel Island, southwest of the base. MMCG provided remote video monitoring of the coastal rookeries, biological monitoring of the island rookeries, and sound pressure level measurements of the sonic booms.

KEY GOVERNMENT AGENCIES INVOLVED IN CALIFORNIA EROS PROJECTS

Federal

Minerals Management Service
NOAA Fisheries: most marine mammals and ocean fish
U.S. Fish and Wildlife: sea otters, sea birds and salmonid fish
U.S. Army Corps of Engineers: excavation
U.S. Coast Guard: marine safety; oil spills; notifications

Others:
- U.S. Navy and U.S. Air Force: restricted waters
- National Park Service and National Marine Sanctuary: restricted waters

State

California State Lands Commission: submerged lands
California Coastal Commission: coastal access and preservation (certificate of consistency for adjacent federal waters)
California Department of Fish and Game: living marine resources

OTHERS INVOLVED IN CALIFORNIA EROS PROJECTS

In addition to the oil and gas industry and its contractors, environmental groups have exerted considerable influence on EROS projects. As a result, California has the most severe restrictions on the oil and gas industry in the nation. In California, the public can easily observe EROS projects because of the proximity of the continental shelf to shore and the steepness of the drop-off into oceanic waters. Most project sites are close to small boat harbors and coastal communities. Because of this scrutiny, regulatory agencies place considerable importance on the environmental planning and mitigation process. Nonetheless, lengthy, expensive lawsuits against industry, the military and the regulatory agencies have been filed by environmental groups. The resultant publicity is damaging, with repercussions on the economy, on shareholders and on companies dependent upon the oil and gas industry and the military. MMCG has carried out numerous environmental planning and mitigation efforts in California with no complaints from environmental groups, industry, the military, or the regulatory agencies.

PRE-PROJECT ENVIRONMENTAL PLANNING

No consistent standards have been adapted for the maximum sound pressure levels that can be received by marine mammals and sea turtles because our collective knowledge of marine mammal hearing and sound level tolerances remains extremely limited.

Understanding sound pressure levels is important in planning an EROS project so that potential impacts to marine wildlife can be assessed. Intensity of sound is expressed in decibels (dB), which provide a measure of the magnitude of sound. Decibels do not form a linear progression, meaning that 200 decibels would be twice as loud as 100. Instead, they are based on a logarithmic scale something like the Richter Scale for earthquakes. A doubling in sound intensity is indicated by a 3 dB increase, regardless of the level of the original sound. For example, a dB level of 63 is twice as loud as 60 dB and a dB level of 180 is twice as loud as 177 dB. For decibels to have relevance, they must be referenced to pressure. A micropascal (µPa) is a measurement of pressure. Such measurements are expressed as X dB re 1µPa.

In projects involving underwater detonations, 180 dB re 1µPa was formerly used as the peak sound pressure level that could be received by marine mammals without injury. More recently, 182 dB re $1\mu Pa^2$ second was applied to establishing safety zones for marine mammals during the ship shock trials of the submarine *U.S.S. Seawolf*. This measurement represents the energy of pulsed sounds. Energy is proportional to the time interval of the pressure, expressed in micropascals squared over a period of one second. In this application, the measurement refers to the maximum amount of energy that can be received by a marine mammal without injury.

Another measurement was also used in establishing safety zones for marine mammals for the *U.S.S. Seawolf* project: 12 psi-millisecond peak pressure. This amounts to the maximum overpressure that can be received by a marine mammal without injury. Whichever measurement attained the greatest range before reaching its threshold was applied to the wildlife hazard zone for the *Seawolf* project.

Still another measure of pulse amplitudes is the root mean square (rms) pressure level, which is averaged over the duration of the pulse. This represents the average peak pressure and is expressed as X dB re 1µPa-rms. During geophysical projects, a level of 160 dB re 1µPa-rms has been used to establish a hazard zone for baleen whales and the sperm whale, while 180 dB re 1µPa-rms has been used for pinnipeds and small cetaceans.

Sound pressure measurements can also be expressed as X dB re 1 µPa-m, which represents the theoretical sound pressure level within 1 meter of the source. This is often referred to as the source level. The reference distance of 1 meter is included so that a measured or modeled level at a given distance can be compared to the level at the source itself.

One key step in planning is to investigate the structure to be removed, then to consult with demolition experts. An acoustic model can then be prepared so that safe zones for marine wildlife can be estimated. The model should factor in bathymetry, substrata, the structure to be demolished, and the demolition strategy. This strategy can be tested on the model and refined to reduce sound pressure levels. The zone around the project site that is dangerous for marine wildlife can then be predicted. We prefer the term hazard zone. In projects using large amounts of explosives, a buffer zone can be used as an early warning zone. A true safety zone represents an area that is safe.

Another step is to review the literature concerning the marine life of the region, the habitats, bathymetry, and physical oceanography. This information is generally incorporated, to varying degrees, into the environmental compliance documents, such as environmental impact statements, biological assessments, environmental assessments, or other documents. Preliminary mitigation plans are either incorporated into such documents or provided as addendums, along with technical reports or incidental harassment authorizations. Final mitigation plans are prepared once contractors, responsible parties, agency representatives, points of contact, schedules and other matters are known.

Diver and/or ROV surveys are sometimes also conducted prior to a decommissioning to provide information as to the marine life present at the site.

PROTECTED SPECIES OF CONCERN

Some 42 species of marine mammals, 5 species of sea turtles and over 200 species of sea birds exist off the California coast. Some are threatened or endangered, while others are candidates for the federal Endangered Species List.

MONITORING

MMCG has a group of monitors that have been approved by NOAA Fisheries. These monitors have an academic background in a related field, such as marine biology, environmental studies or wildlife biology. They have completed a course in marine mammal and sea turtle rescue and rehabilitation and have hands-on experience with handling marine wildlife. They have logged sufficient hours of sea time to demonstrate that they can handle the rigors of life at sea as well as interact professionally with contractors, company and government representatives, and others. Finally, the monitors have completed courses in marine wildlife identification, data collection and monitoring techniques. MMCG also has monitors trained to represent state agencies to check for compliance with installation or decommissioning permit requirements not related to marine mammals or sea turtles.

Marine wildlife monitoring for EROS projects is generally conducted two to three hours before a detonation. Vessels and aircraft used by the regulatory agencies for their own wildlife surveys are used by MMCG monitors. Line transect surveys are conducted around each project site. This same method is used by the regulatory agencies and is a proven scientific technique. Aerial monitoring can be waived during foggy or severe weather if, in the opinion of the chief monitor, adequate surveys can be conducted by vessel or from land. Any dead floating wildlife found before a detonation is tagged so that it cannot be confused as a project casualty.

Commercial divers employed in the decommissioning project are requested to watch for marine mammals, sea turtles, or diving sea birds, although underwater visibility frequently prohibits any accurate assessment.

Active sonar is used to determine the presence of large schools of pelagic fish over a detonation site. The detonation can be delayed until the pelagic fish move out of the hazard zone. Active sonar is not used to locate marine mammals. Sonar with sufficient range and definition to locate marine mammals within a large hazard zone can harass marine mammals. Passive sonar is used, although it is only considered an additional tool in detecting marine mammals. Frequently, marine mammals are present but are not vocalizing. For example, during the Chevron 4H Decommissioning Project, 1681 marine mammals were sighted, representing seven species, yet no vocalizations were detected. Passive sonar was useful in detecting the presence of some species of whales and dolphins during Exxon's geophysical surveys. To be more useful for EROS projects, passive sonar should be capable of locating the position of the animal relative to the hazard zone.

A much more useful mitigation tool is the deployment of a calibrated hydrophone system capable of determining sound pressure levels from detonations so that the validity of the hazard zone can be assessed. Such a system should be capable of real-time sound pressure level measurements, or at least of determining sound pressure levels within minutes of each detonation. This method was employed quite successfully during the Mobil Seacliff Pier Decommissioning project.

After the detonation, monitoring is continued for at least half an hour. In addition, all fish mortalities are quickly picked up to avoid attracting marine life. The fish are identified and counted, then donated to a charitable or research facility.

Demolition Strategies

A number of demolition strategies have been used in EROS projects in California. These include:

1. Detonate in the daytime only.
2. Individual charge weights less than 50 pounds, or Section 7 Consultation and Incidental Take Authorization often necessary.
3. Charge sequence will be staggered; no interval specified, except that interval must be sufficient to prevent buildup of sound pressure levels.
4. Detonate as many series of charges as possible to avoid "dinner bell" response to fish. Also, potential risks about the same for one series of detonations as they are for several series of detonations in rapid sequence.
5. Use internal charges when possible: targeted charges inside pilings; stemmed charges inside concrete.
6. In shallow water, time detonations for low tide and in California, even when the waves recede. Direct charges toward shallow water.
7. For piling cuts, reduce height of piling stub to avoid shotgun barrel effect.
8. Use heterogeneous berms to attenuate sound pressure levels. These should be engineered by an acoustic physicist, but they are inexpensive and employ readily obtainable materials.
9. Consider use of blast mats, Gunderboom or other manufactured devices to attenuate sound pressure levels in appropriate applications, such as the severing of pilings.
10. Bubble curtains must be engineered to have value in sound attenuation. Sometimes valuable in reducing fish mortalities, but can also cause resident fish to hide in structure to be demolished.

SOUND PRESSURE LEVEL MEASUREMENTS

During the Chevron 4H Decommissioning project, sound pressure levels were attenuated compared with what might be expected for open-water detonations. The results are shown in Table 1E.1. Each piling was severed using a 45-pound targeted charge five feet below the mudline.

During the Mobil Seacliff Pier Project, sound pressure levels varied considerably (Table 1E.2), in some cases actually increasing with range because of the convergence of reflected waves. Little correlation was found between the total amount of explosives used and the sound pressure levels. This was attributed to inconsistent structural integrity—some structures were far weaker than others—as well as the amount of explosives exposed to the water column.

Table 1E.1. Received sound pressure levels during Chevron 4H decommissioning project.

Range	Duration (seconds)	Energy (dB re I μPa ^{2}-S)	SPL (rms) (dB re 1 μPa)	Peak SPL (dB re 1 μPa)
48' (15 m)	0.141	213	222	240
89' (27 m)	0.126	214	223	238
141' (43 m)	0.136	205	215	229
279' (85 m)	0.134	203	212	226
1017' (310 m)	0.114	189	199	212
1575' (480 m)	0.643	172	174	186
2625' (800 m)	2.931	180	175	187
2887' (880 m)	0.769	168	169	182
4265' (1300 m)	1.15	157	156	168

Source: Greene *et al.* 1998, courtesy of Chevron

Table 1E.2. Sound pressure levels (SPL) during the Mobil Seacliff Pier Project.

Date	Location	Caisson Size	Pounds of Explosives	SPL at 1000 yds.
3 April 1998	Whitten	22 feet	594.6	195.9 dB
30 April 1998	Short	8 feet	88.5	176.8 dB
	Short	8 feet	88.5	186.3 dB
6 May 1998	Whitten	8 feet	150.0	201.8 dB
	Whitten	8 feet	150.0	197.5 dB
8 May 1998	Whitten	12 feet	163.0	186.3 dB
	Whitten	8 feet	111.0	177.4 dB
	Whitten	8 feet	111.0	200.9 dB

Source: Howorth 1996

NOTES ON OTHER PROJECTS

Exxon Geophysical Surveys

The remote hydrophone array picked up ambient sounds, anthropogenic sounds such as oil production sounds from nearby platforms, geophysical airgun sounds, and marine mammal vocalizations. No data have been released about sound pressure levels.

During the vertical seismic profiling operation, the power was ramped up to provide warning to any marine mammals in the area. At night, deck lights on the vessel attracted plankton, which in turn attracted fish, then sea lions and dolphins. After the lights were turned off, the animals soon left, allowing a resumption of operations.

Ship Shock Trials

Three 10,000-pound charges were detonated in deep ocean waters. A 4-by-8-nautical-mile moving corridor was monitored by ship and aircraft. Sonabuoys were also deployed by aircraft to listen for marine mammals. No marine mammal or sea turtle impacts occurred.

Pile-Driving, Carpinteria

The pile-driver was ramped up during a period when no seals were present at the rookery. Pile-driving was conducted with no significant impacts.

EFFECTIVENESS OF MITIGATION

No takes were documented during any of the MMCG projects. No significant impacts, injuries or mortalities occurred to any marine mammal or sea turtle. Systematic, comprehensive monitoring minimized potential impacts. The proximity of these projects to the highly populated coast ensured that previously undetected significant impacts would be reported. No complaints were made by environmental groups, the public, industry, the military, or the regulatory agencies.

RECOMMENDATIONS

Based on experience with successful projects in California, we offer the following mitigation measures for consideration:

1. Noise attenuation strategies in lieu of or in addition to below-mudline requirement.
2. Use of line transect survey methods.
3. Real-time sound pressure level measurements.

In addition, we offer the following suggestions regarding the proposed measures:

1. Assess the possibility of reducing the pre-detonation monitoring time to a minimum of two hours before detonation.
2. Assess the effectiveness of diver and ROV surveys for sea turtles and marine mammals by comparing with concurrent detection means, such as topside monitors, passive listening, etc. Eliminate measure if ineffective.
3. Assess the effectiveness at reducing sound pressure levels by staggering charges at an interval of 0.9 seconds. Provide a minimum and maximum time interval instead for staggering charges if feasible.
4. Do not limit the number of blasts per detonation to eight if sound pressure levels can be kept at acceptable levels by using small charge weights and staggering the charges.

5. Provide passive listening devices or systems capable of establishing the approximate distance of any marine mammal from the detonation site so that its position relative to the hazard zone can be determined.

Peter Howorth, a Principal and the Senior Biologist for the Marine Mammal Consulting Group, Inc., has worked with marine mammals for 40 years. He is recognized by the regulatory agencies as a marine wildlife mitigation expert. As founder and director of the Santa Barbara Marine Mammal Center, he has worked with thousands of whales, dolphins, porpoises, seals, sea lions, and sea otters over the past few decades. He also works with numerous agencies and institutions throughout the U.S. and in other countries.

REMOVAL MITIGATION PLANNING AND IMPLEMENTATION: NORTH SEA/UK CASE STUDY

Jeremy R. Nedwell, Subacoustech Ltd.
Jonathan Gordon, Ecologic

INTRODUCTION

As UK offshore oil fields mature, increasing well abandonments will occur each year. Current regulations call for complete removal of offshore oil and gas industry structures once oil production has finished, to leave a clear, unimpeded seabed. For this reason, when wellheads are decommissioned, the reservoir and subsurface formations are isolated with concrete, and the upper part of the wellhead, including a few meters of the casing below the seabed, is explosively cut and recovered.

The use of underwater explosives prompts concerns about the possible effects of detonations on the marine environment and in particular on marine mammals. The effects of blast comprise:

- Primary effects: The most obvious effect, when it occurs, is the death or serious injury of animals that are unfortunate enough to be within the blast injury range. Hence, operating protocols required by licensing authorities often ensure that blasting is suspended when aquatic mammals are within visible range.

- Secondary effects: Much more difficult to detect and therefore less well understood are the non-lethal types of injury that can occur at greater range but which nonetheless may be debilitating. Examples of this are swimbladder rupture in fish, lung injury in marine mammals and auditory damage in both.

- Tertiary effects: The subtlest effects, exerted at lower energy levels and therefore over a much larger spatial area, are behavioral effects (any changes in the behavior of the animal).

While it is accepted that there is a small risk of an unlucky animal straying into the immediate area of the blast and suffering primary or severe secondary injury, the secondary and tertiary effects are of more concern in that they are pernicious, and at the current state of knowledge difficult to quantify as an environmental impact. Consequently, a consortium of oil companies funded a monitoring and research project during a well abandonment campaign. The wellheads being removed were in the North Sea, and were at depths of between 32 and 116 m. The operation took place between mid-December 2000 and the end of January 2001. The operation was conducted from the well intervention vessel CSO Seawell. The wellheads were cut using a cartridge of liquid high explosive, of 36 to 81 kg charge weight, within the casing strings and conductor of the wellhead.

MONITORING AND MITIGATION PROCEDURES

The mitigation program was undertaken by Dr Jonathan Gordon of Ecologic. The program involved monitoring the immediate area of the blast; the explosive was only fired if the area was considered to be free of marine mammals. However, a seal scrammer was also used to minimize the likelihood of marine mammals straying into the area (Gordon *et al.* n.d.).

The monitoring program involved both visual and acoustic monitoring of the area in the vicinity of a wellhead site prior to, during, and after an explosive blast. Sighting conditions were generally poor, and many of the severance blasts took place at night; thus, acoustic monitoring was provided in addition to visual searching. The charge was not detonated if there was confirmed marine mammal activity within visual range or if vocalizations detected by the acoustic monitoring suggested that any marine mammals were in the vicinity of the vessel.

Visual Monitoring

The Marine Mammal Observers (MMOs) conducted a general watch during all available daylight periods, and in particular the four hours prior to any detonation. If any cetacean was observed it was to be monitored and tracked until it had moved out of visual range. If possible, this was to be video recorded. If, once sighted, a cetacean was not spotted again for 45 minutes, then it was to be assumed for the purposes of mitigation that it was no longer present.

Acoustic Monitoring

The hydrophones used in the acoustic monitoring equipment were lowered through the moonpool three hours prior to the detonation, and sonobuoys were launched at an agreed time dependent on surface current conditions. Again, once 45 minutes had elapsed since the last detected signal, it was to be assumed that the area was clear. The hydrophones were withdrawn 45 minutes prior to the detonation, prior to the seal scrammer being activated. Fifteen minutes before firing, the hydrophones were deployed for a short period to finally check for any marine mammals; the hydrophone assembly was finally recovered 10 minutes prior to the detonation.

Mitigation

The mitigation strategy hinged primarily on not firing explosives if there were any marine mammals detected in the vicinity of the blast. However, in addition, a seal scrammer was used to avoid accidental exposure. Seal scrammers are an example of an Acoustic Harassment Device, or AHD. AHDs generate sound at a level and frequency that is sufficient to cause a behavioral response in a target species, typically to encourage it to move away from the AHD. AHDs for marine mammals typically operate in a frequency range from about 11 kHz to 19 kHz. Other AHDs include devices intended to remove fish from an area; these operate at lower frequencies of about 10 Hz to 1 kHz. The seal scrammer was activated 45 minutes before firing, and remained active for 30 minutes. The AHD was switched off 15 minutes prior to the detonation and withdrawn from the water.

Results of Monitoring

It was found that there were limitations to the usefulness of the acoustic monitoring using a streamer hydrophone, as the noise generated by the ship's positioning thrusters dominated in the low- to mid-frequency range. Acoustic monitoring with sonobuoys was less influenced by the ship's noise, as the sonobuoys drifted away from the ship.

Throughout the first stage of the campaign no cetaceans were detected close to the wellheads, although a group of white-sided dolphin was seen on the morning of 12 January while the vessel was traveling back to Aberdeen. Grey seals, observed regularly, seemed to be attracted to the wellheads to forage. They were observed by the ROV camera catching fish on a number of occasions.

There was one instance of a seal hauling out on a ledge in the working moonpool and remaining there for about four hours. Because the pool was often covered, it is possible that they spent more time in this moonpool than the crew or MMOs realized. On another occasion, a seal was found in the working moonpool as the ship was transiting to a new site; the ship was slowed and the seal encouraged to leave by activating the seal scrammer in the moonpool.

BLAST MEASUREMENTS

Recordings were simultaneously made of underwater sound pressure near the blast site around the time of the blast. The details of the charges used are given in Table 1E.3 and Table 1E.4. Two sorts of measurements were made. First, measurements were taken of the blast pressure waves arriving at the CSO Seawell when at its standoff position of 600 meters or more from the explosion. Second, on an opportunity basis, measurements were made using a submersible blast recording workstation. This was attached to the firing line, and hence could be used to record the blast closer to the wellhead. All measurements were made using calibrated equipment traceable to International Standards.

Blast Instrumentation

The blast wave arriving at the master station, on board the CSO Seawell, was measured using two Bruel and Kjaer Type 8104 Hydrophones deployed from the vessel's moonpool, at depths of between 25 and 40 meters. The signals from the hydrophones were pre-emphasized, conditioned, and digitized at 250 ksamples/sec. The useable bandwidth of this equipment was 10 Hz–130 kHz, and it retained an adequate signal-to-noise ratio over the whole of this range.

The slave workstation comprised a pressure vessel tested and certified to 400 meters depth, on which was mounted a Bruel and Kjaer Type 8103 precision hydrophone, and which contained recording equipment. After the blast the workstation was retrieved and the data from the system was downloaded onto the master system. The useable bandwidth of this equipment was from 10 Hz–22.5 kHz.

Table 1E.3. Parameters relating to the 16 wellhead blasts recorded: peak pressures.

Master station measurements					Slave station measurements		
	Channel 1		Channel 2				
Range (m)	Depth (m)	Peak press. (kPa)	Depth (m)	Peak pres. (kPa)	Range (m)	Depth (m)	Peak press. (kPa)
600	30	100	-	-	-	-	-
600	30	53	25	57	-	-	-
600	30	52	25	50	-	-	-
650	-	-	-	-	300	91	392
600	-	-	-	-	-	-	-
800	30	117	-	-	-	-	-
650	25	198	-	-	-	-	-
650	40	63	35	75	300	84	312
650	40	83	35	80	-	-	-
650	40	54	35	68	125	87	201
650	40	115	35	130	-	-	-
650	30	43	25	49	-	-	-
650	30	118	25	130	-	-	-
600	40	47	35	51	200	110	169
575	30	37	25	36	400	108	147
650	30	77	25	74	75	116	236

A Typical Result

Figure 1E.1 illustrates a typical pressure-time history recorded at 600 meters at the master station. It may be seen that the pressure rises rapidly to a positive peak of about 40 kPa; there is some evidence of a precursor prior to this, possibly caused by a head wave transmitted through the seabed. There are two negative peaks, which are probably inverted reflections from the sea surface.

It may also be seen that there is an extended low frequency oscillation at about 10 Hz; it is probable that this is a “bubble pulse.” Bubble pulses occur when hot gases associated with an underwater

Table 1E.4. Parameters relating to the 16 wellhead blasts recorded: physical details.

Well id.	Water depth (m)	Depth below seabed (m)	Pipe height (m)	Casing	Date of blast	Time of blast	Charge weight (kg)
49/23-7	32	3	7	30"	28/12/00	14:16:44	73
30/17-9	81	3	7	9.625", 13.375", 20", 30"	31/12/00	07:19:27	81
30/17b-5	75	3	4.85	9.625", 13.375", 20", 30"	7/1/01	09:01:22	45
22/20-5z	91	3	3.8	9.625", 13.375", 30"	11/1/01	02:12:09	45
22/20-5z	91	2	3.8	9.625", 13.375", 30"	11/1/01	~05:30:00	45
13/28a-6	78	above	3.8	external cutting charge	12/1/01	00:35:11	36
13/28a-6	78	3	3.8	30"	12/1/01	03:19:48	73
23/22a-3z	84	3	2.48	9.625", 13.375", 30"	16/1/01	05:50:37	45
23/22a-3z	84	2	2.48	9.625", 13.375", 30"	16/1/01	08:38:02	45
22/20-3z	87	3	3.45		19/1/01	01:00:53	45
22/20-3z	87	2	3.45		19/1/01	03:49:38	45
22/23-3	95	3	3		24/1/01	04:12:55	45
22/23-3	95	2	3		24/1/01	07:34:47	36
16/6b-6	110	3	2.1	13.375", 20", 30"	25/1/01	22:51:39	45
16/7a-22	108	3	-	9.625", 13.375", 20", 30"	28/1/01	00:28:15	45
16/3b-3z	116	3	0.88	9.625", 13.375", 20", 30"	30/1/01	11:21:29	45

explosion of an unconfined charge force back the surrounding mass of water. The momentum of the water immediately surrounding the gas bubble causes the bubble to expand beyond the volume it would occupy when subjected to the ambient hydrostatic pressure. Hence, when the bubble is at its maximum radius, the pressure within the bubble is lower than that of the surrounding water, and the bubble starts to recompress. The momentum of the water mass forces the gas bubble past equilibrium once again, this time into compression. This resonant behavior produces a series of secondary pressure waves that gradually decay towards static ambient pressure.

Primary Effects of Blast

Figure 1E.2 shows the peak pressure levels plotted as a function of the range of the measurement from the charge. For comparison, the figure also shows the estimated peak pressure of a 45 kg unconfined charge (See Cole *et al.* 1946), given by:

Parameter	**Symbol**	**Value**	**Units**
Peak pressure	P_{max}	$5 \times 10^{7}\ W^{0.27}\ R^{-1.13}$	Pa
Impulse	I	$I6 \times 10^{3}\ W^{0.63}\ R^{-0.89}$	Pa.s

Where W is the charge weight in kilograms and R is the range from the explosive in meters.

In general, it may be seen that the peak pressures agree reasonably well with the theoretical result for unconfined charges, with no apparent indication that the peak pressure has been attenuated as a result of the charge being confined within the wellhead. It may be commented that while some of the charges are larger or smaller than the 45 kg used as the basis of the theoretical result, due to the dependence of the peak pressure on approximately the cube root of the charge weight, little difference in the predicted peak pressures would result.

It is possible that the measurements near to the blast indicate a slightly lower level than the theory but this cannot be conclusively demonstrated without further measurements. It is noted by Nedwell and Thandavamoorthy (1989a, 1989b) that during borehole blasting in rock, the peak pressure levels are typically 10% or less of those for unconfined charges. However, in that case, there is an additional efficient loss mechanism, caused by better confinement of the explosive energy and losses caused by explosive products venting through fragmented rock, which account for the lower levels.

Figure 1E.3 illustrates an identical result to Figure 1E.2, but for the case of the measured impulse from the blasts. Similar features to those of Figure 1E.2 may be seen; in general the measured impulse is close to that of the theory for unconfined charges.

Yelverton *et al.* (1975) quotes an impulse of 69 Pa.s as leading to a low incidence of trivial blast injuries for marine mammals, with no eardrum ruptures. The above results indicate that the range for a typical 45 kg charge at which the blast will fall to this level is about 2.2 kilometers. Similarly at a range of about 500 meters an impulse of 276 Pa.s could cause severe blast injuries.

Secondary and Tertiary Effects of Blast: Hearing Damage and Behavioral Effects

Unweighted peak pressure levels are of little use in estimating hearing damage and behavioral effects of underwater noise as they embody an implication that the hearing of all affected species is uniform, flat in frequency, and of equal sensitivity. Much of the sound energy may be at frequencies that an animal is unable to perceive, and which may as a result have no effect on it. To be of any use in estimating effect, consideration of the acuity, and frequency range of the species' hearing is required, to reflect the *perception* of the sound by the animal.

In the dB(A) scale used to estimate such effects of sound on humans, the sound is first of all weighted by being passed through a filter which may be thought of as approximately mimicking the effectiveness of human hearing. It is measured after undergoing this process. The level of sound that results may be considered to be related to the degree of stimulation of the hearing process and hence to the *perception* of the sound. Hence measurements of sound level in dB(A) relate well to the degree of both physical and behavioral effects of sound on humans.

This approach has also been extended to underwater human exposure to sound (where the hearing ability differs greatly from that in air) yielding the dB(UW) which has allowed the effects of sound on submerged humans to be estimated (Nedwell *et al.* 1993). It has been further suggested that it might be extended to a wide range of species (Nedwell and Thandavamoorthy 1998) to yield the dB_{ht} (Species), which is conveniently thought of as a measure of how much the sound is above the species' threshold of hearing. The scale has been developed since it will enable better estimates of the effects of sound on marine species to be made, and for measurements relating to environmental effect to be generalized and applied to other situations.

It may be proposed that discomfort, hearing damage, and avoidance of sound are related to the upper limits of the dynamic range of an animal's hearing process being approached. For instance, in humans, the dynamic range of hearing is about 140 dB; discomfiture arises when the sound is in the upper 40 dB of this range. Sound in the upper 50 dB can cause hearing damage. The lower end of the dynamic range is set by the minimum displacements which can be detected. The upper end of the dynamic range is set by displacements of the hearing organs which are large compared with cellular dimensions, and which cause physical damage. At the current state of knowledge, it cannot be ascertained if the dynamic range in other species is similar to that in man, but there are good evolutionary reasons why other animals should also make use of this available dynamic range.

Figure 1E.4 illustrates the pressure-time history presented in the unweighted results; it has in this case been passed through a dB_{ht} filter which mimics the hearing process of a harbor hair seal (*Phocoena phocoena*). The result may be approximately thought of as representing the pressure from the blast with "species hearing thresholds" as the fundamental unit of pressure, although it should be noted that this is a frequency-dependent quantity and not a simple ratio.

It may be seen that the pressure when expressed in this way is greatly above the threshold of hearing of the harbor hair seal. The peak pressure is about 3,400,000 hearing thresholds, and so would in this case be expressed as 131 dB_{ht} (*Phocoena phocoena).*

Figure 1E.5 illustrates a similar quantity, but for the cod (*Gadus morhua*). The peak pressure is 9,000,000 hearing thresholds, and so the level is 139 dB_{ht} (*Gadus morhua*).

Table 1E.5 lists the dB_{ht} values for a range of species, which have been averaged over all of the measurements made at the standoff distance of 600 meters. There is no suggestion that there is a significant population of all of these species at the location in which the measurements were made; rather, the intention is to illustrate the potential effect of such a blast on a range of species. All of the levels were considerably in excess of 100 dB_{ht}, and in the case of the harbor porpoise and killer whale, are in excess of 150 dB_{ht}. If a similar dynamic range of hearing is assumed for a cetacean as for a human, it would appear that there is a significant risk of irreversible hearing damage to all of the species considered at the range from the blast at which measurements were made, 600 meters.

Table 1E.5. Averaged results for dBht values.

Weighting system	Linear	Catfish	Cod	Dab
Average dB_{ht}	217.0	149.9	136.8	114.5
Weighting system	**Harbor seal**	**Harbor porpoise**	**Killer whale**	**Human diver**
Average dB_{ht}	135.8	152.1	158.4	138.8

DISCUSSION: RANGES OF EFFECT AND EFFECTIVENESS OF MONITORING

The results demonstrate that in respect to primary effects of blast, the range at which severe injury or death might occur, about 500 meters, is similar to the range at which trained MMOs might be able to make a visual detection, given luck and good conditions. If the focus of attention is on these effects alone, visual detection in good conditions offers a valuable means to mitigate the effects of the blast, although it is by no means certain that all mammals will be detected.

It is the author's experience that, in Europe, the focus of attention in respect to environmental impact of noise and blast is moving away from death and injury and toward auditory and behavioral effects. These more subtle effects influence far larger numbers of animals, since they typically occur at significantly greater ranges than primary effects, where effective visual monitoring is impossible. The dB_{ht} has been introduced as a means to quantify the range at which effects might occur and to rank order the effects of noise on a range of species. In the case of blast, a wide range of species appears to be at risk at significant ranges, primarily as a result of the high level and wide frequency content of the blast.

Under these circumstances, acoustic monitoring for vocalizations offers the only means of detecting the presence of mammals within the radius of effect of the blast. However, simple listening devices do not indicate the range of the animal from the wellhead, so it is possible that blasting operations may be delayed due to vocalizations detected from animals well outside the danger area, or conversely that they may proceed where animals are within the danger area yet make no vocalization or one of sufficiently low level that it is not detectable. Passive sonar systems using static or towed arrays, which allow the location of the vocalization to be determined, may resolve this ambiguity in due course.

CONCLUSIONS

1. The measured peak blast pressures and the impulses of the blast waves agreed reasonably well with the theoretical predictions for unconfined underwater TNT charges, with no apparent indication that the peak pressure or impulse of the blast had been significantly attenuated as a result of the charge being confined within the wellhead.

2. At the ranges at which measurements were made, of 75 to 800 meters, the levels were sufficient to cause both behavioral effects and the moderately severe blast injuries of underwater mammals noted by Yelverton. For a typical 45 kg charge, the range at which the effects would be expected to fall to 69 Pa.s, at which Yelverton noted there would be expectation of a low incidence of trivial blast injuries, and no eardrum ruptures, was therefore 2.2 km.

3. All of the levels expressed in perception units were considerably in excess of 100 dB_{ht}, and in the case of the harbor porpoise and killer whale are in excess of 150 dB_{ht}. If a similar dynamic range of hearing is assumed for marine mammals and fish as for a human, it would appear that there is a significant risk of irreversible hearing damage to all of the species considered at the range from the blast at which measurements were made, 600 meters.

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MEASUREMENTS OF NOISE FROM SEISMIC SURVEYING IN THE NORTH SEA: HOW EFFECTIVE IS MITIGATION?

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INTRODUCTION

During a seismic survey, airguns release air at high pressure into the water, emitting strong impulses of waterborne sound. The sound is usually generated by an array of airguns; the array is designed to maximize the amount of sound that is propagated downwards into the seabed. The sound returning from the seabed is processed to allow an image of the rock strata and underlying geological structures underneath the seabed to be formed.

Marine mammal and fish conservationists allege that the sound may have undesirable side-effects upon aquatic animals over ranges of kilometers or tens of kilometers; consequently, the seismic industry has been obliged to adopt environmental protection criteria proposed by the regulators under the precautionary principle.

Subacoustech Ltd undertook measurements of noise during a 3D seismic survey in blocks 14/14a of the North Sea, during the latter part of July and the early part of August 1998. The purpose of the these measurements was to provide good-quality recordings of seismic noise, to analyze these in units relevant to environmental effects, and to interpret the results in respect of likely ranges of effect and the effectiveness of mitigation procedures. It is recognized that some of the mitigation measures, such as the “soft start” where the airguns are gradually increased to full power over a period of several minutes, are untested and may or may not achieve the objective of reducing environmental impact.

The purpose of the measurements reported in this paper was primarily to investigate the effectiveness of the soft start mitigation measure.

METHODOLOGY

The dB_{ht} (Species)

To be of any use in estimating effect, noise has to be specified in a form that is meaningful for an affected species, and this, as a consequence, will involve consideration of the acuity and frequency range of the species’ hearing. For instance, consider the comparison between the effects of a seismic source on a fish and a marine mammal. Most fish have best hearing at low frequencies. Airguns generate most of their sound energy at low frequencies, and so the effective level of an airgun for fish will be high. Similarly, the low frequencies that fish can hear propagate relatively well, so that the effective rate of attenuation of sound will be low. Marine mammals, other than perhaps the baleen whale, by contrast, hear best at relatively high frequencies, well above the frequency band that an airgun generates most efficiently; the effective level of an airgun for a marine mammal will be low. For marine mammals, the higher frequencies attenuate fast, leading to a high effective rate of attenuation of sound. These facts underpin the need to express quantities in units that are physically meaningful for the species that are effected.

The dB_{ht} (Species) has been proposed as a measure of how much the sound is above the species' threshold of hearing. The suffix ht relates to the fact that the sound is expressed in dBs which are referenced to the hearing threshold of the species. The dB_{ht} (Species) level is estimated by passing the sound through a filter that mimics the hearing ability of the species, and measuring the peak level of sound after the filter; the level expressed in this scale is different for each species and corresponds to the *perception* of the sound by the species. Typical audiograms are shown in Figure 1E.6.

Let *W( )* be the threshold sound pressure of the species' hearing at frequency expressed in any unit of pressure. The weighted version of a sound *P(t)* which might be termed the perception filtered sound, is given by

$$P_{ht} = \int_0^\infty \frac{1}{W(\omega)} e^{-i\omega t} \int_0^\infty P(t) e^{i\omega t} \partial t \partial \omega \qquad (1)$$

The units of the resulting pressure are pressure, divided by pressure at threshold, and hence are non-dimensional. The authors suggest that this approach has significant advantages in estimating the environmental effect of underwater sound. It can be applied equally well to both narrow band noise such as is caused by sonar transmissions, and wideband noise such as is caused by seismic airguns. It enables the *effective* source level of a seismic source and the *effective* Transmission Loss from it to be determined for a particular species, and also lends itself to simple measurement schemes which could be used by non-expert users, such as an "underwater species sound level meter." While recognizing that the approach requires further validation, the authors have found that analyzing data in this format highlights features that on reflection are intuitively obvious.

Human hearing has a dynamic range, from the threshold of hearing, to the threshold of pain, of about 130 dB. The range is determined by physical constraints; at the lower end, hearing is limited by natural background noise, and at the upper end, by displacements of the sensory structures associated with hearing to a degree that causes traumatic damage. When the sound exceeds about 100 dB above the threshold level, it is likely to cause behavioral effects. If the same physical constraints apply to other species, and hence the considerations of dynamic range apply, by implication, any level of sound above 100 dB_{ht} (Species) might cause a behavioral reaction and, above 130dB, auditory trauma. While this suggestion is tentative, the dB_{ht} (Species) approach nevertheless offers a method by which the sound may be measured in a way that is thought to be physically and biologically meaningful and related to its likely degree of effect.

MEASUREMENTS

The measurements presented in this report were made during a 3D seismic survey in blocks 14 and 14a of the North Sea on the 26 July to 18 August 1998.

The survey was conducted using the boat SRV Veritas Viking. A total of 6 seismic streamers were towed behind the seismic boat, covering a width of 600 meters. The seismic boat followed a pattern of east-west lines turning in a “line change” maneuver at each end on a 2500 m radius circle.

The water depth in this area is about 100 meters. The two seismic noise sources each consisted of a 3335 cubic inch, tuned and clustered Bolt airgun array, comprising of 14 airguns, as illustrated in Figure 1E.7. The volumes of the airguns in each array were 70, 90, 105, 110, 125, 145, 160, 185, 196, 250, 2 of 290, and 2 of 370 cubic inches. The port and starboard arrays were fired alternately in what is termed a “flip flop” arrangement.

Noise measurements were conducted from the survey guard boat Northstar on an opportunity basis. Due to considerations of safety, it was not possible to make recordings closer than 1400 meters from the seismic boat. Measurements were made at a maximum range of 12 kilometers.

In all, sound was recorded at 783 measuring points with two simultaneous measurements at two depths at each point; this figure includes background noise measurements. In total, 1586 successful individual recordings of underwater sound from the survey were made. Recordings were made at depths of 5, 10 and 20 m using Brüel & Kjær Type 8105 hydrophones and were conditioned with B&K type 2635 charge amplifiers. Recordings at two of these depths were made simultaneously at every recording point, at 5 meters and one other depth. Every record was inspected, both visually as a time history and audibly using a high quality loudspeaker for imperfections in the data. A total of 920 recordings were rejected, some as a result of spurious noise of electrical origin, and some as a result of a hydrophone subsequently being suspected of being faulty, leaving a total of 596 recordings which were considered to be of acceptable quality.

TYPICAL RESULTS

Figure 1E.8 and Figure 1E.9 illustrate a typical result at a depth of five meters. The graph presents measurements of the unweighted peak sound pressure level from the seismic airgun discharges as a function of the range separating the source and measurement. The data span a range of about 1.4 km to 14 km. Four sets of data taken on four separate days of seismic surveying are presented.

Four general features may be seen.

1. First, it may be seen that the data at the shortest range in each set of data tend to be higher in level than the general trend in level of the rest of the data. This is due to directivity of the array. Figure 1E.9 shows the same data but as an isometric plot, with the peak SPL as a function of both the range and the bearing between the axis of the array (that is, its direction of travel) and the measurement point. It may be seen that the higher levels correspond to the point of closest approach of the seismic array to the measurement point, which is as the

seismic boat passes with the measurement point on beam, that is, at 90° to the direction of travel. It may be noted that there is a directional effect, with the levels typically higher than the general trend by about 10 dB within an arc spanning about 20°.

2. It may be seen that, if the peaks caused by the directional effects noted above are ignored, there is a regular and uniform reduction in the peak SPL with range, as would be expected from simple physical considerations.

3. The results may be modeled reasonably well by a simple N log (R) curve. In this case, the best fit is given by N= 25.35. If this law is extrapolated to give the source level, or effective level at one meter, a source level of 262 dB re 1 µPa @ 1 meter results. The measured source levels of seismic arrays are typically around 240-255 dB re 1 µPa @ 1 meter, and so this result is rather high. This may be due to error in estimating the value of N due to the propagation in the immediate vicinity of the source differing from that measured at greater ranges or could also be that a high proportion of the energy of the airgun is being trapped in a surface channel.

4. There is a degree of scattering of the results from the best fit, over a range of 10 dB or so. It may be noted that where the source boat has approached the measurement point, and then passed farther away again, that the measurements during approach differ from those at the same range during moving away. This difference is apparently not systematic, and is therefore probably caused by either spatial or temporal inhomogeneities of the sea.

SOFT START MEASUREMENTS

Where possible, airgun arrays are usually operated so as to minimize environmental impact. For this reason, it is a normal mitigation measure, when first starting the airgun array, to use a “soft start” procedure. In the soft start procedure, the number of airguns being discharged is gradually increased from one up to the whole array over a period of a few minutes. The aim of this procedure is to minimize environmental affect by allowing species that might be effected to leave the area. Often the volume of compressed air discharged by each of the airguns in the array is different, and in this case, it is normal to start by initially discharging the airgun having the smallest compressed air volume alone. The total volume of compressed air discharged by the airguns is designed to increase from the volume of this airgun up to the maximum volume that can be discharged by the array in roughly equal increments.

A number of recordings of soft starts were made. In order to remove both the range and array angle dependence, measurements of soft starts were specifically conducted by stationing the guard boat with the recording equipment at the center of the semi-circle described by the path of the seismic boat during line change maneuvers. Drift of the guard vessel proved to be a significant factor when assessing these recordings: the radius of the circles described by the guard vessel was in the region of 2500 m, and drift of over 1000 m of the guard boat during a recording of a soft start was not uncommon.

Figure 1E.10 and Figure 1E.11 illustrate the results for the soft starts at depths of 5 meters and 20 meters respectively; the data presented in the figures is unweighted. The figures show the sound pressure level in dB (lin) re. 1 μPa at a range of 2500 meters as a function of the total volume of the compressed air discharged by the airgun.

The units that have been used to specify the airgun volume, cubic inches, are not the SI units that would normally be used in a paper of this sort;. they have in this instance been used as they are ubiquitous in the seismic industry. One cubic inch equals $1.64\text{x}10^{-5}$ cubic meters, or $1.64\text{x}10^{-2}$ liters.

It may be seen that there is a fairly consistent relationship between the total volume V discharged by the array and the resulting level of sound. Each of the measurements has been fitted to a law of the form:

$$SPL = M \log (V) + V_0 \tag{2}$$

Where M and V_0 are constants, V is the total volume of compressed air discharged and SPL is the resulting sound pressure level. It may be seen that the constant M has a value of 8.4, indicating that the sound pressure P is proportional to the volume of the airgun array to the power 2.4, that is,

$$P\ k\ V^{2.4} \tag{3}$$

Where k is a constant. By implication, in terms of the unweighted levels, the soft start procedure achieves its objective of gradually raising the sound pressure level during the start of the firing of the array.

Figure 1E.12 illustrates the levels at 5 meters depth during soft starts in dB_{ht} (*Gadus morhua*) for cod. It may be seen that the results are very similar to those of Figure 1E.11; this is as expected since the majority of the acoustic energy from the array is at frequencies that the cod can hear. There is rather more scatter in the results at the higher volumes than is the case for the unweighted data, however.

Figure 1E.13 illustrates similar quantities for the harbor porpoise in dB_{ht} (*Phocaena phocaena*). There is a very significant scatter in the results. It cannot be determined from these results whether this arises from variability in propagation or from variability in the charecteristics of the airgun array; similar results were obtained for the results at 20 meters depth.

DISCUSSION OF RESULTS

In general, the results are interesting in that they indicate that the metric that is chosen to provide an analysis of measurements of underwater noise in respect of behavioral effects is of great importance in interpreting the significance of the measurements. The adoption of a perception-based scale (the dB_{ht}) leads to simple conclusions, some of which, in retrospect, are intuitively obvious.

Regarding variability, it has been noted by many authors that the variability of propagation in the sea increases with increasing frequency, since the medium appears increasingly inhomogeneous and time-dependent. In the case of marine mammals, which are predominantly high-frequency hearers, it is therefore retrospectively obvious that their perception of the noise from a remote source will vary accordingly. Some of the airgun impulses will appear loud to the species, and others quiet. If, say, one in ten events exceeding a certain threshold are sufficient to cause a given behavioral response in a marine mammal, then the effectiveness of the noise in determining environmental effect will depend not only on the mean features of propagation, but also on its statistics.

This study and the dB_{ht}, therefore have highlighted the significance of randomness of propagation, and it is argued that this is in itself one justification for the adoption of a perception-based scale. While not presented in this paper, it is easily shown that under the criterion indicated above randomness in propagation leads to an increase in the effective source level, a decrease in the effective Transmission Loss, and hence an increase in the range of effect.

Specifically addressing the effectiveness of the soft start mitigation measure, in respect of the harbor porpoise, and other marine mammals, it may be concluded that the results indicate that while there might be a dependence of the level of sound from the airgun on the volume of compressed air discharged by it, at the range at which the soft start procedure was measured this is masked by the random variability in level noted in the results. Therefore, reliance on the soft start procedure to reduce impact on marine mammals may well be misplaced.

CONCLUSIONS

In respect of the soft start mitigation measure,

1. The unweighted peak sound pressure levels measured at a range of 2500 meters gradually rise during the sound pressure the soft start procedure.

2. This is also true of the sound pressure levels expressed in dB_{ht} (Gadus morhua) for cod, although there is rather more scatter in the results at the higher volumes than is the case for the unweighted case.

3. There is a very significant scatter in the results for the soft start in dB_{ht} (*Phoca vitulina*) for the harbor hair seal and other marine mammals, such that the soft start procedure is dominated by random variability in level. It is probable that this arises from variability in propagation, although it could arise from variability in the high frequency output of the airgun array.

4. Hence, it may be concluded that, when the results are interpreted in the in dB_{ht} (Species) scale, the soft start is probably effective in reducing environmental effects on fish, but ineffective in respect of marine mammals.

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SESSION 1F

AIR QUALITY, PART II

Chair:	Chester Huang, Minerals Management Service
Co-Chair:	Richard Karp, Minerals Management Service
Date:	January 14, 2003

BRETON AEROMETRIC MONITORING PROGRAM (BAMP) PHASE II DATA ANALYSIS

B.E. Shannon, Offshore Operators Committee

Click here to see Mr. Shannon’s slide show.

Brian E. Shannon is a Principal Environmental Scientist with his proprietary consulting company, b.e.shannon/ENVIRONMENT.Consultant. Major projects include a contract with the Offshore Operators Committee (OOC) as project manager and lead scientist for the Breton Aerometric Monitoring Program and past chairman of the OOC Gulf of Mexico Air Quality Subcommittee. In these roles he is the prime contact for the offshore oil and gas industry in the Gulf of Mexico for all issues pertaining to air quality. Prior to forming the consulting company, he was employed for 21 years by ARCO Technology & Operations Services as a Principal Environmental Scientist. He provided advanced technical expertise, analysis, and advice on regulatory compliance and environmental issues affecting the worldwide operations of the Atlantic Richfield Company (ARCO). During this time he represented the OOC on the Technical Review Group for the Minerals Management Service’s Gulf of Mexico Qir Quality Study (GMAQS). He has a B.S. in physics/mathematics from the University of Minnesota and a M.S. in environmental science from the Florida Institute of Technology.

DEVELOPMENT OF THE NEXT GENERATION AIR QUALITY MODEL FOR OUTER CONTINENTAL SHELF (OCS) APPLICATIONS

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Earth Tech, Inc.

INTRODUCTION

The purpose of this study is to develop an updated regulatory model for evaluating air quality impacts from emission sources located on federal waters on the Outer Continental Shelf (OCS). The U.S. Department of the Interior Minerals Management Service (MMS) is in charge of a national program to develop the mineral resources, including oil and gas, on the OCS waters of the United States. The areas of development are located at distances ranging from 3 miles to more than 100 miles from shore. In the early 1980s the MMS developed the Offshore & Coastal Dispersion (OCD) model to evaluate impacts from the so-called "nonreactive" pollutants (NO_2, SO_2, CO, PM) emitted from point, line, or area sources located over water.

Since the science of dispersion modeling has made significant advances over the last couple of decades, there is a need to develop a model for application to emission sources on the OCS that incorporates, to the extent feasible, the most current knowledge and is versatile enough to be used in short-range as well as long-range applications. The goal of this study is to modify and/or enhance an existing model so that it can be appropriately applied to overwater applications. The non-steady-state CALPUFF modeling system (Scire *et al*. 2000a) will serve as the platform for the new OCS model and will be modified to enhance its treatment of dispersion in the overwater boundary layer.

The objectives of the study are

1) To perform a comprehensive review of existing models and to evaluate their applicability to offshore applications based on current knowledge of boundary layer and atmospheric dispersion in ocean and shoreline environments.
2) To revise or enhance an existing air quality model to make it suitable for offshore and coastal applications.
3) To develop a software package that includes the needed meteorological pre-processors, meteorological model, air quality model, source codes, test cases, and user's guide.
4) To carry out sensitivity testing and evaluate model performance against available tracer data.

REVIEW OF MODEL FORMULATIONS

The focus of the model review is the treatment of overwater and coastal meteorological conditions and dispersion processes by currently available models. Three models have been reviewed for their adequacy for simulating these processes: OCD, CALMET/CALPUFF, and SCIPUFF/SCICHEM. A detailed discussion of the various models in the Task 2 Report (Earth Tech and Environ, February 2003). A brief summary of the main features of the model evaluation is described below.

OCD

The OCD model (DiCristofaro and Hanna 1989) is an hourly, steady-state Gaussian model. The OCD model code was based on the EPA MPTER model. Its treatment of dispersion over land in simple terrain retains the MPTER algorithms. However, a set of new routines was added in OCD to treat overwater boundary layer dynamics, offshore dispersion, plume fumigation at the shoreline and to parameterize dispersion in complex terrain.

OCD determines offshore stability class as a function of wind speed, surface roughness and Monin-Obukhov length (calculated with virtual temperatures) following Golder (1972). Overwater turbulence intensity and stability stratification are either taken from observations or estimated from bulk transfer theory considerations of the overwater boundary layer.

OCD's offshore dispersion rates are estimated through empirical formulas combining contributions from turbulence, buoyant plume rise enhancement, wind direction shear, and building downwash. The turbulence component is estimated using turbulence intensity (either measured or empirically-derived calculations) and stability-class dependent, empirical, dimensionless functions of transport distance.

The model's empirical offshore dispersion parameterizations share many similarities with other currently available dispersion models that are based on current understanding of turbulence in the surface boundary layer. Extension or modification of the OCD approach may be needed to better conform to observed offshore plume dispersion data, or to take advantage of prognostic meteorological model output. Particular attention should be given to data collected further offshore, under conditions other than onshore flow, and with wider water temperature variations than those in the Santa Barbara channel.

OCDs employs an empirical two-piece linear description of TIBL height growth combined with a virtual source concept to treat the shoreline transition of plumes from the offshore to onshore dispersion regimes. The OCD approach is not completely transferable to the new OCS model, which is unlikely to invoke steady-state plume approximations. Furthermore, the steady, onshore flow paradigm of OCD's TIBL growth and geometry is unlikely to apply to many complex coastline situations. A new approach must be developed that will be applicable to a wider range of puff dispersion conditions within a regional modeling domain. For example, the new model should be able to treat puffs moving along the shoreline, moving offshore, and moving onshore, all simultaneously in a large modeling domain. The complexities of actual shoreline geography need to be addressed (e.g., Louisiana shoreline often has no well-defined TIBL or significant land-sea breeze circulations because of the large swamp areas there.) OCD also does not account for potential three-dimensional mesoscale circulation aspects of land-sea breeze; these probably should be treated in the wind field input preparation step for the new model, whether using CALMET, a prognostic model, or some combination of both.

OCD employs empirical wake algorithms derived by Petersen (1986) from data collected during APIsponsored wind tunnel test of flow and dispersion around oil platforms. These empirical formulas attempt to account for increased initial dispersion and reduced plume rise in the wakes of

OCS platforms. The OCD formulas require no special meteorological data and only two platform geometric parameters (platform width and height).

The first-order chemical kinetics and deposition approaches of OCD are too primitive for a modern OCS model, even for relatively slow reacting species such as SO_2. Given the larger modeling regions, transport times, and the number of potential emission sources, a new OCS model should possess the ability to treat non-linear chemical affects, temporal and spatial rate variability, changing ambient concentrations, and plume interactions.

The features of the OCD model that should be compared and considered for adaptation in CALPUFF are (a) overwater stability class parameterizations; (b) overwater plume dispersion rate parameterizations; and (c) platform wake effect parameterizations.

CALMET/CALPUFF

The CALPUFF modeling system includes a diagnostic meteorological model (CALMET), the nonsteady-state Lagrangian puff dispersion model (CALPUFF), and a large set of pre- and post-processing programs to interface the model to standard, routinely-available meteorological and geophysical datasets. Both CALMET and CALPUFF have special algorithms for accounting for overwater effects on transport and the effects of the land-water interface on meteorological conditions and dispersion. A detailed description of CALMET and CALPUFF are described in Scire *et al*. (2000a, b). The relevant features of the model for OCS applications are summarized below.

CALMET produces a three-dimensional wind field and temperature field and two-dimensional field of meteorological and geophysical parameters. Over land, CALMET uses an energy balance method to compute heat fluxes and turbulence parameters. Over water, a profile method, using air-sea temperature difference is used to define the marine boundary layer structure. A subgrid-scale coastal algorithm allows a refined treatment of the coastline and TIBL development, including effects of land use variability and wind trajectory relative to the coastline. A new feature of CALMET is its “no-observations” mode, which allows the model to run using data only from gridded prognostic model output, such as MM5, RAMS, or Eta.

CALPUFF is a multi-layer, multi-species, non-steady state model that simulates the effects of time- and space-varying meteorological conditions on pollutant transport, chemical transformation and removal. CALPUFF contains algorithms for near-source effects such as building downwash, transitional plume rise, partial plume penetration, sub-grid-scale terrain interactions, as well as longer-range effects such as pollutant removal (wet scavenging and dry deposition), chemical transformation, vertical wind shear, over-water transport, and coastal interaction effects. Most of the algorithms contain options to treat the physical processes at different levels of detail depending on the model application.

The areas where CALPUFF’s algorithms may be improved for OCS applications include the following: (a) add an option to treat downwash from offshore platforms, such as exists in the OCD model; (b) evaluate and if needed, improve the operation of CALPUFF in the coastal transition zone;

(c) compare overwater plume dispersion estimates in CALPUFF with data from overwater dispersion experiments; (d) improve the treatment of plume chemistry.

SCIPUFF/SCICHEM

SCIPUFF (Sykes *et al*. 1998) is a second-order closure integrated puff model. Numerical techniques are employed to solve the dispersion model equations in which a collection of three-dimensional puffs is used to represent an arbitrary time-dependent concentration field. The turbulent diffusion parameterization used in SCIPUFF is based on second-order turbulence closure theories, providing a direct connection between measurable velocity statistics and predicted dispersion rates. SCIPUFF has been expanded to include gas and aqueous phase chemistry and aerosol thermodynamics. The reactive SCIPUFF model is referred to as SCICHEM. SCICHEM is capable of modeling two material types, gases and particles, and multiple sources, both as continuous plumes and instantaneous puffs.

What most distinguishes SCIPUFF from other puff models is its approach to calculating puff spread (sigmas). Other Gaussian puff models usually rely upon empirically derived relationships between puff sigmas and a few measured or inferred meteorological parameters (wind speed, turbulence velocities, stability class). SCIPUFF employs elegant mathematical diffusion parameterizations based in part on second-order closure theories to develop relationships between sigmas and velocity statistics. However, these diffusion parameterizations also employ critical empirical constants, for example two empirical parameters (A and υ_c) proposed by Lewellen (1977). The range of applicability of these empirical constants is not discussed.

The implementation of the SCIPUFF diffusion parameterization in the new OCS model requires input of certain meteorological parameters—turbulence length scales and velocity variances. If the new MMS OCS model's met inputs are to be derived from prognostic meteorological models it should be remembered that in characterizing turbulence most meteorological models utilize first-order bulk similarity theory, empirical parameterizations, or diagnostic expressions for friction velocity, mixing length, convective velocity scale, boundary layer height etc. In most applications of the new OCS model, we expect that few measurements of turbulence statistics will be available. This could severely constrain the applicability of SCIPUFF's second-order closure dispersion parameterization, especially aloft and across the shoreline TIBL. Also, if a large number of offshore sources spread over a large area is modeled, a means of extrapolating measured statistics over this area needs to be addressed. It seems sensible to use the SCIPUFF dispersions parameterization if and where turbulence data are available. Elsewhere, current OCD or CALPUFF dispersion parameterizations or dispersion fields derived from prognostic models are probably as good or better than SCIPUFF's first-order dispersion options.

Other Algorithms and Datasets

The COARE bulk algorithm for air-sea fluxes (Fairall *et al*. 2002) has been identified by the Scientific Review Board (SRB) on this project for consideration as a replacement for the overwater algorithms currently used by OCD and CALMET. The new algorithm remains based on MOST, and includes gustiness, surface temperature (or submodels to estimate it), surface current velocity, and a new wave-effects module. The algorithms have been exhaustively tested and represent the best characterization of the bulk transfer approach. The bulk transfer approach and MOST have proven very effective in the open ocean, but wind stress estimates in shallow water have not been as reliable (NAS 1992), possibly due to changes in the directional wave spectrum. The COARE algorithm developers believe that the wave module will allow it to be applied in coast/shallow water areas, such as the Gulf of Mexico (GOM). A key input into both prognostic and diagnostic meteorological models in the OCS and coastal environments is the sea surface temperature (SST). The temperature difference between the air over land compared to that in the marine layer is a measure of the density gradients that drive the sea breeze circulation and penetration distance. The air-sea temperature difference over water is an important factor determining the boundary layer structure in the marine layer. Currently, air-sea temperature data is derived from widely spaced buoys or is estimated from climatological data. In the new OCS model, recent sources of high resolution SST data will be incorporated into the modeling system. In particular, the Moderate Resolution, Imaging Spectroradiometer (MODIS) satellite measurements will be used to provide ~4 km resolution SST data for input into the OCS model.

Another feature of the new OCS model required by the MMS is a high degree of user-friendliness. This will be accomplished by expanding the Graphical User Interfaces (GUI) currently available in the CALMET/CALPUFF modeling system to include all of the pre- and post-processing components of the model. Also, to ease the burden of developing the three-dimensional meteorological datasets for regulatory applications in the GOM area, the modeling system will be delivered with a “standard” meteorological dataset, which will be based on the best available dataset for the area at the time. It is likely this dataset will include a high-resolution MM5 simulation for an annual period plus all available surface, upper-air and overwater observations for the same time period.

SUMMARY

The MMS has sponsored the development of a new generation OCS dispersion model. In the first phase of this study, a review has been conducted of several currently available dispersion models. The features of algorithms in each model that may be used for testing and inclusion in the new OCS model have been identified. In addition, the overwater parameterizations in the COARE model are recommended for use in the OCS model. New sources of data to feed the models, such as high-resolution satellite SST data have been identified for inclusion in the modeling system.

The CALPUFF model will be used as the starting point for the model modifications. The proposed design of the modeling system includes the expansion of the CALPUFF GUIs to include all of the model processor programs. In addition, a “standard” one-year meteorological dataset will be provided with the modeling system for use in regulatory applications in the GOM area.

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A NON-GAUSSIAN DIFFUSION MODEL FOR AIR QUALITY MODELING IN THE MARINE ENVIRONMENT

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INTRODUCTION

In this paper, we are concerned with the practical applications of a non-Gaussian dispersion model for air quality modeling in the marine environment and for the environmental impact assessment, in particular, the environmental impact from the oil and gas development activities in the Gulf of Mexico (GOM). Almost all of the dispersion models currently in use for the air quality assessment are based on the Gaussian dispersion models, which were developed for land use applications, but not for over water applications. In regulating the emissions sources and air quality in the GOM, according to 30 Cfr 250.303, there are as yet no screening models developed for use with offshore emission sources. Instead, Minerals management service (MMS) adopts the simple formulas, which have a simple linear relation between the emission amount and distance; they are used to determine the emission exempt amount for each pollutant in the permit application. Other applications of an air quality model are the diffusion estimates for the accidental releases of hydrogen sulfur from the natural gas pipe break, well drilling operation, burning spilled oil, flaring of hydrogen sulfur, gas release from a vent, and the incineration of chemical waste in the offshore. In the accidental release, the more precise diffusion estimates of toxic gas are required to protect the worker's safety and to assess the impact of air quality on the environment.

The Guassian diffusion model has been widely used for assessing air quality, which can be shown to be as a special case of the non-Gaussian diffusion model (Huang 1979). It has been observed in the field as well as the wind tunnel experiments that the shape of the vertical concentration profile follows the exponential form rather than the Gaussian distribution (Elliott 1961; Huang and Drake 1977). Scientists were interested in obtaining the solution for the diffusion equation in the lower atmosphere for a very long period of time.

An exact solution for a three-dimensional non-Gaussian dispersion model for an elevated point source was developed by Huang (1979) (also see a number of textbooks, Seinfeld 1986; Turner 1994; and Arya 1999 etc.); the solution shows that the vertical distribution of concentration indeed follows the exponential form. For practical applications, the parameters in the model that are free from the adjustments can be derived based on the Monin-Obukhov similarity theory in the atmospheric boundary layer or from the observational data. In this paper, we are concerned with the application of this non-Gaussian dispersion model to assess the air quality over the water.

THEORETICAL APPROACH

The equation of diffusion for an elevated continuous point source released in the atmospheric boundary layer may be expressed as (Huang 1979):

$$u\left(\frac{\partial \chi}{\partial x}\right) = \frac{\partial}{\partial y}\left(K_y \frac{\partial \chi}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial \chi}{\partial z}\right) + S \qquad (1)$$

$$s = Q\ \delta(x)\delta(y - y_s)\delta(z - z_s)$$

Where is the concentration of a diffusion substance; U is the mean wind speed depending on the height z; x and y are coordinates in the longitudinal and lateral directions, respectively; K_y and K_z are diffusivity coefficients in the y and z directions, respectively; S is the source term; and Q is the source strength. The origin of the source is assumed to be located at the point ($x_s = 0$, y_s and z_s) in the x, y and z directions respectively; and is the dirac delta function. In obtaining the exact solution, the mean wind speed, u, and the vertical diffusivity coefficient, K_z, are expressed as the power functions of height as:

$u = az^p$, and

$K_z = bz^n$.

The parameters p and n are the power exponents associated with the power laws for wind speed and the vertical eddy diffusivity, respectively; and the parameters a and b are to be evaluated from the wind profile and the vertical eddy diffusivity, respectively.

The horizontal diffusivity coefficient, K_y, may be defined as (Huang 1979):

$$K_y = \left(\frac{1}{2}\right) u \frac{d\sigma_y^2}{dx}$$

The apparent lateral eddy diffusivity K_y is related to the mean square particle displacement, y^2, where y is the lateral standard deviation (for more detail, see Huang 1979).

The exact solution of Equation (1) for an elevated point source was obtained as (Huang 1979; also see Seinfeld 1986):

$$\chi = \frac{Q}{\sqrt{2\pi}\sigma_y} \exp\left[-\frac{(y - y_s)^2}{2\sigma_y^2}\right] \frac{(z.z_s)^{(1-n)/2}}{b(\alpha)x}$$

$$x \exp\left[-\frac{a(z^{\alpha} + z_s^{\alpha})}{b(\alpha)^2 x}\right] . I_{-v}\left[\frac{2a(z.z_s)^{\alpha/2}}{b(\alpha)^2 x}\right] \qquad (2)$$

Where = 2 + p – n; = (1-n)/ ; is the concentration; and I_{-v} is the modified bessel function of the first kind of order - .

SOURCES NEAR THE GROUND

The point source and the cross-wind integrated concentration derived from the point source are described in the following sections.

A Point Source near or at the Ground Level

For a point source near the ground level, Equation (2) becomes:

$$\chi = \chi_g \, . \, e^{-\frac{z^{\alpha}}{B(x)}} \tag{3}$$

$$\chi_g = \frac{QA((\alpha,\beta))}{\sqrt{2\pi}\,\sigma_y x^{\beta}} .\exp\left[-\frac{(y-y_s)^2}{2\sigma_y^2}\right] .\exp\left(-\frac{z_s^{\alpha}}{B(x)}\right) \tag{4}$$

Where

$$\mathrm{A}(\alpha,\beta) = \frac{\alpha}{a^{\upsilon}(b\alpha^2)^{\beta}\Gamma(\beta)}$$

$$\beta = \frac{1+p}{\alpha}$$

$$B(x) = \frac{b}{a}\alpha^2 x$$

and k is von Karman constant which is equal to 0.4 and a and b are some constant values, which may be dependent on the friction velocity, surface roughness, or the atmospheric stability.

Equation (3) shows that the theoretical derived concentration profile follows the exponential form with a shape factor of rather than the Gaussian form. Where $_g$ is the gas concentration at the ground level, setting $z_s = 0$ in Equation (4). Equation (3) indicates that the distribution of gas in the vertical direction follows the general exponential form (in general $\neq 2$) rather than the Gaussian distribution. This form of the concentration profile has been suggested by Elliott (1961); his result is based on the analysis of the Prairie Grass field data. The exponent of the shape function was theoretically derived from Equation (3) (Huang 1979); the derived value for is dependent on wind speed or friction velocity, surface roughness, and the atmospheric stability.

The Cross-Wind Integrated Concentration

The cross-wind integrated concentration can be obtained from the exact solution of Equation (3). Integrating the Equation (3) in the lateral direction, we obtain the cross-wind integrated concentration as (Huang 1979):

$$y = \int_{-\infty}^{\infty} \chi dy_s = \exp\left(\frac{-\left(z^{\alpha} + z_s^{\alpha}\right)}{B(x)}\right) \cdot \left(\frac{Q.A(\alpha,\beta)}{x^{\beta}}\right) \tag{5}$$

Then, from Equation (5) the cross-wind integrated concentration at the surface may be written as:

$$y = \int_{-\infty}^{\infty} \chi dy_s = \left(\frac{Q.A(\alpha,\beta)}{x^{\beta}}\right) \tag{6}$$

Equation (6) shows that the cross-wind integrated concentration is dependent on the friction velocity, the surface roughness, the atmospheric stability, and downwind distances.

WIND PROFILES AND VERTICAL EDDY DIFFUSIVITY

Wind Profiles

In this section, two kinds of expression for wind profiles are discussed: one is the power law wind profile and the other is the well-known Deacon's wind profile. In the earlier studies of turbulent boundary layer, it was recognized by Blasius (see Schlichting 1968) and others that the velocity profile can be represented by the power law. The Blasius formula can be expressed in the form as

$$\frac{u}{u_*} = q\left(\frac{u_* z}{\nu'}\right)^{p} \tag{7}$$

Where ' is the viscosity of air. The parameters q and p are equal to 8.74 and 1/7, respectively, for flow with the value of u*z/ ' up to 700. In analogy to the abovementioned wind power distribution for turbulent flow in smooth pipes. The wind profile for the fully rough flow may be written as the power function of height as

$$\frac{u}{u_*} = q\left(\frac{z}{z_o}\right)^{p} \tag{8}$$

Where the parameters p and q may depend on the surface roughness and atmospheric stability. Frost (1946), based on the mixing length hypothesis, gave a value of q = 7 for flow under neutral condition. Calder (1946) determined various values of p and q for down wind distances from the velocities observed at heights of 2, 3, and 5 m under adiabatic condition over a short and a long grass surfaces.

Equation (8) can be written in the form of a power function of height as

$u = az^p$ and

$$a = \frac{qu_*}{z_o^p} \tag{9}$$

The power law exponent p can be obtained by fitting the observed wind profile or the theoretical wind profile. The exponent in the power law for wind speed, p, expressed as functions of the non-dimensional wind shear and wind profile based on the Monin-Obukhov similarity theory was first derived by Huang (1979) (also see Seinfeld 1986).

Thus, the value of p can be calculated if we know the surface roughness z_o and the Monin-Obukhov length L.

The power exponent p can also be calculated as follows (Huang 1979):

$$p = \frac{\phi_m\left(\frac{z}{L}\right)}{g\left(\frac{z}{L};\frac{z_o}{L}\right)} = \frac{C_d^{1/2}\phi_m\left(\frac{z}{L}\right)}{k} \approx \frac{\phi_m\left(\frac{z}{L}\right)}{\ln\frac{z}{z_o} - \psi_m\left(\frac{z}{L}\right)} \tag{10}$$

The second term on the right hand side of Equation (10) is by the definition of drag coefficient, which is defined as:

$$C_d = \left(\frac{u_*}{U_{10}}\right)^2$$

Where U10 is the wind speed at 10 m above the sea surface.

The value of p also can be found to be written by some authors in the form as shown in the third term of Equation (10), where

$$g\left(\frac{z}{L};\frac{z_o}{L}\right) \approx \ln\frac{z}{z_o} - \psi_m\left(\frac{z}{L}\right)$$

Vertical Eddy Diffusivity

Let us consider the vertical eddy diffusivity, K_z, for diffusion applications. The exchange coefficient K_z may be defined as

$$K_z = \frac{u_*^2}{\frac{du}{dz}} \tag{11}$$

Since in the atmospheric surface layer, the shear stress is independent of height; with the specification of the wind shear in Equation (11) or the use of the Deacon's wind profile, Deacon (1953) obtained the vertical eddy diffusivity as

$$K_z = kN\left(\frac{z}{zo}\right)^{\beta_D} \tag{12}$$

Where N = u_*zo is the macro-viscosity, and k is the von Karman constant, k=0.4. Equation (12) is a power law expression for the vertical exchange coefficient, which form is very useful for obtaining the analytical solution for the diffusion equation. Equation (12) may be written in a power function representation as

$$\begin{aligned} K_z &= kN\left(\frac{z}{zo}\right)^{\beta_D} \\ &= bz^{\beta_D} \end{aligned} \tag{13}$$

Where the parameter b associated with the vertical eddy diffusivity from Equation (13) is equal to

$$b = ku_*z_o^{1-\beta_D} \tag{14}$$

Thus, the parameter b can be determined if the friction velocity u_*, the surface roughness length z_o, and the Deacon's stability parameter, $ß_D$, are known. The $ß_D$ is dependent on the atmospheric stability, with $ß_D$= 1 for the neutral atmospheric condition, $ß_D > 1$ for unstable condition, and $ß_D < 1$ for stable condition, i.e.,

$ß_D > 1$ for Ri < 0 unstable condition
$ß_D = 1$ for Ri = 0 neutral condition
$ß_D < 1$ for Ri > 0 stable condition

Where Ri is the Richardson number. The range of β_D is approximately in the range between 0.75 and 1.2.

CHARNOCK'S LAW

At the sea, the surface roughness length, z_o, according to Charnock (1955), is related to the friction velocity, u_*, it can be expressed as

$$z_o = \alpha' \frac{u_*^2}{g} \tag{15}$$

Where ' is the Charnock's constant and is equal to 0.017 (see Garrett 1972; Arya 1999). In reality, the Charnock's constant may be dependent of the characteristics of the sea state such as wave age. Charnock's law is often expressed in the form as

$$\frac{u}{u_*} = \frac{1}{k}\ln\left(\frac{gz}{u_*^2}\right) + C \tag{16}$$

Where g is the gravity and C is a constant.

For convenience and the ease of use or computation, the Charnock's law can be written in the form as

$$u = \left[\frac{gz}{\alpha' c_d . e^{\frac{k}{c_d^{1/2}}}}\right]^{1/2} \tag{17}$$

Where g is the gravity, and z is the height of the wind measurement, it usually is set at 10 m. The above equation shows the relationship between the wind speed and the drag coefficient C_d, which indicates that the wind speed is only a function of the drag coefficient. It shows that the drag coefficient can be calculated if the wind speed is known or vice versa.

It is also common to express the drag coefficient empirically as a function of wind speed. The C_d, can be empirically written as (Garrett 1977)

$$C_d = (0.75 + 0.067u)10^{-3} \tag{18}$$

The comparison of the Charnock's formula with the empirical formula is given in Figure 1F.1. As can be seen in the figure, two curves are in close agreement with each other.

LATERAL SPREAD

There are several approaches for the specification of the lateral spread of the plume in the horizontal direction. One approach that is widely used in the diffusion estimates is the Pasquill-Gifford stability categories in which the lateral spread of standard deviation, σ_y, can be expressed as the downwind distances and the various stability conditions. Another approach is to utilize the turbulent intensity as demonstrated in the following section.

The standard deviation, σ_y, also can also be written in the following form:

$$\sigma_y = \left(\frac{\sigma_v}{u}\right) x f_y \left(\frac{x}{uT_L}\right) \tag{19}$$

Here, T_L is the Lagrangian time scale and σ_v is the standard deviation of the horizontal velocity fluctuation in the lateral direction. Equation (19) may also be written as:

$$\sigma_y = \left(\frac{\sigma_v}{u}\right) x f(x) \text{ and} \tag{20}$$

Draxler (1976) suggested that the empirical function f(x) can be approximated as

$$f(x) = \frac{1}{\left(1 + 0.9\left(\frac{x}{1000u}\right)^{\frac{1}{2}}\right)} \text{ for } x \leq 10^4\,m \tag{21}$$

The horizontal turbulent intensity in Equation (19) is defined as

$i_y = \sigma_v/u$

The horizontal turbulent intensity may be dependent on the atmospheric stability and may also be calculated from the empirical formulas. At present, the following turbulent intensities for various stabilities are specified for this study as

i_y = 0.139 for unstable
= 0.066 for neutral
= 0.05 for stable

With this specification, the lateral standard deviation can be calculated from Equation (19).

THE CROSS-WIND INTEGRATED AND POINT SOURCE CONCENTRATIONS

As shown in Equation (6), the cross-wind integrated concentrations at the ground level for a point source release at the ground level can be written as:

$$\chi_g = \frac{QA((\alpha, \beta))}{\sqrt{2\pi}\sigma_y x^{\beta}} \tag{22}$$

Where

$$A^{(\alpha,\beta)} = \frac{\alpha}{a^{v}(b\alpha^{2})^{\beta}\,\Gamma(\beta)}$$

$$\beta = \frac{1+p}{\alpha} = 1$$

$= 2 + p - n$

$= (1\text{-}n)/\ a = 0$

As an example, we set

= 0.017,
u = 7 m/s,
z_o= 1.036x10^{-4} m,
x = 100 m

As shown in Table 1F.1, the cross-wind integrated concentrations as well as the concentrations from a point source released at a ground level under various atmospheric stability conditions are calculated for a downwind distance of 100 m. In Table 1F.1, χ_y is the cross-wind integrated concentration; χ is the concentration for a point source along the central line; Q is the emission rate from a point source; β_D is the Deacon's stability parameter; p is the wind profile power exponent; L_v is the Monin-Obukov stability length; u_* is the friction velocity; q is the constant associated with the wind profile; a is a parameter associated with the wind profile; and b is a parameter associated with the vertical eddy diffusivity.

As shown in Table 1F.1, the value of the Deacon's stability parameter β_D decreases with increasing stability, while the value of power exponent p increases with the increasing stability. As expected, the value of χ_y/Q or χ/Q increases with increasing stability at the downstream distance of 100 m. The values of χ_y/Q or χ/Q for various downwind distances and atmospheric stability conditions are shown in Figure 1F.2.

Table 1F.1. The cross-wind integrated concentrations per unit source strength and the concentrations for a point source per unit source strength (χ_y/Q and χ/Q) at a downwind distance of 100 m for various stability conditions and diffusion parameters.

Stability	β_D	**p**	L_v	u_*	**q**	**a**	**b**	χ_y/Q	i_y	χ/Q
Unstable	1.15	0.07	-7.5	0.274	11.431	5.953	0.434	0.0200	0.139	$1.044\text{x}10^{-3}$
Neutral	1.00	0.10	∞	0.244	9.106	5.561	0.098	0.0931	0.066	$9.701\text{x}10^{-3}$
Stable	0.95	0.25	17.5	0.195	2.033	3.929	0.049	0.1569	0.05	$2.0\text{x}10^{-2}$

CONCLUSIONS

Scientists and researchers tried to solve this three-dimensional diffusion equation for more than half a century. The solution of this diffusion equation was obtained by Huang (1979). In this paper, we have demonstrated that a non-Guassian diffusion model can be used for applications to calculate the gas concentration down wind of a point source over the water. We have presented a method for determining the parameters in the diffusion equation, which are free from the parameter adjustments. These parameters can be determined from the wind and the vertical eddy diffusivity profiles. It has been shown that the Guassian diffusion model that is widely used in the air pollution applications is a special case of the present formulation. The examples for calculating the gas concentrations from an accidental releases from a point source released in the offshore environment are given in this paper. The results show that the calculated concentration, χ_y/Q or χ/Q, increases with increasing stability at the downstream distance of 100 m and various downwind distances. The results also show that the model can be used for air quality assessment for the oil and gas production activities in the offshore environment to protect the worker's safety and to assess the impact of air quality on the onshore area.

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Dr. C. H. (Chester) Huang is a meteorologist at Minerals Management Service with a Ph.D. degree in environmental fluid dynamics and atmospheric sciences. He specializes in atmospheric boundary layer, environmental impact assessment, and the meteorological and air quality modeling. His publications have appeared in a number of books and textbooks. He is a Certified Consulting Meteorologist and the Contracting Officer's Technical Representative (COTR).

OVERVIEW AND STATUS OF THE SO_2 AND NO_2 INCREMENT ANALYSIS FOR THE BRETON NATIONAL WILDERNESS AREA

Neil J. M. Wheeler, Sonoma Technology, Inc.

PROJECT BACKGROUND

The Breton National Wilderness Area (BNWA) is surrounded by onshore sources of oxides of sulfur (SO_x) and nitrogen (NO_x) to the north and west and offshore sources to the south and east. The 1977 Clean Air Act sets limits called increments on how sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) concentrations may increase over Class I areas such as the BNWA. The magnitude and distribution of the sources introduce the possibility that SO_2 or NO_2 concentrations in the BNWA may exceed regulatory limits, which could result in regulatory consequences affecting several federal (Environmental Protection Agency [EPA], Fish and Wildlife Service [FWS], and MMS) and state agencies and the groups they regulate. As the Federal Land Manager, the FWS has expressed concerns that SO_2 and NO_2 increments may be consumed on a cumulative basis and has requested a cumulative increment analysis.

Over the past several years, the MMS has funded several studies to provide the emissions and meteorological databases needed to support a modeling-based cumulative increment analysis for the BNWA. The most recent study involves collecting meteorological and air quality data from October 2000 through September 2001 (year 2000-2001), and provides the final data needed to perform the increment analysis. The databases from these prior studies will be used to perform air quality modeling for past and present years. The model results will be used to evaluate the contribution of Outer Continental Shelf (OCS) emission sources to SO_2 and NO_2 levels over the BNWA and determine the amount of increment consumed.

This increment analysis is being carried out by a team that includes Sonoma Technology, Inc. (STI), the Pennsylvania State University (Drs. David Stauffer and Nelson Seaman), Hanna Consultants (Dr. Steven Hanna), and Northlake Engineers & Surveyors (Mr. David Scalfano)

SCIENTIFIC REVIEW BOARD

A four-member Scientific Review Board (SRB) has been established for the project. The SRB members include Dr. S.A. Hsu of Louisiana State University, Dr. Richard McNider of the University of Alabama at Huntsville, Dr. Steven Ziman of ChevronTexaco, and Mr. Tim Allen of the Fish and Wildlife Service. The SRB will evaluate project-related work products, interact with the project manager, and inform the project participants (MMS and the project team members) of recommendations to improve the project.

TECHNICAL APPROACH

Model Selection

The objective of this task is to determine the best available air quality model for performing the cumulative increment analysis. A critical review of available literature, model documents, examples of applications, and reviews by others will be carried out. The team will expand on Chang *et al.* (1998) by considering recent model developments such as SCICHEM and CMAQ-APT to identify candidate models. Based on the review, two air quality models will be selected for evaluation. One of the models will be an Eulerian photochemical grid model and one will be a Lagrangian puff model. The final air quality model selection will be based on the episodic modeling and performance evaluation and the sensitivity and uncertainty analysis.

Analysis of Air Quality and Meteorological Data

The objectives of this task are to acquire, validate, and archive observational data; analyze the acquired data; identify episodes for model simulation and evaluation; develop meteorological and air quality (initial/boundary) inputs for selected air quality models; develop a database suitable for model performance evaluation; and develop visualization routines for displaying analyses in ArcView®. Subtasks include: data acquisition; database development; data validation; analysis of meteorological data; analysis of ambient air quality data; and review of analyses and selection of episodes.

Meteorological Modeling

Meteorological modeling is being with the Penn State/NCAR Mesoscale Model, MM5. The proposed MM5 domains are shown in Figure 1F.3. Episodic modeling will investigate approximately five to six periods of six days each. Two of the episodic periods will be modeling with a 4-km nest to investigate the importance of horizontal grid spacing on model performance. Annual modeling will be performed on the 36- and 12-km domains only for 1 October 2000 through 30 September 2001.

Emission Inventory

The objectives of this task are to consolidate and archive emission inventories; provide tools for visualization of the emission inventory; and process emissions for input into selected air quality models. Three emission inventories will be prepared in this task: 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), the Gulfwide Offshore Activity Data System (GOADS), and the National Emission Trends (NET) inventory or National Emission Inventory (NEI) will be used. STI will consolidate the databases and perform checks for completeness, duplication, and reasonableness. NO_x, SO_x, CO, and VOC emissions will then be speciated and spatially allocated.

Episode Type Study

The objective of this task is to determine whether meteorological and air quality model performance is sufficient to continue with the cumulative increment analysis. The selected episodes will be modeled using both air quality models selected in the model selection task and the meteorological fields prepared with MM5. A model performance evaluation will be undertaken for each episode and model combination.

Sensitivity and Uncertainty Analysis

The objective of this task is to improve model performance and assess model response. Sensitivity simulations are an integral part of model performance evaluation and will be used in evaluating the episode-type air quality simulations. The model inputs will be modified based on estimates of uncertainty, and air quality model simulations will be performed. Examples of sensitivity simulations that may be carried out include

- Meteorology: Sensitivity to air minus water temperature, wind speed, wind direction, and mixing depth
- Air quality: Sensitivity to initial and boundary air quality with special consideration to ozone
- Emissions: Sensitivity to variations in emissions from large sources and individual source categories to assess model response
- Chemistry: Sensitivity to the use of parameterized chemistry or explicit chemical mechanisms

Air Quality Simulations

The objective of this task is to establish baseline and current year concentrations of SO_2 and NO_2 for use in the increment analysis. Annual simulations of NO_2 and SO_2 with year 2000-2001 emissions will be performed. The results of these simulations will be evaluated for model performance both statistically and graphically using the same methods as used for evaluating the episode-type simulations.

Annual simulations of SO_2 with year 1977 OCS-related emissions and of NO_2 with year 1988 emissions will be performed to establish the PSD baseline air concentrations. Onshore and non-OCS related offshore emissions will be for year 2000-2001, the same as used for the current year air quality simulations.

Air Quality Assessment

The objective of this task is to determine the amount of PSD increment that has been consumed in the BNWA. Receptors in the BNWA will be identified using ArcInfo software. The annual average NO_2 concentrations at each receptor in the BNWA will be calculated from the 2000-2001 year and the 1988 baseline year simulations. Annual, daily, and three-hour average SO_2 concentrations at each receptor in the BNWA will be calculated from the current (2000-2001) year and the 1977 baseline year simulations.

PROJECT STATUS

In Progress

- Air Quality Model Selection
- Analysis of Meteorological and Air Quality Data
- Meteorological Modeling
- Development of Emission Inventories

Future Work

- Episode Type Study
- Sensitivity and Uncertainty Analyses
- Annual Air Quality Simulations
- Air Quality Assessment

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SESSION 2A

DEEPWATER TECHNOLOGY

Co-Chairs: G. Ed Richardson, Minerals Management Service
Jim Grant, Minerals Management Service

Date: January 15, 2003

U.S. COAST GUARD UPDATE

Lt. Commander John Cushing, U.S. Coast Guard

Click here to see Lt. Commander Cushing's slide show.

ABSTRACT

Deepwater Port (DWP) Act

Recent legislation has modified the DWP Act to streamline the licensing process and to allow natural gas as well as oil to be imported via DWPs. DWPs offer economic and security-related benefits, and several companies are already moving forward with plans to build DWPs in the Gulf of Mexico.

Dynamic Positioning (DP)

The Coast Guard is finalizing local policy for the Gulf of Mexico to establish minimum requirements for DP systems on Offshore Supply Vessels, for DP systems that will be used to "moor" the vessel (hold station) during any transfer operations involving oil or hazardous materials.

Offshore Security

The Coast Guard plans to work with industry to develop guidelines and policy on security measures for the offshore industry, working primarily through the Security Subcommittee of the Gulf Safety Committee (GSC).

Lieutenant Commander John Cushing is Chief of the Merchant Vessel Safety branch for the Eighth Coast Guard District. He is also filling the role of Chief of Offshore Compliance. He is a 1984 graduate of the U.S. Coast Guard Academy with a bachelor's degree in civil engineering, and a 1992 graduate of the Massachusetts Institute of Technology with master's degrees in mechanical engineering and naval architecture and marine engineering. Career highlights include two separate four-year tours at the Coast Guard's Marine Safety Office in Portland, Oregon, where he was heavily involved in inspection and steel repairs on Trans-Alaskan Pipeline Service (TAPS) tankers. He was also the Coast Guard's lead naval architect during the salvage response for the NEW CARISSA, a 600' freighter that grounded and broke apart on the Oregon coast. He has served one four-year tour at the Coast Guard's premier technical office, the Marine Safety Center in Washington, D.C., where he did structural and stability plan review and analysis for drilling rigs, liftboats, OSVs, and crewboats.

MINIMUM FACILITY BOUYS

Clay Anderson, ABB Offshore Systems, Inc.

Click here to see Mr. Anderson's slide show.

SUBSEA PRODUCTION SYSTEMS

Ian Ball, Shell International Exploration and Production Inc.

Click here to see Mr. Ball’s slide show.

Ian Ball joined Shell in London in 1968, and for the past 30 years his working life has been devoted exclusively to subsea production system evolution. He has had assignments in Holland, Brunei, Norway and Aberdeen, before joining Shell’s Deepwater Services organization in New Orleans in 1998. He currently leads the Shell Group Subsea Technology Development program called Subsea to Beach™ out of New Orleans. This program is primarily focused on creating a viable suite of deepwater subsea processing technologies that can be deployed in flexible configurations to optimize the value of Shell’s global offshore hydrocarbon reservoir portfolio.

POST-STORM SPILL RESPONSE MOBILIZATION IN LOUISIANA

Charles A. Bedell, Manager, Environment & Government Affairs,
Murphy Exploration & Production Company

BACKGROUND

When tropical storms and hurricanes threaten the Gulf Coast and the oil and gas platforms located offshore, personnel and vessels are brought ashore and into safe harbor until the storm passes. Although excellent engineering during the construction of platforms and the well control mechanisms on all wells continue to prevent loss of well control in virtually all cases, if an offshore well suffers a loss of well control as a result of the storm, the spill response assets on which we depend to respond to the release of oil have to quickly make their way back out into the Gulf. Experience over many years has shown that there may be problems which prevent the spill response mobilization effort from coming up to speed as rapidly as desired.

The experience my company had after Hurricane Hurricane Lili is described elsewhere in this volume by Ken Soyez. In the past, similar problems were encountered after Hurricane Andrew and other storms. As a result of this latest experience, Murphy has initiated a cooperative effort among various agencies within the state of Louisiana, the U. S. Coast Guard, and the MMS, oil spill response organizations, and the oil and gas industry to review the difficulties experienced in the past and to look for ways to minimize the potential for difficulties when we respond to future storms.

A preliminary scoping meeting was held on 9 January at Murphy's offices in New Orleans involving representatives from the Office of the Governor of Louisiana, the MMS Gulf of Mexico Regional Office, the U.S. Coast Guard Eighth District and two MSO offices, Clean Gulf Associates and the Offshore Marine Service Association. This ad hoc group came together to discuss what happened after Hurricane Lili and to explore the possible need for formal consideration of issues and problems experienced at that time.

UNIVERSAL CONCERN

A concern shared by all participants was that we do what we can to learn from our past storm response experiences and to maximize that communications and coordination of efforts. It was agreed that everyone from individual companies to state and federal agencies are acting within their areas of responsibility but that steps should be taken to insure integration of all of the individual activities.

FORUM FOR FURTHER DISCUSSION

The group discussion began with an effort to determine whether a mechanism an exists to ensure future discussions. There is a strong state interest, since control over the onshore infrastructure of roads and bridges—which are essential for the movement of response personnel and machinery is the province of the state of Louisiana. The state's Office of Emergency Preparedness (http://www.loep.state.la.us/) and the local parish emergency response organizations have broad responsibility for devising and updating plans for responding to all aspects of the state's response to a hurricane or tropical storm. Specific focus on oil spill response planning and clean-up efforts is coordinated out of the governor's office by Roland Guidry, Governor Foster's Oil Spill Coordinator.

However, the federal government is also concerned. The Coast Guard has responsibility for control of the navigable waters and for coordinating oil spill clean-up efforts on the navigable waters of the United States. Other federal agencies such as the EPA and the Corps of Engineers are also involved.

The oil and gas industry is also a stakeholder with major concerns on the policy, planning and implementation levels. Over the years, Clean Gulf Associates has served as the industry's focal point for spill response issues. Company experts with practical experience in dealing with spills share what they have learned through various trade organizations such as the Offshore Operators Committee and the American Petroleum Institute. The formation of the Marine Spill Response Corporation in the 1990s and the ties that now exist between it and Clean Gulf have added to industry's ability to contribute to the resolution of oil spill related problems. Dick Armstrong and Frankie Palmisano are here representing Clean Gulf/MSRC.

Clearly the mechanism for further discussion must be inclusive. All responsible agencies, industry and public sector experts must be able to take part. Every opportunity must be taken to learn from experience gained from dealing with problems which have arisen after past storms.

Among the existing groups discussed above, the Louisiana Office of Emergency Preparedness (OEP) was selected as a likely candidate to be the possible forum for future discussions. Roland Guidry will make contact with the appropriate people at the OEP.

DEFINITION OF PROBLEM AREAS

Whether an existing forum is charged with going forward or a new group is formed, the first step in the process will be to reach out to those who have been involved in mobilizing spill response equipment and personnel after past hurricanes and tropical storms.

The ad hoc group discussed problems experienced after Lili and found that many similarities existed to experiences participants had in the aftermath of previous storms. Several categories of challenges were discussed.

Draw bridges are critical transportation links in South Louisiana for both storm evacuation and response purposes as well as related public safety activities. They are operated by the Louisiana Department of Transportation and Development. Because they depend on electrical power for their operation, the draw bridges may be unable to open even if they do not suffer significant damage from storm winds. The bridges are operated by trained and experienced people, but they must evacuate and then return to duty before full operation can resume. The DOTD took special steps to protect its draw bridges as Hurricane Lili approached the coast. Critical equipment was protected from water and some removed to be reinstalled after the storm threat was over.

In addition to other physical impediments to mobilization efforts such as downed power lines and flooded roads, the group also discussed some communications and informational difficulties which have been experienced both after Hurricane Lili and after previous storms. One in particular had to do with the availability of information regarding the status of draw bridges and the related topic of whether or not a particular waterway had been closed to traffic by the Coast Guard. As operators and boat companies sought to mobilize spill response units and other vessels to go offshore to check on the condition of platforms, they needed to know which bridges were open, which were closed, and how soon closed bridges were expected to reopen. If the most direct route out of the sheltered areas was blocked, alternative routes needed to be selected which would get the boats to their destinations in the fastest time. If the most direct route was closed by the Coast Guard or blocked by a closed bridge, or both, the vessel's master and spill response personnel needed to know where they can get reliable, readily available information about reopening of the primary route as well as information on possible alternative routes to open water.

DEVELOPMENT OF RECOMMENDATIONS

Before any thought is given to the development of specific recommendations, steps will have to be taken to gather information from all sectors of government and industry regarding their past experiences. To develop this comprehensive picture of the types of problems experienced and how they were dealt with, it may be necessary to hold a series of meetings around the state.

Once the input of all stakeholders is received, the reviewing body will work with responsible agencies and attempt to draw conclusions and draft all appropriate recommendations for maximizing our ability to respond to offshore oil spills in both Louisiana and Federal waters.

CONCLUSION

Learning from our past experiences is the key to progress. While everyone is working to be sure that our response to "the next storm" will be better than the one to the last storm, acting to insure the maximum use of past experiences is a constructive and, hopefully, beneficial pursuit. If this effort is begun soon, some results may be possible before Hurricane Season 2003 rolls around.

Charles Bedell is presently Manager, Environmental and Government Affairs for Murphy Exploration and Production Company in New Orleans, Louisiana. Mr. Bedell has an A.B. in biology from Kenyon College and a J.D. from the University of Kentucky, College of Law. He is a member of the Offshore Operators Committee, Chairman of the Environmental Effects of Operations Subcommittee of the National Ocean Industries Association, as well as a member of several committees of the American Petroleum Institute, the American Bar Association, and the U.S.C.G. National Offshore Safety Advisory Committee.

WHITE PAPER: CASE FOR API GUIDELINE ON QUALIFICATION OF NEW TECHNOLOGIES FOR OCS OIL & GAS DEVELOPMENTS

Peter J. Hill, Risk Reliability and Engineering

ABSTRACT: API GUIDELINE FOR QUALIFICATION OF NEW TECHNOLOGY

The white paper below was developed from an Offshore Technology Research Center (OTRC) workshop held in October 2002. It has been circulated among oil and gas companies, within the Minerals Management Service (MMS), and within the U.S. Coast Guard.

The API Guideline advocated by the white paper will serve to de-mystify the process by which the federal regulators assess the equivalence or acceptability of a new technology. It will outline standards for certifying, testing, and assessing technologies based on a number of factors.

If the white paper is adopted by API for guideline development, the drafting committee will require authoritative participation by the MMS and the USCG. When the draft is completed and published by API, some guidance within each agency will likely be necessary to enable the agencies to make full use of the guideline.

The guideline is not intended to replace regulatory approval. It will rather present a formula and protocol for determining the information required to assure an expedited approval, based on the degree of newness and risk inherent in the new technology. Such approval may be unconditional, or may be limited to a specific project until more field experience is obtained. This process will greatly reduce the schedule risk often associated with the introduction of new technologies, and will also provide a mechanism for operators, manufacturers, vendors, or consortia to complete essential evaluations and testing using a standardized protocol acceptable to both federal agencies.

INTRODUCTION

A key imperative to the development of oil & gas on the U.S. Outer Continental Shelf (OCS), particularly in deepwater, is continued technological advancement to reduce development and life cycle costs on the one hand and to maintain reliability and environmental stewardship. As part of the oil industry's efforts to achieve cost reduction and reliability improvement, considerable attention is being devoted to the development and qualification of new technologies. The primary mechanism now in place for operators to submit new technologies/concepts for review and approval through the MMS is via the "Deepwater Operation Plan" (DWOP). This process, as it currently exists, curtails the time the MMS needs to properly review the newly proposed technology since only an operator may submit a DWOP. This makes it necessary for many operators to accept increased project risks associated with the short time allotted for new technology reviews, and try to submit conceptual DWOPs as early as possible.

There is an urgent need for a mechanism by which new technologies can be properly evaluated and qualified for use on the OCS prior to submission to the MMS, as part of a DWOP. This mechanism should also be applicable to the approval of new technologies by the U.S. Coast Guard.

PURPOSE

The purpose of this paper is to propose the development of an API Guideline that defines a process an operator, manufacturer, consortium or other entity may use to "qualify" a new technology for use in offshore oil & gas developments on the OCS. This "qualification" process would optimally result in an expedited approval of a new technology when it is eventually proposed to an agency as part of a site-specific project. Having the qualification process for a new technology accepted by an agency should shorten its review time once it has been submitted since it has met a recognized standard. Therefore, once a new technology has been "qualified," it would then be added to the toolbox of alternatives that operators could consider for future offshore operations, particularly in deepwaters.

BACKGROUND

This paper is the result of recommendations developed in the workshop, "Qualifying New Technologies for Deepwater Oil and Gas Development," held in Houston, Texas, 29–30 October 2002, co-sponsored by the MMS and the Offshore Technology Research Center (OTRC). This workshop involved participants from oil and gas operators, manufacturers/suppliers of offshore services or equipment, classification societies, the American Petroleum Institute, the Offshore Operators Committee and the MMS. It included presentations by representatives of NASA, the U.S. Naval Air Program and the aerospace industry on the insertion of new technologies in their applications.

The primary existing process for introducing a new technology to the MMS for use in deepwater is through a project-specific DWOP, associated with a pre-defined lease activity, which is submitted for review and approval by the MMS. The U.S. Coast Guard has a separate process for approving the introduction of a new technology. Although the regulations of both agencies contain provisions for obtaining approval of new technologies, the time required by both agencies for properly reviewing the first applications of this new technology does not typically match the operator's project schedules of recent deepwater oil and gas developments. While operators should consider the MMS/USCG review periods of new technologies when establishing their schedules, the development of an API Guideline on "qualifying" new technology will help streamline the review process and reduce project risks.

To address acceptance of new technology under their respective rules, several classification societies have either developed or are developing processes for qualifying new technologies.

WHAT IS NEW TECHNOLOGY?

It is widely accepted by the industry and the regulatory bodies that the term "new technology" encompasses a wide range of "newness": from a new material that is applied to a component that has been widely used, to an existing component that is used in a new application, to totally new technologies that have never before been applied. The definition of "new" also has a geographical component, for instance, a technology that exists in other parts of the world, but has not been reviewed or approved by U.S. regulators.

It is intuitive that different degrees of "newness" would require different levels of analysis and/or testing as part of the qualification process. The proposed API Guideline will define the different degrees of "newness" and identify appropriate levels of testing, analysis, and support information to be accomplished by the owner, the supplier or an independent third party. Concepts submitted and documented in accordance with this API Guideline would receive an expedited review by the MMS in the DWOP process, and where applicable also receive an expedited review by the USCG.

OVERVIEW OF CURRENT PROCESSES

The insertion of a new technology involves the following key participants:

- Operator
- Manufacturer or supplier of the new technology
- Approving agency (MMS and/or USCG)

and may also involve:

- Classification Society
- Certified Verification Agent (which may be the Class Society in some cases)
- Consortiums, Joint Industry Projects (JIPs), trade groups or other advocates of the technology
- Engineering firms, testing laboratories, academic institutions, etc.

The current process varies depending on which agency has jurisdiction over the system employing the new technology. A Memorandum of Understanding (MOU) between the USCG and the MMS[1] determines the jurisdiction based on type of facility and the particular system and subsystem. In broad terms, drilling and production systems are under the MMS, and systems associated with lifesaving, firefighting and marine systems are under the USCG. Structure of fixed facilities is under the MMS, and floating facilities have shared jurisdiction between both agencies.

MMS PROCESS

The MMS regulations assign responsibility for compliance to the lease operator, and the agency generally does not provide technical review until the operator of record applies for regulatory approval under a definitive project. While the MMS participates in industry forums, JIPs and other activities to explore and facilitate eventual approval of new technologies, the MMS does not engage

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[1] Memorandum of Understanding Between the Minerals Management Service and USCG. Current document is dated 16 December 1998, but is under consideration for revision.

in type approval, or any specific pre-approval on behalf of a manufacturer or supplier of a technology.

The MMS regulations at 30 CFR 250.141 provide the operator an opportunity to propose the use of any alternate procedures or equipment that provides a level of safety and environmental protection that equals or surpasses current MMS requirements. The regulations allow for either submission of information or oral presentation describing the site-specific application(s), performance characteristics, and safety features of the proposed procedure or equipment. The regulations are open as to when alternatives may be submitted for approval, but typically new technologies are presented in the Conceptual DWOP when an operator is sure they wish to use it.

An operator choosing to employ a new technology assumes a certain amount of risk. When the technology is selected and presented in the Conceptual DWOP[2] of a project, the MMS may either accept or reject the technology, but typically requires the operator to provide additional data, testing, or risk analysis. Ultimate acceptance depends on the review of data submitted and may take several months to complete. Certain technologies may trigger environmental reviews that can take up to two years to complete. It can be seen that operator's consideration of a new technology needs to begin long before it may be employed on a specific project. Also the operator considering an unproven technology can mitigate approval uncertainties by including a fallback plan for use in the event the new technology is not accepted. This process duplicates engineering design costs and can introduce schedule risk.

USCG PROCESS

The USCG routinely accepts and approves material and equipment submitted by vendors, subject to various USCG material specifications. In the marine industry, vessel owners or operators typically buy the materials and equipment carrying USCG approval numbers. In the case of new technologies of material or equipment regulated under such a specification, a manufacturer or vendor applies for an approval number and demonstrates the performance of the material or equipment to the USCG.

Vessel owners or operators may also propose alternatives not addressed in regulation through a process known as "equivalency." Under this process, the submitter must demonstrate to the USCG that the proposed technology provides the same level of safety as that prescribed by regulations. These submittals are assessed internally by the USCG Marine Safety Center or Headquarters. The USCG has developed several guidance documents addressing the substitution of composite and other materials within metal piping systems. These documents establish an alternative specification and identify the testing and level of documentation necessary to determine acceptance of those materials.

For material or equipment not addressed in the aforementioned guidance, the USCG equivalency approval process can take six months or more. Turnaround is impaired further by shifting of resources within the USCG. This API Guideline would benefit both industry and the USCG by providing a uniform protocol for the evaluation of equivalency, and allowing the qualification of material or equipment by competent authorities already recognized by the USCG. This would reduce the USCG workload associated with reviewing equivalencies, reduce uncertainties, and improve approval time.

Also, under various international agreements such as SOLAS, the USCG may accept materials and equipment tested and approved under other regulatory regimes subject to SOLAS requirements.

SO WHY AN API GUIDELINE?

While, as indicated, the regulators have processes in place for approving new technology, these processes do not lend themselves to accommodating fast-track project implementation necessary for the financial success of many offshore developments, particularly those in deepwater. Also, the science of materials and their application offshore is advancing far more rapidly than the regulations, and these advances take a number of years to become established in consensus standards. The processes developed by class societies address acceptance under their respective rules, but they do not address the steps to pursue regulatory approval. Also, classification is not a requirement in every case. This API guideline would reach a wider audience and provide the essential components for obtaining regulatory approvals by removing uncertainty of acceptance for the operator. The API guideline will complement and fast track the regulatory processes already in place. Ideally the process should be sponsored under a consensus standard making entity such as API, which is uniformly recognized by classification societies, industry and regulators.

The API Guideline would define a systematic approach to the qualification for new technology to ensure that the technology functions reliability within the specified limits. The guideline would address the qualification approach and basis. It would include a methodology for defining and ranking failure modes, establishing consequences, performing reliability calibration, and establishing maintainability The API guideline would also define the appropriate testing, analysis and documentation, and define the role of a qualifying third party agent, such as a classification society. The qualifying agent role may include overseeing testing, evaluating and documenting performance, and making an assessment of the reliability and safety level equivalence under applicable regulations. The API guideline would provide a basis for recommendations concerning temporary or permanent safeguards or mitigations and requirements for in-service monitoring, sampling, and/or inspection.

The submission of information and findings developed under this API Guideline would not replace regulatory review, but would expedite the review in a manner similar to the Certified Verification Agent program[2] under the MMS or the Classification Society Plan Review[3] permitted by the USCG.

The MMS and the USCG with representatives of leaseholders, manufacturers and other stakeholders would participate in the preparation of this API Guideline. The MMS and USCG would also develop and adopt policies that recognize the guideline and facilitate its use in the approval process.

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[2] 30 CFR 250.900(c) Platform Verification Program

[3] NVIC 10-82 Acceptance of Plan Review and Inspection Tasks Performed by the American Bureau of Shipping for New Construction or Major Modifications of U.S. Flag Vessels

PATH FORWARD

The concept of this guideline has the general acceptance of industry and regulatory participants in the workshop. Additionally, this white paper has been reviewed within the USCG and the MMS. If this guideline is adopted for development, a task group that includes representatives of operators, contractors, regulatory bodies and class societies will be established to coordinate the effort and prepare the guideline.

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SESSION 2B

DEEPWATER PHYSICAL OCEANOGRAPHY I

Chair: Carole Current, Minerals Management Service
Co-Chair: Alexis Lugo-Fernandez, Minerals Management Service

Date: January 15, 2003

HIGH-SPEED SUBSURFACE JETS OF THE NORTHERN GULF OF MEXICO: OBSERVATIONS, MECHANISMS, AND MODEL CASE STUDIES

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INTRODUCTION

There are four major classes of energetic currents in the Gulf of Mexico (GOM) of primary concern to offshore petroleum operators. These are 1) currents resulting from energetic, episodic atmospheric events, 2) currents associated with the Loop Current and related eddies, 3) vertically coherent currents below 1000 m (e.g. those believed to be associated with topographic Rossby waves), and 4) high-speed sub-surface intensified currents.

Based on observations, high-speed subsurface intensified currents, also known as jets, typically have temporal durations on the order of a few hours to one day, have subsurface speed maxima that can exceed 4 knots (200 cm/s), have peak speeds that occur between 150–350 m below the surface, and have little or no surface expressions. Offshore operators design drilling and production systems to account for forces exerted by currents at all depths; therefore frequency, persistence, and speed characteristics of jets are important design criteria.

OBJECTIVES

Begun in 1999, the MMS-sponsored "Study of Subsurface High-speed Current Jets in the Deep Water Region of the Gulf of Mexico" seeks to address the fourth class of currents. The objectives of the study are to characterize subsurface jets that occur in the GOM and speculate on the physical mechanisms responsible for their generation.

The activities to achieve these goals include 1) identifying and acquiring data sets believed to contain subsurface jets; 2) characterizing each identified jet and jet environment (through collection of ancillary data such as satellite, meteorological, and CTD data); 3) examining relationships between jets occurrence and potential forcing mechanisms; 4) identifying and analyzing jets found in numerical model output; 5) attempting to identify physical and other mechanisms responsible for jet generation. Additional objectives are 6) to provide guidance to MMS as to how data collection should be improved on oil and gas industry platforms; 7) to apply analysis schemes to outputs of model runs both with and without data assimilation; 8) to consider internal/inertial and filamentary causal mechanisms.

DATA AND APPROACHES

The short temporal character and relatively small vertical extent of jets provide a challenge to researchers attempting to investigate them. Because of the coarse vertical coverage of moorings instrumented with conventional single-point current meters (usually hundreds of meters), practically all current meter data collected prior to 1990 are useless for investigation of jets. With the advent of acoustic Doppler current profilers (ADCP), investigators were afforded the opportunity to collect high spatial resolution vertical profiles (order several meters) of current velocity over vertical ranges of tens to hundreds of meters

We have examined all available current meter records obtained from academic, government, and industry sources. Presently, the Texas A&M University Gulf of Mexico deepwater current meter archive contains over 8 million instrument-hours of quality-controlled current meter data.

FINDINGS

Studies of Observations

To date, we have identified a total of 12 candidate cases of subsurface jets in our data inventory. Table 2B.1 summarizes the locations, dates, and maximum speeds of the five jets contained in non-proprietary current meter records.

Table 2B.1. Summary of subsurface jets.

No.	Lease Block	DATE	LON °W	LAT °N	J-Dep m	Speed cm/s	T-Dep m
1.	GC200	30 APR 1994	90.749	27.767	210	60	600
2.	VK956	10 FEB 1997	88.094	29.045	275	105	1200
3.	MC628	10 APR 1997	89.366	28.332	325	80	760
4.	DC977	28 SEP 1998	87.494	28.003	Unk	25	1300
5.	EW913	16 AUG 1999	90.399	28.066	160	210	500

J-Dep = depth of jet core, T-Dep is total water depth, Speed is maximum speed during jet

The locations of the jets summarized in Table 2B.1 are indicated in Figure 2B.1 by filled stars. As the figure shows, the jets are confined to the slope region of the north-central GOM. This is expected due to the high density of observations associated with offshore operations in that region. Locations of proprietary data containing jets are roughly within the same region.

Four of the five jets summarized in Table 2B.1 (numbers 1, 2, 3, and 5) show the development of a subsurface speed maximum over time ranges from 6 to 24 hours. The jet found at lease block DC977 (number 4) consists of an inertial wave packet caused by Hurricane Georges which propagated downward to at least 500 m depth. The depth of the speed maximum is unknown because the water column was not instrumented between 100 and 500 m. The inertial oscillations at 500 m occurred without any surface expression and several days after the hurricane's passage.

Several of the observed jets have unusually large (> 10 cm/s) vertical velocities. We have not ruled out the possibility that the measurement limitations of acoustical instruments may be responsible for certain biases in the data record. In particular, we have simulated a non-homogeneous flow field passing a realistic alignment of off-axis acoustic beams (typical of standard acoustic current instrumentation). We find that inhomogeneities, both vertical and horizontal, can significantly affect the estimates of both horizontal and vertical current velocities. Further, for beam angles of 20 degrees, oppositely directed vertical velocity components in each beam path can correspond to the appearance of horizontal velocities 2.74 times the vertical velocity magnitude. Such inhomogeneities could be caused by structural interference, internal waves, or motions attributed to ship/rig thrusters and could masquerade as energetic features in data records.

STUDIES OF MODEL OUTPUT

We have obtained the model outputs of two versions of the Princeton Ocean Model for the GOM: the Princeton Regional Ocean Forecasting System (PROFS) model (data courtesy L. Oey, Princeton University) and the University of Colorado Princeton Ocean Model (CUPOM) (data courtesy L. Kantha, University of Colorado) (Kantha *et al.* 1999). We have designed virtual current meter arrays to investigate the time and space scales and frequency of occurrence of subsurface jets from models. The purpose of the virtual current array is to simulate the deployment of current meter arrays into the model domain.

Figure 2B.1 shows the locations of the virtual moorings from each model. The PROFS virtual array locations were chosen to be in the vicinity of the jet candidates summarized in Table 2B.1. The PROFS arrays, which are depicted as filled circles in Figure 2B.1, were in two general locations: one is centered at 88° W and the other just west of 90° W. The locations were chosen to investigate across- and along-slope variability during jet occurrences. Both the CUPOM and PROFS models can assimilate satellite altimeter data.

Hourly CUPOM output with assimilation are available at longitude lines near 90° W and 88° W with full vertical resolution (23 sigma-levels) and are depicted as triangles in Figure 2B.1. A non-assimilated run of the CUPOM outputs are not available. Outputs from the PROFS model with approximately 5 km grid spacing (course grid) and 2.5 km spacing (fine grid) were examined. Runs with and without data assimilation spanning three model years were available for analysis for the course grid scale version, while a non-assimilative run spanning 30 days were available for analysis of the fine grid scale version. Figure 2B.2 shows the sub-domain of the fine grid scale model.

Hourly outputs of the seven-year run of the CUPOM model were analyzed at the virtual array locations for subsurface jets. Speed contours plotted on depth versus times axes were examined. Vertical current structure was present throughout the records. Four candidate jet events were identified in the vicinity of the twelve observational jet candidates and at comparable water depths and placement over the slope. Computer animations of six-hourly outputs with full horizontal (1/12 degree by 1/12 degree) and vertical resolution were constructed to depict flow in a volume of ocean during the time of the identified jets. The animations superimposed on sea surface height contours (to track eddy movement) allowed more refined analysis of the spatial development of the jets and an estimate of horizontal scales.

Generally, all four of the model jet candidates could be associated with motions of filamentary structures extending from the Loop Current or eddies associated with the Loop Current. The temporal duration of the subsurface features found in the model were typically much longer (order 2–6 days and longer) than those seen in observations (one-third to 2 days). Also, the high-speed core (as large as 70 cm/s) in the model was generally higher in the water column (150–250 m) than in observations (200–400 m). The filaments can have lengths of 75 km and more and widths of 50 km. The filaments are believed to be caused by the interaction of the Loop Current with bottom topography and/or eddy-eddy interaction.

Analysis of the coarse grid scale version of the PROFS model revealed no instances of intense sub-surface jets in the study region. However, there were several occurrences of isolated internal wave trains of inertial period. These wave trains, with peak speeds over 20 cm/s, are likely associated with the downward propagation of energy associated with the passage of eddies. Comparisons of outputs of the assimilative and non-assimilative runs show deeper penetration of surface energetics for the assimilative version. Preliminary findings of the fine grid run are consistent with the coarse grid findings.

Outputs of the Navy Layered Ocean Model during August of 1999 when an unusually large Loop Current Eddy (Eddy Juggernaut) was impinging on the north slopes show some filamentary structure in the region of interest; however, the subsurface motions between 200–300 m depth are generally associated with motions at the surface (outputs courtesy T. Townsend of Naval Research Laboratory).

MECHANISMS

We continue to pursue the theoretical investigation of candidate mechanisms of the jets found in observations and in the CUPOM and PROFS outputs. Some candidate mechanisms seem more likely than others. For example, unlikely candidates (and reasons for unlikeliness) include subsurface jets associated with coastal buoyant fronts (too far from shore and river plume), upwelling (slower peak speeds and usually surface-trapped motions), and undercurrents (no evidence these exist in the Gulf of Mexico. The more likely mechanisms include: (a) motions derived from the Loop Current and associated eddies in the form of filaments and meanders, (b) motions due to eddy/eddy and/or slope-shelf/eddy interaction, (c) manifestations of internal waves with unusually large speeds, e.g. internal soliton, like those observed in the Andaman Sea (Osborne and Burch 1980), (d) the combined effects of transient surface winds and deep flow over an undulating sea bed (Rhines 1977), (e) reversed geostrophic flow (Onken 1990), (f) inertial wave packets, and (g) frontal instabilities and the development of small-scale (15–25 km) preferentially cold-core features along frontal boundaries (Weller 1991; Samelson 1993; Samelson and Chapman 1995).

CONCLUSIONS

Twelve jet candidates are present in the observational record. This is a reflection of the few data sets with instrumentation adequate to resolve the vertical structure of a jet and located in the region likely to produce a jet. There is an apparent disparity of time scales between jets observed in the real world and the jets found in model output. The observed jets usually have time scales of the order of several hours to one day; model jets seem to occur higher in the water (maxima in the upper 200 m) and last two to six days. Large vertical velocities seen in some observations may result from inhomogeneities in the flow field. We see no evidence in the model output of any jets which last less than one day. We believe the model/data disparity may be caused by the eddy resolving limitations of the models being investigated. Further analysis of the PROFS fine grid model is needed to demonstrate that small-scale eddy generation is a plausible jet mechanism.

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DEEP CYCLONIC CIRCULATION IN THE GULF OF MEXICO

Wilton Sturges, Florida State University

The upper layer circulation in the Gulf of Mexico is anticyclonic (or clockwise) in the eastern Gulf, in the Loop Current. The flow in the central and western Gulf is anticyclonic as well although considerably weaker in the mean. A surprising observation, however, is that the warm-core temperature pattern in the deep Gulf "looks the same" as in the upper layers. A warm-core feature can be found at depths of ~1000–2000 m beneath the Loop Current as well as in the central Gulf. We have examined a variety of observational evidence and conclude that the mean deep flow is cyclonic (or counter-clockwise). The historical hydrographic data, moored current meter records, and several years of PALACE floats are all consistent with the idea of cyclonic mean deep flow. The evidence from any single bit of data is not overwhelming, but taken as a whole it appears quite convincing. The instantaneous, time-dependent flow is mainly back-and-forth, as in the upper layers, with speeds of many tens of cm/sec. The mean deep flows tend to be of the order of a few cm/sec.

There are several fundamental reasons why we expect cyclonic deep flow. Bottom rectification of oscillatory currents would lead to flows that are cyclonic near the boundaries. The cold deepwater from the Caribbean Sea, flowing into the Gulf over the sill at Yucatan, provides a source of cold, dense water (Figure 2B.3) rather like that of the Deep Western Boundary Current flowing along the east coast of the United States. In the Gulf, the effect of this source leads to cyclonic flow.

Figure 2B.4 show results from a long-term current meter mooring in 1800 m depth on the West Florida Escarpment, beneath the southward-flowing Loop Current. The mean flow at 800 m and deeper is consistently to the north. We estimate the standard error of the mean (at depth) to be on the order of 0.5 cm/sec.

And in the east, if not in the central Gulf, the flow coming in over the sill goes into much deeper water. The effect of deepening would lead to vortex stretching, and this causes the production of cyclonic vorticity. The fact that Gulf is so weakly stratified at those depths (in comparison with the Caribbean) enhances this effect. Finally, Loop Current Rings propagate to the west; we suspect that they should drag a column of fluid beneath them, leading to a weak mean flow to the west. The return flow (in a rotating system) would be expected to be on the north side. So this combination of flow should produce a large-scale mean flow that is cyclonic.

We have compared these results with several numerical models. Most models find most of the features we find, such as a consistent flow to the east along the steep north slope on the Mexican coast. But there appear to be no direct observations of this flow. Figure 2B.5 is a result from the Princeton Ocean Model (based on the original Mellor-Yamada model) from Ezer's work.

In Figure 2B.5, the blue shows flow to the west. The yellow and orange show flow back to the east. The strong flow along the Mexican slope near 24 N is a striking result. We can not find this result, however, in geostrophic calculations. We cannot say whether it is because the flow is barotropic or because the observations simply are too sparse to resolve a small mean from the large variability—or perhaps both.

In the central Gulf, the deep flow is found to be cyclonic in most numerical models. The flow right next to the boundary in the north, however, differs between models presumably as a result of their treatment of bottom boundary friction.

One of the most compelling new results is the observation that the deepwater at the edges of the Gulf—at 2000 m—is coldest near Yucatan; as we go away from the sill, in the counter-clockwise direction, the water gets progressively warmer, over a range of approximately 0.1 C.

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RECENT MEASUREMENTS OF DEEPWATER CURRENTS IN THE NORTHERN GULF OF MEXICO

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INTRODUCTION

In August 1999, the Minerals Management Service (MMS) funded the deployment of an array of three moorings, clustered near the 2000 m isobath at the base of the continental slope, south of the Mississippi delta (Figure 2B.6). This array was designed to study energetic deep currents that had been previously observed by a mooring deployed for BP Exploration Inc. in Block 618 of the Atwater Valley lease area. Both the previous BP mooring and the MMS array were situated south of a relatively steep slope known as the Sigsbee Escarpment, which is an extensive geological feature that meanders across the deep northern slope between the Mississippi delta and east Texas. The MMS array consisted of one extensively instrumented full depth mooring (I1) and two short bottom moorings (I2 and I3). In order to discover how far up the slope high-speed deep currents might extend from the Atwater site, BP contracted with SAIC to deploy another short bottom mooring on a block (Green Canyon 782) north of the escarpment (Figure 2B.6). This mooring, denoted J1, was deployed in conjunction with the three MMS moorings. The array of moorings was deployed in August 1999, and J1 was retrieved in August 2000 after one rotation in January 2000. The three MMS moorings were redeployed and, after a further rotation in February 2001, finally retrieved in September 2001. The last six months of the I1, I2 and I3 deployments were supplemented additional measurements. BP funded another deep short mooring, named I4, on the middle part of the escarpment, just west of I2. Further, three Inverted Echo Sounders, equipped with precision bottom-pressure sensors (known as PIES), were deployed at positions equidistant from the main mooring I1. These positions are denoted K1, K2, and K3. These latter were deployed to test the ability of PIES to measure temperature and salinity depth profiles and, through the geostrophic equations combined with bottom currents, absolute velocity profiles in the Gulf of Mexico.

DEEP CURRENTS

The two years of data, from the three main moorings in the region of the Sigsbee escarpment on the lower slope south of the Mississippi delta, have shown unusual deep current flows. The bottom intensified, nearly depth-independent motions are typical of topgraphic Rossby waves (TRW) observed in this and other regions of the deep Gulf. However, energy levels are exceptional and the dominant periods of the motions are about 10 to 14 days, which is short compared to other regions of the eastern and western Gulf (Hamilton 1990). Maximum currents at the I2 mooring were of order 85 to 95 cm/s for an event early in the record. This energy seems to spill over the escarpment to the BP J1 site on some occasions when the very-high energy events occurred at I2. Otherwise, the velocities at J1 were much less energetic than at the moorings south of the escarpment. Similarly, bottom velocities at another site (I4), just west of I2, on the escarpment, were also much weaker than measured at the base of the escarpment, and in deeper water depths.

The records show a number of distinct wave trains passing through the site (Figure 2B.7). The first, between September 1999 and January 2000, showed the highest current speeds, and at the beginning of the record there were indications that upper-layer disturbances, caused by cyclonic frontal eddies on the Loop Current (LC) front, were coherent with the lower layer flows. In this first period, upper-layer currents were vigorous due to the presence of the LC and later, the recently shed eddy Juggernaut. The second period began in April 2000 and lasted to the end of the record in August 2000. These TRWs were also energetic though with slightly longer characteristic periods, stronger bottom trapping, and larger westward amplification between I1 and I2, than observed in the first period. The upper layer currents were quiescent during this second period as eddy J had moved off into the western Gulf. Thus, there was no evident connection with the initiation of the April TRWs with simultaneous fluctuations of the upper-layer currents. A third period of energetic TRWs, beginning in February 2001, was related with the shedding of eddy Millennium and associated cyclonic circulations. In all, five wave trains, with differing periods and wavelengths, were identified in the bottom records. Ray-tracing suggests that the west side of the LC is the most likely source region for these waves and that it is difficult for such short period waves to penetrate into the western Gulf basin. This is in accord with earlier measurements (Hamilton 1990) that showed 20 to 30 day TRWs dominating in the central and western Gulf. If the mechanism for coupling of surface propagating eddies or meanders with deep TRW motions that has been put forward for TRW generation by the Gulf Stream in the North Atlantic (Pickart 1995) applies here, then small cyclonic frontal eddies on the LC and LCE fronts could be candidates for generating deep, short-period TRWs in the eastern Gulf.

It is apparent from these measurements and the previous one-year of current data obtained by BP at a site close to I1, that TRW activity is fairly continuous at the base of the escarpment in this region. The distribution of energy across the array was quite inhomogeneous, and varied with the different observed wave trains. The rotation of the principal axes of the motions from partly across-isobath at I3 to along-isobath at I1 and I2 suggests that the steep escarpment may be influencing the propagation of the TRWs, possibly by reflecting the energy back into deepwater. The weak currents at J1 and I4 suggest that it is an effective barrier to TRW motions propagating into shallower water.

EDDY MILLENNIUM

Upper-layer currents were dominated by the passage of the two major LC anticyclones (Figure 2B.7). The periphery of these eddies seems to produce the most energetic temperature and velocity fluctuations that are often associated with rapidly translating cold cyclones. The passage of eddy Millennium into the western Gulf, between February and June 2001, allowed partial analysis of radial and azimuthal flows from mooring I1. This eddy moved further north than the previous eddy J, and the center of the eddy passed within 60 km of the mooring, so that a substantial portion of the eddy interior was measured. The path and characteristics of the eddy were analyzed using drifters deployed by Horizon Marine (Figure 2B.8). Eddy M was probably forced northwards and towards the slope by a large cyclone on its western side that probably formed while the eddy was still attached to the LC. This cyclone eventually moved up onto the slope and blocked further westward passage of eddy M, which moved rapidly southwards during May 2001, and then resumed a more usual southwestward path into the western deep Gulf. The azimuthal velocity and temperature profiles behaved roughly as expected for an elliptical eddy in solid body rotation with a period of 8 to 10 days. However, there were significant anomalies that were associated with either attachment to the Loop Current or interactions with the cyclone and slope. The passage of the eddy allowed estimation of the distances from the center to the maximum velocity, along the semi-major axis, and the width of the cyclonic shear zone outside the maximum velocity position. These were 150 and 50 km, respectively. The narrow cyclonic shear zone implies a large positive vorticity anomaly and thus, a generation region for non-linear instabilities.

INVERTED ECHO SOUNDER DATA

This study deployed, around I1, three bottom-mounted PIES to test the viability of using the gravest empirical mode (GEM) method (Sun and Watts 2001) to generate low-frequency temperature, salinity and geostrophic velocity depth profiles. Deployment of an array of PIES and bottom-current meter moorings is much more cost effective for large-scale measurement programs in deepwater than deploying arrays of full-depth moorings like I1. A preliminary GEM was constructed from historical CTD data for the Gulf and applied to the bottom-pressure and travel-time records from the three PIES deployed in the last six-months of the study. The resulting derived profiles of temperature, salinity, and geostrophic currents were compared with appropriate direct measurements of these quantities from mooring I1. The time series comparisons were good for all depths with high statistical significance and confidence. The last six months of the deployment included part of the passage of eddy M. This work will allow the confident use of PIES in future deep Gulf physical oceanographic measurement programs.

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THE PHYSICAL PROCESSES IN THE GULF OF MEXICO THAT GOVERN THE CIRCULATION IN THE DESOTO CANYON

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INTRODUCTION

As a part of the MMS-funded program “Cross-Shelf Exchange Processes and the Deep-water Circulation of the Gulf of Mexico,” we conducted a numerical investigation analyzing the physical processes controlling the circulation in the DeSoto canyon and its vicinity. Our data analysis and numerical experiments were focused around conceptual models of circulation in the DeSoto canyon proposed by Hamilton *et al.* (2000) on the basis of their analysis of the data collected during the DeSoto Canyon Eddy Intrusion Study (1997–99). The main goal of the investigation was to reproduce the eddy interactions described by these conceptual models in numerical simulations and to investigate the physical mechanisms involved.

In particular, two conceptual models were investigated. The first conceptual model (mode 1a in Hamilton *et al.* (2000) represents the direct interaction of a warm-core ring south of the canyon. The second conceptual model (mode 1b in Hamilton *et al.* (2000)) is a form of remote warm-core ring interaction with a steep slope. Both of these modes occur when the Loop Current (LC) is positioned far to the south and, thus, should not have any direct effect on the circulation in the canyon (the role of the LC is still important for the formation of warm-core rings and their propagation towards the DeSoto canyon region). Below we present the results of our process-oriented numerical analysis of these conceptual models.

DIRECT INTERACTION WITH ANTICYCLONES

Our first step in studying the physical mechanisms involved in this circulation mode was to identify the structure of anticyclones typically found at the mouth of the canyon. The typical structure of the anticyclones was derived from the analysis of nine detailed hydrographic surveys of the DeSoto canyon region conducted as a part of the Eddy Intrusion Study. Warm-core eddies were classified by the depth of the potential vorticity (PV) anomaly associated with them. According to this classification, three types of warm-core eddies were found:

- Shallow eddies—the PV anomaly is localized to the upper thermocline.
- Deep eddies—the PV anomaly is localized to the lower thermocline.
- Full eddies—the PV anomaly is distributed throughout the entire depth of the thermocline.

Our numerical experiments demonstrate that despite their natural tendency to propagate westward due to the beta-effect, all three types of warm-core eddies can propagate eastward as the result of interactions with the northern shelf break. This effect might be responsible for transporting warm eddies toward the mouth of the canyon in the absence of the LC and its frontal eddies. The orientation of the shelf break was shown to be crucial for the existence of this effect. It is also demonstrated that warm-core eddies need to be forced against the shelf initially to trigger the eastward propagation. This initial forcing is likely to be provided by LC frontal cyclones.

Warm-core eddies at the mouth of the DeSoto Canyon are shown to generate cyclonic circulation in the Canyon (Figure 2B.9). This circulation pattern is consistent with the "mode 2" of circulation in the Canyon identified by Wang *et al.* (2002) from surface current observations. Thus, our numerical simulations identify a link between a conceptual model of eddy interaction within the DeSoto Canyon proposed by Hamilton *et al.* (2000) and a statistical circulation mode derived by Wang *et al.* (2002). The off-shelf PV advection is identified as the primary physical mechanism responsible for the generation of the cyclonic circulation. This mechanism is identified using a passive tracer technique developed for the analysis of our numerical experiments.

REMOTE GENERATION OF EASTWARD JETS

According to this conceptual model, a remote LC ring interacting with the coastal topography west of the Mississippi River delta generates a warm eastward jet along the shelf break that reaches the DeSoto canyon region producing eastward currents. This model is based upon the hydrographic survey combined with current meter data and satellite SST observations during one particular event: the so-called "Eldorado eddy" interacting with the northern Gulf of Mexico (GOM) slope just west of the Mississippi Canyon.

Using the available information about the event and our experience in simulating the LCE interaction with coastal topography, we conducted a series of realistic simulations of the Eldorado eddy interacting with the northern slope. Simulations with several different eddy structures and locations within the observational uncertainty range failed to reproduce the eastward shelf-break jet observed at the foot of the canyon in November–December 1997. Even though this result cannot be regarded as conclusive evidence, it suggests that some other processes may be responsible for the eastward shelf-break jet observed at the foot of DeSoto Canyon.

Observational data from this time period, in particular the sea surface height fields derived from the TOPEX satellite data, suggest the presence of a large cyclone centered just east of the Mississippi River delta. We propose that it is the interaction of this cyclone with the shelf break east of the Mississippi River delta that produces the eastward jet along the shelf. The jet is generated as a result of low PV water, which is initially wrapped around the cyclone in the upper thermocline, stripping off the perimeter of the cyclone when its core approaches the shelf break (Figure 2B.10). Numerical simulations of this process showed the generation of a topography following eastward jet similar to the one observed (Figure 2B.11).

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Sergey A. Frolov received his B.S. degree in theoretical physics from University of St. Petersburg (Russia) in 1994. In 2001 he received a Ph.D. in physical oceanography and M.S. degree in computer science from University of Rhode Island. From 2001 to the present, Dr. Frolov has worked for Accurate Environmental Forecasting, Inc. as a Senior Research Scientist.

EXPLORATORY STUDY OF DEEPWATER CURRENTS IN THE GULF OF MEXICO

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In March 2002, the MMS initiated a project entitled “An Exploratory Study of Deepwater Currents in the Gulf of Mexico” to study currents and oceanographic conditions in an area that extends from 88°W–94°W and between the 1000 m to 3000 m isobaths (Figure 2B.12). As a key bathymetric feature, the Sigsbee Escarpment extends approximately from the northeast to southwest across the study area.

The study objectives are to make observations that support evaluation of a sequence of eight hypotheses concerning the oceanographic nature and character of conditions in the study area. Observations to be used in addressing these questions include current, temperature and salinity profiles at fixed locations, trajectories of deep and profiling drifters, and satellite remote sensing.

This study’s measurement program has a data-rich design that uses proven measurement techniques that are readily and cost effectively scalable to the entire Gulf. The diverse data types combine well to produce comprehensive and integrated descriptions of oceanographic conditions.

A key methodology in this study is use of a spatial array of Inverted Echo Sounders with Pressure sensors (PIES). These bottom-mounted instruments periodically transmit an acoustic signal that propagates to and is reflected from the ocean surface. These observations are measured and averaged in such a way as to produce a stable estimate of roundtrip travel time three times per day. A methodology (Gravest Empirical Mode–GEM) developed at the University of Rhode Island uses the resulting measurement of roundtrip travel times in conjunction with historical hydrographic observations to yield time series estimates of the vertical profiles of temperature, salinity, and density. With the resulting spatial array of appropriately spaced density profiles, geostrophic current shear profiles can be computed. These shear profiles can then be referenced to an appropriately located measured current velocities.

The distribution and type of current moorings, and the location of PIES is shown in Figure 2B.13. Generally, a current mooring is located within a polygon of PIES so that the current measurements can be used to reference the geostrophic profiles developed using the surrounding PIES. A total of 25 PIES will be deployed, as will 16 current meter moorings. Of the 16 current moorings, 12 will be “short,” extending 500 m above the local bottom. Each short or near-bottom mooring will have current meters 100 m and 500 m above the local bottom. Four of the current meter moorings will be full depth with an ADCP providing detailed velocity profiles from 400 m to about 25 m below the water surface. Above 1000 m current meters will be at approximately 250 m spacing. Below 1000 m the current meters will be at approximately 500 m spacing. This spacing is consistent with the expected character of currents and shears in this essentially two-layer system. On all moorings, a current meter will be placed 100 m above the local bottom. At selected depths above 1000 m, temperature/conductivity sensors will provide detailed time series of these variables.

The history of temperature and salinity profiles at each of the 25 PIES locations provides a larger and encompassing regional setting within which the 16 current profiles can be framed. This larger temperature/salinity field will help put the velocity field in a larger spatial context.

Measured currents, temperatures, and salinities can be used to help evaluate the accuracy of the corresponding profiles developed using acoustic travel times. During the rotation cruise, a full depth CTD cast will be made at each PIES for further data evaluation. During each cruise leg, CTD casts will be made at a selected set of PIES sites so repeated profiles will be available for data evaluation. During the deployment and recovery cruises, deep XBTs will be released at each PIES site.

Two types of deep drifters will be released. RAFOS floats will be ballasted to follow pressure surfaces between 1000 and 3000 dbar. At the end of a year, these 36 floats will rise to the surface and transmit a three-per-day time series of locations. PALFOS floats profile from a set depth to the surface every ten days. As they rise and sink every ten days, a temperature and salinity profile is recorded. While at the surface, these profiles are transmitted via ARGOS, as is the surface transmission location and trajectory of the drifter while it was at depth. The PALFOS floats provided relatively uncorrelated trajectory segments while at depth. Three sound sources will be placed to allow the trajectories of both RAFOS and PALFOS drifters to be computed (Figure 2B.14).

Remote sensing (altimetry and radiometry) will provide an essential regional characterization of important ocean processes. In this measurement design, selected PIES are to be placed on ground tracks of the various satellites that provide microwave altimetry (Figure 2B.15). These combined data sets will support PIES/altimetry comparisons to quantify the sampling and measurement characteristics of the altimeter systems, as well as the space-time statistics of the observed oceanographic variability. In addition, this integration will provide high resolution and validated surface height maps and surface geostrophic velocity fields, based on synthesis of all available altimeter/PIES data and statistics, using optimal interpolation techniques.

Lead PIs for this program are Peter Hamilton (Eulerian); Kevin Leaman (Drifters); Robert Leben (Remote Sensing), and Randolph Watts (PIES). Each PI with their team of supporting scientists and engineers will have access to and utilize the complete and comprehensive database in developing the enhanced understanding of upper and lower layer current patterns and dynamics within the study area. This understanding will provide the basis for evaluating the eight hypotheses that are an essential part of the overall program's objectives.

Field measurements will begin in March 2003 and extend through March 2004. A mooring/PIES rotation/telemetry cruise will occur after six months (September 2003). The Draft Final Report will be submitted to the MMS in September 2005.

Evans Waddell received a Ph.D. in marine science (physical oceanography) from LSU in 1973. He has worked on and managed major Gulf of Mexico oceanographic programs for 25 years. Dr. Waddell is an Assistant Vice President at SAIC, where he has been employed since 1977.

SESSION 2C

SPERM WHALE RESEARCH IN THE GULF OF MEXICO

Chair:	William Lang, Minerals Management Service
Co-Chair:	Lee Benner, Minerals Management Service
Date:	January 15, 2003

SPERM WHALE RESEARCH IN THE GULF OF MEXICO

William Lang and Sarah Tsoflias, Minerals Management Service

The Natural Resources Defense Council (NRDC) report, *Sounding the Depths*, is about the increase of ocean noise from human activities and the fears that this noise will have negative effects on marine mammals and other marine life (Jasny 1999). The report begins by noting that Jacques Cousteau's "silent world" is actually an exceptionally noisy place. By some estimates, ambient noise in the world's oceans rose by as much as 10 decibels, one full order of magnitude, between 1950 and 1975 alone. As Jasny elaborates, much of the blame belongs to commercial shipping, but there is also concern about military operations by the world's navies and offshore industry activities. Here in the Gulf of Mexico (GOM), industry operations are the primary concern for Minerals Management Service (MMS), including seismic exploration, explosive structure removals, and drilling operations (Figure 2C.1).

In June 1999, MMS hosted a GOM marine protected species workshop (McKay *et al.* 2001) that did much to define the research priorities and resulting efforts that will be presented today. As industry moves into deeper waters for exploration and production, a dramatic change occurs in the marine mammal community. At depths of 200 meters and less, only two species of marine mammals, the bottlenose dolphin and Atlantic spotted dolphin, are usually seen in the GOM. In deeper waters, over 20 species occur (Davis *et al.* 2000), including one endangered species, the sperm whale. While the Gulf is home to a diverse community of toothed whales (including killer whales), only one baleen whale (Bryde's whale) resides here. Four species of beaked whales have been reported.

Given the concern of the effects of noise on marine mammals, industry's moving into areas of the Gulf that contain a diverse and abundant marine mammal community and the amazing lack of information on effects of noise on these animals, the workshop identified research on this topic as a high priority. A panel of experts further recommended, as a starting point, that the effects of seismic air guns on sperm whales be studied. Air guns represent a strong, pulsed sound source, a source of logical concern. Sperm whales are not only endangered but are also the species of dominant biomass in the Gulf. Recent unpublished estimates from the National Marine Fisheries Service (NMFS) suggest that as many as 1200 individuals may occur in northern Gulf waters.

In 2000, MMS initiated a cooperative pilot study in partnership with the Office of Naval Research (ONR) and NMFS to establish methods to study acoustic effects on sperm whales. The Sperm Whale Acoustic Monitoring Program (SWAMP) completed work in 2001. Of particular note was the successful testing of a digital tag (DTAG) developed with ONR funding by the Woods Hole Oceanographic Institution (WHOI) and establishing methods for effective coordination of multiple teams (visual, acoustics, small boat, bridge) to study sperm whales.

While the notions that loud noise is harmful to marine mammals are easy to grasp, the data to verify these hypotheses are difficult to obtain. The repeated instances of beaked whales stranding in correlation to naval exercises leaves little doubt that, in some instances, sound (most likely military sonar in this case) can be a factor in harmful effects. In contrast, the effects of seismic exploration on marine mammals are unknown. The few studies and secondary observations to date have produced inconsistent results (Lawson *et al.* 2000).

The Sperm Whale Seismic Study (SWSS) is intended to contribute to the documentation/verification of responses of sperm whales to seismic operations. Using a combination of methods, the basic SWSS objectives are to understand a "normal" sperm whale, characterize industry noise (specifically, air guns), and then determine if air guns alter sperm whale behavior in any detectable way (Figure 2C.2). This session reveals the complexity of achieving these goals.

SWSS exists only through extensive cooperation and pooling of resources. In addition to MMS, ONR and International Association of Geophysical Contractors (IAGC) funded year one efforts. In 2003, the National Science Foundation and a broader coalition of industry sponsors will join the effort. The SWSS research effort is managed through the Texas A&M Research Foundation by Dr. Ann Jochens, Dr. Douglas Biggs, and Dr. Matt Howard. Coordination of the funding components of SWSS has succeeded through the efforts of Dr. Robert Gisiner at ONR, and an industry team led by Chip Gill at the IAGC, Phil Fontana at Veritas, Dr. Jack Caldwell at WesternGeco, and Jim Thompson at Fairfield Industries. In 2002, research was conducted on the Texas A&M vessel Gyre and IACG provided vessel Rylan T. It truly was a cooperative effort from all (Figure 2C.3).

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Ph.D. in marine sciences from the University of South Carolina. His training is in physiology and pathology/toxicology. Before joining MMS, Dr. Lang worked for the Environmental Protection Agency on sublethal effects of marine pollutants. Among many roles in MMS, Dr. Lang has worked on protected species research, beginning in 1981 on the Mid- and North Atlantic marine mammal and sea turtle surveys (CeTAP). He had a lead role in planning one of MMS's first multidisciplinary marine mammal studies, the South Channel Ocean Productivity Experiment (SCOPEX), which studied right whale distribution and behavior concurrent with plankton and physical oceanographic components.

Sarah Lindsay Tsoflias received a B.A. degree in geology and environmental studies from the University of Pennsylvania and a M.S. degree in geological sciences from the University of Texas at Austin. Since 1999, she has been employed as a physical scientist in the Environmental Sciences Section of the Minerals Management Service in New Orleans, Louisiana. Ms. Tsoflias has been involved in research programs investigating noise impacts on protected species since 2000, including the Sperm Whale Acoustic Monitoring Program (SWAMP), the Sperm Whale Seismic Study (SWSS) and topics related to the Explosive Removals of Offshore Structures (EROS).

SPERM WHALES IN THE GULF OF MEXICO: PHOTO-IDENTIFICATION, PHOTOGRAMMETRY, ACOUSTIC ANALYSIS AND OBSERVATIONS OF MEDIUM-SCALE MOVEMENTS DURING SWSS 2002

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INTRODUCTION

Our brief for this presentation was to provide a general introduction to the sperm whale and give an overview of research activities carried out as part of the Sperm Whale Seismic Study 2002 (SWSS) project using "standard" non-invasive sperm whale research techniques such as photo-identification and acoustic monitoring and photogrammetry.

SPERM WHALES

Sperm whales rank among the most impressive of any animals. Even within cetaceans they are remarkable, differing in many respects from the other great whales:

- They are the largest of the toothed whales. Males reach lengths of 20 m while females grow to 12 m.
- They are the most sexually dimorphic of cetaceans. At 44 tons, a mature male is over three times the weight of a 13.5 ton mature female.
- They are the most accomplished of mammalian divers. Dives of over an hour to depths below 2000 m have been recorded.
- Their massive heads, which can account for up to a third of the body length of the males, is the largest sound-producing organ in the animal kingdom. Sperm whales are very vocal, producing loud clicks for most the time they are under water. Recent research by Bertel Møhl and colleagues indicates that they produce the most powerful of animal-made sounds (>230 dB re 1 P @ 1 m) focused in narrow beam (Møhl *et al.* 2000).
- They have the lowest rate of reproduction of any mammal. Females mature at about nine years of age. Gestation takes about a year and a half, and suckling continues for a few years. Average calving intervals in stable populations are around five years. Calves may be cared for communally, and the oldest females may contribute to calf care and may have a leadership role when they cease reproducing. Sperm whale populations were decimated by pre-industrial and industrial whaling and have been very slow to recover.
- The have the most highly developed social organization of any of the great whales. Females and their young live together in stable family groups of between 12 and 30 individuals.
- They are extremely wide ranging. Sperm whales are found in deepwaters in all of the oceans of the world. Uniquely, although females and their young are confined to tropical and temperate waters, mature males spend most of their time in cold temperate waters ranging right up the ice edge.

- They are very ecologically successful, exploiting populations of deep-living fish and squid about which we still know little. Before whaling, sperm whales were thought to have been numerous, consuming more biomass than the world's entire modern fishing fleet.
- Perhaps most intriguingly of all, sperm whales have the largest brains that have ever existed.

Sperm Whales in the Gulf of Mexico

Sperm whales are the most common species of large whale in the Gulf of Mexico (GOM). Extensive surveys conducted during the Cetaceans in the Gulf of Mexico programs (GulfCet I and GulfCet II) (1992-1998) in the offshore waters (100-2000 m deep) of the northern Gulf showed that most sperm whales were concentrated around the 1000-m depth contour south of the Mississippi River Delta (Davis *et al.* 2000; Baumgartner *et al.* 2001). The Texas-Louisiana shelf has been a focus of activity for the offshore oil industry over the past 30 years, with over 15,000 rigs operating in the area. As inshore resources have become fully utilized and deep sea drilling technology has developed, oil exploration beyond the continental shelf has become feasible and is increasingly commonplace. Oil industry activities, including seismic surveys and increased levels of ship traffic, are now impacting offshore areas that are believed to be important sperm whale habitat.

Underwater noise, including that from seismic exploration, sonar and shipping, has been shown to impact cetacean species. A number of observations have indicated that sperm whales are highly acoustically sensitive and are easily disturbed by unusual sounds. For example, sperm whales showed dramatic responses to military sonar signals in the Caribbean (Watkins *et al.* 1985), and in New Zealand their vocal behavior changed when whale-watching vessels were present (Gordon *et al.* 1992).

There is little direct information on the effects of oil industry noise on sperm whales. Some researchers have recorded quite dramatic responses: Mate *et al.* (1994) reported that sperm whales moved out of an area after seismic surveys began, while Bowles *et al.* (1994) found that sperm whales stopped clicking in responses to weak seismic pulses from a ship perhaps hundreds of miles away. Others, in contrast, have not been able to document such substantial effects (e.g., Swift *et al.* 1999). A number of unique features of sperm whale biology may make them particularly vulnerable to acoustic disturbance. They are highly acoustically-oriented animals and are vocal for most of the time that they are underwater on their long and deep foraging dives (Gordon *et al.* 1992; Jaquet *et al.* 2001). In addition to these vocalizations, which probably serve for short and long range echolocation, they produce complex patterns of clicks, called codas, which are used for communication. Their deep diving, complex social organization, and extended period of calf dependence may also contribute to a heightened vulnerability to disturbance.

Research on Free Ranging Sperm Whales

Sperm whales' offshore distribution and deep diving habit made them one of the most difficult of species to study in the field. Bill Watkins was an early pioneer who realized the importance of using passive acoustics as a means of finding and following sperm whales (Watkins and Moore 1982). A comprehensive research approach, which involved passive acoustics, and photo-identification, photo-grammetry was developed by Whitehead and coworkers (Whitehead and Gordon 1986, Leaper *et al.* 1992, Gordon 1990, 1991; Arnbom 1987). Crucial to the success of these studies was the use of modest motor-sailors as low-cost, non-disruptive, independent research platforms (Whitehead and Gordon 1986). This approach has been used by a variety of research groups in many parts of the world including Sri Lanka, Azores, Caribbean, Mediterranean, Canaries, Madeira, Canada, New Zealand, and the Gulf of California. Whitehead and his group have been particularly successful working around the Galapagos, where they have developed methods for investigating population size, social organization, movements and cultural structure (e.g. Jaquet and Whitehead 1996; Whitehead 1990, 1994, 1998, 2001a, b).

SWSS has incorporated many of these techniques into its core program, in particular the use of acoustics to find and follow whales. However, the exciting new telemetry projects that have become its main focus require a very substantial research vessel, which is not appropriate for the "traditional" sperm whale research approach and little time has been available for this sort of study. Nevertheless, during 2002, we were able to conduct photo-ID and observational work from a small Rhib as a secondary activity during the satellite tagging project. In addition, the process of finding and tracking whales for tagging provides us with both passive acoustic data and tracking information of sperm whale groups at a medium scale. Analysis of these data is at a preliminary stage, but we can provide an overview of data collected and some very preliminary results.

PRELIMINARY RESULTS AND DISCUSSION

Photo-Identification

Photo-identification images were taken from a small Rhib when opportunities allowed in the course of satellite tagging, and the tagging team also collected some images from the tagging vessel. Good quality images were compared with existing photographs in the North Atlantic and Mediterranean Sperm Whale Catalogue (NAMSC). Most GOM images within this collection come from the GulfCet and Sperm Whale Acoustic Monitoring Program (SWAMP) projects. Some 44 individuals were identified from images collected during SWSS 2002, bringing the total GOM catalogue to 102 individuals. (This remains a rather small collection for such an important area, a result no doubt of the lack of dedicated photo-identification research in the region.).

In a situation like this where new images are being compared to a very large existing collection (there are thousands of images in NAMSC), automated matching tools are extremely useful. During SWSS2002, we used and tested a prototype automated fluke matching program being developed by Dutch Scientists (Eric Pauwels and Adri.Steenbeek) as part of the Eurphlukes project.

Mark Recapture Population Estimate: Mark recapture analysis using photo-identification images can provide estimates of population size; indeed, the best current estimates of whale population sizes have been made in this way. Although the existing data are still rather sparse for such an analysis, we have used them to calculate a simple Peterson estimate for the population. This circulation indicates a population of 298 with 95% confidence intervals of 137 and 890. Low sample sizes mean that this estimate, however, is very imprecise. It is in general agreement, though a little lower than the population sizes indicated by visual surveys.

Defining what is meant by the term “population” is a knotty problem in any cetacean survey. Often, populations are determined according to management divisions rather than any biological relevance. Its interesting to note therefore that mark recapture studies conducted within an area of human influence such as this one provide an estimate of a “population” which is very relevant to management. In this case, photo-ID will provide an estimate of the number of animals that pass through the study area (and might thus be subjected to human activities) over the course of the field seasons.

Habitat Use and Site Fidelity: In spite of the low sample sizes, several resightings from previous years have been noted with one resighting over a period of eight years. Whales tend to be resighted close to their original sighting location as has previously been noted by Weller *et al.*, (2000)—but this may partly be a function of very geographically restricted research effort. (Further analysis of these data will be carried out in collaboration with the groups that collected the original data.)

Photogrammetry

It has been suggested that sperm whales in the Gulf are smaller than those in other areas; this could be a cause for concern, but no measurements of length have been made. Photogrammetric techniques have been used in previous studies to measure sperm whales, but they require a vessel with a mast or specialized stereo-photogrammetry equipment. We have been experimenting with simpler methods, compatible with conducting photo-ID from small Rhibs. Laser-range finding binoculars are use to measure the range to fluking whales; fluke width is then measured from images taken as the whale flukes up to dive. Only eleven individuals have been measured so far, but these preliminary data tend to support the contention that Gulf sperm whales are small.

Tracking of movements and Headings in Response to Seismic

During the 2003 field season, seismic airguns could be heard clearly at 52% of monitoring stations when the vessel was within what seems to be the whale’s preferred area (south of the Mississippi delta, between longitudes 88 and 90° W). Airguns and sperm whales were heard at 16% of monitoring stations.

The visual observers that search for whales, spot animals, and then guide the tagging boat to them during tagging sessions record the range and bearing to all sightings and also estimate the animal’s headings. In some cases, range is also measured accurately using video techniques (Gordon 2001). These data could provide medium-scale data on an animal’s responses to seismic surveys complimenting the very detailed data from digital acoustic recording tags DTAGs and the longer-term data from satellite tags (STAGs). The bearing to seismic pulses was measured using the Ishmael analysis program to compare arrival time at the hydrophones in the main towed stereo array, and these were compared with the net movements of the whale groups. At this stage there are no indications for whales to move away from seismic sources. However, a better analsyis could be conducted if the location and activity of seismic vessels in the area were known.

Coda Analysis

Codas are stereotyped patterns of clicks made by sperm whales in social situations. There is growing evidence that coda repertoires vary between different regions and between different social groupings. Indeed, an exciting new paper (Rendell and Whitehead 2003) suggests that coda repertoires reflect broad-scale cultural clans within sperm whales populations. The existence of such "cultural" population structure could have important management consequences. Clans may differ in experience and in many learned behaviours, for example, in the way they respond to perturbations such as human activity. These indications of "cultural" population structure complement the insights on population structure that genetic analysis can provide.

Again, we are at a preliminary stage of analysis but indications are that the coda repertoires of GOM sperm whales are quite different from those in the Azores and strikingly distinct from codas recorded in the Windward Islands.

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Jonathan Gordon is as biologist who has studied sperm whales at sea for over 20 years with a particular interest in their social organization and acoustic behavior. Much of this work has been conducted from small independent boats using techniques such as passive acoustic monitoring and photo-ID. Dr. Gordon has been involved with the first Sperm Whale Acoustic Monitoring Program (SWAMP) and now the Sperm Whale Seismic Study (SWSS) to explore how these methods can be applied to learning more about sperm whales in the Gulf of Mexico and how they interact with offshore oil related activities. When not in the field, he is based in Scotland working from a small consultancy, Ecologic. He is also a member of the Sea Mammal Research Unit at St. Andrews University.

Nathalie Jaquet received a B.S. in natural science at Lausanne University and a M.S. from Aberdeen University. Her doctoral work at Dalhousie University involved the distribution of sperm whales in the South Pacific. From 1997 to 2001, Dr. Jaquet was a postdoctoral fellow at Otago University in New Zealand, where she investigated the acoustic behavior of sperm whales. She is currently a postdoctoral fellow at Texas A&M University in Galveston and is researching the vocal behavior of large mature male whales in the Gulf of California.

IDENTIFYING THE SEASONAL DISTRIBUTION OF SPERM WHALES IN THE GULF OF MEXICO WITH SATELLITE-MONITORED RADIO TAGS

Dr. Bruce Mate, Oregon State University, Hatfield Marine Science Center

BACKGROUND

Knowledge of the seasonal distribution of sperm whales has been limited to stranding data and by the expense of logistics for recent aerial and vessel-based surveys, the Cetaceans in the Gulf of Mexico (GulfCet) program and Sperm Whale Acoustic Monitoring Program (SWAMP). These surveys identified a few “hot spots” of seasonally concentrated sperm whales in the vicinity of the Mississippi Canyon and Delta region, as well as DeSoto Canyon. In 2001, a 10-day cruise for tagging sperm whales was restricted by Tropical Storm Barry to just 3.5 days of operation. Four tagging attempts resulted in one successful tagging. That whale spent 95 days in the Northern Gulf-from eastern Louisiana to western Florida-generally along the slope edge and roughly along the 900 m depth contour. The whale then traversed the upper Gulf in 23 days, traveling at an average speed of 3.7 km/h and an average distance of 191 km from shore over waters up to 3000 m deep ($\bar{x}$ = 1677 m) to arrive in the Gulf of Campeche (Mexico), where 19 days of activity were recorded before the tag’s batteries were exhausted. Dive rates were highest during the high-speed directed movements as the whale moved from the upper Gulf to Mexico.

ANALYSIS OF 2001 TAGGING DATA WITH SEISMIC SURVEY DATA

An analysis was done on the movements of the 2001 S-tagged whale during the time a single seismic vessel, the Polar Search, was active in the same general vicinity off the Mississippi Delta (data courtesy of Phil Fontana, IAGC). Because of the tag’s low duty-cycle (4 h/d) and the polar orbiting nature of satellites carrying Argos receivers, we obtained an average of only 1.7 locations per day. Thirty-four percent of those were of excellent location quality (with location error of <150 m to 1000 m). Using these, there was only a single day when two locations were determined <30 km from the vessel track line but within 10 hours of each other. The locations were 45 minutes apart and showed the whale moving away from the vessel’s track at a speed of ~3.7 km/h. This single “sample” is too small to warrant serious attention. The whale’s locations were an average of 46.7 km from seismic track lines (range 6.6 to 133.0 km), but these cannot be interpreted as either tolerance or flight from seismic activities. On the large scale, it is obvious that the whale did not leave the general Mississippi Delta region during the seismic surveys.

2002 STUDIES

At its completion, the track of a single whale in 2001 constituted 95% of everything known about the movements of individual sperm whales in the Gulf and became the model (expectation) around which 2002 tagging studies were planned. Improvements in tag attachment techniques and changing the tag’s transmission schedule provided the opportunity for tags lasting up to one year. Multiple duty cycles were incorporated to 1) provide locations every third day for the first 55 days; 2) operate daily for 35 days (starting five days before the D-tag experiment); and 3) then provide locations every fourth day to extend operation as far into the rest of the year as possible.

The cruise to apply satellite-monitored tags ran from 19 June to 9 July 2002 aboard the Texas A&M research vessel Gyre, starting from Galveston, Texas and ending in Gulfport, Mississippi. It included visual and acoustic survey efforts along a saw-tooth pattern, generally centered along the 1000 m contour, as well as photo-identification and behavioral studies once whales were found. We did not see whales during the first four days due in part to poor weather. When the weather improved, whales were not sighted consistently.

Eighteen sperm whales were tagged during the cruise between 24 June and 7 July. Location data were received from all of the tags. Because sperm whales rest at the surface for prolonged periods (usually >10 minutes) after long dives (often > 40 minutes), higher quality locations are achieved with this species than for any other large whale tracked by satellite thus far. Only two tags were not deployed completely, and these were the only tags to last <60 days. At this writing, six months after tagging, eight tags are still operational. So far, the 18 whales have been tracked >47,000 km during 2286 tag-tracking days and individuals have moved >4600 km. Tagged whales have ranged over most of the upper Gulf, from Florida to the U.S./Mexico border with a strong preference for slope and canyon regions. However, several individuals have gone offshore into waters more than 3000 m deep. None of the whales has yet gone into the Gulf of Campeche, begging the question as to whether this contrast to last year's tagged whale is due to individual variability or year-to-year variation in the Gulf environment (possible El Niño effect). Many interesting observations on social structure have been made, especially in relation to the composition of pods, their geographic range and temporal stability, which may be unique to the Gulf.

Continued analyses will include more detailed assessments of the type revealed here and tendencies for whales to associate with temporal oceanographic features (SST from AVHRR, Chlorophyll concentrations from SeaWifs, cold and warm core rings identified from TOPEX data. Analyses are ongoing and preliminary at the present time as the experiment is still under way, so data should not be quoted without consulting the principle investigator.

PLANNING FOR 2003 FIELD WORK AND BEYOND

In planning for 2003, more focus could be directed at the seismic effects objectives of the Sperm Whale Seismic Study (SWSS) at a variety of spatial and temporal scales: 1) present Argos tags can be programmed with a different duty cycle to achieve higher resolution (more locations per day), but at the sacrifice of longer-term seasonal distribution data; 2) a depth-sensing S-tag (presently under slow development because it is not funded) could describe the whale's use of the water column over a period of 4 months. These intermediate-duration tracks with summaries of dive activities (depths, durations, surface times, percent of time in specific depth strata) would be useful in estimating sperm whale exposure to seismic sounds. The technology is similar, but smaller, to that used by Krutzikowsky and Mate (2000) in their bowhead whale study; 3) with additional funding, a GPS-linked Argos tag can be developed for the 2004 field season, which would provide one or more precise locations after every long dive (~36/d) for up to about 40 days. Such precision, resulting in directional vectors, could produce useful information for evaluating the responses of whales to seismic surveys in either a controlled-exposure experiment (CEE) or by analyzing seismic vessel operations, which happen to occur in the vicinity of tagged whales. A CEE is the only way to assure that an adequate sample size of such circumstances would be achieved for a definitive analysis of "immediate response."

Bruce Mate holds an endowed chair at Oregon State University, where he directs the OSU Marine Mammal Program at the Hatfield Marine Science Center. He has served as a Scientific Advisor to the U.S. Marine Mammal Commission and the U.S. Department of the Interior's Outer Continental Shelf Development Program; a Scientific Expert to the International Whaling Commission and the United Nation Environmental Program; and a member of the International Union for the Conservation of Nature's Species Survival Commission. Dr. Mate has studied the migrations of marine mammals since 1968 and pioneered the tracking of manatees, dolphins and large whales with satellite-monitored radio tags. With collaborators, his research group has tracked nine stocks of seven large whale species in six different oceans/seas, including equatorial, Arctic and Antarctic regions. His specialty is the identification and characterization of seasonal habitats for endangered whales and how they migrate between them.

ANALYSIS OF SPERM WHALE VOCALIZATIONS FROM A TOWED PASSIVE ACOUSTIC ARRAY

Aaron Thode, Marine Physical Laboratory, Scripps Institution of Oceanography

The 2002 Sperm Whale Seismic Study/Digital Acoustic Recording Tag (SWSS DTAG) cruise on the R/V Gyre contained an onboard passive acoustics team, comprising Natascha Aguilar de Soto, Matt Howard, Aaron Thode, and Sarah Tsoflias. The acoustics team had both short-term “tactical” and long-term scientific goals. The tactical goal was to perform real-time monitoring and tracking of sperm-whale sounds, to guide the tagging vessel to areas where tagging could be performed, starting at first daylight. Potential longer-term scientific goals included 1) an analysis of the possible effects of the tagging boat on acoustic contact times for individual whales, and 2) passive 3D acoustic tracking of the animals at close ranges, either by combining acoustic tag data with towed array data, or by deploying two towed arrays simultaneously. The tactical role was performed well, despite equipment failures and limited tracking range due to poor acoustic propagation conditions. Some of the scientific goals were also demonstrated to be achievable in principle.

Herein is contained a brief description of the acoustic system, an analysis of potential correlations between acoustic contact times and presence of tag boat, and a proof-of-concept demonstration of passive range-depth tracking using two arrays, for possible use in extending analysis of tagging effects to baseline behavior.

ACOUSTIC EQUIPMENT AND PROCEDURES

The acoustics team used two arrays: a three element “WHOI” (Woods Hole Oceanographic Institution) array with ~150 m of cable terminating in a tow-fish instrumented with a pressure/depth sensor, and a two-element “Ecologic” array with 300 m cable. Both arrays had been previously used on the satellite tags (STAG) cruise. A variety of software was used for the real-time tracking. The primary monitoring tool was Rainbowclick, developed by Doug Gillespie at the International Fund for Animal Welfare (IFAW). When fewer numbers of animals were present, or the acoustic contacts were faint, the program Ishmael, developed by David Mellinger of Oregon State University, proved very useful. To record notes and record signals to hard disk, the program Logger 2000 was used, also written by Doug Gillespie of IFAW. Arrays were monitored 24 hours a day and were deployed during 20 of 25 days at sea. The only time when arrays were out of the water was during long-distance transits, when large distances needed to be covered.

A fundamental performance metric of an acoustic tracking system is the maximum range at which signals of interest (e.g. sperm whales) can be detected above the background noise level. Twice during the cruise, experiments were performed to estimate the detection range of the arrays. Results of two separate detection range tests suggested an effective detection range of about 4 km at 4 knot tow speed for both arrays. Acoustic modeling of sound propagation in the region using the normal mode code KRAKEN produced similar detection range estimates and suggested that deep sensors would have a detection range of around 10 km.

ANALYSIS OF ACOUSTIC CONTACT TIMES

Tagging an animal is an intrusive process, and it remains unknown to what degree, if any, the effect of tagging or the attached tag has on fine-scale animal behavior. Ideally, detailed visual and acoustic observations of a single "focal" animal should be made prior to tagging, but establishing a long-term acoustic follow was difficult in the Gulf, however, because of the large number of animals present at any given time, and the emphasis placed on placing tags as quickly as possible. Instead, the acoustic team investigated two alternative approaches for statistically measuring baseline dive behavior of untagged animals: statistical analysis of acoustic contact times and the use of 3D passive acoustic tracking to measure descent rates and maximum dive depths.

Figure 2C.4 shows computed distributions of all daylight acoustic contact times, considered here as a proxy of animal dive times. Contact times have also been broken down into times where the tagging boat was in or out of the water. The wide variance in acoustic contacts, particular the large number of 10-minute and 2-hr+ contacts, is not an accurate measure of the true distribution of animal dive times for two reasons. First, during a large fraction of the daytime observations, the visual observations and tagging operations had control of the ship, so the passive acoustic monitoring was not able to position the vessel to optimize acoustic tracking. As a result, acoustic bearings often merged, split, or faded away before the start or end of a dive could be ascertained, biasing the data toward short dive times. Second, Thode made an early decision to focus most monitoring effort during the day, with much more casual monitoring protocols during the evening. In retrospect, this decision was probably a mistake, in that higher-quality dive time measurements could have been made at night, when acoustics had control of the ship motion.

Despite these confounding factors, a distribution of dive times with a center moment between 30-40 minutes is visible in the data. The problems with a relatively small sample size are starkly visible here in the form of wide histogram bin widths, so it appears that multiple years of data would need to be collected to establish a sufficient sample size to make statistically significant conclusions about potential tagging effects on animal dive time. That said, to within the uncertainty caused by the small sample sizes, there seems to be no obvious difference caused by the deployment of the tagging boat.

PASSIVE ACOUSTIC RANGE-DEPTH TRACKING FOR PRE-EXPOSURE STUDIES

Passive acoustic 3D localization of sperm whales provides another possible approach for measuring baseline diving behavior, before exposure to tagging and/or seismic operations. This approach, if successful, could yield behavioral parameters besides total dive time that could be compared with data collected by the tag, including initial dive descent rate, maximum dive depth, and location of an animal during certain acoustic events. In theory, only two hydrophones, deployed with a 100–200 m aperture, are needed to make range-depth measurements, by exploiting surface echoes to create a virtual planar array. To obtain azimuth a third hydrophone needs to be placed adjacent to one of the other two. The tracking performance would be poor whenever the animals are broadside of the arrays, but much better whenever the animals are directly ahead or behind the ship.

On 5 September 2002, both arrays were deployed to explore whether range-depth localizations could be achieved with the array hardware. Four hours of data were collected for analysis, and the best result over a fifteen-minute period between 22:15 and 22:30 is shown in Figure 2C.5. The red and green tracks were obtained from whales forward of the ship, while the blue track was derived from a whale broadside to the arrays, which yielded an unstable inversion, as is apparent from the figure.

The computed whale depths in Figure 2C.5, 200 and 300 m, are shallower than what one would expect from standard sperm whale dives, but several tagged animals dove to similar depths during a similar time period. More convincing, the descent rates of the animals obtained from the depth subplot are 91 and 96 meters per minute, respectively. A tag deployed on an animal from the same group the following morning (249a) had descent rates of 88 and 79 meters per minute for the two dives recorded. Thus the passive acoustic trajectory estimates are consistent with tag measurements, and the feasibility test seems successful. The key to the success of the technique is a wide separation between the two arrays, and a quiet ship, so that the whales' baseline behavior is not disturbed by platform noise. Both conditions were not quite met during the present cruise, but if appropriate equipment is available in the future, passive 3D tracking may provide additional pre-exposure data on the baseline behavior of tagged and untagged sperm whales.

Aaron Thode studied physics and electrical engineering at Stanford University before obtaining a Ph.D. at the Scripps Institution of Oceanography in 1999. After a post-doc in the Massachusetts Institute of Technology Ocean Engineering Department, he obtained a research position at Scripps in 2002, where he was awarded the Office of Naval Research Acoustic Entry-Level Faculty Award (2002). Dr. Thode's research interests include acoustic inversion methods, advanced acoustic tracking algorithms, and bioacoustics. He has been involved in sperm whale acoustic research since 2000, collecting towed array data during the Sperm Whale Acoustic Monitoring Program (SWAMP) and SWSS projects.

DIVING BEHAVIOR OF D-TAGGED SPERM WHALES

Patrick Miller, Peter Tyack, Mark Johnson,
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The digital acoustic recording tag (DTAG) was developed to enable controlled exposure experiments for deep divers:

1. To track responses of marine mammals, especially deep divers, throughout their dives,
2. To improve understanding of functions and costs of behaviors in order to infer biological significance of behavioral disruption,
3. To develop dose: response technique to measure received level of stimulus at whale while also measuring behavioral and physiological responses.

The scientific literature regarding the effects of airgun sounds on sperm whales is limited and largely consists of anecdotal observations suggesting that animals silence or move away from survey vessels. Such naturalistic observations are potentially biased and provide little information to help us understand the biological significance of observed reactions. Experimental exposure of animals to carefully controlled sounds, while recording the response of the whale on a state-of-the-art digital recording tag (DTAG), may allow us to 1) observe even subtle responses by whales to noise; 2) evaluate the effect of the noise level on the likelihood of disturbance; and 3) infer the biological significance of disturbance reactions.

We combined findings from SWSS '02 and previous sperm whale tagging cruises to describe the diving behavior of sperm whales. During SWSS '02, we tagged at total of 19 sperm whales with the suction-cup attached DTAG, and recorded at least one deep dive from 14 whales. On-animal recording time totaled 76 hours or more than 13 Gigabytes of data recording animal movement and sounds heard and produced by the whale.

The rich acoustic data-set recorded by DTAG includes natural and man-made sounds including seismics with received levels up to 143 dB re 1 Pa. Natural sounds include: codas, that often lead to physical contact between whales; regular clicks, that produce audible echoes from the sea-surface and sea-floor; and rapid-series clicks called “creaks” that appear to mark prey-capture events. Echoes from the seafloor can be used to identify different foraging modes, “open-water” and “bottom” foraging. Previous work during the Sperm Whale Acoustic Monitoring Program (SWAMP '01) suggested that animals might specialize in one foraging strategy. Bottom-foraging was exclusively observed in one animal, “Deep-Dan,” tagged in DeSoto Canyon. The data from SWSS '02, however, showed a significant number of animals employing a mixed feeding strategy. These animals combined open-water and bottom foraging in the same dive, suggesting flexibility in hunting techniques and prey choice. We suggest that the whales make use of echoes to orient to the sea-bottom, and also to the sea surface.

With the addition of 14 deep-diving animals recorded during SWSS '02, we have found greater diversity in swimming patterns during descent and ascent. The most common pattern is limited gliding (<10%) during descent, and extensive gliding (>40%) during ascent. Certain whales, however, made prolonged ascent glides of over 350 m after steady fluking during descent. Others glided extensively during descent, but fluked steadily on the ascent. Based on our model of animal drag, air-buoyancy, and tissue buoyancy forces acting on gliding sperm whales, we suggest these different fluking patterns result from differences in tissue buoyancy. The most likely explanation is that these swimming patterns reflect differences in fat stores carried by the tagged whales. Our model of forces acting on sperm whales is useful to explain these swimming behaviors and provides a quantitative index of the effort expended by animals to forage at depth.

Data from SWSS '02 also confirms our earlier finding that rapid-series “creaks” occur at outlier points on the depth record during deep dives. Also, animal movement roughly doubles at the end of creaks. This pattern of behavior supports the hypothesis that creaks mark the capture phase of foraging. While every capture event may not be successful, creak-rates over whole dives are likely to correlate with feeding by the whale. Thus, we propose to use creak-rates as a measure of feeding disruption during controlled exposure experiments.

The SWSS '02 data set is rich in social “coda” sounds, and the coda exchanges commonly result in approach and physical contact between whales. We were able to conduct one successful trial of a coda playback in SWSS '02. The tag recorded the unfamiliar Mediterranean coda as the whale ascended after a 40-minute dive. The tagged whale and other nearby whales produced extensive codas during the subsequent surfacing. More replicates of these playbacks are needed to experimentally explore how sperm whales use codas to communication and how noise might affect this type of communication.

A significant breakthrough in SWSS '02 was the first simultaneous tagging of multiple sperm whales with DTAGs. Our primary motivation for tagging multiple animals is to increase the chance that a tag will stay on a whale for sufficient time to conduct a controlled-exposure experiment (roughly 5 hours). Based on longevities of 40 tag deployments, 50% of tags that stay on for an hour remain attached for 5 hours or more. Thus it is critical to attempt to tag multiple animals prior to conducting a controlled exposure experiment.

Simultaneous tagging of multiple animals also has revealed a promising new technique to study social coordination and communication in sperm whales. Measure of dive synchrony, underwater spacing, and acoustic exchanges enable a much more powerful study of natural social behavior in sperm whales. This knowledge will help up to understand the biological consequences of disturbance by noise sources.

Patrick Miller is a Royal Society International Fellow based at the Sea Mammal Research Unit at the University of Saint Andrews, Scotland. Dr. Miller also maintains guest affiliations at the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution where he is a co-Principal Investigator on the DTAG portion of the SWSS project. He received his Ph.D. in 2000 from the Woods Hole Oceanographic Institution/Massachusetts Institute of Technology Joint Program in biological oceanography for research on the design and use of acoustic signals by killer whales. Dr. Miller has also been involved in several studies of the effects of noise on marine mammals, including the LFA scientific research program.

Peter Tyack is a Senior Scientist in the Biology Department of the Woods Hole Oceanographic Institution. He obtained his A.B. summa cum laude in biology from Harvard College and his Ph.D. in animal behavior from Rockefeller University. He joined the Woods Hole Oceanographic Institution as a Postdoctoral Scholar in 1982 and has worked there ever since. Dr. Tyack is interested in social behavior and acoustic communication in whales and dolphins and has conducted research on bottlenose dolphins, sperm whales, humpback whales, gray whales, right whales and bowhead whales. He has focused on developing new techniques to monitor vocal and social behavior of marine mammals. These include methods to tag whales, to locate their calls and for video monitoring of behavior. His research has focused on how these animals use sound for critical activities. This made him sensitive to the possibility that human-made sounds might pose a risk to marine mammal populations by disrupting critical behaviors. He has been involved in the design, planning and field work for a series of experiments investigating the possible impact on marine mammals of human-made sources of noise. The DTAG developed by Tyack and Johnson will enable similar experiments with deep diving whales whose behavior has been impossible to study.

Mark Johnson is a Research Engineer at Woods Hole Oceanographic Institution. Dr. Johnson has a Ph.D. in electrical engineering from the University of Auckland, New Zealand. His research interests include real-time digital signal processing for acoustics applications in communications, environmental monitoring, and marine mammalogy.

MOLECULAR ECOLOGY OF SPERM WHALES (*PHYSETER MACROCEPHALUS*) IN THE NORTHERN GULF OF MEXICO

Dan Engelhaupt, University of Durham, Durham, England

BACKGROUND

Several fundamental genetic related aspects for endangered sperm whales occurring in the northern Gulf of Mexico (GOM) were assessed during the 2000–2002 Sperm Whale Acoustic Monitoring Program (SWAMP) and SWSS cruises. A deeper understanding of the population structure and social structure of sperm whales using genetic techniques is presently being integrated with a variety of ongoing research projects such as digital acoustic recording tagging (DTAG), satellite-monitored radio tagging, distribution and abundance estimates, habitat use patterns, and behavioral information to help establish realistic conservation and management strategies for these whales. In addition to providing important gender information for whales that have been satellite and DTAG tagged, our project provides essential data on social and population structure required to fully assess the impacts that the oil and gas industry and seismic exploration may have on endangered sperm whales occupying potentially critical habitat areas in the northern Gulf. Sperm whales are highly social whales that occur in small clusters to large aggregations, in many cases, maintaining long-term bonds between female group members. Their dependence on acoustic communication between members and use of echolocation when feeding at depth make them vulnerable to anthropogenic noise. Could an outside noise influence disturb the dynamics of the group, or on a much larger scale, the population over time? The quantity and quality of knowledge gained from the combination of genetic (via degrees of relatedness among associates), satellite-monitored radio tagging, and behavioral studies provides the essential components to accurately describe social structure on a detailed scale. The original designation of a single Gulf sperm whale stock that is separate from the adjacent Atlantic and Caribbean is thought to be conservative. Stocks must be defined using several parameters, including genetics. Once stocks are defined, human-caused disturbances or mortalities that occur to a stock can be managed appropriately. Such information is vital for creating meaningful management strategies for these animals in general, and relative to petroleum exploration and production in particular.

SWAMP AND SWSS CRUISE SAMPLE ANALYSES

Tissue samples were collected during both SWAMP and SWSS cruises throughout 2000, 2001, and 2002. Overall, 89 individuals (including satellite-tagged, DTAG tagged, opportunistic, and stranded whales) were genotyped using both mtDNA and microsatellite techniques. Gender was determined for nearly all of these samples using molecular sexing techniques.

Population Structure & Male-Mediated Paternal Gene Flow

A comparative analysis of matrilineal mtDNA and biparentally inherited nuclear genetic markers (microsatellites) have begun to show population structure for female lineages, which is expected given previous findings on social and reproductive behavior in this species. Nuclear DNA variation across oceans appears non-significant, suggesting males disperse and spread their genes to the more site-faithful females. Of particular interest are four individuals located within three separate geographic regions (the Gulf of Mexico (N=2), Mediterranean Sea (N=1), and the North Sea (N=1)) that appear to be paternally related at the level of half-siblings. This trans-oceanic paternal gene flow concept provides genetic evidence that sexually mature males may be ranging over 12,000 km to breed with females from multiple geographic populations.

Group Structure

Members of 'groups' were predominately females, although some groups appeared to contain only males (suggesting that bachelor groups may reside in the Gulf). During the 2002 SWSS cruise, multiple members from two groups of whales (Group 3 & 5) were tagged with satellite transmitters and subsequently biopsy sampled for genetic analyses. Relatedness levels for each satellite-tagged group (and groups in general) suggest that the overall group is often unrelated, although groups did contain related whales. mtDNA analyses showed that groups are composed of both single and multiple matrilines, which combined with the relatedness levels, may provide additional evidence to the idea of 'constant companions and casual acquaintances' among sperm whale groups.

FUTURE GOALS FOR 2003

Genetic techniques supply a powerful set of detailed data that can be directly integrated with both the movements of satellite tagged whales and the dive profile data of D-tagged whales. The gender of a tagged whale may prove crucial to improve our understanding of movement patterns and dive profile data (i.e. do males and females react differently to anthropogenic noise influences?). Simple modifications are underway to provide a skin sample from all whales tagged with DTAGs. This procedure will significantly increase our dataset with very minimal additional effort or cost. Future work will continue to build on previous year's population and social structure results by incorporating biopsy sampling with both satellite-tagging and opportunistic sampling of whales (particularly focusing on whales of sexually mature size). This population has already been subjected to many years of human activity, and there is likely to be major oil-related activity offshore here for many years to come. Social organization is an important component for sperm whale survival yet seems vulnerable to disruption by disturbance. Understanding sperm whale social organization in this putative population before it is exposed to any more disturbance, and exploring whether it is affected by offshore activity is thus a priority. To increase the resolution for population structure and trans-oceanic gene flow analyses, we recommend sampling sperm whales located in additional geographic areas. A continuation of the genetic components previously described will maintain both the quality and quantity of information required for management purposes.

Dan Engelhaupt is in the final stages of his Ph.D. at the University of Durham, England. His field of study includes the assessment of population structure and social structure for endangered species, with a particular emphasis on sperm whales. Over the past three years, as part of the Minerals Management Service sponsored SWAMP and SWSS projects, he has examined the genetic variation and social structure of endangered sperm whales with a particular focus on putative 'populations' in the northern GOM, Mediterranean Sea, and the North Atlantic Ocean using a suite of molecular techniques. He is currently collaborating with a number of other researchers to provide an accurate sperm whale dataset so that management can effectively oversee sperm whale populations that exist in areas of anthropogenic noise.

ACOUSTIC CETACEAN MONITORING ON THE ATLANTIC MARGINS 1996 TO 1998

Douglas Gillespie, International Fund For Animal Welfare

INTRODUCTION

Twenty different species of cetacean are found in UK waters. Cetaceans are acoustically orientated animals, using sound both actively and passively to communicate, to navigate and to find food. The intense sounds produced by the air guns used during seismic surveys are capable of disturbing and potentially harming cetaceans. UK government guidelines stipulate that seismic survey activity should not start if cetaceans are known to be within 500 m of an airgun array. They also require a soft start, whereby gun power is ramped up over a period of 20 minutes so that any cetaceans still in the vicinity can move out of the way.

Many species of cetacean are hard to spot even in ideal sighting conditions. On the other hand, the sounds that they make can often be heard over considerable distances. The purpose of this project was to investigate the potential of passive acoustic monitoring for cetaceans in the vicinity of seismic vessels and to develop detection equipment that would be appropriate for offshore seismic surveys, would be largely automatic, require the minimum of operator intervention, and would be easily reproducible.

Although they recommend the use of hydrophones to detect marine mammals, the guidelines were primarily designed for visual observers stationed on the seismic vessel itself. For a number of reasons it was impractical to deploy the cetacean monitoring hydrophone from the seismic vessel, so acoustic monitoring took place from a guard vessel stationed approximately 1 mile ahead of the seismic vessel. Monitoring would start 65 minutes before a line start. At a typical survey speed of 4 knots, the seismic vessel would be in the middle of a cetacean free corridor 20 minutes before it reached the start of the line and could start the slow ramp up of its guns.

Equipment was tested at sea for a period of one or two months each summer during 1996, 1997 and 1998. The types of vocalization made by cetaceans are many and varied and the level of information that can be extracted from an acoustic detection depends on the type of vocalization. For instance, the regular clicks of sperm whales allow accurate positions for that species to be determined. For faster-moving species traveling in groups (many species of dolphin) it is still difficult to determine position, and acoustic information can currently only reliably indicate presence/absence.

AUTOMATIC ACOUSTIC DETECTION SYSTEM

Due to the considerable variation in the types of sounds made by different cetacean species, there is not a single detection system which can be sensitive to the sounds made by all of them. Cetacean sounds were therefore divided into four broad categories:

1. Mid-frequency (200 Hz to 20 kHz) clicks (sperm whales and pilot whales)
2. High-frequency (> 20 kHz) clicks (harbor porpoises)

3. Mid-frequency (200 Hz to 20 kHz) whistles (Many dolphin species)
4. Low-frequency (< 500 Hz) tones (many baleen whales)

A different detector was developed for each of the first three categories of sound. Due to the problems of detecting low-frequency sounds in a noise environment which was in itself predominately low frequency, little attempt was made to detect sounds in the last category.

To avoid a single operator from having to monitor the output of three separate detectors, an additional program was written to collect data from the three detectors and display information in summary form. This program also collected GPS data and stored that, along with information from the detectors, in a database for later analysis. The complete detection system in shown schematically in Figure 2C.6. Further details of the mid- and high-frequency click detectors can be found in Gillespie 1997 and Gillespie and Chappell 2002 respectively. During development, each component of the monitoring system was run on a separate computer. A modern implementation consists of a single 19" electronics rack just 32 cm high, and all software can run on a single PC compatible computer.

MONITORING EFFICIENCY

During the surveys, visual monitoring was conducted from the bridges of both the seismic and guard vessels. On occasion, dedicated observers were employed, but generally the observations were made by the vessel's crew. (This situation has not changed, and dedicated observers are present on all seismic vessels.) Particularly on the guard vessel, one of the crew's main jobs was to look for objects in the water which might damage the seismic vessel's streamers so they should have been efficient at spotting cetaceans. Members of the acoustic monitoring team were generally asked to provide species identification.

Figure 2C.7 shows the visual and acoustic detection rates from the seismic vessel *Mintrop* and guard vessel *Antares* in 1997 and acoustic detection rates from the *Antares* for various species groups. It can be seen that the visual detection rates are slightly higher from the *Mintrop* than from the *Antares*. This may be due to the increased eye height on board the seismic vessel. The acoustic detection rate is considerably higher for all species groups, except baleen whales which, as mentioned above, produce predominately low-frequency vocalizations which are hard to detect acoustically.

Overall, the acoustic detection rate during good sightings conditions was over six times higher than the visual detection rate. Since many of the sightings were only made in response to an initial acoustic contact (Figure 2C.8), it is likely that the benefits of acoustic verses visual monitoring are even greater.

OTHER APPLICATIONS FOR ACOUSTIC MONITORING

The sperm whale detection and analysis software was originally developed to study the acoustic behaviour of sperm whales in response to ATOC-like sounds during play back experiments. The software continues to have applications in the study of vocal behavior and disturbance, particularly since it can separate out the clicks from different whales when several are vocalizing simultaneously. It may also be used for the study of codas (stereotyped sequences of between 3 and 40 clicks, usually lasting less than 3s in total—Watkins and Schevill 1997). Recent research (Rendell and Whitehead 2003) suggests that patterns of coda usage may be useful as in indicator of population social (or ‘clan’) structure in this species.

The sperm whale detection program has also successfully been used to carry out abundance surveys for sperm whales (Leaper *et al.* 2000). Since sperm whales are relatively slow moving, vocalize for a high proportion of the time, and can be detected several miles away, it is possible to use successive bearings to individual whales to calculate a position for each animal. The distances from the survey track can then be computed and a standard line transect approach (Buckland *et al.* 1993) used to calculate an estimate of abundance.

DISCUSSION

Acoustic monitoring proved considerably more effective than visual monitoring alone for detecting cetaceans in the vicinity of seismic survey vessels. The detection system was automated using three different detectors for different types of sound. The level of information varied with species. Sperm whales could be tracked to accurate positions. Other species, particularly fast-moving ones such as dolphins, could not be reliably located. Since the seismic operators were only interested in whether or not cetaceans were with 500 m of their vessel, the lack of accurate position information led to considerable problems in interpreting the guidelines. It is possible that in the future, detectors will be developed which can provide the additional information. Modifying the start-up procedures to take into account imperfect information would, however, be more practical, particularly in the short term.

UK guidelines only apply to gun start-up periods and do not require any action on the part of the seismic operators should cetaceans be detected within 500 m of the guns after they have started. There is in these guidelines an implicit assumption that if animals do not move away, they cannot be coming to any harm. The reasons for an animal’s being at a particular location are many; there could be an overriding nutritional or social reason for an animal to stay put that is greater than any urge to move away. An additional unwanted effect of this part of the guidelines is that if cetaceans were known to be in the area, operators would leave their guns running during turns, thereby increasing the total amount of noise input to the ocean and increasing disturbance.

The detection system was not capable of detecting baleen whales, which vocalize at low frequencies that were generally masked by the high levels of background noise from the guard vessel and seismic vessels engines. Fortunately, most baleen whale species are more visible at the surface than many odontocetes and could therefore be detected visually (except at night and in inclement weather). Acoustic monitoring should therefore be considered a complement to visual monitoring and not a complete replacement.

Mitigation over a 500 m radius circle around an airgun array may be beneficial in reducing the risk of physical injury to cetaceans. However, it does nothing to reduce disturbance of animals outside this zone. There are a number of practical difficulties inherent in monitoring either visually or acoustically over a large area. The most effective way of protecting marine mammals is to operate airguns at the lowest practical source level. For instance, assuming a 20log(r) transmission loss (spherical spreading), a 10 dB reduction in source level will reduce the sea area exposed at or above a particular received level by a factor 10 (for 10log (R) (cylindrical) spreading, the area exposed would be reduced by a factor of 100). On average therefore, the number of animals exposed will also be reduced by a factor 10. Beyond the range at which monitoring is practical, and for species that are hard to detect, reductions in source level would be the most effective way of reducing disturbance. Even where monitoring is taking place, such a reduction in source level would as effective as 90% efficient monitoring.

ACKNOWLEDGMENTS

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Douglas Gillespie received a B.Sc in physics with electronics from the University of Bath, UK, and a Ph.D. in particle physics at the University of Liverpool. Following a fellowship at the European Centre for Particle Physics in Geneva, Dr. Gillespie started to work on the automatic detection and tracking of marine mammal sounds. He has developed a suite of detectors for tracking different marine mammal species that have applications in population surveys, studies of vocal behavior and mitigation against anthropogenic threats. He currently works for the International Fund for Animal Welfare.

SESSION 2D

GULF OF MEXICO CONTINENTAL SLOPE STUDIES AND SURVEYS

Chair: Robert M. Avent, Minerals Management Service
Co-Chair: Gregory Boland, Minerals Management Service

Date: January 15, 2003

OBSERVATIONS OF *LOPHELIA PERTUSA* AND SURFICIAL GEOLOGY AT TWO DEEPWATER SITES IN THE NORTHEASTERN GULF OF MEXICO

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Moore and Bullis (1960) were the first to report *Lophelia pertusa* (= *L. prolifera*) from the Gulf of Mexico (GOM). Their collection site was on the continental slope about 74 km east of the Mississippi River Delta in the vicinity of 29°05'N, 88°19'W in 420–512 m. Since then, additional reports of *Lophelia* in the GOM have been published by Cairns (1979), McDonald *et al.* (1989) and Schroeder (2002). In addition, Newton *et al.* (1987) described Late Pleistocene age *L. pertusa* buildups on the west Florida carbonate ramp slope at depths of 500 m. While the extensive *Lophelia* reefs and banks off the coasts of Europe have been well studied (for example see: Joubin 1912; Pratje 1924; Dons 1944; Ekman 1953; Mortensen *et al.* 1995, 1998, 2000), very little information is available about deepwater *Lophelia* communities in the GOM. This paper presents an overview of what is currently known about the morphology and distribution of *L. pertusa* and of the associated surficial geology at two deepwater sites in the northeastern GOM.

The first site is a low-relief mound on the upper DeSoto slope at approximately (29°09.5'N/88°01.0'W) in the SW corner of Viosca Knoll lease block 826 (VK826). The mound rises up to 90 m above the surrounding seafloor to a depth of about 430 m. Bottom sediments consist of unconsolidated clay, silty clay, disarticulated shells and shell hash, and authigenic carbonate deposits that have formed in conjunction with biogeochemical activity associated with hydrocarbon and associated fluid seepage (MacDonald 1992). Ranges of near-bottom temperature, salinity, and dissolved oxygen values, obtained from seven vertical profiles over the period 11/97 to 11/99 in the vicinity of 29°12'N/87°52.8'W (or approximately 13 km east of the study site), were 7.0–9.3 C, 34.9–35.1 psu, and 2.6–3.2 ml L^{-1} respectively (unpublished USDI-MMS data).

Schroeder (2002) published observations of *Lophelia* and of the surficial geology at this site based on *in situ* observations, video and 35 mm photography obtained during three Johnson-Sea-Link (JSL) surveys in 1990 and two surveys in 1992. He describes carbonate formations in the form of large plates, slabs, and irregular shaped blocks, boulders and rubble. This hard substrate occurs on the crest and flanks of the mound and has been successfully colonized by *Lophelia*. The coral colonies have the typical bushy morphology comprised of irregular, dendritic branches that are highly anastomosed (for example see Cairns 1979). Individual colonies range in size from a few centimeters to over 1.5 m in diameter while aggregations of closely associated colonies with linear orientations were observed to attain 1.5–2 m in height and width and 3–4 m in length.

Many of the aggregated colonies appear to be in the first phase of the “thicket” building stage described by Squires (1964). Colonies less than 50–75 cm in diameter were nearly always completely pure white. Larger colonies and the aggregated colonies are often light to dark brown in coloration at their base and center with many having only white terminal branches and some with no white corallum at all.

This is not the first time *Lophelia pertusa* has been reported in an area of active hydrocarbon seepage. Hovland *et al.* (1998), working in water depths of 220 to 310 m on the continental shelf off Norway, report that many of the large *L. pertusa* banks they investigated occur at sites where there are relatively high levels of light hydrocarbons present in the near-surface sediments. Specifically, they suggest that the establishment and growth of coral banks in this region preferentially occurs at locations of hydrocarbon micro-seepage. Whether the occurrence of *L. pertusa* at the DeSoto site is similarly linked to local hydrocarbon seepage or present simply because hard substrate is available will not be known until additional investigations are undertaken.

Additional observations and video of the extent and condition of *Lophelia*, made during two OE/NFS funded JSL dives in October 2002, support these findings. Further, in July 2002, over 50 km of 150 kHz side-scan sonar data (150 m swath/135 m line spacing) and video were acquired by the USN submarine NR-1. These data are currently undergoing initial processing. Draft versions of side-scan sonographs clearly illustrate the complex spatial distributional pattern of the exposed carbonate formations. On a smaller scale, the texture of the surfaces of many of the features likely depicts the presence of attached colonies of *Lophelia* and/or the sea fan *Callogorgia* or possibly an unidentified antipatharian. It is anticipated that the resolution of some segments of the final versions of the sonagraphs will permit the delineation and enumeration of individual colonies.

The second site is an exposed carbonate complex, most likely also precipitated in conjunction with biogeochemical activity associated with hydrocarbon and related fluid seepage, situated on a topographic high northeast of the eastern rim of a submarine canyon. Water depths range between 300–500 m. The site is located at approximately 29°06'/88°23'W in the SE corner of VK862/northeastern corner of VK906 or approximately 37 km west-southwest of site #1. I believe this is the area where Moore and Bullis (1960) found coral in 1955. This site was also surveyed in July 2002 by the USN submarine NR-1. Over 60 km of 150 kHz side-scan sonar data (150 m swath on 135 m line spacing) and video recordings were collected and are currently undergoing initial processing. The goal of phase one of data analysis is to develop a first order characterization of the surficial geology and of the associated epibenthic communities at this site. Preliminary findings indicate that both *Lophelia* and *Callogorgia* occur at this site. The dominant organism, in terms of numbers and biomass, may very well be an unidentified sea anemone.

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William W. Schroeder is a Professor of Marine Science at the University of Alabama, Dauphin Island, Alabama. He has been involved in interdisciplinary oceanographic investigations for over 38 years and has conducted research in the Gulf of Mexico for the past 29 years. In addition, Dr. Schroeder has participated in research endeavors in the Bahamas, Caribbean, Gulf of Papua, Azov Sea, Australia and South Africa. He has authored and coauthored over 125 scientific publications dealing with geological and biological characterizations of estuarine and marine habitats to estuarine, shelf, and open ocean hydrography and circulation. His current research activities include 1) coupled biological-geological-physical studies of deepwater 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. Dr. Schroeder received his Ph.D. in oceanography from Texas A&M University.

DEEP GULF OF MEXICO BENTHOS (DGoMB), A STUDY OF THE STRUCTURE AND FUNCTION OF SEA-FLOOR COMMUNITIES

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Increasing exploration and exploitation of fossil hydrocarbon resources in the deep Gulf of Mexico (GOM) has prompted the Minerals Management Service of the U.S. Department of the Interior to support an investigation of the structure and function of the assemblages of organisms that live in association with the sea floor in the deep-sea ["The Deepwater Program: Northern Gulf of Mexico Continental Slope Habitat and Benthic Ecology" (Contract No. 1435-01-99-CT-30991)]. The program, referred to as Deep Gulf of Mexico Benthos or DGoMB, is studying the northern Gulf of Mexico continental slope from water depths of 300 meters on the upper continental slope out to greater than 3000 meters water depth seaward of the base of the Sigsbee and Florida Escarpments. The study is focused on areas that are the most likely targets of future resource exploration and exploitation. However, to develop a Gulf-wide perspective of deep-sea communities, sampling in areas beyond those thought to be potential areas for exploration has been included in the study design. A major enhancement in the program is the extension of the transects onto the abyssal plain of the central GOM through collaborative studies with Mexican scientists. This additional work effort will allow assessment of benthic community structure and function throughout the basin by sampling on the deep Sigsbee Abyssal Plain within the Mexican Exclusive Economic Zone (EEZ).

The program is designed to gain a better ability to predict variations in the structure and function of animal assemblages in relation to water depth, geographic location, time and overlying water mass. Biological studies are integrated with measurements of physical and chemical hydrographic parameters, sediment geochemical properties and geological characteristics that are known to influence benthic community distributions and dynamics. Eight (8) hypotheses are being tested on the basis of measures of benthic community structure. It is hypothesized that community structure varies as a function of

1. water depth,
2. geographic location (east vs. west),
3. association with canyons,
4. association with mid-slope basins,
5. sea surface primary productivity,
6. proximity to hydrocarbon seeps,
7. time (seasonal and interannual scales), and
8. association with the base of escarpments.

Measures of community structure used to test the hypotheses are variations in diversity, similarities in assemblage composition (at the species level), variations in biomass and abundance, and the mean size of individuals within specific size categories.

The underlying premise of the hypotheses to be tested is that deep-sea communities are food limited. This premise leads to the hypothesis that variations in community structure in time and space are a function of the input of food to the seafloor. In other words, community dynamics and structure are dependent on the availability and quality of food resources. Corollary hypotheses test the possibility that each independent variable is related in some way to how organic matter from multiple potential sources is utilized by the benthic community.

After defining community structure, the next objective is to make comparative measurements of community function. In this context, "function" refers to rates of dynamic biogeochemical processes. The study design is based on what has been learned from gradients in community structure. It uses the information to infer the flux of organic carbon into and through the ecosystem. The conceptual model assumes that community structure and function are tightly coupled. Presently, there is little reason to reject this generalization, but direct evidence for it in the deep-sea is at best fragmentary.

The conceptual model represents each of the principal size categories of the living components as standing stocks at each study site in the survey. The model includes demersal fishes, megafauna, scavengers, macrofauna, meiofauna, and heterotrophic bacteria. This model of a sediment-associated food web, can be coupled with a model of fossil hydrocarbon utilization by chemoautotrophic organisms including large invertebrates that house endosymbionts. This linkage is yet to be explicitly established and is the basis for one of the hypotheses being tested. The boxes in the model represent standing stocks which have units of biomass (organic carbon per unit area) whereas the arrows represent flux between boxes and hence have units of organic carbon per unit area per unit time. For consistency, the units are mg C m^{-2} and mg C m^{-2} day^{-1}. Data from the survey portion of the program quantify standing stocks across the survey area. Respiration rates are estimated on the basis of organism size and temperature from established relationships in the published literature. The fluxes represent transfers between components and are calculated by difference to balance respiratory losses at steady state. Burial loss of carbon is organic carbon (detrital) concentration times sediment accumulation rate. Input to the bottom is assumed to be equal to the sum of the respiration and burial losses at steady state.

The second phase of the project is designed to test the model. Direct measurements will be made of fluxes on cruises that conduct process experiments at selected locations. The model is tested based on results from process experiments completed in June of 2001 and process experiments performed in 2002. Total sediment community respiration is determined by benthic lander and incubation chambers. Total respiration is partitioned by measuring bacterial activity in pressure chamber incubations at *in situ* temperatures. Uptake and respiration are determined using mixed amino acids labeled with radiocarbon. Sulfate reduction rate are measured using radio-labeled sulfate incubation of sediment. Lander/chamber flux measurements include oxygen, dissolved inorganic carbon, inorganic nitrogen, phosphate, and silicate. The distribution of natural radionuclides is used to determine scales of biological mixing of the sediments. Scavenger domains of occupation are estimated using baited traps, time-lapse cameras and an ADCP to calculate vertical and horizontal eddy mixing and mean current direction. Stable isotopes of carbon and nitrogen are used to determine the food chain's structure and linkages. Physical and biological mixing are estimated using a suite of natural radionuclides characterized by an appropriate range of decay rates. Data from the second and third field year are used to adjust model parameters. The locations of the experimental sites were chosen based on model outputs, sampling results, and on-going testing of programmatic hypotheses. Experiments during the third field year are designed to further validate revised model rates and parameters.

FIELD WORK STATUS

The field work is now completed. The first year (2000) was spent taking survey samples (box cores, trawls, bottom photographs and CTDs) at 43 sites along the GOM U.S. continental slope. In the second year (2001) four process stations were occupied (Mississippi Trough, DeSoto Canyon, upper Florida slope, and deep Mississippi Cone) whose locations were determined based on the results of the faunal surveys. The third and final year, five sites were added on the abyssal plain within Mexican waters, composed of two east and west process sites and three geographically intermediate survey sites.

PRELIMINARY RESULTS (AS OF 1/03)

Based on the data being generated from the survey samples, detailed maps are being constructed of the following variables:

- Variations in biomass and density of each size or functional component
- Variations in diversity of each size or functional component
- Variations in assemblages or re current groups
- Individual species distributions-of dominant species
- Key abiotic variables

The eight hypotheses are being tested as the data become available. Presently, this is being done at the meta-taxon level (major group), using biomass and abundances. As species lists are generated, they will be tested at the species level.

CONTINUED STUDIES (INFORMATION NEEDS)

- Hard bottom assemblages
    - Corals
    - Escarpments
    - Seep communities
- Model validation
    - Measures of respiration of individual organisms or groups
    - Estimates of secondary production of dominant species or types
- Experiments involving manipulations related to O&G exploration and development (model based)

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Rowe's specialty is benthos and biogeochemical processes. His research interests are deep Gulf of Mexico benthos, cycling of organic carbon and nitrogen, benthic-pelagic coupling, and models of carbon cycling in benthic food webs. He has authored over 100 publications and contributed to three books. Additionally, he organized the first NATO workshop held at Texas A&M, which was devoted to the deep-sea biota and its relation to the global carbon cycle, the results of which were published as a book in the NATO ARW Series.

UTILIZATION OF ROV SURVEYS REQUIRED UNDER MMS-GOMR NTL NO. 2001-G04 TO ESTIMATE EFFECTS OF DRILLING ON THE GULF OF MEXICO CONTINENTAL SLOPE: THE BP HOLSTEIN DEVELOPMENT EXPERIENCE

Benny J. Gallaway, Larry R. Martin, LGL Ecological Research Associates, Inc.

MMS GOMR NTL No. 2001-G04, requires that ROV surveys be conducted in association with deepwater oil and gas developments in the Gulf of Mexico. One survey is to be conducted before the initiation of development activities or drilling, and another is required immediately after drilling activities are completed at the site. The NTL provides guidelines for conducting the surveys, as well as standard forms for recording the observations.

We conducted the required set of ROV surveys for BP’s (BP Exploration and Production, Inc.) Holstein Development, which is developing and producing the hydrocarbon reserves located in the Green Canyon Block 644 Unit (Blocks GC644 and GC645, Figure 2D.1). BP had previously drilled and abandoned two wells in the Green Canyon area: 1) a discovery well in GC Block 644, and 2) an appraisal well in GC Block 645 which is now Well No. 1 of the Holstein Development. Development of this discovery was initiated in December 2001 with the arrival of a Mobile Offshore Drilling Unit (MODU), Ocean Victory Rig 145, at the GC645 Appraisal Well Site. Fifteen additional wells were drilled between December 2001 and August 2002.

Below, we describe the results of our pre- and post-drilling surveys for BP’s Holstein Development.

ROV SURVEY DESCRIPTIONS

For the pre-drilling survey, one of us (LRM) flew to the MODU immediately prior to its departure to the GC 645 Well No. 1 site. The MODU arrived on site on 23 December 2001, and the ROV surveys were initiated following deployment of the fourth of eight anchors. The ROV vehicle was a Magnum 28 ROV with a subsea deployment system (cage). The ROV was equipped with video imaging capabilities and an MS900 sonar system capable of locating the well structure at a distance of approximately 70 m or 230+ ft. The system was owned and operated by Oceaneering International, Inc.

The problem associated with locating and tracking the position of the ROV on the seafloor was solved by personnel from John E. Chance and Associates, Inc. who were to use the ROV to mark the well sites immediately following our surveys. The ROV position was determined using LBL (long baseline) Acoustics consisting of an APS3 Solardyne Acoustic hardware package and Starfix.com navigation software. This permitted precise tracking of the ROV and aided the ROV operator in flying the transects by displaying the actual ROV position relative to planned tracklines on a CRT in the control van (Figure 2D.2).

Following the NTL guidelines, six approximately 100-m long video transects were run centered on the existing wellhead, Green Canyon 645-1 (Figure 2D.2). Video records were not recorded during transit between transects as the ROV was flown high above the bottom to avoid further disturbance of bottom sediments within the survey area. Due to limited visibility during all six transects, the ROV was flown very near the bottom, less than 1 m. The precise height above bottom was not known as the ROV's altimeter was not functional.

The videotape was voice annotated as it was being taken by periodically describing the location of the ROV in terms of the distance from the end of the specific line being recorded, the time of the observation, the bottom type being seen, and the types and categories of organisms and objects being seen. This information, equivalent to field notes, was also recorded on MMS forms (form MMS-141, September 2000).

The ROV was lowered into the water at 1235 h on 23 December 2001 and the last bottom observation was at about 1530 h on the same date. LRM was able to depart the MODU at 0750 h on 24 December 2001.

The voice information on the tape that had not been transcribed on the MMS-141 forms was reviewed and transcribed to provide an expanded videotape transcript or survey log sheet. We (LRM and BJG) next made both independent and joint reviews of the tape and survey log sheets, carefully recording bottom type, kinds and numbers of organisms and other objects, and the location of these observations along the transect. Invertebrates were classified as shrimp, sea pens, or unidentified swimming invertebrates. The latter were mostly very small and crustacean-like, resembling amphipods. Fish were noted as such and were identified to family where possible. These observations were recorded in an "ROV Video Analysis Log" organized by transect, time, observation type and number, and the estimated location of the observation along the transect.

LRM flew to the MODU on 7 August 2002 to conduct the post-drilling surveys. The post-drilling surveys were conducted using the same equipment, except for the navigation and positioning system, which was unavailable. Wellhead 644-15 was selected as the center of the survey array so that we could range off it with the ROV scanning sonar to measure transect lengths.

Six approximately 100-m video transects (Figure 2D.3) were again run on headings of 050° (1), 110° (2), 170° (3), 230° (4), 290° (5), and 350° (6). These were the same compass headings used in the pre-drilling survey. The first transect surveyed on this study, 1, began as planned, at well 644-15 located in the approximate center of the well pattern. After this transect was completed, it was apparent that our concerns about ROV tether length were well founded and that we would have to move the center of the survey to a point directly beneath the ROV cage. Otherwise we would not be able to obtain the required 100-m transect lengths for the five remaining transects (2 through 6). This change was made, and all transects were successfully sampled. Transect 3 (95 m were surveyed) fell slightly short of the targeted goal of 100 m. However, this deficiency was more than "made-up" on transects 2 and 6 where we surveyed 102 and 124 m, respectively.

Distances along the transect lines were determined using a Simrad Model MS 900 scanning sonar. Accuracy of location may have decreased beyond 230 ft from the reference structure, but the approximate locations were considered reasonable. Video records were not recorded during most of the transits between transects as the ROV was generally flown higher above the bottom to avoid disturbance of bottom sediments within the survey area, and to avoid entanglement of the tether on well structures. In general, the water was much more clear on the post-drilling survey than it had been during the pre-drilling survey. The transects were flown an estimated 1 to 3 m above bottom, except when an organism was seen. To facilitate recognition of small organisms on the sea floor, the ROV was flown to very near the bottom, sometimes less than 1 m. However, the precise height above bottom was not known as the ROV's altimeter was not functional.

As before, the videotape was voice annotated as it was being taken by periodically describing the location of the ROV in terms of the distance from the beginning of the specific line being recorded, the bottom features being seen, and the types and numbers of organisms and objects being seen. This information, equivalent to field notes, was recorded on MMS forms (form MMS-141, September 2000) and on the Oceaneering Video Log forms. The ROV survey commenced about 1318 h on 7 August 2002 and the last bottom observation was at about 1641 h on the same date. LRM was able to depart the MODU at 1100 h on 8 August 2002.

In the office, we (LRM and BJG) next conducted independent and joint reviews of the tape and survey log sheets, carefully recording bottom type, kinds and numbers of organisms and other objects, and the location of these observations along the transect. Invertebrates were classified as shrimp, crabs, or sea pens. Fish were noted as such and were identified to family where possible. These observations were recorded in an "ROV Video Analysis Log" organized by transect, time, observation type and number, and the estimated location of the observation along the transect.

RESULTS

The distribution of the wells and sediment color information is shown by Figure 2D.4. The well-pattern area and areas with dark sediments reflects the area most impacted by drilling and drilling discharges; the "impact" area. In Figure 2D.5 we show the relationship of the impact area to the ROV survey transects that were run in each survey. Areas outside the "impact" area are referred to as the "control" or reference area. The analytical design followed the BACI model (Before-After Control-Impact), where one compares the observed differences between control and impact observed before an event to the differences observed after the event.

In Figures 2D.6 and Figure 2D.7 we show the types and numbers of organisms observed in control and impact areas before and after drilling. The quantitative differences are shown by Figure 2D.8. Direct effects of drilling on the impact area are evident. However, the shrimp concentrations observed in the control area in the post-drilling survey was remarkable for this depth in the deep-water Gulf (Figure 2D.9).

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DEVELOPMENT OF A DELTA DATABASE AND INTERACTIVE KEY FOR GULF OF MEXICO POLYCHAETES

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A critical quality assurance (QA) requirement of the long-term and wide-area studies undertaken to meet Minerals Management Service (MMS) information needs is consistent and accurate identification of species. Errors in identification can lead to misleading indicators of impact, possibly masking real impacts or producing false positives. Unfortunately, achieving the necessary QA has been difficult until now due to the nature of standard practices in systematics and taxonomy. Underlying the seemingly simple task of identifying fauna is a process of conditional identification that shifts as new information is accumulated. In traditional taxonomy, the incorporation of new information about species and traits is a process that may take years. Computer aided identification provides a means of improving identification and incorporating new information rapidly.

This study has been a trial effort in development of a computer aided identification system suitable for MMS needs both as a tool in identification and a procedure in MMS-supported taxonomic studies. Polychaete worms were selected due to their numerical importance, their high species diversity, the perceived difficulty in identification using traditional keys, and the availability of MMS-supported reference materials (Uebelacker and Johnson 1984, Hubbard 1997, Blake 1994). Although not considered initially, another important aspect of the polychaetes is the progress towards consistent use of terms being brought about by new systematic syntheses (Fauchald and Rouse 1997, Rouse and Fuachald 1997, Rouse and Pleijel 2001). The project was restricted to literature; no specimens were examined for production of the system.

In this study, the most widely accepted computer aided identification system was employed, Descriptive Language for Taxonomy (DELTA) (Dallwitz 1980; Dallwitz, *et al.* 1993,1995,1999, 2000). DELTA was selected for five primary reasons:

1. It is used widely and explained in the peer reviewed literature (Aiken *et al.* 1997; Askevold and O'Brien 1994; Dallwitz 1974, 1980, 1993; Dallwitz *et al.* 1993).
2. Extensive user documentation is available.
3. It is an exceptionally comprehensive and flexible system.
4. It is mature in the sense of having been under development and refinement for over 25 years.
5. It was adopted as an international standard in 1988 by the International Working Group on Taxonomic Databases for Plant Sciences.

DELTA is a flexible-format data convention capable of encoding all the types of traits used to identify and classify organisms: counts, measurements, descriptive text, multistate structures, etc. As such, it is a compact means of describing organisms. It is a database about taxa and characters that can be corrected, enlarged, and otherwise modified. A DELTA database can be examined by a variety of specialized computer programs to produce normal text descriptions, traditional keys interactive keys, or modified data suitable for cladistic analysis. INTKEY (Dallwitz 1980; Dallwitz *et al.* 1993, 1995, 2000) is an especially important companion program that generates interactive keys for identification. DELTA and associated programs are available as compressed download files at http://biodiversity.uno.edu/delta.

The DELTA system is distributed with restrictions that include license fees and required citation. This study was done in full compliance with those restrictions. Users of the polychaete database must also comply.

DELTA and its associated programs for interactive identification INTKEY are not especially difficult programs to use. The data entry subsystem (DELTA Editor) is now in the form of a multifunction interactive window. For the purposes of this study, the primary database query subsystem is provided by the program INTKEY. It also runs as an interactive window. Successful production of a database and interactive key requires considerable familiarity with a multifunction program CONFOR (Dallwitz 1980; *et al.* 1993). CONFOR combines the functions of a format translator, a structured query language, an error checker, and others. CONFOR may be run from the DELTA editor window, but the user must first create files that provide sequential instructions. Termed directive files, these employ fixed set of commands, a specific format, and a rigid priority sequence. In effect, full use of DELTA and INTKEY require familiarity with programming.

The Northern Gulf of Mexico Polychaete DELTA database contains 476 taxa and is limited to the genus level. It is based upon 160 morphological characters and 10 “house-keeping” characters used to facilitate upkeep of the database. The decision to limit the database to genus was largely pragmatic. The available literature is inconsistent in the detail included in species descriptions, and in excess of 200 traits may have been needed to code at the species level. In addition, identification to genus is less dependent upon high-power magnification of setae, a procedure now considered to need scanning electron microscopy.

Building a taxonomic database consists of three main tasks: compiling a list of taxa, a list of characters, and then coding each taxa according to its own character states. Of these, development of the character list is the most time-consuming task. The developer must adopt a consistent terminology, make decisions about the level of detail, make decisions about character dependencies, and try to describe or illustrate character states in a useful manner. As more taxa are added, the characters must be expanded and revised. During trial runs of the interactive key developed from the DELTA database, the system proved very reliable for identification to family and reasonably reliable to genus. As expected, well defined genera could be easily identified. Genera that are poorly described in the literature could not be consistently identified.

This study has produced two products for use or additional development, an interactive key and a full DELTA database. These will be posted as a compressed file available for FTP download after 1 March 2003 at http://biodiversity.uno.edu/delta. The interactive key requires the program INTKEY running under the Windows operating system 95 or later. Persons wanting to modify the underlying database must have DELTA running under the same operating system.

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Michael John Dallwitz holds a doctoral degree in physics from the Australian National University. In 1970 he used his mathematical background to explore ecological modeling. Dr. Dallwitz began collaboration with entomologists at the Australian Commonwealth Scientific and Industrial Research Organization on computer-aided taxonomy. The DELTA system was developed between 1971 and 2000. Recent activity has focuses upon application of the DELTA system and developing databases for a wide variety of organisms.

FORAMINIFERA OF HYDROCARBON SEEPS, ALAMINOS AND MISSISSIPPI CANYONS

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ABSTRACT

Core samples from upper abyssal and lower bathyal hydrocarbon-seep sites in Alaminos and Mississippi Canyons (depths ~2200 m and ~1100 m, respectively) have yielded about 200 species of benthic Foraminifera. The calcareous assemblage at the deeper sites is dominated by *Nuttallides decorata*, *Ioanella tumidula*, and *Bolivina lowmani*, that at the shallower sites by and *Bolivina aculeata*. The geochemistry of the sedimentary environment is reflected in the baritic shell composition of an agglutinated species (*Hyperammina* sp.) and the pyrite infilling of *Nuttallides decorata*.

INTRODUCTION

Benthic Foraminifera respond rapidly to environmental disturbances, and their large extant populations and well-preserved shells make them excellent recorders of present and past marine biodiversity. Some species are capable of inhabiting environments where oxygen is depleted to extremely low levels, or even absent (Sen Gupta and Machain-Castillo 1993; Bernhard and Sen Gupta 1999). Furthermore, many foraminiferal species are tolerant to methane and H_2S emission on the seafloor (Sen Gupta and Aharon 1994; Sen Gupta *et al.* 1997). In this context, the ongoing MMS project on cold-seep Foraminifera of Gulf of Mexico (especially, Alaminos, Mississippi, and Green Canyons) is related to four major tasks:

1. Identification of all species and ecophenotypes of benthic Foraminifera present in various hydrocarbon-seep habitats (including those on hydrate mounds) that have been sampled in bathyal and abyssal depths off Louisiana and Texas.
2. Production of a taxonomic atlas of these species and variants.
3. Analysis of the distribution of the taxa in the context of environmental processes.
4. Investigation of the history of seepage at selected sites by examining cores for the record of species adjusted to the presence of methane and H_2S.

This report relates to current findings from sampling sites in the Alaminos and Mississippi Canyons.

MATERIAL AND METHODS

Foraminiferal data were obtained from surface and near-surface (0–1 and 1–2 cm) samples from 12 cores: 1) 8 push cores and 4 box cores from Alaminos Canyon (water depth ~2200 m) and 2) 2 push cores from Mississippi Canyon (~1100 m). The laboratory work so far has consisted of standard micropaleontological processing of core samples, including 1) use of the Rose Bengal stain to distinguish between living and dead Foraminifera; 2) wet-sieving through a 63-µm screen; 3) species identifications and counting under an optical microscope; 4) preparation of a species-percentage data base; 5) species illustrations with a scanning electron microscope; and 6) EDS X-ray analysis to determine compositional aspects of selected foraminiferal shells.

RESULTS AND DISCUSSION

Foraminiferal Assemblages and Species

So far we have identified about 200 species. Of these, *Nuttallides decorata*, *Ioanella tumidula*, *Saccorhiza* sp., *Hyperammina* sp., *Trochammina* sp. 1, and *Bolivina lowmani* are dominant in Alaminos Canyon (at ~2200 m). *Ioanella tumidula*, *Hyperammina* sp., *Uvigerina peregrina*, and *Bulimina aculeata* are dominant in Mississippi Canyon (at ~1100 m). Living specimens of *Nuttallides decorata* and *Ioanella tumidula* are present in several core-top samples, and empty shells of these two species are found in all samples from Alaminos Canyon except those that were nearly barren of Foraminifera. *Ioanella tumidula* exhibits a similar distribution in Mississippi Canyon. *Nuttallides decorata*, absent or rare in the Gulf of Mexico above 1000-m water depth (Phleger and Parker 1951; Denne and Sen Gupta 1993), is absent from the Mississippi Canyon samples. *Gavelinopsis trnaslucens* is present in the shallower Mississippi Canyon samples and absent from Alaminos Canyon.

Within the order Buliminida, *Bolivina*, a genus with calcareous biserial shell morphology, is an important member of foraminiferal seep communities (Sen Gupta *et al.* 1997). In Mississippi and Alaminos Canyons it is the genus with the most species. These include both ornamented and unornamented forms (e.g., *B*. sp. cf. *B. pusilla* and *B. lowmani*, Figure 2D.10a,b). Other important genera of the Buliminida include *Uvigerina*, *Bulimina*, and *Globocassidulina*. All of these taxa are known to be infaunal. The calcareous trochospiral group (Order Rotaliida) are represented by a variety of different species including *Nuttallides decorata* (Figure 2D.10c) and *Ioanella tumidula*; other common taxa include the genera *Pullenia*, *Epistominella* and *Gyroidinoides*.

All common orders of agglutinated Foraminifera (Astrorhizida, Lituolida, Trochamminida, Textulariida) are present in the assemblages. They exhibit a morphologic variety from simple tubular forms to planispiral, streptospiral, or trochospiral coils, or a biserial chamber arrangement. Agglutinated shells composed of sponge spicules, coccoliths, or small planktonic Foraminifera (e.g., *Saccammina helenae*, Figure 2D.10d) are common in both Alaminos and Mississippi Canyons. In addition, barite crystals constitute the shell walls of *Hyperammina* sp. at a Mississippi Canyon site (Figure 2D.10e). These shells have an orange color because of the presence of an iron-oxide cement (as determined by EDS X-ray analysis. Barite crystals have never before been observed as the building blocks of foraminifer shells.

Reflection of Sedimentary Environment in Agglutinated Shells

Barite chimneys are associated with hydrocarbon venting in Mississippi Canyon at 510–520 m water depth (Fu *et al.* 1994). Besides barite, the constituents of these chimneys include minor amounts of pyrite, iron oxide, Mg calcite, and detrital silicates. Our finding of barite rosettes cemented by iron oxide in shells of *Hyperammina* sp. at a 1100-m deep site extends the water depth of barite formation in Mississippi Canyon.

Pyrite-filled shells of calcareous and agglutinated Foraminifera have been recovered from Alaminos Canyon cores; Figure 2D.10f shows pyrite framboids infilling a calcareous *Nuttallides decorata* shell. The presence of pyrite is an indicator of anoxia in sediments (e.g., Lin and Morse 1991), and pyritized foraminiferal shells have been found in diverse oxygen-deficient environments, including heavily polluted areas (e.g., Yanko *et al.* 1999). Of particular relevance to our study, however, is the reported occurrence of pyrite framboids within shells of *Uvigerina peregrina* in cold-seep sediments of Monterey Bay, California (Stakes *et al.* 1999), attesting to anoxia and bacterial reduction of sulfate there, as is the case at Alaminos Canyon seep sites.

Epibenthic Species

A preliminary microscopic examination of tubeworms (*Lamellibrachia*) from Mississippi Canyon has revealed the presence of attached Foraminifera (e.g., *Spirillina*, Figure 2D.10g). Such species inhabiting tubeworm surfaces decimeters above the seafloor may be relatively unaffected by the severe physical/chemical constraints of the cold-seep sedimentary environment (e.g., CH_4 or H_2S profusion and oxygen depletion). A fuller investigation of seep tubeworms as a foraminiferal habitat is planned.

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SESSION 2E

DEEPWATER PHYSICAL OCEANOGRAPHY II

Chair: Carole Current, Minerals Management Service
Co-Chair: Alexis Lugo-Fernandez, Minerals Management Service

Date: January 15, 2003

EXTERNAL FORCINGS THAT CAUSE THE LOOP CURRENT TO SHED EDDIES AT IRREGULAR INTERVALS

Lie-Yauw Oey, Princeton University

SUMMARY

The Loop Current (LC) is known to shed eddies at irregular intervals from 3~17 months; the causes have not, however, been previously identified. We conduct numerical experiments in the western North Atlantic Ocean (96°W-55°W, 6°N-50°N), force the model with six-hourly winds (ECMWF), and eddies (from ERS/Topex satellites) in the Caribbean Sea, and examine their separate effects. It is shown that large-scale wind (curl) over the Gulf Stream recirculation gyre drives the (observed) southward transport through the Greater Antilles passages, and accounts for the additional transport through the Yucatan Channel with (mean, range) = (27, 15~36) 10^6 m^3 s^{-1} comparable to those observed. When Caribbean eddies and winds are absent the shedding period is nearly constant 9 ~ 10 months. Short-period (3~6 months) wind-induced transports through the Greater Antilles passages cause shedding at shorter intervals, as short as 4~5 months, while Caribbean eddies cause shedding at longer periods, as long as 14~16 months (Figure 2E.1). Anticyclonic vorticity at Yucatan deters northward extrusion of LC, which explains the prolonged periods in the latter. Yucatan fluctuating inflow by winds and/or Caribbean eddies can cause a LC eddy to temporarily (~ 1 month) detach from, and then reattach back to, the LC, a phenomenon sometimes observed (Figure 2E.2). Model results suggest that southwest of Hispaniola warm eddies are periodically spun up by the local wind stress curl. The eddy drifts southwestward and amplifies as it progresses towards the Yucatan Channel; they significantly affect LC shedding behaviors. Satellite data supports their existence in the real ocean (Figure 2E.3).

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ANATOMY OF A FULL DEPTH CURRENT MOORING OVER THE LOUISIANA SLOPE

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With funding from the MMS-LSU Coastal Marine Institute, we have deployed a long-current meter mooring, for two six-month periods, over the plateau landward of the Sigsbee Escarpment near 92°W and, for one year, immediately seaward of the escarpment. This presentation is limited to the data collected during the first deployment over the plateau.

The eight Aanderaa current meters on the mooring returned good data. One meter had a timing problem and those data are not included in these analyses. The flows observed were not very energetic. The flows at the deep meters did not exceed the rotor threshold velocities for approximately one third the time. These speeds have been replaced with the threshold speed (1.1 cm/s), but test replacing these speeds with zeros did not alter the statistics significantly. The mean flows were highly sheared in the east-west direction. The mean upper layer flows were eastward and the weak mean lower layer flows were westward. A very weak southward flow was recorded at all meters. The principal axes were closely aligned with the east-west direction. Maximum observed currents at the Aanderaa meters below 500 m depth did not exceed half a knot. (The strong deepwater currents observed further eastward over the continental rise [Hamilton and Lugo-Fernandez 2001] were not observed on any of the other deployments, either.)

The mooring was deployed in mid-February within Eddy Juggernaut. After Eddy Juggernaut moved away from the mooring, strong, low-frequency, vertical, thermal variability continued to be recorded at the mooring, presumably in response to general surging of the deep layers of the ocean (Figure 2E.4). Stickplots of the low-passed currents indicate the flow variability associated with this structure. At times, e.g. near day 100, the flow appears to be strongly barotropic, while at other times, e.g. near day 140, significant vertical reversal of the flow is observed. (Figure 2E.5). Spectra from the current meters are red, the low frequency flows favor clockwise rotation except at the top two meters, and the diurnal band strongly favors clockwise rotation of the flow at all depths. The first empirical orthogonal function accounts for 87% of the variance and is highly sheared, but nearly unidirectional. The second empirical orthogonal function accounts for 7.5% of the variance and describes a bottom-trapped motion with a spectral plateau between 6 and 10 day periods.

Throughout the water column, diurnal-band motions are strong. Attempts to isolate the tidal motions from the inertial were unsuccessful. A Gabor spectrum of currents from a single level indicates significant variability in the diurnal band that is not related to the fortnightly period, suggesting that this variation is due to internal tides responding to changes in the density stratification or trapping of internal inertial energy by local eddies.

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LAGRANGIAN STUDY OF DEEPWATER CIRCULATION AND TRANSPORT

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INTRODUCTION

The recent increased activity associated with offshore oil and gas exploration and production in the outer continental shelf and slope regions of the northern Gulf of Mexico (GOM) calls for a better understanding of the ocean circulation in these regions and the potential environmental effects of those activities. Safe operation of offshore facilities during exploration and production is required for the protection of human life and the marine environment. Moving into deepwater places the oil and gas operations closer to strong surface-intensified currents associated with the Loop Current (LC) and LC rings. Sub-surface current measurements over the northern continental slope provide evidence of vigorous currents and Topographic Rossby Waves. In the deep GOM below 1000 m, vertically homogeneous currents are observed to intensify near the bottom. Understanding how these deep energetic currents and eddies interact with the bottom topography is important to ensure that deepwater activities are safe and environmentally sound. Three other considerations in the mining of deep sea mineral resources are (1) the transport of material by deep currents in both the horizontal and vertical; (2) mixing and ventilation of deepwater; and (3) the residence time of water in the deep GOM.

The GOM is a semi-enclosed sea with maximum depths of approximately 3400 m in the eastern portion and 3700 m in the western portion. Direct current measurements below 2000 m have been rare, and limited attention has been focused on the deep circulation in the GOM by the modeling community. Although the deepwater of the GOM below the deepest sill depth is completely isolated from outside, it is well-ventilated. Renewal of deepwater should take place only via vertical exchange of water with the water above the sill depth. Several modeling studies of the GOM have indicated the presence of energetic deep vortices (e.g., Hurlburt and Thompson 1982; Sturges *et al.* 1993; Welsh and Inoue 2000). Generation of deep vortices, interaction of deep vortices with bottom topography, and the spin down of upper layer anticyclones appear to play an important role in the vertical exchange of water in the GOM.

METHODS

A primitive-equation, numerical ocean model was developed for the GOM that features high vertical resolution and seasonally-varying inflow through the Yucatan Channel. The Modular Ocean Model version 1.1 (Pacanowski *et al.* 1991), which has evolved from the Bryan-Cox model (Bryan 1969; Cox 1984), was chosen for this study. This model is ideal for this project because the effects of bottom topography and the resolution of eddy dynamics are both important in the GOM. In order to achieve a realistic inflow condition, the model domain extends outside the GOM into a synthetic return flow region that links the Straits of Florida with the western Caribbean. The bathymetry in the return flow region is altered to allow flow exiting the GOM to re-circulate around Cuba and enter the GOM through the western Caribbean. The method of forcing the inflow is the same as implemented in previous modeling studies by Welsh (Welsh and Inoue 2000). The first goal of this project was to realistically reproduce the observed upper-layer circulation features of the GOM, including the vertical structure of the LC and LC rings, which dominate the circulation in the eastern GOM. The model circulation in the deep layer agrees with output from other modeling efforts, but there is little data available to verify these results.

The Lagrangian technique of seeding and tracking tracer particles is used to examine detailed transport and mixing processes and to identify the processes responsible for ventilation of the deepwater. Several different experiments were designed that feature different starting positions of the tracer particles that depend on the region or process that we are interested in. For the deepwater release experiment, the model was seeded below 2000 m with 19,105 inert particles that drift freely within the model domain in response to the velocity field (Figure 2E.6). Every ocean grid box at levels 15 through 20 (depths 2200 m through 3700 m) was seeded with a single particle. Groups of particles are referred to by their initial geographic locations: west, central and east. The positions of the tracer particles were recorded every 10 days for 16 model years (from the beginning of model year 24 through the end of model year 39). Animations of the particle positions superimposed on the model flow fields were made to identify flow features and processes responsible for advection of individual particles.

RESULTS

The deepwater release experiment was designed to identify regions of vertical exchange between the surface and deep layer. Upward motion of particles from below 2000 m to above 1000 m is observed to occur in the ring separation region in the eastern GOM. Tracer particles are advected away from the steep northeastern Campeche slope as the LC penetrates northward into the eastern GOM. During the process of ring separation, the deep circulation beneath the LC changes from anticyclonic to cyclonic. The tracer particles ascend in the water column when the currents reverse and advect the particles back toward the slope. In other areas of the Gulf, sporadic vertical motion of particles near the slope is observed as a result of currents interacting with the steep topography. The continual descent of particles north of the Yucatan Sill at depths greater than 2000 m is correlated with the inflow of relatively cool, salty Caribbean water that enters the GOM at sill depth and sinks to the appropriate density level.

The vertical exchange of particles in the deep is most apparent in the eastern basin. The percentages of particles to rise above selected levels from below 2000 m according to starting locations are presented in Figure 2E.7. Particles from the east group ascended most rapidly to all levels compared to particles from the central and west groups. The projected time for all tracer particles to ascend from below 2200 m to above a 1000 m is approximately 100 years for the eastern region, but it is 450 years for all particles that were initially west of 88°W.

Within the upper 500 m, the most active area for vertical exchange of particles is in the northwestern region, where the LC rings are observed to spin down. After arriving in the western GOM, most LC rings move northward along the slope into the ‘eddy graveyard,’ which has a center at approximately 26.5°N and 95°W. The eddy graveyard is the termination point for nearly all ring paths in this and other modeling studies. The ascent of particles in this region is likely due to the shoaling of the isotherms as the rings decay. The path of tracer particle 17976 provides a perfect example of vertical motion in the deep eastern basin and the upper layer in the northwestern region (Figure 2E.8).

CONCLUSIONS

The exchange of particles across density surfaces occurs mainly beneath the LC in the eastern GOM, in the northwestern region where LC rings spin-down, and near steep slopes. During the process of ring separation, particles were observed to spiral slowly upward in the water column within the lower layer. The descent of particles occurs in the eastern GOM as relatively cold, salty water cascades over the sill beneath the Yucatan Current and flows northward along the Florida Escarpment before turning westward. A conceptual model for the ventilation of the deepwater has developed from this study that features downwelling of relatively cool, salty water in the far eastern basin, a deep mean cyclonic current, and upwelling of older, relatively warm water onto the Campeche Bank beneath the western limb of the LC. The dissolved oxygen present in the deepwater of the GOM is likely derived from the relatively cold, highly oxygenated mixture of UNADW and Caribbean water overflowing the Yucatan sill. During a 16-year simulation in which the waters below 2200 m were seeded with nearly 20,000 particles, fewer than 10% of particles were transported across 88°W in either direction. This lack of communication between the eastern and central basin is also reflected in different estimates for residence time for these two basins. The residence time for the deep eastern basin based on particle statistics is approximately 100 years compared to 450 years for the central basin.

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OBSERVATION OF DEEPWATER CURRENTS IN THE EASTERN GULF OF MEXICO BELOW THE LOOP CURRENT

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INTRODUCTION

The upper-layer circulation in the Gulf of Mexico (GOM) is dominated by the Loop Current (LC) in the eastern GOM and the Loop Current eddies (LCE) in the central and western GOM. The deepwater in the GOM is isolated below the sill depths (~800 m in the Florida Strait and ~1900 m in the Yucatan Channel). Deepwater in the GOM appears to be well ventilated, suggesting some energy propagation from the upper layer to deepwater inside the GOM. Presence of cyclonic eddies in deepwater (e. g., Hurlburt and Thompson 1982) and topographic Rossby waves over the northern continental slope region (e. g., Hamilton 1990; Hamilton and Lugo-Fernandez 2001) have been suggested in various numerical model studies as well as in observations. In order to fully understand deepwater dynamics and circulation in the central and western GOM, knowledge of the upstream condition is required. The objective of this study is to observe the upstream conditions in the eastern GOM, i. e., deepwater currents in the eastern GOM below the Loop Current in a flat-bottom area away from the slope region. A two-year deployment of a deepwater mooring near the center of the eastern GOM was successfully completed, and the preliminary results are presented here.

METHODS

Previous study by Vukovich and Crissman (1986) indicated a location in the eastern GOM where all the LC rings appear to pass on their generally westward journey toward the western GOM. A deepwater mooring was deployed near that location at 87°W and 25.5°N at a water depth of 3356 m in 1 June 2000. 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 to sample the entire water column. The mooring was successfully turned around in 1 August 2001. The second deployment lasted until 3 June 2002 when the mooring was successfully recovered.

RESULTS

The water column sampled behaves basically as a two-layer system with an interface located near 750~1000 m (Figure 2E.9 and Figure 2E.10). The LC dominates currents in the upper layer. In the upper layer, there were five strongest events over the two-year period with observed maximum current speeds reaching approximately150 cm/s at 60 m. In comparing to the altimeter data archived at the University Colorado (TOPEX/ERS-2 observations), it appears that those events correspond to the time when the high-speed core of LC was sweeping past the mooring site. Once the high-speed core moves away from the mooring site, upper-layer currents weaken significantly. Currents in the lower layer are generally decoupled from the upper-layer currents. However, currents in the lower layer are nearly depth independent (i. e., vertically coherent) within the lower layer with maximum current speeds reaching 30~ 35 cm/s between1500 m and 3200 m. Coupling between the two layers increases significantly during a few episodic events. Concurrent TOPEX/ERS-2 observations suggest that one of those episodic events coincided with the formation of a LCE, namely Millennium Eddy in early 2001. Two other energetic events, one in August–September 2001 and the other in early 2002 are associated with the formation of another eddy. Effects of bottom-boundary layer can be clearly seen within 30 m of the bottom. The weakest currents were observed at 750 m; that appears to be located near the interface between the upper layer and the lower layer.

In comparison to the upper-layer currents that appear to contain significant low-frequency component (periods longer than ~50 days), deepwater currents appear to be dominated by current variability with periods 20~50 days. Strong directionality exists in the upper layer, where occasionally normal north-northeasterly flow is replaced by south-southeasterly flow when the formation of a new LCE is imminent. In deepwater, current direction is more isotropic, suggesting more wave- or eddy-like features (Figure 2E.11). Those eddy-like features are characterized by currents approaching ~ 30 cm/s and appear to be associated with temperature variability of order ~ 0.01°C and salinity variability of order ~ 0.001 psu at 2500 m.

CONCLUSIONS

The first direct observations of deepwater currents were made in the central eastern GOM below the LC. A two-year deployment (June 2000–June 2002) of a deepwater mooring was successfully completed at a location in the eastern GOM where all the LC eddies appear to pass on their generally westward journey toward the western GOM. The upper layer above 750~1000 m is dominated by the LC. The observed variability of the upper-layer currents can be interpreted as the reflection of the proximity of the mooring site to the high-speed core of the LC. During the two-year period, the formation of LCE took place twice separated nearly by a year. Deepwater is nearly vertically coherent within the deep layer and is generally decoupled from the upper layer except during a few episodic energetic events with characteristic time scales of 20~50 days associated with the formation of LCE. Energetic events in deepwater are eddy-like with associated maximum currents reaching 30 cm/s, temperature variability of order ~ 0.01°C and salinity variability of order ~ 0.001 psu at 2500 m. They are equivalent to vertical excursion of ~100 m for temperature and of ~500 m for salinity, suggesting relatively energetic mixing of deepwater.

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SESSION 2F

SPERM WHALES: PHYSICAL ENVIRONMENT & ACOUSTIC EFFECTS

Co-Chairs: Sarah L. Tsoflias, Minerals Management Service
William Lang, Minerals Management Service

Date: January 15, 2003

SHIP AND SATELLITE STUDIES OF SPERM WHALE HABITAT

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To characterize the physical and biological environmental patterns where sperm whales were encountered along the continental margin of the northern Gulf of Mexico (GOM) in summer 2002, hydrographic data from two cruises of R/V *Gyre* were combined with remote sensing of sea surface height using the TOPEX/POSEIDON and ERS-2 satellite altimeters and with ocean color mapped by the SeaWiFS satellite. Texas A&M University oceanographers are responsible for the hydrographic data collection and for the overall program management that is in place among the several universities cooperating for these Sperm Whale Seismic Studies (SWSS). Our co-authors from University of Colorado and University of South Florida provided weekly averages of altimetry and ocean color from January 2002 through September 2002 and daily satellite data for the June-July and August-September SWSS fieldwork periods that R/V *Gyre* was at sea.

R/V *Gyre* cruise 02G08 (SWSS Leg One) surveyed for sperm whales along the middle continental slope (MCS) of the north central GOM from 94.7°W to 86.4°W. The cruise departed Galveston, Texas, on 19 June 2002, and concluded in Gulfport, Mississippi, on 9 July 2002. From 20 June–8 July, five CTD stations were made, thirty-five T7 XBTs were dropped to profile temperature in the upper 760 m, and seven supplemental drops were made with T10 XBTs to collect additional data from the upper 200 m (Figure 2F.1). Ocean current velocity was logged every five minutes from two hull-mounted acoustic Doppler current profilers (ADCPs), and we pumped near-surface water from ship's hull depth of 3.5 m through SeaBird temperature and conductivity sensors and a Turner Designs Model 10 fluorometer to log surface temperature, salinity, and chlorophyll fluorescence once per minute. Although the ship track was centered on water depths of 900–1000 m, the SWSS Leg One survey generally followed a zig-zag course between water depths from 575–820 m (zigs upslope) to 1125–1430 m (zags downslope).

Visual and acoustic observers found sperm whales in seven locations during Leg One, mostly as groups of 2–9 animals. These groups were not encountered randomly in time or space, but instead most were heard/seen when the ship was between 89.9°W and 87.1°W. Most of the contacts with whales were in water depths of 900–1000 m, but some whales were heard/seen in water depths both shallower (to 700 m) and deeper (to 1300 m). Most of the places were where whales were seen were high-salinity blue water rather than low-salinity green water environments. Specifically, surface salinity was generally > 36 between 94°W and 89°W, and in most the region east of 89°W surface salinity was generally > 34, and chlorophyll (CHL) all along the MCS was generally 0.5 µg/L or less. Only in three places were biological "hot spots" of CHL > 1 ug/L documented locally. The ADCP record (Figure 2F.2) shows that currents along most of the MCS generally ran along or directly on to the margin, tracking anticyclonically around the northern edge of a warm-slope eddy (WSE) that is very evident in the SSH field 92°W–88°W. Although the Leg One cruise track did not extend south far enough to reach the center of that WSE, we documented 15°C depths > 270 m in XBT drops made at the deeper (southernmost) zags downslope from the 1000 m isobath. Our colleagues at Oregon State University are determining the frequency with which whales they radio-tagged in the northern part of this anticyclone ranged seaward from the 900–1000 m isobath into this WSE, and into the deepwater regions of cyclonic circulation to the east and southeast of this anticyclone.

R/V *Gyre* cruise 02G11 (SWSS Leg Two) departed Galveston, Texas, on 20 August 2002, and returned to Galveston again on 16 September 2002. Eight CTD stations were made and thirty-eight T7 XBTs were dropped to profile temperature in the upper 760 m (Figure 2F.3), though for most of the cruise the ship worked a geographically limited area of the MCS between 90°W and 88°W, in and around the Mississippi Canyon to the head of DeSoto Canyon. Water was again pumped to temperature, salinity, and chlorophyll fluorescence sensors in the main lab, but during Leg Two the ship's ADCPs were run only during transits into and away from the principal operations areas.

During Leg Two, low-salinity green water was found along a much greater area of the MCS than on Leg One. Property-property plots of in vivo CHL fluorescence versus salinity were mostly non-linear, with "hot spots" of CHL > 1 µg/L along the MCS in a wide range of surface salinity (27–34). These surface hot spots occurred over water depths of 700 m to 1000 m throughout most of the region 91°W to 88°W, as "new" deepwater primary production was enhanced in salinity fronts. Most of the sperm whales seen during Leg Two were in green water environments.

The range of physical processes that create and maintain such surface hot spots of CHL in the GOM are becoming better understood (Walsh *et al.* 1989; Muller-Karger *et al.* 1991; Wiseman and Sturges 1999; Biggs and Ressler 2001). However, because sperm whales eat squid and they forage for squid at depth rather than at the surface, it is unlikely these apex carnivores respond immediately or directly to surface salinity, surface CHL, or other surface conditions. Thus, encounters with sperm whales may show only limited correlation with "snapshot" surface conditions during individual cruises. On the other hand, sperm whales do appear to aggregate in deepwater areas of the GOM where time-averaged planktonic productivity has been greater than usual for time-scales of weeks to months (Biggs *et al.* 2000). Finding the location of such areas, which may be spatially variable while being temporally persistent, is best accomplished by remote sensing using a combination of altimetry and ocean color.

The Sea Surface Height (SSH) anomaly data show a gradient of increasing SSH from N to S (from shelf to slope) over most of the north central GOM for most of the first four months of 2002. This is evident in animations of the near-real-time data as a temporally persistent although spatially variable region of negative-to-positive sea surface height anomaly. In the negative SSH part of this gradient, which usually includes the 800–1000 m isobaths, the doming of nutrient-rich midwater close to the surface favors enhanced planktonic new production along this continental margin. In March 2002, the Loop Current shed a Loop Current Eddy (LCE) and in April 2002, this LCE in turn shed a warm filament that extended north into the DeSoto Canyon. By May 2002, this warm filament had consolidated into a warm slope eddy (WSE), the inshore edge of which reached the

Mississippi Canyon region south of the Mississippi River delta. The SeaWiFS ocean color imagery shows that the anticyclonic circulation around this WSE pulled green water offshore into the eastern part of the SWSS field area, and that by late May to early June 2002, this off-margin flow was best developed east of 88°W.

By mid-June, the gradient of increasing SSH over the slope 94°W–88°W indicates west to east flow along most of the 1000 m isobath, but off-margin flow west of 94°W and east of 88°W. Leg One XBT, CTD, and ADCP data confirmed that off-margin flow was present in both of these areas. However, subsequent SSH altimetry maps indicate that what on Leg One had been large-scale anticyclonic circulation in deepwater south of 27°N had between early July and mid-August 2002 broken up into several much smaller anticyclonic eddies. By mid-August, these minor eddies were distributed pretty much all along the continental margin of the north central Gulf. By combining altimetry with ocean color, it can be seen that a pair of WSEs south of Mississippi Canyon and in DeSoto Canyon were entraining green water from the shelf and transporting this off margin. SWSS Leg Two confirmed that off-margin flow of low salinity green water was present in most of the region 90°W to 88°W and also documented locally high chlorophyll in a "bulls-eye" of high ocean color visible in SeaWiFS imagery in deepwater southeast of Mississippi Canyon. The radio-tag location data reported by Bruce Mate elsewhere in these proceedings show that one of the sperm whales he tagged during Leg One had moved out into this deepwater hot spot of CHL by August and that it stayed in or near this hot spot for 2–3 weeks. However, most of the other radio-tagged whales remained either in the green water between 91°W to 88°W along the 1000-m isobath, or they ranged west to the Texas continental margin.

SUMMARY

Cyclonic and anticyclonic eddies contribute biological and physical heterogeneity along the continental margin of the northern GOM. Temporal and spatial variations in the geometry of the eddy field along the 800–1000 m isobath determine whether low-salinity green water flows off margin or if high-salinity blue water flows on margin. Green water is biologically rich and will support more food for the squid upon which whales prey. Locally high CHL can also develop when or where nutrient-rich water domes upward in cyclonic eddies. Cyclonic eddies and other nutrient-rich features that persist for three to four months may be important feeding grounds for sperm whales along the GOM continental slope.

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REGULATING THE IMPACTS OF SEISMIC EXPLORATION

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Since the early 1990s, concern has mounted over the environmental impacts of underwater noise pollution. Most of the public attention has been directed at naval activities that produce intense sound, such as ship-shock trials and sonar exercises, but OCS exploration and production activities were among the first to receive the attention of regulators and have increasingly come under scrutiny. For three summers between 1997 and 2001, the western Pacific population of gray whales, possibly the most endangered population of large whales in the world, was observed to abandon habitat within its feeding grounds as seismic vessels ran transits 20 and 30 kilometers away (Weller *et al.* 2002). Last September, two Cuvier's beaked whales, a species known to strand in connection with mid-frequency sonar, were found beached in the Gulf of California shortly after an airgun array moved into the area (Hildebrand 2002). These events have heightened concerns within the environmental and scientific communities over the biological impacts of seismic exploration, and have significantly raised the profile of seismic within the broader issue of ocean noise.

Arriving at practicable solutions to the challenge of ocean noise pollution must take place within the framework of law. The principal federal laws that apply to seismic ships in U.S. waters or otherwise under U.S. jurisdiction are the National Environmental Policy Act (NEPA), a procedural statute that directs federal agencies to incorporate environmental considerations into their decision-making; the Marine Mammal Protection Act (MMPA) and Endangered Species Act (ESA), which prohibit both government agencies and private parties from "taking" species of concern without meaningful review and mitigation; and the Magnusen-Stevens Act, which requires that agencies consult with the National Marine Fisheries Service over activities that affect essential fish habitat. A number of other federal statutes, the Outer Continental Shelf Lands Act (OCSLA) and Coastal Zone Management Act (CZMA), are also applicable. Nearly a dozen foreign governments have begun to require environmental assessments and to impose mitigation requirements on seismic surveying, or have proposed to do so, and such jurisdictions as Australia have adopted standards that, in certain respects, are more conservative than those governing activities under American jurisdiction.

At the core of every regulatory system that has been applied to seismic exploration is an assessment of environmental impacts, which may take the form of a programmatic document (usually undertaken at the leasing stage), a project-specific document (to be completed before a particular transect is shot), or a tiered set of documents prepared at different stages. In the U.S., this process has sometimes been marked by scientific controversy, particularly in how existing data have been interpreted. Given the vicissitudes of studying impacts in the wild, the subtle or long-term nature of certain effects, and the tendency of some species to hazard intense noise in order to remain in productive habitat, it is not necessarily accurate to assume no impact is occurring even in the absence of a measured response (Richardson *et al.* 1995; International Whaling Commission 1999). Even under controlled conditions, it is difficult to account for demographic and other variables that may affect behavioral responses to ocean noise. The reaction of individuals from the same species may differ depending, for example, on whether they are migrating or feeding (Richardson *et al.* 1995, 1999) or whether their group consists of males or of females and calves (McCauley *et al.*

2000). In some cases, preparers of environmental assessments have taken an inconsistent position with regard to data interpretation, extrapolating broadly from studies that suggest an absence of impact and unaccountably narrowing the findings of others where the impacts appear significant or severe—an approach that is scientifically and legally unjustifiable.

Under the Marine Mammal Protection Act and, by incorporation, the Endangered Species Act, the wildlife agencies are required to prescribe means and methods of effecting "the least practicable adverse impact" from permitted activities. Following this standard, passive acoustic monitoring should be required during survey operations, especially in the Gulf of Mexico where deep-diving sperm whales are of major concern; and any data obtained from shipboard monitoring, including records of sightings and shutdowns, should be made easily available to the public. It is also necessary, given the range of potential impact, for the National Marine Fisheries Service to go beyond the concept of a monitored "safety zone" in setting mitigation requirements. NMFS should require use of the least impactful available technologies and control technologies; should set seasonal restrictions for avoidance of feeding and breeding areas, migratory corridors, and high concentrations of vulnerable species; should time operations to avoid consecutive or concurrent transits in close proximity of one another; and should at least consider requiring companies to share data or employ a common surveyor in some instances.

RECOMMENDATIONS

- Passive monitoring should be required, especially where sperm whales are concerned.
- Minimum number of observers should be required to scan in all direction from source.
- All research should be conducted in an open and transparent manner, with independent review and public availability of data.
- Observer data in particular should be made publicly available.

BEYOND MONITORING

- Require use of best Available Control Technologies (BACT).
- Set seasonal restrictions for avoidance of feeding and breeding areas, migratory corridors, and high concentrations of vulnerable species.
- Avoid conducting surveys in close proximity of one another concurrently or consecutively.
- Reduce or eliminate redundancy by requiring companies to share data or employ a common surveyor.

DIALOGUE

- Support multi-stakeholder process that brings together scientists, regulators, industry, and environmental NGOs to identify and evaluate research: e.g., right whale ship-strike group.
- Engage in discussion about practicability of alternatives and mitigation measures.
- Support pooling of funds from user groups to get at common research issues.

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SEISMIC SURVEYS AND MARINE MAMMAL PROTECTION

Philip Fontana, Veritas DGC

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USING ACOUSTIC BUOYS TO ASSESS AMBIENT NOISE AND SPERM WHALE VOCALIZATIONS*

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ABSTRACT

The Littoral Acoustic Demonstration Center (LADC), consisting of the University of Southern Mississippi (USM), the University of New Orleans (UNO), and the Naval Research Laboratory at Stennis Space Center (NRL-SSC), with guidance and technical assistance from the Naval Oceanographic Office (NAVOCEANO), was formed to do ambient noise and marine mammal acoustic measurement and analysis. Three Environmental Acoustic Recording System (EARS) buoys, designed and produced by NAVOCEANO, were deployed by LADC in the northern Gulf of Mexico (GOM) in the summers of 2001 and 2002 during MMS exercises Sperm Whale Acoustic Monitoring Program (SWAMP) and SWSS and in the Ligurian Sea in the summer of 2002. These bottom-moored omni-directional hydrophone recording systems were modified by NAVOCEANO to record the vocalizations of sperm whales. The EARS buoy hydrophones, 50 m above the bottom, were placed on a downslope line, ending at the largest concentration of sperm whale sightings in the northern GOM, in 600 m, 800 m, and 1000 m depths. The moorings were instrumented with self-recording environmental sensors to obtain time series data of temperature, conductivity, and pressure at specified depths spanning the water column. Each GOM EARS buoy recorded up to 5859 Hz continuously for periods ranging from 21 to 58 days. The Ligurian Sea buoy recorded up to 12,500 Hz for 21 days. These data clearly reveal sperm whale vocalizations, passing ships, and seismic airguns. Spectral levels for ten-minute averages of ambient noise on four different days from the summer 2001 recordings show moderate shipping levels except during passage of a storm. A plateau in the noise spectrum from 200 to 1000 Hz during the storm passage is probably due to bubbles and spray from surface agitation and breaking waves. Elevated noise levels above 1000 Hz on one day are due to the presence of sperm whales. Aural analysis of the data reveals the presence of other whales and shipping noise which varies from intense to quiet. Spectrograms show sperm whale clicks and creaks and the seismic airgun signal very clearly.

BACKGROUND

The Littoral Acoustic Demonstration Center (LADC) is a consortium of the University of New Orleans (UNO), the University of Southern Mississippi (USM), and the Naval Research Laboratory

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at Stennis Space Center (NRL-SSC). It receives technical guidance and support from the Naval Oceanographic Office (NAVOCEANO). It was formed in the spring of 2001 to perform and analyze underwater acoustic measurements of ambient noise and marine mammal vocalizations. The first measurements were made in the Gulf of Mexico to coincide with the MMS SWAMP in the summer of 2001 from 17 July to 21 August.

Figure 2F.4 shows the LADC study area, which is the same for summer 2002. The black dots indicate oil platforms, and the whale symbols indicate sperm whale sightings. The red downslope track shown is 43 km long and extends from the 200 m contour to beyond the 1000 m contour. The red cross-slope track is 81 km long and approximately follows the 1000 m contour. Figure 2F.5 shows the study tracks in more detail. The red circles indicate the acoustic/environmental mooring placements and the black circles indicate CTD casts. The environmental considerations that went into choosing the mooring locations are discussed by Newcomb *et al.* (2002a, 2002c). The cruises and measurements made that summer are listed in Figure 2F.6. The second measurements were made in conjunction with the Saclant Centre (SACLANTCEN) exercise Sirena02 in the Ligurian Sea from 01 July to 23 July in the summer of 2002. The study area is area A shown in Figure 2F.7. The third set of measurements was made during the late summer and early fall of 2002 concurrent with the second leg of the MMS Sperm Whale Seismic Study (SWSS). Again see Figure 2F.4 and Figure 2F.5.

All the acoustic measurements were accomplished with moorings which included Environmental Acoustic Recording System (EARS) buoys from NAVOCEANO. The EARS buoys each had a single omni-directional hydrophone and an instrument package which autonomously recorded the acoustic signals up to 5859 Hz. The hydrophones for these buoys were tethered 50 m from the bottom. The remainder of the mooring, spanning almost all the rest of the water column, was instrumented with self-recording environmental oceanographic sensors which provided time series data of temperature, conductivity, and pressure. See Figure 2F.8. In both the summers of 2001 and 2002 the moorings were deployed at the 600, 800, and 1000 m contours on the downslope track, as shown in Figure 2F.5. The acoustic recordings in summer of 2001 lasted 36 days. The cruise dates and acoustic recording duration for the summer of 2002 are shown in Figure 2F.9. The EARS buoy in the Ligurian Sea in the summer of 2002 recorded for 21 days in a water depth of 989.6 m. It is a new design which recorded up to 12,500 Hz. The cruise dates were 1 July to 23 July. For all experiments the ocean environmental sensors recorded the whole time the moorings were in the water.

Additional oceanographic data were gathered on various cruise legs to augment the mooring measurements and give a more complete description along the study tracks. For example, in the summer of 2001, 38 CTD and 77 XBT casts were made. Four articles (Caruthers *et al.* 2002; Newcomb *et al.* 2002a, 2002c; Turgut *et al.* 2002), and 2 abstracts (Ioup and Ioup, 2002; Newcomb *et al.* 2002b) have been published about the experiment to date. Four abstracts will be published in connection with the Acoustical Society of America spring meeting in Nashville (Eller *et al.* 2003; Snyder *et al.* 2003; Vinogradov *et al.* 2003; Walker *et al.* 2003). Also in the summer of 2001 Turgut *et al.* (2002) performed a chirp sonar survey along the study tracks. The data have been inverted to give sound speeds and densities in the bottom.

AMBIENT NOISE

Figure 2F.10, Figure 2F.11, Figure 2F.12, and Figure 2F.13 show ambient noise levels from four different days. The noise spectra are given as spectrum levels (dB re 1 µPa/√Hz) versus the log of the frequency from 5 to 5000 Hz. Each figure represents a 10-minute average of the noise for a hydrophone at a depth of 750 m in 800 m water depth. Each figure is labeled with the Julian day of the year 2001 and Zulu time in hours, minutes, and seconds. Day 214 (Figure 2F.10) was before the passage of Tropical Storm Barry, Day 217 (Figure 2F.11) was during, and Days 224 and 230 (Figure 2F.12 and Figure 2F.13) were after.

Distant shipping noise is generally dominant in a frequency range from 10 Hz to 300 Hz with a peak in the spectrum near 50 Hz. More local shipping effects often include many tonal lines superimposed upon the distant shipping spectra. The spectrum for Day 214 (Figure 2F.10) includes many of these lines indicating the probable presence of relatively nearby ships. During Tropical Storm Barry these lines diminish greatly (see Figure 2F.11). In addition, the overall levels from 100 Hz to a few hundred Hz decrease. The broadband "hump" in the spectrum at about 60 Hz remains at the same general level for the two spectra. Since the EARS are battery-powered there is no narrowband 60 Hz electrical component. Besides, this feature of the spectra is not narrowband, and thus must be a component of the noise field. The large "hump" in the spectrum from about 1000 Hz and higher on Day 214 (Figure 2F.10) is consistent with sperm whale emissions. Indeed, sperm whales are very prominent when listening to this segment. Sperm whales are faintly discernable by listening during the Day 217 segment. The low-frequency portion of the spectrum for Day 214 includes seismic airguns in addition to the ship noise. There is no sign of geophysical prospecting or shipping on Day 217 (as expected).

On Day 224 (Figure 2F.12), after the passage of Tropical Storm Barry, the overall spectrum levels are much higher. Geophysical prospecting is obvious and seemingly close as indicated by an aural survey of the data. There is also nearby ship noise later in this segment. Sperm whales are still aurally evident, but seemingly not in as great numbers and not as loud relative to the other noise. On Day 230 (Figure 2F.13), clicks are definitely due to sperm whales.

Ross (1987) Figure 8.23 (p. 281) gives an estimate of the ambient noise levels due to various levels of shipping as a function of frequency from 10 to 1000 Hz. Figure 2F.10, Figure 2F.12, and Figure 2F.13 show spectrum levels of about 60–90dB in the range of 10–1000 Hz for Days 214, 224, and 230, respectively. This corresponds to moderate to heavy shipping activity, according to Ross. In general, above 300–500 Hz other noise sources begin to dominate the received noise field, which is illustrated in Figure 2F.11 (Day 217). From about 200 Hz up to 1000 Hz there is a plateau in the noise that is uncharacteristic for shipping noise. This region is consistent with deep-water noise generated by bubbles and spray (surface agitation/breaking waves most likely due to Tropical Storm Barry). According to Wenz (1962) the levels, from 200–1000 Hz on Day 217 correspond to Douglas Sea States between 3 and 4 and Beaufort Wind Forces between 4 and 5.

A rule-of-thumb description of these includes the following: a) Wind speeds (sustained, NOT gusts) between 11 and 21 knots; b) Numerous white caps; some spray; and c) Rough seas; wave heights between 5-8ft. Tropical Storm Barry was at least 60–120nmi away from the buoys, passing to the east. According to the National Weather Service reports, the winds and seas varied greatly within each quadrant centered upon T. S. Barry. On Day 217, there were expected to be up to 12ft seas out to 60nmi (NW quadrant) and 125nmi (SW quadrant) with maximum gusts of 34kt out to 45nmi (NW quadrant) and 60nmi (SW quadrant). So the data on Day 217 from 200–1000 Hz (the plateau) are consistent with the prevailing wind and sea conditions and with Wenz. Wilson (1980, 1983) did some early work on a semi-empirical model of wind speed source levels and his model agrees with the Day 217 measured values from 200–1000 Hz for wind speeds of about 15 knots.

AURAL ANALYSIS

The recordings revealed considerable amounts of anthropogenic noise at all depths, as well as frequent sperm whale clicks and occasional killer whale sounds. Several sample recordings were presented at the MMS ITM03 meeting. Hourly comparisons of sperm whale click production are underway to determine the times of day during which sperm whales are most likely to produce clicks. In addition, comparisons will be made of sperm whale click production across different levels of anthropogenic noise. The anthropogenic noise in the recordings consists primarily of sounds produced by either ship or boat engines or airguns employed in seismic exploration. Different levels of shipping noise have been found, ranging from none to very intense shipping. It proved impossible to determine aurally the presence of sperm whale clicks when intense boat noise occurred. Although we do not know if whales produce clicks in extremely noisy environments, it seems possible that periods of intense shipping noise may affect sperm whale sound production, particularly if the whales can neither hear clicks nor perceive returning echoes during this time. Less intense noise did not seem to affect click production, suggesting that the whales have adapted to such levels of noise, at least insofar as the production of clicks at these depths is concerned.

SPECTROGRAM ANALYSIS

A 60sec segment of data from the 800 m buoy has been selected for presentation because it contains very clear recordings of multiple sperm whales. The recording begins on Julian Day 213, Zulu 0 hr, 9 min, 37 sec. A representative four-second segment is shown in Figure 2F.14. In this figure, the top two graphs show the time signal, on the left as originally recorded and on the right after the application of a 300 Hz highpass filter, as suggested by Mellinger (2002). Removing the low-frequency components makes the sperm whale click train sequences quite clear. The bottom four graphs in each figure are spectrograms. The top pairs show all frequencies up to 5859 Hz while the bottom pairs contain only frequencies to 1000 Hz. Broadband transform lines in the middle figures are sperm whale clicks and closely spaced clicks sound like creaks, although they are distinct from the spectrogram patterns which correspond to what are generally known as creaks in the literature. The seismic airgun signal is clearly visible as the red peak in the bottom left spectrogram of Figure 2F.14. Because the seismic vessel is 107 km from the EARS buoy, there is considerable reverberation. The low-frequency noise without the airgun present, which still dominates the spectrum, is visible after the airgun finishes.

Listening to the recorded sound gives an audible confirmation of what is shown by Figure 2F.14. The airgun boom containing reverberation can be heard, and it repeats every 10 to 12 seconds. The sperm whale clicks and “creaks” are recorded very clearly. The small separation time between groups of "creaks" indicates the presence of as many as six sperm whales in the sixty-second segment, as suggested by Martinez (2002). Initial inspection has revealed many time periods with sperm whales present. The entire unfiltered 60 seconds recording was played at the MMS ITM03 presentation with the corresponding 4 seconds spectrograms synchronously displayed. The filtered spectrogram was discussed but the recording was not played. The data set in general and the sperm whale data in particular are quite rich in content. Several analysis approaches for these data are now underway, including the use of spectrograms.

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SPERM WHALE ACOUSTICS IN A NOISY WORLD

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THE ACOUSTIC WORLD OF SPERM WHALES

The sperm whale (*Physeter macrocephalus*) is a cosmopolitan species that inhabits the blue waters all over the world from the equator to the polar ice in estimated numbers between 300,000 and a million. Sperm whales undertake long (30–40 minutes) and deep dives (300–1500 meters) in the quest for medium-sized squid and fish. The estimated annual biomass turnover by foraging sperm whales is comparable to the total catch in human fisheries, and sperm whales are thus playing a very important role as predators in mesopelagic ecosystems worldwide.

The most dominating feature of the sperm whale's appearance is the enormous nasal complex, weighing up to 10 metric tons and accounting for up to 1/3 of the total body length in old males. It contains hypertrophied structures (Figure 2F.15) homologous with sound producing structures in smaller odontocetes (Cranford *et al.*). A number of theories have been advanced to account for the function of this gigantic nose. Norris and Harvey (1972) proposed that this large nasal complex is sound generator used for echolocation and communication. Recent investigations have presented compelling evidence to support the Norris & Harvey theory by demonstrating that sounds are produced by the monkey lips (Madsen *et al.* 2003), and that the spermaceti compartments of the nasal complex can transmit sound (Møhl *et al.* 2000). Thus, the primary function of this gigantic nasal complex is indeed sound production, and in the light of the enormous size of this structure, it can be surmised that sound plays a very important role for sperm whales.

Sperm whales are highly vociferous and produce more than half a billion clicks during a lifetime (Madsen 2000). The sperm whale sound repertoire encompasses a number of different click types with significantly different properties (Madsen *et al.* 2000). The most abundant click type, usual clicks, is produced almost continuously during foraging dives with an interclick interval (ICI) of 0.2 to 1.5 seconds (Madsen *et al.* 2002a). Usual clicks are highly directional (Møhl *et al.* 2000; Møhl *et al.* 2003; Ridgway and Carder 2001) with an estimated directionality index (DI) of at least 27 dB (Møhl *et al.* 2003). The clicks are multipulsed with a pulse spacing corresponding to the two-way-travel time between the reflective air sacs in the nose (Gordon 1991). However, the multipulse structure of a click recorded on the acoustic axis is totally dominated by a single, short duration (around 100 µsec) p1-pulse with estimated source levels (SL) up to 230 dB re. 1µPa (rms) (Møhl *et al.* 2003). This is the highest sound pressure level ever measured in the animal kingdom. Usual clicks are not only highly directional with regard to the apparent SL and waveform, but also with regard to frequency. Usual clicks measured off the acoustic axis have messy waveforms and frequency emphases between 2 and 10 kHz, whereas the same clicks recorded on the acoustic axis have frequency emphases around 15–18 kHz (Madsen *et al.* 2002; Møhl *et al.* 2003).

Another sound type produced during foraging dives is creak clicks. The name refers to the creaking sound of clicks with a fast repetition rate of about 30–200 click/sec. Creaks may last from 10 to 30 seconds and are normally terminated by silence for 5 to 20 seconds. Creak clicks are also highly directional, but compared to usual clicks, they have a lower SL of about 200 dB re. 1µPa (rms) (Madsen *et al.* 2002a). The waveform of an on-axis creak consists of a single pulse with a duration of some 100 µsec and a centroid frequency around 15 kHz. Hence, both on-axis usual clicks and on-axis creak clicks, having a frequency emphasis around 15 kHz, provide geometric backscatter from potential sonar targets in the size range preyed upon by sperm whales (Madsen *et al.* 2002a). Novel tagging data (Johnson *et al*. 2001) has shown that creaks are associated with fast 3-D movements of the tagged animal, implying that the whale is pursuing moving prey. Hence, the source parameter estimates and the recent behavioral observations substantiate the contention that sperm whale creaks serve the same function as buzzes from echolocating bats and delphinids in the terminal phase of prey collection (Madsen *et al.* 2002a).

The high phonation rate of foraging sperm whales, adjustment of ICI with potential sonar range, and the estimated source parameters of usual clicks and creak clicks lend weight to the view that echolocation is an important sensory cue for detection of mesopelagic prey (Madsen 2002; Madsen *et al.* 2002a). It has been speculated that the hypertrophied nasal complex of the sperm whale may have evolved to maximize directionality and source levels of 15 kHz pulses with low absorption and sufficient resolution to be used for long-range biosonar detection of mesopelagic cephalopods with low target strength (Madsen 2002a).

A third sperm whale click type is coda clicks. Codas are stereotyped, repetitive sequences of 3–40 clicks lasting 2–5 seconds (Watkins and Schevill 1977). Codas are generally closely associated with social behavior at the surface in groups of females, calves and juveniles (Weilgart and Whitehead 1993). Codas do not appear to be used for individual identification (Thode *et al*. 2002), but are more likely maintaining social cohesion within clusters of whales and reaffirming social bonds between individual whales (Weilgart and Whitehead 1993)). Recent data from deployment of sound recording tags has revealed that coda clicks differ significantly from usual clicks (Madsen *et al.* 2002b). It appears from the tag recordings that coda clicks have a much lower decay rate between the pulses, and that the pulses are longer, with a frequency emphasis around 5 kHz and more narrow-banded than the multipulses of usual clicks. The tag study also revealed that the acoustic outputs in coda clicks are reduced by some 20 dB compared to usual clicks, and that coda clicks supposedly have a lower directionality than usual clicks, making them more suited for communication than echolocation (Madsen *et al*. 2002b). The acoustic repertoire appears to contain even more click types, see (Gordon 1987; Madsen 2002).

In conclusion, the highly phonatious sperm whales carry the largest and most powerful sound generator in the animal kingdom. They are capable of producing a number of different click types with very different acoustic properties suited for different tasks. Compelling evidence suggests that sperm whales rely heavily on sound production and reception for communication, orientation and echolocation of prey.

SPERM WHALES AND ANTHROPOGENIC NOISE

Sperm whales produce sound with most energy between 3 and 25 kHz (Madsen 2002). This frequency band matches the frequency range of best hearing from 5 to 20 kHz measured in a neonate sperm whale calf (Ridgway and Carder 2001). Sperm whales produce sounds at frequencies one to three octaves below that of other odontocetes investigated, and their frequency of best hearing is also one to three octaves lower than that of other odontocetes. Together with a number of other teuthophageous odontocetes, sperm whales undertake deep dives during which they at times intercept or forage in the so-called SOFAR channel where low frequency sounds can travel long distances with little attenuation. Most anthropogenic sound sources in the sea generate low frequency sounds below 30 kHz, whereas high-frequency sources, if any, are of less importance due to the high absorption. Thus, being deep-divers relying on medium-frequency sounds between 3 and 25 kHz, sperm whales are potentially more vulnerable to low frequency anthropogenic noise in terms of masking, temporary/permanent threshold shifts, and behavioral effects than are smaller odontocetes.

MALE SPERM WHALES AND REMOTE AIR GUN PULSES IN A HIGH LATITUDE HABITAT

Air guns are used for seismic exploration world wide and may potentially have a large impact on the marine environment due to the high sound pressure levels and low-frequency nature of the generated pulses. Data presented in this study are opportunistic in the sense that the study was designed to gain information on properties of sperm whale clicks and diving behavior. Only three of the recording sessions happened to coincide with the presence of the operating seismic survey vessel. The interpretation of the data should therefore be evaluated in the light of limited sampling. For details on this study see (Madsen *et al*. 2002).

Recordings were carried out from 12 to 21 July 2000 in Bleik canyon, off Andenes, northern Norway (69° 30N, 15° 50E). Variable numbers of adult, male sperm whales inhabit the canyon all the year round, presumably engaged in feeding. A seismic survey vessel was exploring the continental shelf between 20 and 140 km SW of the canyon between the 12 and 25 July 2000 at water depths varying between 30 and 1100 m (Figure 2F.15). The survey vessel towed a tuned HGS sleeve air gun array with four sub-arrays of 10 guns. The array was towed at a depth of 7 m, and the guns were firing simultaneously. The total volume of the array was 3800 cubic inches (62 L) with a nominal working pressure of 2000 psi and a 10 sec repetition period. The far-field signal was a one-cycle transient with 30 msec duration and most energy in the frequency range of 10–80 Hz. The SL (with the amendments of a point source) of the downward propagating part of the signal was 109 bar-m (p-p) (filter bandwidth unknown), corresponding to 261 dB re. 1μPa (p-p) The SL of the horizontally propagating part of the signal was lower due to the downward directing properties of the array.

The properties of the pulses received at the location of the whales were different from the output signal of the sleeve air guns. The received sound pressure levels measured in the canyon, being the best available estimates of the levels received by the whales, varied between 130 and 146 dB re. 1μPa (115–130 dB re. $\mu Pa^2 s$ in energy terms). The duration had increased by a factor of 40 to more than a second, and the signal had a frequency emphasis at 200 Hz compared to the 50 Hz peak of the signal at the source. These changes are the effects of multipath propagation in shallow and subsequently deep water before the pulses reach the hydrophones and the whales in the canyon. The influence of the submarine topography and water depth is also illustrated by the fact that the seismic pulses recorded on 15 July propagating some 40 km in shallow water, had a lower received level than the seismic pulses recorded on the 18 and 20 July, propagating mostly in deeper water for 86 km and 94 km, respectively (Figure 2F.15).

It is predicted that the sperm whales would have detected the seismic pulses with received levels between 130–146 dB re. 1µPa (p-p). Since the spectral content (-10 dB) of the seismic pulses was in the frequency range of 110–260 Hz, it is unlikely that these pulses, being more than an order of magnitude lower in frequency, interfere strongly with the reception of echoes from sperm whale clicks in terms of masking. The pulses could interfere with low-frequency sounds originating from prey items and surroundings, potentially used by the sperm whales for passive sonar and navigation. However, the discontinuous nature of the seismic pulses presumably would have a strong ameliorative effect on any masking that might occur. The possible effects of the seismic pulses on the sperm whale prey could not be assessed from the available data.

Sperm whales were sighted from the research vessels and Whale Safari boats every day (except on 17 July) throughout the entire exposure period of 13 days (Figure 2F.15), demonstrating that the received levels from the seismic survey vessel did not elicit general avoidance or displacement of the sperm whales in the canyon. In addition, the rather limited body of recordings from seven specimens shows that sperm whales in this habitat do not cease clicking, nor do they seem to alter their normal acoustic behavior during feeding as a response to the seismic pulses with received levels up to 146 dB re. 1µPa (p-p). During start-up of the seismic survey on July 18, the first pulse did not evoke any abrupt changes in click rate as the mean click rate 10 sec before and after the first pulse was not significantly different.

CONCLUSION

Sound production and reception are of great importance to sperm whales as they are using sound for communication, orientation and echolocation of prey. The frequency range of sperm whale sounds and the frequency range of best hearing are between 3 and 25 kHz, potentially making sperm whales more vulnerable to low-frequency anthropogenic noise than smaller odontocetes. In the present study, sleeve air gun pulses with received levels up to 146 dB re. 1µPa (p-p) did not elicit any apparent avoidance behavior of the male, adult sperm whales in a high latitude habitat, nor did the pulses evoke changes in the acoustic behavior during foraging. It is estimated that the pulses were well within the zone of audibility of the sperm whales, but that the pulses had no masking effects in the frequency band of sperm whale clicks. The limited body of data in this study lends weight to the view that foraging male sperm whales are not more sensitive to remote air gun pulses than are other cetaceans investigated. The present data should not be extrapolated to the possible effects of seismic pulses with higher received levels and different sperm whale stock compositions in different habitats, as female sperm whales with calves may respond differently to the same exposure levels. At present, the small body of data on this issue is contradictory, and mitigations of seismic surveys in the presence of sperm whales must await data from controlled exposures and, optimally, deployment of sound recording tags on different animals in different habitats. Future investigations should also focus on the possible effects of seismic survey pulses on sperm whale prey, and on the other more elusive theutophageous odontocetes foraging in the same mesopelagic habitat as the sperm whale.

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RESPONSES OF TAGGED SPERM WHALES TO CONTROLLED EXPOSURE OF AN AIRGUN ARRAY IN THE GULF OF MEXICO

Peter Tyack, Woods Hole Oceanographic Institution

This paper expands on the information elsewhere in these Proceedings about the digital acoustic recording tag (DTAG), which was developed to enable controlled exposure experiments for deep divers. This device

1. tracks responses of marine mammals, especially deep divers, throughout their dives,
2. improves understanding of functions and costs of behaviors to illuminate the biological significance of behavioral disruption, and
3. develops dose/response technique to measure received level of stimulus by whale while also measuring behavioral and physiological responses.

The Sperm Whale Acoustic Monitoring Program (SWAMP) cruises demonstrated our ability to track details of behavior of tagged deep divers. We have focused on item #2 to select specific measures for behavioral disruption:

- avoidance
- evaluation of energetic costs and benefits of foraging dives—critical for growth
    - benefit of dive: successful foraging runs
    - cost of dive: measure drag, calculate work done by flukebeats
- social disruption: response to coda contact, masking of codas

During the SWSS cruise, we were able to conduct two controlled exposure experiments to study the responses of tagged sperm whales to sounds of an airgun array. Figure 2F.16 shows a map of the first experiment on 10 September 2002.

The red dots on the Gyre track mark the location of the ship when visual observers spotted the tagged whale at the location of the red dots to the left of the Gyre track. The next surfacing is marked with blue dots, and the third with green. The track of the source vessel is indicated on the lower left, with colors indicating the number of airguns that were firing.

The tag was able to record the sounds of these airgun signals, and this showed different spectra for airgun pulses recorded at different depths (Figure 2F.17).

The airgun signature from the shallow 20 m depth has much stronger high frequency components than the same airgun array recorded at a depth of 600 m. We developed a matlab tool to estimate the received level of these pulses. Figure 2F.18 shows the received level analysis for an airgun impulse recorded at 600 m depth and 10 nautical miles from the array.

This pulse was logged as having a received level of 143 decibels.

The primary analysis we conducted to test for responses of this sperm whale to these airgun pulses was to tally the rate of creaks, which the Miller presentation describes as a proxy for feeding events. Creak rates should indicate foraging success of the tagged whale. Figure 2F.19 shows the dive pattern of this whale, along with creak rates, before, during, and after exposure to the airgun impulses.

During the pre-exposure dive, the whale made 10.6 creaks/hour, during exposure, 16.4 and during the post exposure interval, 13.7.

The second controlled exposure experiment was conducted on 11 September 2002 to three whales each of which was simultaneously carrying a DTAG. These whales were so close together that the map plotting their movements shows just one track (Figure 2F.20).

The source vessel is indicated in the upper left, the Gyre track is indicated by the long black line, and the pseudotrack of the tagged whales is indicated by the colored line starting to the left, crossing, and then finishing to the right of the Gyre track. The seismic vessel more or less paralleled the tagged whales. Its closest point of approach was 4.5 nautical miles, at which time the whales were exposed to a maximum received level of 148 dB. There is no indication that the whales showed horizontal avoidance of the seismic vessel.

Figure 2F.21 shows the dive profiles and creak rates of all three tagged whales during this experiment. We can summarize the variation in creak rates before, during, and after exposure as shown in Figure 2F.22. If we compare the difference in creak rates before versus during exposure to 143–148 dB, there is no indication of a change in creak rate (Figure 2F.23).

However, this apparent lack of reaction comes with the caveat that it represents a small sample size, especially when one considers that the three whales tagged at the same time may not represent independent samples. This presentation should be taken as an example with pilot data of our experimental approach. The top priority for the next field season will be to increase the sample size, especially at higher exposure levels.

Peter Tyack is a Senior Scientist in the Biology Department of the Woods Hole Oceanographic Institution. He obtained his A.B. summa cum laude in biology from Harvard College in 1976 and his Ph.D. in animal behavior from Rockefeller University in 1982. He joined the Woods Hole Oceanographic Institution as a Postdoctoral Scholar in 1982 and has worked there ever since. Dr. Tyack is interested in social behavior and acoustic communication in whales and dolphins, and has conducted research on bottlenose dolphins, sperm whales, humpback whales, gray whales, right whales and bowhead whales. He has focused on developing new techniques to monitor vocal and social behavior of marine mammals. These include methods to tag whales, to locate their calls and for video monitoring of behavior. Dr. Tyack's research has focused on how these animals use sound for critical activities.

SESSION 3A

THE GULF OF MEXICO OIL HISTORY PROJECT: RESULTS FROM A YEAR OF RESEARCH

Co-Chairs: Allan Pulsipher, Louisiana State University
Harry Luton, Minerals Management Service

Date: January 16, 2003

INTRODUCTION: HISTORY AND EVOLUTION OF THE OFFSHORE OIL AND GAS INDUSTRY IN SOUTHERN LOUISIANA

Harry Luton, Minerals Management Service

The development of Louisiana's offshore petroleum industry is a remarkable story of inventiveness, entrepreneurial spirit, hard work, and risk-taking that turned the state's relatively isolated and impoverished coastal communities into significant contributors to the U.S. and world economies.

The Minerals Management Service began this study to document the history of this industry before its pioneers disappeared. MMS began the study to evaluate the social impact of the offshore industry on Southern states and, particularly, on the coastal communities in which it developed. The idea is to allow people who grew up with the industry and who helped develop the industry speak for themselves.

The presentations that follow are based on oral histories from pioneers in an industry that is little documented. The pilot year of the study focused on the early years of the offshore industry, from the 1940s to the 1960s.

Harry Luton is employed by the Minerals Management Service (MMS) and works primarily on the Gulf of Mexico Region's Studies Program. He completed his Ph.D. in American studies at the University of Michigan. After working on native subsistence issues in the Alaska OCS office for a decade, Dr. Luton served a stint at MMS Headquarters in Washington, DC, before moving to the Gulf of Mexico Region in 1994.

HISTORY AND EVOLUTION OF THE OFFSHORE OIL AND GAS INDUSTRY IN SOUTHERN LOUISIANA: EXPLORATION TECHNOLOGY AND THE FEDERAL LEASE SALES THAT OPENED UP THE GULF OF MEXICO

Tyler Priest, History International, LLC

When did offshore oil development begin in the Gulf of Mexico (GOM) and what propelled the industry forward into deeper water? These questions are subject to debate among students of the offshore oil industry. Kerr-McGee's Ship Shoal Block 32 platform, installed in 1947 in eighteen feet of water, ten and one-half miles from the Louisiana shore, has been typically recognized as the first offshore platform "out-of-sight-of-land." The point can be and has been made, however, that this is an artificial landmark, and that the 1938 Pure-Superior platform in the Creole field, a mile and a half from the city of Cameron, was the first truly free-standing structure that produced oil in the Gulf. It all depends on what one means by "offshore" and at what depth one thinks offshore oil and gas operations begin to differ fundamentally from marine operations in shallow and inland waters.

While interesting, this debate is not very useful; more importantly, it is misleading. By trying to pin down the origins of the industry in the 1930s and 1940s, we are tempted to see the history as a slow evolution from our designated point of origin, when in fact, as Stephen J. Gould argued in the case of human evolution, change in the offshore oil industry came in fits and starts through a process of "punctuated equilibrium." If we take fixed platforms as our standard of reference in viewing the history of the industry, then it is true, change appears gradual and incremental. The key challenge to offshore development, then, appears to be gaining the technical ability to build and install platforms in progressively deeper water. While recognizing the amazing accomplishments and accelerated learning curves of production engineers, construction and shipbuilding companies, and all the mechanics and tinkerers along the Gulf Coast who made this happen, I would argue that the key challenge was not figuring out how to build these platforms, but figuring out where exactly to build them and how much to pay for them. One common refrain from the interviews we have done with production engineers is that when asked, "how deep can you build a platform," their typical reply was, "tell us how much you are willing to pay for a platform, and we'll tell you how deep we can build it." So, for me, the most vital historical question in understanding the evolution of this industry is "how did oil companies determine how much they were willing to pay for a platform?"

The answer to this question, of course, depended on the costs of finding new reserves, which in turn depended on two things: 1) favorable terms of access to offshore lands; and 2) the costs and accuracy of exploration. Finding commercial quantities of oil in a risky, high-cost environment was the name of the game. Yet the story of offshore GOM has really not been told from the perspective of the managers and geoscientists who pioneered pathbreaking exploration technologies, took the risks, found the oil, and made the play. The drillers and platform builders, so far, have captured the limelight. The first phase of my research for this history project thus has focused on trying to acquire this perspective of exploration managers, geologists, and geophysicists, as well as the agents of leasing in the federal government. The story that emerges from this research points to the late 1950s and early 1960s as the first moment of fundamental transformation, with the first real conceptual breakthroughs, in the entire history of the offshore industry. For prior to that time, despite some experimentation with mobile drilling, which was still quite limited to 50–100 feet depths, the industry had not really moved much beyond "backyard stuff," as one engineer put it. But during the 1958–1964 conjuncture, the industry learned how to move beyond the backyard into "deepwater." In fact, not until this period of punctuated equilibrium, which I will argue witnessed the true origins of the industry as we know it today, did oilmen even begin using the term "deepwater."

UNCERTAINTY AND STASIS IN THE LATE 1950S

During the late 1940s and early 1950s, oil companies found tremendous oil reserves not far from shore offshore Louisiana. Giant discoveries were made, for example, on Shell Oil's South Pass Blocks 24 and 27 and Eugene Island 18 leases, The California Company's (Chevron) Bay Marchand 2 and Main Pass 69 leases, and Humble Oil's Grand Isle 18 lease. The success rate for wildcat exploratory wells was exceptionally high, much higher than onshore. But these finds were in relatively shallow waters of 30 feet or less, on relatively large salt domes. By the late 1950s, however, the prospects for further success offshore dimmed. Leasing was suspended in 1955 after the state of Louisiana obtained an injunction against federal lease sales pending a resolution of the Tidelands dispute over jurisdiction in submerged lands. Although a complicated agreement between Louisiana and the federal government was finally worked out in 1956, an economic recession, an oversupply of crude, a series of hurricanes, and declining oil finds in deeper waters soon forced a slowdown in offshore exploration. Both dry holes and capital costs increased for water depths beyond 60 feet. Fixed platforms, even tender supported ones, were economically unfeasible for exploration. Submersible drilling vessels were impractical and unstable in deeper water. Early jack-up rigs designed for greater depths were prone to capsizing. Insurance premiums soared.

Many people believed offshore development had reached its limits. Upper management in the Shell Oil Company, one of the leaders in the Gulf, for example, engaged in serious debate on this question. The vice president of the company's New Orleans Area office, a driving force behind Shell's early moves into shallow water, now argued that the technology required for going deeper than 60 feet might be impossible to develop, and even if it were, the costs would be prohibitive. Better to be happy with what Shell had and stick to production. His pessimism about the future of marine operations for oil companies was not uncommon in the industry (Priest in press).

ADVANCES IN EXPLORATION TECHNIQUES AND STRATEGIES

Drilling Technology

Other intrepid souls thought differently. The top exploration and production officials in Shell Oil overrode the objections of its New Orleans manager and funded research on new marine drilling technologies that would ultimately break the industry's tether to shallow-depth submerged lands. In January 1962, Shell successfully tested drilling from a new kind of "floating drilling platform." This converted submersible vessel, the Blue Water 1, was equipped to operate in 300 feet of water without resting on the bottom. It was a space-framed structure consisting of three large columns on each side and a submerged hull—the first "semi-submersible." To complement the new floating platform, Shell also tested the first successful subsea wellhead completion, all by remote control because the practical limit of diving at the time was only 150 feet. Overnight, Shell's Blue Water

1 and subsea completion system changed the mindset of the entire industry, leading to the immediate construction of new, purpose-built semi-submersibles after Shell shared its technology in early 1963. "We're looking now at geology first, then water depths," said one Shell official (Anonymous 1962).

Geophysical Technology

The industry's way of looking at geology, and its close relation geophysics, was also changing radically at this time. In the 1930s, the seismic reflection method (measuring the waves of a sound source that is bounced or reflected off subsurface layers to determine geological structure) had become the dominant method of geophysical prospecting. But in the mid-1950s, several developments combined to enhance greatly the acquisition and processing of reflection seismic data. The introduction of continuous velocity well logs (sonic logs), in which sound velocity measurements within a well were correlated with rock density, gave greater insight into the origin of seismic reflections. Of major importance, in 1955, was the innovation of magnetic tape for recording seismic sound waves (previously all calculations and interpretations were made on the original paper records acquired during seismic survey). Cross sections prepared from analog magnetic-tape playback, commercially developed in 1958, could include desired "filters" to adjust for time delays caused by surface effects and path geometry. Most importantly, magnetic-tape playback provided a means for economically applying the "common-depth-point" (CDP, sometimes called common-mid-point or common-reflection-point) or "horizontal stacking" method of shooting. CDP stacking, in which tapes of individually corrected traces were combined or "composited," vastly improved the acquisition of seismic data by enhancing "primary" reflections and filtering out unwanted "multiple" reflections or "noise." Invented by Harry Mayne of Petty-Ray Geophysical, it revolutionized the shooting and processing of seismic data. Between 1960 and 1962, the most technologically advanced companies in the industry licensed the technology. Still the main signal-to-noise enhancing technique today, CDP stacking was a watershed that divided previous seismic exploration from all subsequent innovations (Lawyer *et al.* 2001; Mayne 1989).

Other innovations flowed out of magnetic recording and CDP shooting. Magnetic recording made feasible the employment of various sound sources to replace the thousands of tons of dynamite exploded every year in the Gulf and the disturbances to aquatic life they caused, or even to beach life when undetonated charges washed up on them (Evans 2002). Recording capability was such that 50-pound dynamite charges were overkill, no pun intended. The technique most widely adopted used a vibrating device, the Vibroseis, that emitted a pulse as the sound signal. Developed by Conoco in the late 1950s, the Vibroseis also made the multiplicity of source points and geophones required by CDP feasible without the associated increased in costs if dynamite were used as the energy source.

Magnetic recording, with its capacity for storing seismic information in reproducible form, intensified interest in what one geoscientist referred to in the 1950s as "mechanized automatic means of data processing," or, as we would say today, computing. Conventional methods of seismic data processing involved tedious, human computational labor, converting time to depth, making all sorts of corrections for various factors, and then plotting this information profile on a two-dimensional, subsurface cross-section. The job title for the seismologists who performed this work indeed was often "computer" (Reilly 2002). In the mid- to late-1950s, analog seismic data processing computers made their appearance, which relieved the human computer of some of the busy work in processing. Fairly swiftly, many companies moved to using analog-to-digital converters and digital processing (general purpose digital computers had become commonly available by 1957). Field recording in digital format soon followed. In 1962, Geophysical Services Inc., the undisputed leader in this field (it spun off computer research into a separated company called Texas Instruments), performed the first digital recording on a two-year proprietary contract for Mobil and Texaco, and by 1965 most oil companies were working with digital field recordings (GSI n.d.). Digital computers enabled a quantum leap in the amount of data that could be handled and manipulated, leading to an almost continuous innovation in seismic processing and interpretation, with the "deconvolution" of signals caused by reverberations in water in the early 1960s, the "direct detection" of hydrocarbons in the late 1960s ("bright spots"), three-dimensional seismic in the late 1970s, and four-dimensional or "time-lapse" seismic today—all of these having the greatest application offshore. By the early 1960s, in other words, a revolution in seismic technology was underway, exponentially increasing oil companies' understanding of the subsurface and accuracy in finding oil and gas, and lowering the considerable risks of offshore exploration.

Quantitative Analysis of Prospects and Bidding

Increasingly sophisticated scientific means of collecting and processing seismic data was accompanied by new methods of analyzing prospects and developing bidding strategies for offshore lease sales. In the 1960 and 1962 GOM federal lease sales, the most sophisticated oil companies began to use geophysical data to develop their bids, for the first time really, with rigorous and quantitative studies of reserve estimates, risk discounting, rates of return, and bidding tendencies of competitors. In previous sales, a lot of guesswork and hunches had gone into formulating "back-of-the-elbow" bids. But by 1962, the some companies began to arrive at bids with more concrete numbers.

In 1959–1960, for example, Shell Oil geologists undertook a major quantitative study of all the known salt dome fields of southern and offshore Louisiana and tried to discover why some were better than others. They discovered that the better fields had certain characteristics in common, such as a good balance between sand and shale in the section, a minimum area of uplift, and certain kinds of geologic closure and quality of objectives. Then they plotted out correlations on a chart to help them evaluate the huge number of prospects that were going to be put up for sale in 1962. Shell also had paleontologists estimating the age and environment of deposition in order to help predict the kind of sand-shale section in the prospects. Once all the geological work was done and advanced geophysical data collected and processed, the next step was determining how much oil and gas from a prospective field would be in a particular block, which was very tricky. This involved looking at the probabilities for certain amounts of oil or gas, or both, deciding on a development scheme, and then calculating a bid. The other major players were developing similar quantitative approaches to bidding, allowing them to put their money where their mouth was in the sale (Anonymous 1960).

A NEW ERA IN FEDERAL LEASING

The 1960 Sale

On February 26, 1960, the federal government held its first general lease sale in the GOM since 1955, according to the procedures set out by an "interim agreement" between the State of Louisiana and the Department of the Interior that allowed leasing to go forward until the dispute over the boundary between state and federal jurisdiction over submerged lands was settled. The director the USGS cautioned against offering too much acreage, because any leases acquired in depths exceeding 100 feet would be highly speculative. But as the nominations came in for an announced February 1960 sale, John Rankin, the OCS regional manager in New Orleans, compared the tracts nominated in the ill-fated 1956 lease sale, canceled by federal district court injunction, with those nominated for the proposed sale. He found that there was very little overlap, which demonstrated to him how much the industry had learned in the intervening three years. The move into deeper waters might not be so speculative after all.

Indeed, Shell Oil had developed its Blue Water 1 semi-submersible which could take exploratory drilling into 300-feet plus water depths. Upon publication of the initial Call for Nominations for the 1960 sale, the company's representatives convinced the Department of the Interior to withdraw the call and issue a new set of leasing maps with deeper acreage beyond the 300-foot depth contour. With Shell's assistance, the BLM redrew the maps with "south additions" to all the old original blocks off Louisiana and issued a new call for nominations. In the sale, the BLM offered 1.17 million acres offshore Louisiana and 437,000 acres offshore Texas. Offshore operators spent big—$285 million in high bids ($249 million for the tracts off Louisiana)— more than double the amount spent in any previous sale. Shell Oil leased a number of tracts in the Grand Isle Area South Addition, which the company eventually drilled, starting in January 1962, with the Blue Water 1. The 1960 sale truly opened what many people began referring to at the time as "deepwater."

The 1962 Sale

The next sale, in 1962, was even bigger. Aware of the increasingly pent-up demand for leases, the BLM believed it was time to give the companies a chance to really prove what they could do. Leasing officials decided to open up the sale and auction everything that industry nominated—3.67 million acres. This was a bit of a tough sell to Secretary of the Interior Stewart Udall. John Rankin remembered writing pages of "justifications" for such a large sale. With decreasing oil finds onshore in the United States, combined with rising foreign production, he argued it was increasingly imperative that U.S. companies develop the technology required to explore, drill, and produce oil from the deeper waters of the Outer Continental Shelf. In fact, he anticipated more opposition than what actually materialized. Expecting an argument about the offering when he presented the leasing map at a meeting in Washington, he was surprised to find that the only comments from his superiors were: "boy, that sure is a pretty map!" (Rankin n.d.).

The 13 March and 16 March 1962 lease sales became legendary in the industry. Everyone from that era remembers the "the sale so large it took two days to read the bids." A total of nearly 2 million acres (over 400 tracts) were leased for total cash bonuses of almost $450 million. The sale was a landmark in the history of offshore development in the GOM, for several reasons. First, it reopened the GOM to a broader range of players. Forty companies or combinations of companies bid successfully in the sale. Although independents like Kerr-McGee, Pure Oil, and Magnolia Oil had been early pioneers in the Gulf, the majors integrated companies, especially Shell Oil and The California Company, had quickly overtaken them as the dominant players. During the 1951–1960 period, the majors drilled over 90% of the wildcat wells in federal waters (beyond three miles) and over 75% of the wells in state waters. The majors also accounted for nearly 100% of the discoveries in federal waters and over 80% in state waters. By the late 1960s, however, non-majors were drilling nearly 30% of wildcat wells in federal waters with a corresponding rise in their share of discoveries. Putting so much acreage up for sale, first in 1960 and then really opening up in 1962, not only provided more leases for a larger number of companies to choose from, but it also drove down the price of cash bonuses, allowing smaller companies to acquire a piece of the action, although the majors still retained a commanding lead in exploration, especially in deeper water (Attanasi and Drew 1984).

From the oil industry's perspective, the 1962 sale turned the GOM into the major focus of oil and gas exploration in the United States. Oil companies acquired almost 2 million acres of new leases, much of them in unprecedented water depths (the average water depth of leases in the 1962 sale was 125 feet, compared to 67 feet in 1954–1955 and 89 feet in 1960). The sale also opened up larger areas in the western part of the central Gulf— Eugene Island, South Marsh Island, Ship Shoal areas—in addition to the delta regions which had been the scene of the most activity until then. This inventory of leases would keep the industry busy for the next five years. Indeed, the BLM did not hold another general sale until 1967. Meanwhile, all phases of exploration and development offshore Louisiana enjoyed boom times. Oil companies wasted no time drilling their leases. By September 1963, there were nearly 90 drilling operations in progress. According to one estimate, the industry was spending $1 million per day on drilling alone (Pittman 1963). The risks and expenditures laid out by the industry were amply rewarded. Although the success rate of exploratory drilling offshore Louisiana in the immediate years after 1962 could not match the extraordinary record of the late 1950s, overall drilling success in the Gulf approached the U.S. average of 60%. The truly impressive numbers were in the drilling success on federal leases issued in 1962 compared to earlier sales, and the reserve finding rate per exploratory well. Out of 420 leases issued in the1962 sale, 252 or 60% were productive as of 1969, compared to 178 productive leases out of 410 for the four previous federal sales. Most significant was the number of exploratory wells per giant field (100 million barrels) discovery: 155 for offshore Louisiana versus 3773 for the United States as a whole. As of 1968, 14 of the 62 giant fields discovered in the United States were offshore Louisiana, and 11 of those 14 lay either wholly or partially within federally administered areas. Total offshore production from the GOM rose from 127.6 million barrels in 1962 (4.8% of total U.S. production) to 334.6 million barrels in 1968 (8.6% of the U.S. total), all but about 30 million barrels of this increase coming from federal areas, and most of it from acreage leased in 1960 and especially 1962 (U.S. Dept. of the Interior n.d.).

The 1962 sale had another important, long-range effect on the offshore industry. It fostered greater technological cooperation among firms and the standardization of practices. With only five years to establish oil and gas production on 420 leases, companies in the industry had to work together to find ways to operate safely and economically in increasingly precarious depths. Shell Oil set things in motion in January–February 1963 when the company held its famous and unprecedented three-week "school" on offshore technology for representatives from industry and government. Paying "tuition" of $100,000, seven companies along with the USGS signed up for a series of courses on all aspects of Shell's innovative deepwater drilling and production program, from floating drilling to subsea well completions. Shell offered its technology to the industry, explained Ron Geer, a top engineer in the deepwater program, because in the 1962 sale the BLM had not honored some of the company's bids on the deepest tracts in 300 feet of water where Shell was the only bidder. Senior management concluded that there had to be greater competition, both to enable Shell to continue acquiring deepwater acreage and to stimulate the commercialization of the technology. The costs and risks were so high that no one company could venture alone into deepwater. Other oil companies, as well as suppliers, manufacturers, and construction firms could only progress deeper together. "We realized that the only way we could ever have access to those frontier areas was to share our knowledge with the rest of the industry, to give them a base of technology from which they could expand," said Geer (Abbott 1984). The 1962 sale, in other words, sparked the diffusion of drilling and production technology and created a greater sense of technological purpose that eventually culminated in 1969 with the organization of the Offshore Technology Conference (OTC).

Finally, the 1962 sale had major implications for federal offshore leasing. The $445 million dollars collected in bonus bids opened people's eyes to the importance of the program. Government analysts, particularly in Interior, were awakened to the fact that this program, with only about 30 people total, part of whom did not even devote full time to it, took in more money in a single sale (and in later years a single tract) than all the timber sales in Oregon and California and onshore mineral leasing for the year *combined*. "My office began receiving daily attention rather than only on sale day," said John Rankin. The 1962 sale, of course, was an anomaly. It brought an end to lease sales where most tracts nominated, with a few exceptions, were offered. In future sales, the BLM and the USGS Conservation Division, like industry, would become more rigorous and scientific in its approach to evaluating and leasing tracts. Offshore leasing was now big business, and the federal government had large and expanding responsibilities for regulating it.

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HISTORY AND EVOLUTION OF THE OFFSHORE OIL AND GAS INDUSTRY IN SOUTHERN LOUISIANA: A BRIEF LOOK AT COMMERCIAL DIVING AND THE ROLE OF PEOPLE, TECHNOLOGY, AND THE ORGANIZATION OF WORK

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> *"…it is never clear a priori and independent of context whether a problem should be treated as technical or as social, and whether solutions should be sought in science, economics, or some other domain"* (Bijker 1995).

The offshore oil and gas industry in southern Louisiana has a complex history marked by environmental, social, and political challenges. As an extension of the vast U.S. petroleum industry, the offshore industry was and is influenced by the operational, technological, economic, political, and moral issues of that industry (see Yergin 1993, Olien and Olien 2000). Nevertheless, the move offshore produced unique contests (see Freudenberg and Gramling 1994, Gramling 1996). Among these, the technological challenges of offshore exploration and production are perhaps the most obvious: constructing drilling rigs and platforms that can withstand wave action; developing techniques for cutting and welding metals underwater; and transporting materials and equipment over vast expanses of open water. The social challenges are equally daunting: attracting and maintaining a workforce able and willing to live on a small metal structure for weeks at a time or to work hundreds and even thousands of feet below the water's surface; organizing a workforce to take action and achieve results quickly and efficiently; and establishing a huge and oftentimes uncertain industry amid isolated rural communities. This paper addresses these technological and social challenges.

The offshore oil and gas industry is perceived to have a specific beginning—the first successful completion of a well out of sight of land—but the people and technology that made this industry possible, and the social and political environments within which it evolved, date back centuries earlier. Both steady modification and sudden breakthroughs characterize this history. It is impossible in a single paper to capture the rich and dynamic nature of the seemingly straightforward process of moving exploration, drilling, and production of oil and gas from solid land across marshes and swamps, into bayous and lakes, and finally out across the Outer Continental Shelf to depths greater than two miles beneath the surface of the ocean. This paper explores this process with a brief overview of some of the highlights of this evolution and the specific example of diving and underwater welding to illustrate the complex interplay between human and technical achievements. Though supported with data from elsewhere, the information in this paper comes from workers who experienced this history firsthand.[1]

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[1] The author conducted interviews with divers, engineers, and company owners between December 2001 and November 2002. Special thanks go to Tom Angel, Buddy Ayers, William Brown, Mitch Cancienne, Walt Daspit, Andre Galerne, Maryann Galletti, C.E. "Whitey" Grubbs, Tom Hynson, Robert Merriman, Drew Michel, Don Murphy, Scott Naughton, Joe Sanford, Joseph Schouest, Joyce Savoie, Roy Smith, George Taylor, Oran Tarleton, Al Warriner, and Wayne Willet. The author also obtained transcripts of several additional interviews, conducted between 1996 and 1999 for a history of Brown & Root. Thanks to Mark Banjavitch, Anthony Gaudiano, Lad Handelman, and Ken Wallace. Quotes from interviews are set off from the text by indentation and followed by brackets indicating the speaker and year of the interview.

THE STUDY OF TECHNOLOGY AND HISTORY

Approaches to the study of technology, its evolution, and its impact vary from discipline to discipline (see Parayil 1973). The approach taken here is interdisciplinary—technology includes both what things are made and used (artifacts) and how they are made and used (knowledge) and evolves within a particular economic, political, and cultural context. This paper also maintains that an effective history of technology must incorporate the evolution of work organization (Perrin 1990).

The oil and gas industry benefited from national and international demand for its products—it, in turn, has provided sufficient economic, social, and political support for the development of specialized sectors such as commercial oilfield diving. Capturing the history of the offshore industry presents special challenges; development and production do not occur in factories where the artifacts can be catalogued and the activities of workers and managers are regulated and can be readily investigated. Instead, the industry is a vast configuration of individuals and organizations working in numerous sectors responsible for exploration, drilling, fabrication, transportation, and production. It comprises small, specialized companies and large, integrated corporations. As the industry has moved from solid land to encounter swamp, lake, marsh, shallow waters over the Outer Continental Shelf, and now depths greater than two miles, the companies and sectors have evolved and changed. Consequently, the industry provides an excellent case for examining the interplay of technology and work organization.

From its inception, extensive scientific, technical, and organizational know-how have been required to get to where the oil is and to survive once there. “The learned abilities of a diver may keep him employed; those of his tender and supervisor keep him alive” (Seib 1976). Some of this know-how has been brought from elsewhere, some borrowed from other industries already present in the region, and some developed locally for the industry. Old technologies persist alongside new ones.

MOVING OFFSHORE

The story of offshore oil and gas has no definitive beginning and certainly has not come to an end. Morgan City, Louisiana and Kerr McGee claim 14 November 1947 as the official date of the first producing offshore oil well out of sight of land, but the first wooden piers built to support drilling operations over seawater were constructed by pile driving crews in 1896 off the coast of California. Those operations depended on divers who borrowed equipment and techniques from sponge and salvage divers who had been practicing their craft for hundreds and even thousands of years on several continents. They were motivated by the search for oil, a substance that Native Americans within the Gulf Coast region had recognized as a source of medicine for centuries and Europeans had first used to restore their ships there in 1542. Industrialization in Europe increased demand for underwater construction and established commercial diving as an enterprise. Divers began using helmets supplied with compressed air from the surface as early as 1828 (Parker 1997). By the late 1800s, large commercial diving projects, such as deepening shipping lanes and constructing bridges and ports, were undertaken, and divers were hired to place concrete, cut and weld metals, and lay pipelines. Both the diving industry and the recognition of oil as a resource for an expanding industrial state received major support during the two world wars and the intervening years. Both also benefited from an American culture that revered technological invention and individualism and had seen the two of these come together in what was to become one of its most sought-after artifacts—the automobile.

Against this backdrop flourished the oil economy, which by WWII had gained a place in national security such that young men who worked on the seismic and drilling crews active in the swamps and shallow waters of southern Louisiana were kept home to continue their work. When the war ended, vast numbers of people and new technologies were poised for action. Many men returned to the communities from which they had joined the service to find that jobs were scarce. Their wartime knowledge and experiences made them particularly well suited to the oilfield. They brought with them technologies for transporting goods, fabricating large metal structures, and working underwater. And they had become accustomed to working in harsh, dangerous environments. They appreciated that the waters of the Gulf of Mexico (GOM) were at least situated in friendly territory. The rapid development of the offshore industry off the coast of Louisiana meant that the GOM soon became the "place divers went to earn their stripes" (Austin *et al.* 2002) so that for many companies and workers offshore oil and gas work came to occupy the vast majority of their time, attention, and resources.

THE EMERGENCE OF DIVING AS A FACTOR IN OFFSHORE OIL AND GAS DEVELOPMENT

The first diving operations in the GOM were little more than topside jobs completed underwater. Men recall jumping off of boats, barges, and platforms to retrieve dropped objects, install clamps, or check for oyster beds. They did not have, nor perceive a need for, any formal training as divers.

However, the progress into deeper water was rapid, and keeping the rigs, platforms, pipelines, and vessels operating called for modification and innovation. Underwater jobs required longer than the time a man could hold his breath and expanded to include inspection, installation of anodes for protection against corrosion, and salvage. Those already working in the industry began to look outward for new technologies developed elsewhere, and those with the interest and training in underwater work saw the industry as a new opportunity.

Working from within the industry, local workers used the air compressors available on boats and acquired war surplus equipment to create systems that would allow them to breathe while underwater. The early jobs were in depths under 100 feet, and divers could stay down as long as they wanted without suffering ill effects, so there were ample opportunities for them to learn how to manipulate tools and perform tasks underwater. Through magazines and trade publications individuals acquired information and ideas. Each diver had to come to the job with his own mask, hose, and compressor, and anyone who acquired the equipment was likely to form his own company. Technological diffusion was rapid, facilitated by the loose organization of diving companies and their propensity to join together when more than one or two divers were needed on a job.

SCUBA (self-contained underwater breathing apparatus) was developed in 1947 but was not readily adapted for offshore work. Specialized tanks and compressors were not available in New Orleans until the mid-1950s, and even then they were rare. Roy Smith, a diver who introduced SCUBA gear to the offshore industry in the Gulf described the early days:

> In the early '50s, around '53 or '54, work was slow, so my friend and I said, "Why don't we go to Grand Isle?"…I was in the U.S. Coast Guard during the war, so I went and got my operator's license and started working on boats. After awhile, the platforms grew in number, and I got more interested in diving. I wanted to dive. There was no SCUBA diving at that time. Since I was the captain of a boat, I got me a gas mask and a hose and would dive around the boat. A friend of mine and I had heard about them diving with SCUBA gear in Florida, so we said, "Let's go see it." …Rowland's Sporting and Army Goods Store in New Orleans ordered an aqualung. They didn't know what to do with it, so they called me. We threw it overboard and all took a dive with the tank. I bought the aqualung from him. They found a surplus compressor from a submarine and put it in their store and started filling tanks. [Roy Smith 2002]

A few years later, in 1957, Ronald Daspit, a native of Lafayette, Louisiana, developed a "bailout bottle" that could be worn on a diver's belt and provide a short-term, emergency air supply for a diver whose surface air supply had been cut off.

Outside the industry, the U.S. Navy was the principal source of technology and personnel. As early as the 1930s, the Navy began experimenting with gas mixtures that would allow divers to go deeper and stay underwater longer. Diving was an important responsibility of the Navy in WWII, and divers conducted salvage operations, helped construct ships, cleared ship channels, and performed numerous other tasks. During the war, new techniques of underwater welding, burning, and the use of explosives were advanced, and new tools and equipment were developed for undersea construction and other work. Several Gulf Coast diving companies were begun by ex-Navy divers during the 1950s, but the attitudes, tasks, technologies, and forms of work organization in the oilfield were markedly different from those of the Navy. The transition was difficult for some divers. The following two career divers describe the same situation from two different points of view:

> After the war was over…life got boring. For some reason or other I decided it would become more interesting if I would become a Navy diver. …I graduated from the Navy Deep Sea Diving School…in 1946. I went on from there and was a Navy Deep Sea Diver up until the time I retired from the Navy…in 1960. …Then, immediately, if I had never tasted boredom before, I got a hell of a taste of it after retiring. I was not finding myself being very well adapted to most civilian occupations so I quickly found myself down at the Gulf Coast—New Orleans—and became a commercial, professional diver in the offshore oil fields. …Most divers on the Gulf Coast were not highly trained or highly experienced, either one. They were just people who knew how to put on the diving gear and make an effort. Yet, the Navy training had value because I knew a lot about decompression and treating the bends that others did not know. On the other hand…even though I was highly experienced,15 years in the Navy, I began immediately a heavy-duty learning curve figuring out how to do things in lightweight gear. The thing that sticks in my mind as heavy duty is how hairy it was. As compared to Navy diving where you always have a chamber setting topside, here you are doing it with nothing. You got your tender, you got a little old compressor, your face mask,

> your wet suit, your gear, and you are pretty much on your own. If you have a diving accident then it is shame on you, especially if it requires decompression because no chambers. Even if there were, nobody who knows how in the hell to use it. …Once I saw that I could do it, it was a horrendously nightmarish thing psychologically. …But it was the hardest part, just getting used to the danger. It was such a relief when I finally got to the west coast where decompression tables and chambers were the norm. [George Taylor 2002]

> I used to do a lot of experimental diving for the Navy, checking out different equipment, showing them how it can work. The Navy divers wouldn't do some things, so we'd do it. …The Navy master divers would come out and see what we were doing, shake their heads, and say, "No way we'd do this in the Navy." That's what you had to do to get the job done. There were some innovations, like the frying pan shaped O ring to use in the flange groove and help keep divers from losing fingers. We got new wrenches. I was concerned about safety, but in commercial diving if you are going to think about safety you are not going to get anything done. Offshore, everything around you is dangerous; you've got to take your chances there. [Joe Schouest 2002]

When the U.S. Merchant Marine began to decline (see Gibson and Donovan 2000), some mariners turned to the offshore oil and gas industry for work. The wages paid to offshore mariners were far below those to which seamen had become accustomed, so some took up commercial diving because it required many of the skills they had developed on ships and offered more lucrative financial opportunities than work on oilfield vessels. Though some of the early divers enrolled in commercial diving schools, formal training was not considered a necessity and some even argued they could better prepare divers themselves. Walt Daspit, a career diver, describes his path through the Merchant Marine:

> I graduated from high school in '45 and I joined the merchant marine when I was 17. In 1946, there was a general seaman's strike. All seamen went out on strike. …When the seaman's strike was over after about three or four months, I went back to sea again. Somewhere around 1950, I was about to get drafted during the Korean War so I joined the Air Force. Right before getting discharged I came across a magazine that had schools for higher occupations and one was Spalding School of Deep Sea Diving. It showed a picture of a diver wearing heavy gear and it said that divers make as much as $200 a day. I said, "Well, that is for me." After I got out of the service about '52, I went back to sea and got enough money to go to diving school. I began diving school in the fall of '53 and got out in January of '54. [Walt Daspit 2002]

Communication problems between divers and those on the surface were significant. In most early underwater jobs, especially those performed under conditions of no or low visibility, a single diver worked alone. Many early divers argue that more than one diver would have increased the danger because divers would then have had to worry about one another. Divers communicated with the surface via hand signals on a rope, and they and their tenders worked out complicated systems known only to themselves. Communication was necessary when a diver required tools, wanted the people on the barge to raise or lower cables and equipment, and needed to inform the tender that he was trapped or could not breathe. Loss of communication required aborting the dive.

Though radios were customary within the Navy by WWII, they were large and bulky, and commercial divers did not commonly use them. Diving helmets were equipped with telephones, but hearing was often disrupted by the noise of breathing gas entering and exiting the helmet. Fixing communication devices to masks proved a significant challenge. Divers experimented with earphones, transceivers, and devices they could purchase at electronics stores, but they did not forego the use of ropes and hand signals. William Brown began diving for his uncle in California at age 16 during WWII when older divers were scarce:

> We had what they called sound powered phones at that time [1945]. You didn't have any magnification or anything. It had two sticks and you wore a skull cap and you put these things on each ear and you would tape it up. It was very uncomfortable. [The diver] had a bull horn on his chest that you could talk into. It was sound powered. We worked with hand signals most of the time. [William Brown 2002]

While maintaining communication with the surface was vital to a diver, controlling that communication was a key point at which the diver could assert his autonomy, control the work setting, and enhance his status. In the early days, everyone depended on the diver to report conditions at the bottom, the time the job would require, and the progress he was making. To regain some of the control, companies began hiring inspection divers to assess initial damage and report on work completed. By the mid-1950s, underwater photography was recognized as a valuable means of augmenting a diver's description of the situation; widespread use in the 1960s was another feature that marked the maturation of the oilfield diving industry.

Though technologies were borrowed and adapted from commercial diving operations elsewhere, rigid forms of work organization were actively resisted. In the early days, a diver needed only his equipment and a trustworthy "tender," someone who would stand at the surface to monitor his hose and compressor and pass him tools. Numerous small companies, comprised of one or two divers and their tenders, formed in southern Louisiana and east Texas. A particularly successful job gave the company a boost. Each successive achievement maintained a diver's reputation; a single failure could damage it. Maintaining relationships with those who hired divers sometimes required being willing to do things other than dive. Two career divers offer a glimpse of the context within which divers operated:

> We really got a boost when a drilling barge got capsized at Avondale. It is on the Westbank across from New Orleans. It is a big shipyard. The barge capsized and they thought there were people inside of it. The officials at Avondale just called everyone that was listed as a diver. I got called and I had just got in from a job out in the Gulf. They got a hold of my wife and told her what happened. They said they needed me there as soon as possible. I called the state police and told them that I needed an escort because I was going to be boogying. [My wife] came with me because my tender had knocked off for the day and I didn't know where to find him. I told her that she would have to come and tend me. All of the divers were there…. After this occurred, they were impressed with me because of all the divers that were out there, I was the only one that was called back. We raised the barge in about six weeks time. There was one other diver besides me. [Walt Daspit 2002]

> The man that worked in the field was the one who had the last say on the divers. The first thing that he would ask you is, “What can you do for me?” “I could furnish you with two or three good divers, but what can you do for me?” This is the way things were done at the time. Not everyone, but nine out of ten. If you could work out a deal with someone that was feasible, then it was fine and dandy. You scratch my back and I scratch yours. [Willie Brown 2002]

Commercial diving schools on the west coast provided a tenuous link between Gulf Coast divers and others, but, though the interaction led to sharing of technology, it had little impact on ideas about and approaches to work organization. Staunch individualists, a fervent anti-union mentality, and an industry structure within which oil companies contracted simultaneously to drilling companies, fabricators, and boat companies and established an environment within which time meant money—huge sums of it—all contributed to the highly competitive and dispersed nature of the workforce. As the industry moved into deeper waters, new challenges emerged and had to be overcome. Divers were rewarded for taking increased risks with a pay structure that included a baseline daily rate and depth pay.

In addition, a nation enamored with individualists and innovation and already lamenting the tedium accompanying factory and office work was captivated by the freedom and excitement associated with nontraditional careers such as diving. In general, underwater achievements were trendy topics for periodicals such as *Popular Mechanics* and *Popular Science* (see Heyn 1972), and, in the Gulf region, newspaper coverage was frequent.

Throughout the early period, to the end of the 1950s, commercial diving and underwater construction were necessary for the construction and maintenance of harbors, ports, piers, and power plants throughout the United States. During those years, diving companies were still working to demonstrate their value to the offshore industry (e.g., Offshore Drilling 1957; Taylor 1958). Soon, though, diving became an integral part of offshore operations, and the oil and gas industry, due to its size and financial strength, eclipsed other applications. Both technology and ideas about work began to flow outward from the Gulf.

TECHNOLOGICAL INNOVATION AND ADAPTATION

As both the depths and the level of offshore activity increased, the largely informal and small-scale diving sector matured. From the perspective of the companies paying the bills, the primary goal was to increase the time divers could stay on the bottom and minimize the time spent in decompression. Numerous changes and innovations made it possible for a person to advance from jumping into ten feet of water for a few minutes to staying at depths greater than one thousand feet for several weeks to complete a job. Gas mixtures allowed divers to achieve greater depths but also withdrew the heat from their bodies and made their speech unintelligible; their use required new masks and the development of hot water suits and new communication devices fitted with unscramblers. Pneumofathometers and decompression chambers and tables removed some of the uncertainty from the return to the surface and reduced injury and death so that underwater operations could continue and saturation diving could develop.

Commercial oilfield diving illustrates the nonlinear process of technological development and how solutions to one problem led to additional problems that needed to be solved.

Getting Divers and Keeping them at Work

To meet the goal of increased bottom time and more rapid ascent, both mechanical and biochemical problems had to be overcome. Under pressure, the density of air increases and impairs breathing by reducing the mechanical efficiency of the lungs. Divers' bodies absorb more air under pressure than at the surface. Atmospheric pressure doubles with each 100 feet of depth, and with each doubling the volume of gas is reduced by half. The longer the diver is down, the more compressed air circulates through his system. When the pressure decreases upon ascent, the gas expands. The diver must rise in stages to allow the blood to circulate and air escape slowly in a process known as decompression. Rapid decompression leads to the dangerous condition known as the "bends." Decompression tables established safe rates of ascent. Then, decompression chambers allowed divers to be brought up quickly, repressurized, and decompressed slowly while at the surface. Other divers could continue the job during the process. Consequently, the ability to function in confined quarters became an important requirement for divers.

The fundamental physiological concern was to provide divers' bodies with levels of oxygen that would sustain life while reducing gases whose volume underwent significant changes with changes in air pressure. By altering the gas mixtures divers breathed, both depth and bottom time could be increased, so various gas mixtures were tried. Oxygen is toxic at high levels and results in convulsions and death; as the pressure of the gas goes up the percentage of oxygen must decrease. Divers with high oxygen tolerance have a distinct advantage. Carbon dioxide is also toxic, and materials to absorb the excess gas were inserted in helmets. Nitrogen has a narcotic effect at depths beyond 100 feet, so a replacement carrier for oxygen was sought. Helium tempers the taste buds, causes dehydration of the sinus cavities, and, because its thermal conductivity is greater than that of air, carries heat away from the diver's body. It also comes out of the system more slowly than nitrogen and affects the vocal cords resulting in the "Donald Duck" effect. Nevertheless, the problems associated with helium proved to be the most amenable to solutions, and helium-oxygen mixtures that had been developed by the Navy decades earlier were widely used in oilfield diving by the late 1960s. The high cost of helium led to efforts in the 1970s to develop rebreathers that would recycle the gas and to efforts to replace helium with nitrogen. Evidence that fat tissue was absorbing the nitrogen led one company to put its divers on a weight loss program and then get rid of divers who could not or did not lose weight.

Divers worked in confined spaces at high pressure, lived for up to several weeks at a time in close quarters, and took risks relying only on the word of supervisors and company doctors that new methods were safe. Every new invention required additional human capacities and experimentation on divers, and many innovations were motivated by injuries and deaths. Still, as each new innovation came along, divers could be found to try it out. Macho pride, the desire to be the first, prospects for higher pay, and a love of diving all played a role:

> I like the gas work. I quit doing anything above 150 feet of water. Greed overcame my fear. You could go down and work an hour or two and you would get paid more than you spent working a week in some waters. [Walt Daspit 2002]

> [Being in diving] a long time starts to define who you are almost. [George Taylor 2002]

Problems with heat were addressed through the use of suits that were heated either by surface-supplied hot water or electric wire. Hot water suits were preferred even though they initially scalded the divers; divers reported that they would leave the front of their suits open to allow cold water to mix with the heated water coming from the surface.

The introduction of new gas mixtures meant new mechanisms for generating and then delivering those gases to the divers; standard air compressors were no longer adequate and gas mixtures had to be purchased from elsewhere. Significant invention and innovation accompanied the development of diving masks and helmets. One of the first Navy artifacts to be modified for oilfield work was the Mark V helmet, which had been developed prior to WWI and remained in use until the 1980s. The helmet and full diving suit with which it was used weighed as much as 200 pounds. Working in the GOM around rigs and platforms, divers needed flexibility and the ability to climb up and down, in and out among platform legs and tangled pipes. In addition, divers were frequently given a small area on the barge from which to work; in this space they had to cram their air compressor, tanks, radio, and everything else they brought along. Masks that were originally designed for SCUBA were adapted for use with hoses and compressors because they were smaller and used less air, However, the lack of any head protection was a disadvantage in construction work. Beginning with the end of WWII, Gulf Coast divers acquired access to Japanese helmets, and these became popular among some divers. William Brown first introduced Japanese helmets to the GOM:

> It didn't weigh as much. It had a quite simple exhaust valve. You had to be used to diving to use it. You could set the exhaust pretty close, but you never got it right. As you move around, the air volume in the thing changes. When it changes, you might take a deep breath and get a head washing with the water that comes in. You usually carry a little extra air in your suit because to take the thing off of your shoulders you can either use a cushion or a towel. You get used to using it. Your head is protected and all of these things. As soon as the war was over, we started getting an influx of shallow water diving gear. [William Brown 2002]

> Desco had not even come into the scene and nobody was making any of these fiberglass masks. The Desco triangular mask was a freeflow mask that was used with the Jack Brown diving dress. Jack Brown was the director with Desco. The other alternative at that time was the Scott mask, which was [built for] mining safety from Scott engineering. It was strictly built for going into a mine. It wasn't built for going into the water, but they did readapt it somewhat. I took one of them and rebuilt the suit myself. [Willie Brown 2002]

By the 1960s, several Gulf coast divers had designed and built their own hats. Walt Daspit, who was motivated by Joe Savoie to design and construct his own hat, describes why:

> The first guy that came out with a lightweight diving helmet was Joe Savoie. We were working on one of McDermott's barges with Chuck Gage and we saw Joe. Joe was explaining to us what he was going to build. He was going to use an aqualung, which was a sterile diving dress that was used at the time. It was a front entry and you would wrap up tight and you would stay dry. Joe was going to put a neck ring on it. …He wanted to build a helmet out of a race car crash helmet. Then he was going to the faceplate visor and a neck ring and tie it. He was explaining that to us and drawing it. I said, "Joe, you can't do that because having that half opening of the dress, when you lean over air is going to go to the highest point. It is going to flip you upside down and you are going to come floating up to the surface upside down." That was one of the things about diving with heavy gear. You had to be careful. If you leaned over too far, the air went to your feet. You were out of control then. You couldn't exhaust it…I am trying to explain this to Joe who has never had any formal diving training. When you argued with Joe, all he did was talk louder. Once he gets something in his head that is where it stayed. He was a hard-headed coonass and I was a hard-headed coonass. I tried explaining to him that he couldn't do that. He said that he was going to put valves on the feet and relieve the air through the feet. I told him he couldn't do that because it wasn't going to work. You have to have a seal around the neck. Joe just kept getting louder. Joe eventually found out that I was right so he made a neck ring for his hats. He made a very good helmet but it took him a while to evolve it into something. What he first had in mind just wasn't going to work. [Walt Daspit 2002]

Though Joe sold a dozen helmets and Walt and a couple of other local divers a few more, Kirby Morgan of California achieved the greatest success. He visited Gulf Coast divers and convinced some of them to try his helmets. Soon Kirby Morgan hats were in widespread use.

Introduction of new gas mixtures required changes to communication devices. Though divers and their tenders learned to understand each other even with the distortions caused by breathing helium, barge superintendents and others at the surface did not. Unscramblers were employed to facilitate communication.

As jobs began to require many divers, supervisors were hired to manage both the work and the divers. Some supervisors managed all communication with the divers, both to maintain control over the job and to ensure diver safety. During the development of new procedures, the highly competitive environment of offshore construction and the huge profits to be made from substantial breakthroughs made secrecy paramount. C.E. "Whitey" Grubbs, the first and long-time director of underwater welding research for several companies that worked in the Gulf, recalls a time he wrote down instructions for a welder inside the chamber:

> I have always been of the opinion that you like to keep information confidential, but in order to gain information you've got to tell the welder what he's doing, why he's doing it, and what you're looking for. So I had written down for a welder and he was in the tank welding. And [the CEO's] got a stool pigeon works for him, that found my note, and he took it to [him]. And [the CEO] called me in his office, and [the CEO] was setting holding his head like this and he goes to screaming at me about confidential information. And I finally he

> realized why he was holding his head. He said, ‘I’m keeping it from blowing wide open.’ Oh, he chewed my ass out and I just let him, I didn’t respond at all. [Whitey Grubbs 2002]

Gas mixtures and helmets continued to be developed and modified, and so did the search for efficiency and ways to keep divers underwater for longer periods of time and maintain continuous operation. Throughout the 1960s as the industry matured, diving companies showed uneven rates of adoption of new technologies and forms of work. For example, a diving bell is a chamber within which divers can descend to depths of thousands of feet, and, though the concept and technology were first recorded over 1500 years ago, it was not adopted by American divers for commercial use until the 1960s (Zinkowski 1976). Then, even after diving bells and decompression chambers were common in the Gulf, divers reported being on jobs where either no chamber was present or no one knew how to use the chamber correctly.

The diving bell provides physical protection for the diver and a more comfortable environment within which to undergo decompression. However, though it enables the diver to descend to deeper depths and facilitates the return to the surface, it does not significantly alter the time on the bottom. The major breakthrough in that area came in 1957 when the director of the Navy’s Submarine Medical Center demonstrated that the body’s tissues would become completely saturated with inert gas within 24 hours so that the period required for decompression for any dive of that duration or longer would be the same (Zinkowski 1976). In the 1960s when the concept was applied widely, the limits of both depth and time expanded exponentially. Military, scientific, and commercial interests converged in a period of rapid research and development of equipment, gas mixtures, and forms of work organization. According to the general superintendent of one of the industry leaders at the time, “No industry today can boast of more rapid technological development than commercial diving” (Morrissey 1966).

Saturation diving systems are themselves complex environments, and their development required parallel development of analyzers to read partial pressure of oxygen (systems were developed to include both galvanic and polarographic types of analyzers); controllers to maintain oxygen levels; and analyzers for carbon dioxide (infrared); carbon monoxide (infrared); helium (thermal conductivity); nitrogen (computation of difference); and relative humidity (electric hygrometric) (UST 1968). Within the diving bell, scrubbers kept the moist atmosphere ventilated; rack operators monitored readouts to safeguard against carbon dioxide and oxygen poisoning; and emergency gas bottles were installed to offer a few minutes of air in an emergency (Seib 1976).

These technological achievements introduced a host of changes in work organization and the social environment within which diving took place. The expense of constructing, operating, and maintaining saturation systems increased the capital needed to remain at the forefront of the industry. Small companies were either absorbed by larger ones or had to restrict their work to shallow environments. They had a hard time attracting divers when the innovation and record-setting was occurring elsewhere.

Companies gained greater control over the divers and their pay. Prior to saturation diving, with decompression time tied to depth and time spent under pressure, deep work was done via bounce dives wherein divers stayed on the bottom only a short period of time. Pay was tied to depth, so divers could make huge sums of money in relatively little time. Both physiological and financial factors limited the depths to which divers could go and the time they would remain there. Saturation diving removed many of the constraints and set up new dynamics between divers and their employers. “With saturation diving and almost unlimited working time at depth, diving performance is now being judged on how long a period of time divers are in the water—that is, 20 hours a day in the water is somehow ‘better’ than 16 hours a day, even when less actual work has been performed. …(O)perators of lockout submersibles welcome a more accurate, qualitative evaluation of work performed, and they are motivated to provide the performance that this approach demands” (Duggar and Majendie 1979).

Saturation diving also changed the nature of the relationships among divers and between divers and their supervisors. Instead of one diver working alone, as many as six divers and a tender would work from a diving bell. Communication was managed via unscramblers on the radio and took place between the divers and the topside supervisor and not with tenders in the bell. Tenders were excluded from decisions about the work to discourage them from taking charge of the operations; if the tender entered the water to aid the diver no one would be tending and two could be lost (Seib 1976).

Despite, and perhaps because of, the continued experimentation and ongoing danger of the early years, divers continued to dive. Long hours in a diving bell could be excruciatingly dull, so divers sought distraction. Some divers became avid readers while others worked longer than their allotted time to avoid getting back into the deck chamber.

The continued advance of exploration and drilling toward deeper waters provided the stimulus for invention, innovation, and dissemination in commercial diving. These technological advances that made it possible for humans to work at great depths below the water’s surface also made way for new technologies associated with the construction, maintenance, and operation of oil and gas platforms and pipelines. In the following section, a brief overview of the history and development of underwater welding illustrates the links.

Underwater Welding: An Example of Technological Change in the Offshore Oilfields

The development of underwater welding was preceded by several alternative approaches to construction and repair of offshore structures and pipelines. When wooden derricks and platforms gave way to steel ones, installation, repair, and removal required men to work with metal. Platforms were fabricated onshore and transported offshore via barges. Pipelines were joined on the decks of barges and then lowered to the seafloor; repairs were initially made by hauling the lines to the surface. Then, successful divers demonstrated the advantages of performing the work on the bottom, installing clamps and mechanical devices where needed.

Soon, cutting, burning, patching, cementing, pipelaying, welding, and inspecting were all done underwater. The tasks to be done and the people to do them had to be modified for this new environment. Whitey Grubbs recalls the early days:

> My primary responsibility was to develop an underwater repair procedure so if while they were installing this an enormous piling would [go] down…[or if] they might drop a ball and puncture a hole in the roof. If they did, they had to be able to repair it. The research department had been working about a year trying to develop the repair procedure with no promising results. So I said to myself, if I were going to repair this in the air—I'd weld it, there is nothing else to do. I had a little welding experience as a construction hand, but I was by no means a welding engineer or metallurgist. So, I…hired the best man I could get. He had worked for me as a welding supervisor; he was an experienced diver and one of the best welders I ever met. So I sent him to commercial diving school. We had to have someone in the crew who knew how to use the big decompression tables and so on. We actually made 131 carefully selected welds, experimental welds. We made about one third each with stainless steel electrodes, nickel electrodes, and mild steel electrodes. We used all different manufactures and types of welding electrodes, different welding machines….[Whitey Grubbs 2002]

Even before WWII, underwater welding had proven an effective temporary means of joining pieces of metal, but the inferiority of wet welds to those performed at the surface limited its use. By the mid-to-late 1960s, however, the idea of welding underwater had captured the attention of a number of key construction companies and personnel. Saturation diving provided the context within which underwater welding could develop. Though not the only source of need, the offshore oil and gas industry was by far the largest and had the most capital. Research and development moved in two directions: creating dry environments within which welding could occur and developing wet welding techniques. In 1967, Taylor Diving and Salvage began developing an underwater welding habitat and alignment frame to facilitate welding underwater in a dry environment; it was used successfully on the St. Lawrence River in 1968. In 1969, Chicago Bridge and Iron began an underwater welding research program focused primarily on wet welding.

Dry habitat welding progressed through several stages, beginning with the gas tungsten arc. This process was considered too slow, so alternatives were tried until the shielded manual arc became the accepted standard. Under pressure, the welding arc becomes constricted. In addition, weld metal chemistry, weld notch toughness, and hardness all are affected by pressure. Different gas mixtures were tried. At increased pressure, hydrogen's solubility increases and leads to cracking. Helium's conductivity is six times that of air, and rapid heat loss from the weld area increased hardness and the risk of cracking. Nitrogen leads to nitrides in the weld deposit and destroys the properties of the weld because molten metal will preferentially absorb nitrogen and form nitrides. To complicate matters, as the welding process was evolving to respond to increased depth, so, too, was the type of metal being used in pipes and structures.

At each stage, both weld procedures and diver/welders had to be qualified to perform to specific standards under specific conditions. The use of x-ray technologies to inspect welds required that some divers be qualified as radiographers. Anthony Gaudiano, who worked as an engineer for Taylor Diving and Salvage from the late 1960s until 1984, describes the environment of the time:

> And you have to understand that when all this was going on, and people were working like 11 to 12 hours a day, we didn't have meetings where we sat down and made presentations.

> We didn't do all of that planning and all of that critical path charts, none of that stuff. You just did it. You got it done. …People did some very impressive things, really very impressive things. Innovative things. And I would think that the habitat welding was one of those innovative things [Anthony Gaudiano 1996].

The OPEC increase in oil and gas prices spurred U.S. interest in developing offshore oil and gas fields and increased interest in underwater welding (Cotton 1977). The 1970s were a period of new development and innovation. Though the first remotely operated vehicles (ROVs) were constructed and used by the Navy in the early 1970s, it was several years before they were available commercially.

WORK ORGANIZATION AND LABOR ISSUES

As the processes and techniques associated with underwater construction evolved, a very specialized labor force was required. Though some jobs, such as pipeline installation and platform removal, had fairly standard procedures, no two jobs were ever the same. Accidents, hurricanes, and general wear and tear presented unfamiliar circumstances for even experienced divers. Pride and the fear that one diver would outdo another and win over a customer kept divers attempting new feats:

> When [the barge] capsized, they had about a 130 foot derrick standing. It capsized and the derrick bent out to the middle of the river. They couldn't do anything. They couldn't move it because the derrick had the barge anchored. It was upside down and you had this derrick bent out towards the middle of the river. I went down and burnt and cut it loose to where it dropped. That was kind of scary and I don't know if I would do that today. The other divers flat out refused to do it. I said that I would do it. [Walt Daspit 2002]

Maryann Galletti, wife of John Galletti and co-owner of J&J Diving, describes how the company evolved:

> We started working out of a garage with two sets of diving equipment and no vehicle. We gradually acquired equipment, property, a building. Within a span of ten years, we had also bought a tractor trailer truck. John informed me he was going to buy this tractor trailer truck for $12,000 and I liked to have a heart attack. He had the sights to see the work that was out there and all I could see was more money, more money. It was like you would pay for one thing before you moved onto another. [Maryann Galletti 2002]

The era of the small companies was short lived. The rapid advance to deeper waters required specialized equipment and knowledge to enable divers to work safely at ever-increasing depths. Thus, during the 1950s and early 1960s the diving companies went through the process of getting organized (see Batteau 2001). A steady increase in offshore activity during the 1960s drove up demand for divers and meant that existing companies expanded and new ones formed. "The explosive growth of offshore oil exploration and development brought round-the-clock overtime and deep diving premiums. There was a lot of money being made by the younger divers, though it was often at great risk" (Parker 1997). Divers were put into the water with little, if any, training, and the greater depths substantially increased the risks associated with inexperience.

In addition, divers were under tremendous pressure to perform. The hierarchical nature of the industry and separation of those with the ultimate authority over decisions from those on the barges, rigs, platforms, and vessels led to circumstances within which divers were pushed to dive even when conditions would dictate otherwise. Both when divers were called out in an emergency and when they performed routine tasks such as laying pipelines, the work of people at the surface was halted until the diver was out of the water. Entire crews were held captive on barges and platforms while divers completed their work. Though the situation gave divers a certain amount of autonomy, it also resulted in significant peer pressure to get the job done quickly. Walt Daspit captures the sentiments expressed by most of the early divers:

> [The barge captain] can't say [to a diving company] you have to put this man in the water. But, the next time they call for divers, he can say that he doesn't want whoever out here. So, you have to keep the barge captain happy. The main thing in keeping the barge captain happy is getting the job accomplished….
>
> The barge was surging. It was going up and down. The water was picking up. They wanted me to go down and cut the pulling head loose. When I went down, the barge surged down and I had my hand on the top of the handrail. A huge block, about 7 or 8 feet tall, came down and side-swiped my hand. My hand just went numb. I unshackled the block and I was going back up to the surface. …When I got to the surface, I pulled the glove off and my finger was just hanging by a string. [Walt Daspit 2002]

Nevertheless, diving was attractive to many young males looking for an exciting career, and would-be divers were not hard to find. Andre Galerne, a company owner and early member of the Association for Diving Contractors, commented on the problems associated with low diver pay and benefits in the GOM:

> The price we were paying the divers was in my book much too low, and if a guy can make the same amount of money by selling hamburgers to Big Mac, than to be a diver, I think it's exploiting the fact that the guy likes diving. [If we advertised this as something other than diving], then the people will not be doing that for the pleasure, so they will demand money. Diving is a different thing. The guy is ready to dive at any price, because they want to dive. [Andre Galerne 2001]

Joe Schouest [2002] confirmed this, "I love diving. I'd dive for nothing. Sometimes I've done it. I like the challenge."

Though divers and welders were easy to find, engineers were not. Several companies struggled to find people to enter the industry. According to Anthony Gaudiano,

> Of course, you have to understand in those days, nobody wanted to be associated with us. We were kind of wild outlaws and anybody who had any smarts would look at this little two by four organization and say, 'I can go to work for General Motors. Why should I be associated with this little bitty place?' There were a few who saw the potential but not very

> many. We didn't get the experts until quite a number of years later when the revenue and the reputation were worldwide. [Anthony Gaudiano 1996]

Due to the high costs of specialized equipment such as decompression chambers and a pool of divers who would work under almost any conditions, the organizational culture of diving was at first slow to change.

Many companies continued to operate at the margins of safety, but injuries, deaths, and expanding liability caught the attention of the oil companies. In the early 1960s, Joe and Tom Sanford came to Louisiana as outsiders and were able to establish a clientele and obtain work because at that time they were one of the only diving companies working in the oilfield with insurance. Soon the largest companies were requiring proof of insurance, and by the mid-1970s the substantial extension of depth limits proved to be too expensive to be undertaken by individual companies and required a joint industry financial program (Jones 1977). Ads for diving companies in the 1950s and early 1960s illustrate how rapidly the change took hold. Rapidly rising insurance costs and fear of government intervention and of unionization among the divers led companies to organize the Association for Diving Contractors to develop industry standards and address safety concerns.

The move from land to water affected the organization, or lack thereof, of the labor force. Divers were engaged in underwater survey work beginning in 1929, about the same time that the first efforts to organize divers began on the east coast (Parker 1997). Near shore, divers worked alongside unionized construction crews but remained independent until pile drivers' unions successfully claimed submarine divers among their numbers. The unions are credited with establishing better working conditions for divers on the west and east coasts. However, the move offshore undermined union activity and influence over the offshore oil industry because oil companies and drilling contractors operating drilling vessels were not signatory to pile driving and diving union agreements. "Other than establishing the fledgling oil divers with standards of safe work rules and pay scales precedent, the union had little influence over the offshore oil diving industry" (Parker 1997). Despite significant efforts in the 1970s, the unions were never able to organize the labor force working in the GOM.

The push into deeper water drove technological development, and the larger companies responded by establishing research divisions. J&J Marine Services, one of the few early Texas companies that also worked out of south Louisiana, was among the few small companies that invested substantially in research. The company owners hired an independent scientist in the early 1960s to help develop decompression tables. At that time, the company employed only a few divers, but the owners recognized the critical role that science and technology would play in the diving industry.

DISCUSSION

Divers and companies in oilfield diving and underwater construction began by adapting technologies and patterns of work developed elsewhere and have continued to maintain links to the U.S. Navy and to commercial diving and construction interests operating outside the oil and gas industry. The steady march from shallow to deep water supported a continual process of innovation and change in both the equipment and methods required to put and keep divers underwater and those required for constructing, installing, repairing, and salvaging offshore structures. Within this regular evolution several events, such as the adoption of mixed gas breathing mixtures and of saturation diving, marked discontinuities that led to periods of rapid research, development, and change. The particular nature of the offshore industry—distributed networks of innovation and implementation, the continued reworking of nearshore fields in the GOM, and expansion worldwide—nevertheless made it possible for companies to continue using old technologies as they developed new ones.

Technological challenges—welding and burning underwater, for example—matched challenges of getting workers to the work site and keeping them there. The challenges of transporting and maintaining workers hundreds of feet below the surface proved to be both physical and psychological. The industry was able to play into key tenets of American culture and society—freedom, individualism, and competition—to attract and hold divers. Divers and the companies they formed fought hard to maintain a significant level of autonomy and defy both larger companies and unions who sought to organize them. Yet, through time, in the face of economic pressures to manage liability, the oilfield diving enterprise became organized. By the 1970s, the technological and social milieu and forms of work organization of oilfield diving were substantially different from those which marked its beginning. Small companies of one or two divers and their tenders had given way to large enterprises. Though several unionization attempts ultimately failed, the organizing drives provide another sign of maturation within the industry. The late 1970s and beyond would bring further changes.

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THE DEVELOPMENT OF THE OIL INDUSTRY ALONG BAYOU LAFOURCHE: ORAL HISTORIES

Tom McGuire, University of Arizona

INTRODUCTION

The Intracoastal Waterway bisects the community of Larose along Bayou Lafourche. Residents of the continuous string of settlements below the Intracoastal—Cut Off, Galliano, Golden Meadow, Leeville, commonly refer to those living above the canal as Yankees. Even locals who have lived along the lower bayou for only a couple of generations may still refer to themselves as outsiders. But that image of provincialism masks the dynamic transformation of a region long connected to, and impacted by, the oil and gas industry. There are contemporary symbols of this dynamism— the fast-growing Port Fourchon at the end of the bayou, the multi-story glass façade of Edison Chouest Offshore's headquarters in Galliano, shaped as a ship's prow. But these are recent manifestations. When the Texas Company and other operators opened up the Leeville Field in 1931, then the Golden Meadow Field in 1938, they brought in outsiders but they hired many locals as well, and for inhabitants fortunate enough to have a clear title to properties overlying these fields, monthly checks began to arrive. Later, respectable fortunes were made, lost, and often rebuilt as the regions' collective expertise on the water was turned to the service of the growing offshore industry, in the bays and water bottoms, out onto the shelf, and into the North Sea and elsewhere.

I will draw upon a handful of the oral histories we are gathering throughout south Louisiana to give some voice to the articulation of industry and community along lower Bayou Lafourche.

WHY ORAL HISTORIES?

Oral histories can be a useful, and often indispensable, complement to the conventional historian's search for documentary material. There is, in fact. simply not a great deal of primary or secondary documentation of the development of the oil and gas industry along the Gulf Coast. Local historians abound, both professional and amateur, but their interests have not been drawn directly to the business of exploring for and producing oil and gas. Instead, hurricanes, the Civil War, sugar cane production and plantation life, and genealogy are predominant subjects. Incorporated towns, which might be expected to preserve community history through public records, are infrequent along the Gulf Coast, indeed in the South as a whole. Blue-collar workers tend to preserve their memories in photographs, not the written word. They seldom write memoirs. Corporate histories can and have been done, but in numerous cases, corporate memories and paper trails have been erased through mergers and acquisitions or closures. And many companies are quick to jettison documentation which is unnecessary to the immediate business at hand. Technological breakthroughs and developments are recorded in trade journals, but these treatments seldom speak to the interface of "men and machines," of how local people developed and modified these innovations. In short, it is our proposition that oral histories provide critical data for reconstructing the development of the industry.

THE EARLY DAYS ALONG BAYOU LAFOURCHE

Chester Cheramie, born in Golden Meadow in 1923, is of seven siblings in a French-speaking family of fishermen and trappers. Although has father would convert his shrimp boat into a tug for servicing new oil fields around Golden Meadow and Leeville in the 1930s, Chester didn't particularly like boats, so he applied himself to his studies and graduated from high school. Like his schoolmates, he suffered the pain of forced English instruction in a school system staffed by monolingual teachers and backed by state legislation that prohibited French. Despite his dislike for boats, he spent a career in the boat business, doing much of the office work for Nolte Theriot's tug company. He recalls the economy of his childhood, where extended families would exchange farm goods for seafood.

> All the fisherman…you know everybody had a relative. Everybody is related down here anyhow. During the shrimp season they'd bring in sacks stuffed with shrimp and crab, they'd [relatives] give them a sack or two of potatoes and they'd give them some onions. Because they all had farms over there. So then they would exchange…. Nobody had no money. I remember my daddy, when he would go trawling, they had one mother boat. All the other boats catch all day long. They all bring their catch to the mother boat. When he had a load, he would come back to Golden Meadow to the shrimp shed and deliver those shrimp. Every mother boat had a company. And all of these companies had a grocery store... There was no money exchanged. Everything was put on the books. …They had the May season and they had the August season. Shrimp season. And after that then you go trappin' and all that. After the season, that's when they split the money. That's when you'd pay the grocery bill. Not only groceries, the grocer had clothes, hardware. Just like a supermarket today.... There must have had 10–12 stores in Golden Meadow. You had to go to the [company's] store. You don't have a choice. People had no money. They had no money.

With the discovery of oil in the region, some families began to receive royalty checks, the first significant infusion of cash into the economy. Despite his professed dislike of boats, Chester joined the Navy in 1942 and, like many of his cohorts, literally "saw the world" for the first time.

> When the [trapping] season's over you split what you make. So all the time you never had any money…. So until you started in the oil field back in the late '30s, that's when people started having a little money because they would come here and they'd spud into the oil well. I don't know how much oil was selling then. Guess it wasn't but one or two dollars a barrel. But you could get maybe your share for 15–20 cents. They keep the rest. So a lot of these people would get a 200–300 dollar check a month. That was a lot of money for those people because they did not have nothing before. And then from there it is up to the war. That's when people, after the war, started making money. You came back from the war people got more knowledge of the world. In fact myself, I had been to New Orleans but one time in my life before I went into the service. I had gone to Thibodaux or something like that, but I had never been out of the state. That's all, you know, I don't know how far back but the only thing that we had was radio. And most of the time we did not have one. If you had a radio you were lucky to have one. Now, these young kids today think that everyone was born with a television and car in their yard. And you tell them about some of these

> stories about how these people started in business and they don’t believe you. All these people they were all fisherman. That’s how they got started. And we survived.

I had met Mr. Cheramie at a boucherie in Cut Off. Annually, a group of men get together to butcher a hog and prepare traditional foods for their families and invited guests. I asked him if this was a conscious cultural revival. Prior to refrigeration, extended families would take turned in butchering a hog of cow and distributing the fresh meat to relatives. Chester said the “revival” started some 20 years ago when he and several of his golfing buddies decided they simply wanted something to do in the wintertime.

OIL IN GOLDEN MEADOW AND LEEVILLE

The Leeville field produced 15 million barrels of oil in the first five years of operation, and continued to produce about a million and a half barrels a year through the 1940s. The Golden Meadow field yielded a modest 750,000 in 1939, then gushed 4 million barrels annually through the 1940s. Chester Cheramie recalls that not all of that production was captured:

> Before the war they were drilling all the wells in Golden Meadow left and right. You go to bed at night, and then get up in the morning and you find an oil field right next door to your house. When I was growing up they must have had 50 rigs. I remember the oil field blowout in1939 or '40 when the oil field all blew up for over a month. The whole town was covered with oil. We had to move out, everybody had to move out. We moved to Leeville with one of my aunts and nobody could come back to town ‘cause all the roofs and the ground had about four, five, six inches of pure oil on the ground. That’s how Galliano, Cut Off, and all these places got to be built…. And besides that every time you had some bad weather, a hurricane coming through town, we had two to four feet of water on the town and eventually people moved out and went to other parts of the parish...but it was a very prosperous town when we incorporated Golden Meadow in 1950.

The Texas Company was the main operator along Bayou Lafourche, and throughout south Louisiana’s marshes and water bottoms, due to a deal worked out in 1928 between the company and the Louisiana Land and Exploration Company. LL&E had acquired vast acreage of seemingly worthless “swamp land” and, after a number of failed exploration attempts, turned production rights over to the Texas Company in exchange for royalties. The oil company was much more successful in its drilling, and began in the 1930s to hire locals. Pep Williams, now in his late 80s, hired on with the company after the war.

> Well, we used to be trawling and trapping. It’s was all you could. That’s about all the work they had down here in Golden Meadow, was either fishermen and trapping. And I finally got an application to work for Texaco. And then I was accepted, that was in ‘45 that I went to work. And I worked 23 years for Texaco. That was a good company to work for. It was like a family. ‘Course when the engineers started, it was a little different. Because Texaco was kinda, you could call it, not cheap, but they was lookin’ at that penny, I mean, they was kinda tight with their money. Only when the engineers came up, well they could spend what they wanted, as long as it was an engineer, whatever they recommend, they had it. I started

> roughneck, and then after a few years went to drilling, and then after that I was a superintendent the last ten years I worked for Texaco. And we enjoyed it, we enjoy working….

Pep Williams was a company man; Texaco, with its large holdings, contracted out much of its drilling.

> Well, as a driller and production foreman, you had to go from one rig to the other and supervise. Tell 'em what they had to do. And watch what they doing. Really, on the rig, you have to stay on the rig and see that they done the right thing. Because we had just a few company rigs. We had mostly contractors. And the contractors didn't know exactly what Texaco was working. So that's why they had to have one man on that particular rig all the time, to see that they do the right thing.

Bertha Williams, Pep's wife, a few years younger than Pep and, recently, a carnival queen, recalls that Texaco was different from the other companies who brought their crews down to south Louisiana from elsewhere:

> And the other companies was coming with their workers, with their own workers. That's why it made it hard for them to get a job. When their company would come with their rig, they would come their workers, 'cause they had them working some other place. And it made the people, the local people, hard to get a job on those rigs. But when Texaco started, they started with only the local people. That's why he was able [to get a job], and 'cause only local men was on that rig. Was hard to get a job with the oil field. 'Cause like I said, they was coming from another field, and they was coming down, and they was bringing their own workers…the whole crews and all. The only way you could get a position to work if they couldn't have nothing to rent, they had to leave. And they couldn't bring their family, 'cause there was no place for them to stay.

Mac Rome got on with Texaco a few years after Williams, and retired as Texaco's production supervisor for both the Golden Meadow and Leeville fields. Mac, himself an "outsider" from Donaldsonville (his father was the iceman along the northern end of Bayou Lafourche), remembers the influx of "Texians" from predominantly Protestant regions of north Louisiana, Texas, and Oklahoma.

> Was there kind of a hierarchy, that the Texians had the top jobs and then…?
>
> Yeah, for awhile. And, in this area, we noticed, lot of 'em, when the Texians came in, lot of 'em had the Masonic ring. And if you didn't belong to the Masonic lodge, you didn't get up too much. The guy in Leeville, when I hired out, was a big Mason. And he turned down a lot of people. At one time the drillers was all Masonic men. Rough…the common hands was alright. But the guys that moves up was Masons. You don't have that anymore now. But, in those days they did. It wasn't fair. Didn't make him better qualified, it's just that he had the right ring. That was the sad part about it. If he'd been better qualified, I could understand it.

Loulan Pitre, who's father was an oysterman working the bays and reefs between Bayou Lafourche and Houma, remembers the halting efforts to explore to open waters right after the war.

> They started drilling in the marshes, oil, oil, oil…in they came here and struck a big field in Leeville, a big, big field, and then they came to Golden Meadow and they were hiring people all along…. The economy was going up because you take $15 a month to $7 a day, it's a big change. And the economy got improved. We stayed with oysters, had nowhere to go…. Then Gulf Oil came and seismographed in the gulf, and they knew oil was there right off of Fourchon. All over the gulf but they couldn't get to it 'cause the storms would wipe them out every time. And I think they drilled one. I remember this, I remember seeing this rig. They drilled once and they struck oil, here comes a hurricane, knocked it over and they never went out. So this was about 1945. By that time all the marshes in Louisiana had been drilled, not completely explored and drilled, 'cause they refined the seismographic system and pin-pointed any oil.

Chevron—The California Company—made a discovery well on the former Gulf property off the beach at Fourchon after the war. Bay Marchand developed into one of the most productive fields, still being worked.

World War II made veterans out of many of south Louisiana's citizens, and the service, perhaps, taught many skills and work disciplines required by the oil industry. Mac Rome came back to the bayou undoubtedly more worldly than when into the armed forces.

> I went towards the end. I took my boot camp in San Diego. And then from there they sent me to Seattle, Washington. We was stationed at Pier 90. I was drivin' these little landing crafts. And the war was comin' to the end…. In Seattle Harbor, a troop ship would come in and they might have 20 of these little landing crafts on it. They'd lower 'em in the water, we'd go get 'em and we'd tow 'em to the dock. And at the dock we'd take only the compass off because they had alcohol in 'em, but most of it was dry. They'd already stole the alcohol. On our boat we had cuttin' torches. We'd go out in the middle of Puget Sound and we'd cut holes in the boat. Never take the engine, nothing, out. And sink 'em. We sunk hundreds of 'em out there. We never could figure out why until one day I read an article and I could understand why. They figured if they'd bring all them boats in and unload them, them General Motor engines, that General Motors wouldn't make another engine for another 10 years. So rather than knock the economy down, they just figured they'd get rid of that and let 'em continue. That's what it is, 'cause there ain't no tellin' what we buried overseas…. And we had some guys sittin' on the end of the dock cuttin' shoes in half, cuttin' shoes, all day long cuttin' shoes and getting rid of 'em. It was just such a circus, you know. Everybody was geared up for the war and everything was bein' made. And if they'd have put that on the market, it'll flood the market and then the companies couldn't make anything and then they'd be out of business for quite a while.

Loulan Pitre returned from the war to build derricks.

> When I got out of the service, I went and worked for Jerry McDermott. He was a contractor for the oil company…. "We need to do a big job in the Gulf." I got all excited "In the Gulf?" "Yeah, yeah biggest rig ever seen, ever built." Sounded good, probably be like that for months, it's getting $3.75 an hour, pretty good wages. Of course not good work but good wages, we're going to build a platform out in the gulf, all steel! OH, man it's looking up…. So we go out, we pack up, we get an old Navy vessel. I've ridden some in the Pacific. I never thought I'd be on one of these junk yards again. But uh, the old sea vessel had been stripped of all the ornaments and had them for living quarters. Went out there about 6 miles off of Morgan City, dropped the hook, dropped the anchor for the next day. Four big barges loaded with big steel…then here comes a derrick, big derrick, man. 176 feet high, everything was double. Everything doubled, girth, braces —doubled. Talk about a job…it's all bolted, not welded, bolted. We tried to run the bolts through, couldn't get the bolts through, they forgot to allow for the galvanizing. Didn't leave enough tolerance, what are we going to do now? We get some reamers, I spent two weeks reaming out every hole in that derrick, so we could run the bolts and we did it. I didn't moan. Working 10, 12, 14 hours a day I could see myself buying something more for my house. And we built the derrick, Kerr McGee, first rig, first derrick.

Loulan, however, wasn't invited to the commemoration of this historic happening.

> …in the 60s, 70s, they had a reunion-like thing in Morgan City of all of the people that had worked on the first rig, drilling, whatever, got invited to a big barbecue, and they didn't invite us. We were not invited. As if we had never been there because without us they couldn't have done it. A lot of times we could've walked off, they would've…they probably would've abandoned the thing. If we hadn't built the derrick they wouldn't have drilled the holes, and they hit oil, they hit oil. That's why it took off from there.

AFTER THE WAR

A generation of south Louisians went to war and returned to begin remarkably "orderly" careers in an expanding oil industry. The careers were orderly in a sociological sense.

The most orderly of careers for this generation involved employment with one of the major oil companies, starting out as a roustabout, learning on the job, working up the ranks to become a field supervisor, then perhaps a production foreman with oversight responsibility for a company's regional operations. Some of these retired with a "package," a pension; a number took early retirement, for family or health reasons, and made do until social security coverage kicked in at age 62.

Martial Babin was raised on his family's farm in St. Charles, along Bayou Lafourche by Raceland. He was turned down for the service, but worked in metal plants over in Texas. He came back to south Louisiana and became one of Chevron's top field men.

> I had an old car and I used to pack all of my belongings and pile it all up because originally when I went up for the physical I sold all the furniture we had. The next time when I went

> back after I didn't make the service, I rented a furnished apartment. We didn't have a whole lot of things to carry, but I had an old Chevrolet and we lived like the Clampits. I had that thing tied all around on top and everything. It took us about 12 hours to make that route back. But, anyways, I had a home already. I had bought me a home before I left and I was renting it. When it got vacant, I moved into it. I worked there and I had a short stay with Joe W. Brown drilling in back of Valentine. Then, I worked with Mobil in Leeville on the east canal. Then, I worked for people in back of Golden Meadow. On August 8, 1947, I went to work for Chevron. I put in eight years on one of their drilling rigs. I barely had a high school education and I was not an engineer, but I learned the trade through practice and later on I was doing engineer work because we had a lot of rigs running and not enough engineers to go around. So, they made a drilling foreman out of me and I was doing everything an engineer would do to a well. Later, as these engineers came out of school my job got lighter and lighter. But still, they had to at least put in three weeks or longer with someone that had practical experience. I broke in many of them. Three years later, I was working for them. They were my bosses.

He retired a few years short of the company's retirement age of 62 and built a camp down on Grand Isle so he and his wife could fish and enjoy the leisure.

> I retired May 1, 1980 at 59 years old. Last May was 21 years of retirement. I was, at one time, known to be the highest-paid field foreman that Chevron had, and I am not bragging. I was a class A1 or 1A. From what my boss told me, I was the only one who had that classification because of my ability to get the job done. When I retired, there was no packages like they had later where the company offers you a year's pay or more. They would retire the older men and replace them with engineers and younger men, which I never understood why…. In fact, I was a volunteer retiree. They did not want me to retire. They gave me a $3000 per year raise right before I retired in hopes to keep me for a couple more years. It was a good life with Chevron Oil Company…. When I went to work, it was the California Company. They changed the name to California something and then it changed to Chevron. It has been Chevron ever since. This was my 30-year watch. It has a couple little diamonds on it but you can barely see them. I only wear it when I go out.

Abraham Griffin's career was less orderly than Mr. Babin's. He worked as a driller—and a shrimper. He's still shrimping at age 80, usually with his wife as his deck hand.

> I never worked for a major company. I was always contract. At times, I worked for two different companies. I could take off and make my season. Whenever I would finish my shrimping season, I would go back to work. I did that through Williams Drilling Company in Baton Rouge and with Guidry's rig. Those people, whenever I needed a job, I would call them. Whenever they needed help, they would call me. We got along pretty good…. I worked in the east part of the state all the way to Lake Charles. I used to work all those places…. I worked offshore for Chevron. In those days it was called California. I worked in Fourchon for them. I made a big mistake when I left them. I could have put in 43 years with them. We didn't know too much about retirement in those days. I was going where I could make more money at the time. I was making $1 an hour there when I could be making $1.25

> on the big rigs. …I was working for Charles O'Neill in this field right around here. I worked for him. I started with him in 1946. Then, I came back and worked for about 10 years drilling the wells and working them over. I left and went to work for Williams Drilling Company. Then, I came back and worked for the old man Charles O'Neill…he is from New Orleans. He is dead now. That was the last ten years that I put in the oil field. I left in 1985. All together, off and on, I put in about 43 years.

All around Golden Meadow in the summer of 2001, the EPA was endeavoring to clean up what Charles O'Neill, and Abraham Griffin, had left behind.

> That is what they are doing now. All those rigs right there? It is just a lot of waste of money for them. That is just to create jobs. They make me sick just watching them. I don't think anybody knows what they are doing over there. They have been here for six months. I drilled all the wells and I worked them over so I know which is which. One day I walked over there and I asked the guy if they were having troubles. He said yes because they couldn't kill the well. I didn't see anything. I told him to give me three hours and I would kill it. They fooled around with that well for two weeks. He said every morning they came back the well made 20–30 barrels of oil. I said "why don't you put it in production?"

Mac Rome, a career man with Texaco, has nothing but respect for Griffin.

> Well, they got a guy by the name of Abraham. Abraham, you know Abraham? Well, we blame that all on him 'cause he produced them damn wells over there. Abraham. Yeah. We kid him, we kid him that old man O'Neill thought he owned 50 wells and he pulled a Christmas tree off 50 of 'em they didn't have no pipe in 'em. Abraham'd sold all the pipe out of 'em. He's a good guy, though. Good, good, good fellow. Oh, yeah. He has a lot of knowledge, had a lot of knowledge. Lots of knowledge. Because the companies he worked with, you know, like O'Neill and stuff, money was not that easy. You know what I mean? You had to make do with certain things. Where us, with Texaco money was no object. When we needed something, we bought it, you know. And they paid for it. But, so he, his experience and his knowledge, using second hand stuff and everything else to, you know, was a lot greater than ours. Because, if we had an old well and we didn't like it, we just buy another one. He, he'd try to re-tap, try to make it work. That's the difference.

Mac Rome has somewhat less admiration for "environmentalists."

> They don't care. They don't give a shit what it cost you to do it, you gotta do it. And that's why we moved out of a lot of wells, why we abandoned a lot of wells, because it was too expensive to try and produce it according to the environmentalists. So we'd plug it and abandon it. We'd pull the casing and everything else and cement 'em off. So, there was a lot of wells that we could have continued producing, if we coulda gone overboard with the water. But treating the water and everything else made it… in other words, they didn't pay you to get $3 a barrel and then spend $2.75 to produce it, you know. So they decided to just get rid of it.

> And then when they saw the production was going down bad in Golden Meadows, they wanted to sell. But no other company would buy ‘em with 300 wells and only 50 producing, and all the rest closed in. Whoever buys ‘em is gotta abandon those wells. So Texaco went ahead and we abandoned. We abandoned at least 300 back here. We plugged and abandoned all the pits, before we could sell it, because Apache couldn’t afford to abandon all that stuff. Now, what they bought now, they’re responsible for.

Mac Rome retired in 1987, after open-heart surgery, and took his pension from Texaco as a lump sum. The company put a $50,000 annuity in his name, and he draws the interest. Company policy also allows you to put 13% of your salary into a savings account, and Texaco would contribute an additional 6%.

THE RISE OF THE BOAT COMPANIES

While many locals went into drilling and production with the majors and the independents, Bayou Lafourche is boats. Loulan Pitre and hundreds of others drove boats—tugs, supply boats, speed boats to make crew changes on the rigs and platforms. A sizable cadre of others built and owned boats, and became wealthy.

This operator’s story is by no means unique:

> We was fishin’ and trappin’ and then we had a trawl boat. We were trawlin’, you see. And then in 1935, my daddy had a boat and I went to work for Gulf Oil Company, seismograph. And from there, I got my…my daddy bought me a boat. ‘Cause we always did work for my daddy. We was five brothers. And then when we got old enough, well, he helped us get into business. So, from there I went to, I stayed with Gulf about six years. I had my own boat and I was getting’ $200 a month for me and my boat. And I was workin’ 11 and 3 off. 27 and 3 off. I always did work by myself. I sunk five times. Five time I sunk my boat. The last time that I sunk my boat there I stayed two days on the back, on top of the cabin. Nobody didn’t know where I was. ‘Bout that much of the back of the boat was stickin’ out…. And then from there, in '51, yeah, '51, that’s when I started in the tug business. I had the netshop and I had the tug business. And then from there I went to offshore crew boats. I had one, then from one, two, three, four, you know. As I was goin’ I was buildin’. So, there, I worked for Humble 22 years. And then from there I went into 65 foot boats. And then from there in '63 I built the first 100-footer that came out in the gulf. A 100-footer by 24.

Engine companies such as General Motors would often underwrite construction of new boats, if you used their power plants. Much of the time, you would have to take your reputation to the banks.

> You know, in those days, huh! $100,000 for me that was some money. Ooooh. How I got it, I don’t know. Well, I had a few boats, you see. I had a few small boats, that was paid for. So I was borrowin’ on that. And when they saw what I was doin’, the bank came over there. The last boat I built, I built it in Houma. I built, altogether I would say I built 30 boats. But I was buildin’ and I was sellin’. The price was there, I was sellin’ and I was buildin’ again. And the last one I built cost me $850,000. It was a 110-footer by 26. I had it built over in

> Bayou Le Batre, Alabama. I had two of 'em, I had three of 'em built there. I had two of 'em built in Mobile. Mobile Ship and Repair. And then I had five of 'em built here in Houma, Universal. And then I had another one built by another guy in Houma. And then I had another big one built right there across the bayou. And I bought three of 'em that was already built. When things got bad in 19, what it was, 1984? Things really got bad. People was buildin', just like they're doin' right now. Just like what happen right now.

The reputation of Lafourche vessels and their captains traveled throughout the offshore oil industry. A documentary film in the mid 1970s chronicled Chester Cheramie's employer, and Chester himself elaborates on the experience.

> Nolte Theriot was the first company that went over to the North Sea, drilling in the North Sea. All the captains went over there. It is all guys, not all of them but I would say 50 percent of the guys were born and raised on shrimp boats. Maybe a few that had little license…tug boat license. Maybe 50–100 ton, maybe. They'd cross the Atlantic Ocean all the way to Great Yarmouth. Went to Great Yarmouth in England, and then to the North Sea…. This fellow [Theriot], at one time, had at least 20 boats working in the North Sea….
>
> See they wind up there and then they send a whole crew. Then, after awhile…then they say, "well you've got to use one of our men…you're in my country, you got to have one of my men on your boat." "We are not going to make him a captain but maybe a mate." So he is a mate to learn the tricks, see. Then they started working in Norwegian waters. "Well, you got to put one of my men on there." So they started using Norwegian seamen and deckhands. Stuff like that. Then it got into Amsterdam. By the time they left the North Sea, the only American they had left on there was a captain, an American captain, and an American assistant captain. That was the law or you didn't work.

The honeymoon drew to a close when England began to make and man their own offshore boats. Cheramie likens the experience to south Louisiana: the "Texians" were no longer needed once the Cajuns learned the business of the oil field.

THE TROUBLED 80s

Ronald Callais, in his early 60s, is a regular at the Fed Pond in Golden Meadow, along Bayou Lafourche, for early morning coffee. I interviewed him in his office at Allied Shipyard, an office well-stocked with novels (James Lee Burke, among them), with walls filled with official certificates, marking his service on Lafourche Parish's Police Jury and his membership on the Levee Board. He acknowledged that he is semi-retired from the shipyard business (started in 1980), though he comes in to the office, often just to read. This yard, and another in Larose run by his son, exclusively do repair work, including much work for the shrimp industry. At one time, Ronald was also involved in the utility boat business founded by his father, but got out of that end of it when it was clear that the two enterprises were in conflict: he was repairing the boats that competed with his own boats. I asked him about the "bust" of the 1980s, when, after a decade of restrained production and falling revenues, OPEC countries opened their pumps wide and crude oil prices plummeted.

> Tom, it just blindsided us. Nobody expected that. Look, I had six boats in those days. I'd just bought this shipyard and I was operating six, medium-sized offshore boats. I had a company talkin' to me about building a job, a boat, for a particular job for them. Within three months I had five of my six boats tied up. [Claps his hands once.] Like that. Nobody expected that! And what we did is we all sat back. We kept crew. We made financial expenditures that lookin' back on we should have never done. But we thought it was temporary. We kept crews, we kept boats tied up, we didn't scale back down on our style of living. But then after a month, two months, three months, then we realized this was gonna be a long haul. And it was. It was, I guess about a year, year-and-half it got halfway back to normal. A lot of companies went under.

Callais goes on to give a perceptive account of local action within a global economy:

> Now, what really hurt us too, really, really devastated a lot of companies, is you had a bunch of doctors, attorneys, people in other forms of business, who invested in these limited partnerships. They put money into it, they mighta put $10 to $50,000 a piece. And they mighta formed a company, ten of 'em together, they mighta owned 15, 20 boats. They formed these limited partnerships, invested this money, and then, because of limited liability, they lost their money and moved on. Well, these banks who had financed boats had their boats in hand. What they did in my case, is they took these boats and turned 'em over to other people, who a lot of 'em were, like, were shysters, fly-by-nights. They took these boats, took the money the bank and give 'em to operate them and they'd run 'em to the ground and then take the money and go. So, what'd happen, the bank'd wind up with the boat on their hands again. But what the bank had did, without realizing, they'd think about going back in, to put that boat back into the market, they were hurting their other customers, people like us. These guys were competing against for the jobs, working for less money. And we mighta had the same financing with the same bank that was doing that. So what they'd do? They were cuttin' the throat of their other customers, instead of takin' those boats and tying 'em up and bitin' the bullet and takin' their lose but at least keep their other customers.

In these brief excerpts, Callais articulates connections from the global political economy to local enterprise strategies and the micro-temporal impact on local livelihoods. He does not flesh out the full picture—the bunch of doctors and attorneys were encouraged to invest in fleet capacity by Ronald Reagan's tax policies, fostering rapid depreciation on capital investments (shrimp boat owners took advantage of this as well, selling off trawlers after three years, then buying bigger and more powerful ones).

Pep Williams, who worked in production, and his wife Bertha pretty much agree with Ronald Callais' picture of the troubled '80s.

> PW: Well, the worst part was the boats, the big boat companies had invested their buyers' money and big boat companies went bankrupt and lost a lot of money. Looked like it hurt the boat people more than anything else. Because what happened, they built boats, and they was building some more boats for the future, because they thought oil would boom. Instead

> of booming, it went down. And they had all that money invested in building new boats, bigger boats. And really, it really, they got hurt, yeah.
>
> TM: Did it hurt other parts of the town?
>
> PW: Not too much. Most of the boat people got hurt.
>
> BW: It's the boat people that got hurt. All the other ones, like you, you continued work.
>
> TM: How 'bout in the community, did any stores have to close?
>
> PW: No, that's why I say, it just hurt the boats. Everybody else survived.

THE MODEST BEGINNINGS OF PORT FOURCHON

Ted Falgout, Port Director of Port Fourchon, recounts a history of the port since a port commission was established in 1960.

> Our Senator at that time, whose name was A.O. Rappelet, had this vision of developing a port at this site [Pass Fourchon]. And pretty much what existed was muskrats and mosquitoes at that time and nothing else…. He envisioned a port that would accommodate the fishing industry of course. Oil and gas was starting to develop at that time. Some of the first offshore wells were off of this area, and because of its proximity, he envisioned the capability to take the banana trade from New Orleans, which was struggling at that time, and bring it to a port closer to the Gulf of Mexico and thus create a more efficient route for moving bananas. Unfortunately, it took a little longer than he had anticipated to get the infrastructure in, to create this port and make it a viable alternative to the port of New Orleans for bananas and fruits and vegetables, and in the interim, the trade went to Gulfport [Mississippi] and New Orleans lost it anyway, but it sits today in Gulfport and, so Fourchon's opportunity there was, short lived and it didn't make that loop. But that may have been a blessing in disguise….

In the late 1970s, Falgout continues,

> We did some major improvements to the channel, to the jetty system, making the channel a lot safer, dredging it down to 20 foot, which was a huge undertaking for a small commission like ours. We sold bonds to help finance that and we got some state money to help, to go into that effort. And, that I guess, put us on the map as being, a solid organization and not fly-by-night and we were gonna be there. And LOOP, Louisiana Offshore Oil Port, had been established Port Fourchon [in 1981]…that additionally showed the logistical advantage of the port close to deep water, and now with the channel improvements, made it very attractive. Several oil companies, such as Bayroid and others were startin' to build facilities, had negotiated leases with the port, and were doin', putting in improvements.

Falgout, interestingly, credits the downturn with solidifying Port Fourchon's position on the oil and gas landscape.

> But it really wasn't 'til the oil bust of the mid to late '80s that the port really got recognized for its logistical advantage. What happened there was oil and gas pre-1980, pretty much had a dock, an offshore loading or a nearshore loading dock at every coastal community along the coast. They had a dock in Grand Isle, one in Fourchon, one in Dulac, one in Morgan City, in Freshwater Bayou, in Intracoastal City and on and on and on. In the bust of mid-'80s forced them to go back and rethink, cutting costs, reducing the number of docks, to do some strategic planning of where they were going in the future and that everything was pointing to deeper water further offshore, and it forced them to identify one or two places on the entire coast to build their facilities. And more often than not, Fourchon was the site chosen to locate facilities for the future. So, actually, during the bust when, bumper stickers were sayin' "The last person out of Morgan City, turn out the lights," Fourchon was in a building boom. We didn't have the people working offshore coming through the port, but the people in the port were in construction building facilities as part of this downsizing effort of oil and gas. So, luckily, that kept our people at least working, in construction and building facilities, although they wasn't goin' offshore.

CONCLUSIONS

Lower Bayou Lafourche, from Edison Chouest's shipyard on the Intracoastal in Larose to Port Fourchon at the end of LA 1, has been transformed by the oil and gas industry since the 1930s, to be sure. But is has also played its part in transforming that industry. "Texians" from Texas, Oklahoma and elsewhere were more often than not landlubbers. When the Texas Company acquired a windfall from the Louisiana Land and Exploration Company in the marshes and water bottoms of south Louisiana—the salt domes underneath—it needed and found people who knew how to navigate that terrain. When the California Company acquired the property not far off the beach at Fourchon, it needed and found the both the captains and the craft to get their personnel out there. When the North Sea fields were opened up, Nolte Theriot's mariners already had practice working closely around rigs and platforms in the GOM. When the engineers were sent down, fresh out of college, Martial Babin could train them. When Charles O'Neill, the lawyer from New Orleans, needed someone to jerry-build a rig, he could find a shrimper like Abraham Griffin to put things together.

Abraham Griffin, now in his 80s, keeps buying second-hand little Lafitte skimmers. The engines go bad and he seldom makes his season, but he is endlessly tinkering with the motors. His compatriots for morning coffee at the Fed Pond in Golden Meadow recommended that he christen the new acquisition the *For Sale*. Then he wouldn't have to remove the sign.

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

THE BRAVE AND THE FOOLHARDY: HURRICANES AND THE EARLY OFFSHORE OIL INDUSTRY

Dr. Joseph A. Pratt, University of Houston

When the oil industry moved offshore into the Gulf of Mexico (GOM) after World War II, it plunged into an ocean of ignorance. Little was known about conditions in the Gulf. As the industry sought to adapt technologies developed onshore to the challenges of operations in the open sea, it also had to collect basic data about wind, waves, and soil offshore. Every-day operations offshore required engineering adjustments in the design of drilling rigs, pipelines, and construction equipment. And out there beyond the horizon loomed an engineer's nightmare, the extreme, unpredictable conditions generated by hurricanes (Veldman and Lagers 1997; Pratt *et al.* 1997).[1]

Those seeking to develop a technological system capable of finding and retrieving oil and natural gas from underneath the ocean faced formidable challenges in defining basic design criteria. Traditional engineering calculations could estimate the environmental forces that would come to bear on the equipment and structures needed to produce oil, but such calculations could be made only after the collection of data about these forces of nature. How strong would the winds blow? How high could hurricane-driven waves be expected to crest? How solid was the foundation provided by the soft, sandy bottom of the GOM, and how would this soil be affected by hurricanes? Underlying these questions was another, more practical one: How much were oil companies willing to spend to develop safe, durable offshore structures?

It was at yet unclear if offshore oil could be developed in a way that made it competitive in price with oil produced onshore in the United States and with growing imports from Venezuela and the Middle East. Numerous companies stood ready to explore the risks and rewards of offshore operations in the late 1940s, in part because of the scarcity of good leases onshore, where large oil companies had locked up giant acreage at low costs in the depressed 1930s. Seismic surveys in the 1930s had revealed numerous large salt domes in the GOM. It made good geological sense that the excellent oil fields discovered in the early twentieth century along the Texas-Louisiana coasts did not stop at the water's edge. At war's end, several major oil companies eagerly extended their on-going quest for large oil fields out into the Gulf. A handful of smaller companies looked out in the same direction seeking "break-through" discoveries that could vault them up the ranks of the independent oil producers. These companies faced an uphill battle offshore. If they could not develop a technological system capable of getting offshore oil to markets onshore at a price competitive with other sources, they could not sustain operations in the GOM.

History was kind to the pioneers of the offshore industry in the GOM. They arrived at the right shore at the right time. The Gulf sloped very gently out, stretching for a hundred miles in places along the continental slope before reaching water depths of 300 feet. Companies thus could walk gradually, step-by-step into deeper waters as they developed new technologies. As they moved out, they could draw on the workforces and expertise of clusters of oil-related manufacturers and service companies

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[1] Veldman and Lagers (1997) provide an overview of the offshore industry; Pratt *et al.* (1997) discuss this history from the perspective of one of the largest offshore construction companies.

that had grown previously to meet the needs of a booming onshore industry in the region. Best of all, significant discoveries in the Gulf quickly rewarded their initial efforts, encouraging them to make larger investments.

In developing new technologies, the offshore industry could draw on previous experiences gained near the shore in California and in a variety of inland waters around the world. Before the 1930s, oil had been developed off the southern California coast near Summerland using a system of trestles that reached out into the edge of the Pacific Ocean to tap oilfields that extended from known onshore deposits. But this region lacked the threat of the extreme weather produced by hurricanes. Extensive development of oil in the protected waters of Caddo Lake in Louisiana, Venezuela's Lake Maracaibo, and the Caspian Sea generated knowledge useful in everyday operations offshore. Finally, work in the marshy areas of "inshore" Louisiana in the 1930s helped prepare the way for operations in nearby areas offshore. None of these previous projects, however, had to be designed to stand up to hurricanes in the open sea.[2]

Griff Lee, a design engineer for Humble Oil and then for offshore construction giant McDermott, aptly summarized the situation facing the industry in 1945: "There had been no construction of open frame structures in open water before." Designers could look at data on the wave and wind forces exerted on seawalls or on ships at sea, but such data could not predict the forces that would come to bear during a hurricane on structures permanently fixed to the ocean's floor (Lee 1996).[3] Given this void of knowledge about conditions offshore, those eager to explore for oil in the GOM would have to take calculated risks while they learned by doing.

This was not unusual in the oil industry or, indeed, in any innovative industry in America in this era. Oilmen lived by the oft-repeated adage: "Fortune favors the brave." With great confidence born of past technical successes and fed by the profits promised to first movers into the Gulf, the oil industry used very rough "best estimates" of wind and wave forces in the initial design of offshore facilities. When problems arose, engineers and construction specialists within the individual oil companies joined forces with their counterparts in offshore construction and service companies to solve them "on the run." Meanwhile research went forward by all involved—including consultants and academics—to generate the data needed to improve the best estimates. This "entrepreneurial" approach was possible in a largely unregulated environment in which the companies enjoyed great freedom to make their own choices.[4]

If fortune favored the brave in the formative years of offshore development, unusually good weather favored the foolhardy. Until 1964, no major hurricanes swept through areas with high concentrations of offshore operations. Thus for almost twenty years, the offshore industry amassed the data and the experience needed to improve the design of its equipment in the relative calm before major storms

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[2] For an overview of these experiences, see Veldman and Lager pp. 13-25.

[3] All interviews cited are in the OEC Collection in Houston, Texas.

[4] This attitude of "can do" engineering is illustrated throughout Pratt *et al.* (1997). Government regulation of offshore activity before the 1970s came from a variety of agencies, none of which exercised strong control. Both state and federal governments had authority to lease offshore lands. The Army Corps of Engineers had power to issue construction permits for projects in navigable waters; it required offshore companies to clearly mark their platforms and to dismantle those no longer in use. The Coast Guard had authority over safety and limited powers over oil pollution.

returned to the region in the mid-1960s. Three major storms, Hilda (1964), Betsy (1965), and Camille (1969) severely tested the technical system that had evolved in the GOM (Tait 1995). The industry received a gentleman's "C" on these tests. The brave and the foolhardy had demonstrated admirable ability to make engineering adjustments on the run, but they had gravely underestimated the risks presented by major hurricanes.

The oil industry first stuck its toe into the GOM to test the waters before World War II, and the results of these early forays identified several key problems presented by storms. In the late 1930s, Humble Oil (then a Houston-based, majority-owned subsidiary of Standard Oil of New Jersey) constructed one of the first drilling sites in the Gulf at McFadden Beach, south of the giant refineries at Port Arthur, Texas. Borrowing from the approach that had proved successful in southern California, the company extended a trestle more than a mile out from shore, with drilling rigs at the end of the line supported by men and materials brought out on a train track over the trestles. The drillers struck no commercial deposits of oil, and after a small hurricane in August of 1938 ripped apart the entire facility, Humble abandoned this venture. The industry subsequently ratified Humble's decision: trestles could not be built high enough or strong enough to withstand hurricane-driven waves in the Gulf (Larson and Porter 1959; Anonymous 1938).

The first real test of offshore construction came up the coast about 50 miles near Cameron, Louisiana. In 1937 and 1938, Pure Oil and Superior Oil together built a large wooden platform about a mile offshore in approximately 14 feet of water. This Creole field became the first producing property in the Gulf. It proved that profits could be made offshore while also revealing the severe challenges posed by hurricanes and the limitations of applying onshore technology in an offshore environment.

The companies constructed a giant platform measuring 320 feet by 180 feet from which to drill the exploratory well and then to produce any oil found. The primary task was to drive some 300 treated yellow pine piles 14 feet into the sandy bottom using pile drivers mounted on barges. This "stick-building" approach sought safety and strength through the clustering of many wooden piles; it sought stability against wave forces by driving the piles as far as possible into the sand. It sought protection from hurricane winds by using design criteria developed for onshore buildings to construct a structure that could survive winds of up to 150 miles per hour (Alcorn [Derrick] 1938).

Hurricane-generated waves were another thing entirely. With no available data on wave heights or wave forces, I. W. Alcorn, the designing engineer from Pure Oil, chose to build the deck 15 feet out of the water. He figured that such height would provide sufficient protection from normal high waves. He could not calculate the strength and height needed to survive a major hurricane; nor did he have the capacity to build such a structure with existing tools. So he struck upon a reasonable compromise. He designed the deck so that it would be swept off the piles by very high waves, thus limiting the damage done by a severe hurricane to the extensive system of piles. The wooden deck could then be replaced after the storm (Alcorn [Marine] 1938).

The Creole platform completed the first successful well in the Gulf on 18 March 1938.[5] Once production began, the problems of transportation and communication became more pronounced, foreshadowing similar problems in the post-World War II offshore industry. Workers lived in houseboats at Cameron, the closest town. But the platform itself was some ten miles along the coast from Cameron, meaning that all men and supplies came to the platform via a long and often rough ride in leased shrimp boats. A one-way ride might take up to an hour and a half. Without communication between the supply point, the boats, and the platforms, the shrimp boats often arrived at the platform only to find seas at the site too rough to allow workers to transfer from the boat to the platform. Rope ladders hanging from the platform could be lowered down to the deck of the shrimp boats in relatively calm waters, but not in rough seas. In the thick fog that often hovered over the platform, boat captains would at times simply cut their engines and listen for noise from the platform in order to find this man-made island. From the start, it was understood that in the event of a major storm, the men would be evacuated after the equipment on the deck had been secured.

The Creole platform proved quite successful in finding and producing oil. Using directional drilling to tap the field at several surrounding locations, it produced over four million barrels of oil over the next thirty years, during which time it was constantly upgraded as the offshore industry became more experienced at construction. Alcorn proved farsighted on one key point. In 1940 a small hurricane moved through the region, sweeping the deck into the ocean and badly damaging the piles. Crews drove some new piles, quickly rebuilt the deck, and the platform returned to production, the first offshore structure in the Gulf to survive a hurricane (Anonymous 1963).

World War II halted development in the Gulf. Workers on several small platforms being built offshore in 1942 remember scanning the horizon nervously in search of German submarine periscopes. But the war set in motion several processes that proved quite helpful to the offshore industry when peace returned. First and foremost was the work of the U.S.Army's oceanography and weather service, which created a corps of well-trained specialists who forecast wind, wave, and soil conditions for use in the amphibious landings in northern Africa, Normandy, and the Pacific. These "weather officers" accumulated data on the behavior of waves and soils in different storm conditions. From such information they sought to predict whether conditions at a specified place and time might be appropriate for an amphibious landing. Several weather officers led the industry's post-war efforts to collect and interpret better data on winds, waves, and soil in the GOM. Their methodology of using observations of past conditions to help forecast current and future conditions evolved into much more sophisticated methods of "hindcasting" hurricanes as a way to more fully understand and predict the probabilities for severe weather at a given location out in the Gulf.[6]

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[5] 18 March 1938 was a momentous day in oil history. As the first offshore well came in, the Mexican government was proclaiming the expropriation of U.S. and British oil properties in Mexico. Half way around the world, the discovery well for the first oil found in Saudi Arabia also came in on 18 March 1938.

[6] For profiles of several of these weather officers, see Offshore Energy Center (OEC), *Offshore Pioneers: A Tribute*. Houston: Gulf Publishing pp. 27-37. This booklet was published as a part of the induction of individuals into the OEC Offshore Hall of Fame. In conjunction with this event, the inductees are interviewed and the interviews are transcribed and placed on file at the OEC in Houston. See, for example, interview of Robert Reid 17 Oct 1998; interview of Curtis Crooke 6 Oct 2001; interview of John A. Focht, 6 Oct 2001; interview of Bramlette McClelland 6 Oct 2001.

The war paved the way for post-war developments in many other ways. Much improved communications at sea could be adapted for use offshore. War-surplus vessels produced in great numbers to support amphibious landings could be purchased and converted for offshore uses at bargain basement prices after the war. Perhaps the most important impact of the war, however, was on attitudes, not equipment. Veterans who had postponed their lives for four or five years returned eager to get back to normal work and family lives. They came back with a sense of urgency and a sense of adventure, two characteristics required of those who leaped out into the Gulf in search of oil after World War II.

The race offshore was on in the late 1940s. Despite uncertainties between coastal states and the federal government over the ownership of offshore lands, despite economic uncertainties, despite technical uncertainties, numerous oil companies headed out into the Gulf in search of big, virgin fields. Economics shaped their technical choices. One young Shell engineer, C.H. Siebenhausen, recalls asking an old hand at Brown & Root (one of the two dominant offshore construction companies in these early years): “In just how deep of water do you think Brown & Root could build an offshore platform?” The simple answer was: “First, young man, you will have to tell me how much money Shell is prepared to spend on such a platform” (Siebenhausen n.d.). The economics of offshore construction included considerations of severe weather in the design and construction of new facilities.

In these formative years, two basic approaches to offshore exploration and production emerged. The first was the Creole approach writ large. Humble, Superior a large independent), and Magnolia (a Dallas-based majority-owned subsidiary of Standard of New York) chose to build permanent platforms to find and develop oil in the Gulf. These platforms could hold crews of up to 50 workers, as well as all needed equipment and supplies. They were sturdy enough to last the life of the field and to survive harsh weather. They were also expensive to build and fixed in place once constructed, attributes that greatly magnified the risk of building them for use in drilling wildcat wells (McGee 1949; Anonymous 1947; Anonymous 1948a).

A smaller company, Kerr-McGee, developed a less expensive approach, using refurbished war-surplus LSTs to house men and supplies and a small platform to support the drilling rig needed to find and produce oil. The LSTs were more than 300 feet long; once most of their insides, including their engines, had been removed, they could be converted into a sort of giant floating storage bin. This small platform with tender approach had obvious economic attractions, at least while war-surplus vessels remained plentiful and inexpensive. In the event of a dry hole, the tender—unlike the large fixed platforms—could be towed to a new location and at least a portion of the cost of the small platform could be salvaged (Pratt *et al.* 1997; Anonymous n.d. Humble).

Severe weather had implications for both systems. Large platforms could be designed and built to withstand hurricane level storms much more easily than the small platforms with tenders. High decks—at least in the context of the prevailing wisdom at that time—and safe procedures for transferring workers could be incorporated in their designs. The first generation of fixed platforms constructed from 1946–1948 placed decks from 20 feet to 40 feet above the mean level of the Gulf, reflecting the broad range of opinion on what was the most likely wave height in a severe hurricane (Anonymous 1949a).

In contrast, the tenders posed serious problems in high wind and waves. These vessels were not self-propelled, and they could become heavy floating sledgehammers in rough seas. After the success of the Kerr-McGee's small platform with tender, Humble invested millions of dollars in buying surplus LSTs and converting them for use as tenders. It developed a mooring system using chain two inches in diameter to hold these large vessels alongside small platforms. Company engineers designed the ship's anchoring system to withstand 100 mile per hour winds. To accommodate the height of the tender, decks on the small platforms were as high as 34 to 44 feet above the ocean. Men and equipment moved from the tender to the platform over a bridge that could be raised from the vessel to the deck. So difficult was passage over this bridge in rough seas that workers came to call it "the widow maker." If a hurricane seemed likely to affect a tender operation, the company would move the tender away from the platform so that it could ride out the storm at anchor while posing less danger of pulling off of its moorings and smashing into the platform. Humble maintained large vessels near its offshore locations to evacuate workers in the event of severe weather (Anonymous n.d. Offshore; Kolodzey 1954).

Problems with the tenders in rough weather did not, however, outweigh the economic advantages the small platform with tender had over the large fixed platforms. The huge downside of permanent platforms remained: a dry hole meant that literally "sunk costs" could not be recovered. Until the development of dependable, cost-effective mobile drilling rigs that could stand up to rough conditions in the open sea, the "semi-mobile" small platform with tender remained the dominant approach to offshore exploration and production.

Oil companies active in the Gulf went forward using both approaches until the late 1940s, when the "tidelands" controversy temporarily halted leasing while the federal government and state governments turned to Congress and the courts to resolve questions of ownership of offshore lands. This controversy became quite heated, particularly in the 1952 presidential campaign. But the pause in leasing gave the industry a short breathing space in which to reexamine assumptions about design criteria for offshore structures and to begin a generation of basic research about waves and soil conditions in the Gulf.

This research proceeded on a number of loosely coordinated fronts. The major oil companies created their own research groups, which worked closely with leading research institutes such as Scripps and the University of California-Berkeley. Consultants also provided much input into the studies of basic conditions. In the 1950s, the American Petroleum Institute (API), the industry's primary trade association, became more active in the collection of improved data about waves and soil, and the API gradually emerged as the focal point of much of the industry's interpretation of the data collected from research.

One key area of concern was the composition and load-bearing capacity of the soft soil in the Gulf. The leading authorities on soil conditions were the founders of McClelland Engineers, a consulting firm based in New Orleans that extended the work of the weather officers into the GOM. Bramlette McClelland, John Focht, and Robert Perkins pioneered the applications of soil mechanics to the problems of the offshore industry. To do this, they had to have data on conditions in the Gulf. With industry funding and cooperation, in 1947 they became boring soil samples offshore, building a data base for use in offshore construction. At times they worked just ahead of the contractors busy designing and installing structures; at other times, they investigated general conditions in areas likely to be explored in the future. Their analysis of the results of oil company-sponsored tests also led the way in applied research on the load-bearing capacity of the piles used to support offshore platforms (Pratt *et al.* 1997).

The API took the lead in the collection of other sorts of data on the soil in and along the Gulf. In 1951 the Institute launched what came to be known as Project 51, which spent four years undertaking basic work on conditions in the Gulf, using core drillings, serial mapping, and seismic surveys. This work, as well as that of McClelland Engineers, provided fundamental information vital to the safe construction of offshore structures. It did not, however, directly address a question that was later revealed as important: what would be the reaction of soil in various parts of the Gulf to the extreme conditions generated by severe hurricanes.

Other research studied the force of waves on offshore structures, both in normal times and in times of extreme weather. Here the oceanography department at Texas A & M University led the way. C.L. Bretschneider and Robert Reid, two more former weather officers, cooperated with several major oil companies to conduct field measurements to determine the wave forces exerted on vertical cylinders placed in the ocean. J. R. Morison later added considerations of inertial components to this work (Reid 1998).

Other primary research was much more directly tied to hurricanes. From 1947 into the 1970s, extreme wave heights remained a critical question on the minds of offshore engineers. This question was attacked from two directions. The first sought to develop better means to track storms and to predict where they would hit; the second sought better information about the maximum height of waves that could be expected in different parts of the Gulf. Weather forecasting in general had advanced steadily over the decades before World War II, but the offshore industry needed more detailed and more frequent forecasts than the U.S. Weather Service could make available to them. To meet this demand, A. H. Glenn, a former weather officer with graduate training at the Scripps Institute of Oceanography and U.C.L.A., mustered out of the U.S. Air Force and created Glenn and Associates, a New Orleans-based weather forecasting agency designed to meet the special needs of operators of offshore facilities. Glenn and others made great strides in using historical data about past hurricanes to "hindcast" the path and the intensity of future hurricanes. By analyzing all available information about past hurricanes with sophisticated theoretical models of the behavior of winds and waves, Glenn and a growing group of hindcasters gave platform designers a much-improved understanding of potential wave forces while beginning the process of categorizing hurricanes according to their intensity (Ward 1998).

But forecasting storms was not quite the same as forecasting maximum wave heights; the particular organization, timing, and location of a hurricane could influence wave heights in localized areas near the eye wall. How could a designer improve his estimate of the maximum wave height and wave force that might challenge the structural integrity of a platform over its life in a specific place in the ocean? With no trustworthy measured data on extreme wave heights, different companies placed their bets using the best guesses of dueling consultants, many with connections to prestigious universities or research institutes. Highly publicized reports by two such consultants, retired naval officers F.R.Harris and H.G. Knox, stated authoritatively that "in 100 feet of water waves will probably seldom, if ever, exceed 20 feet in height." Decks thus should be placed "20 feet above the still water line" (Harris and Knox 1947).

The king of the wave consultants in this era was W.H. Munk, a former weather officer who had forecast weather conditions for the Normandy invasion. After analyzing existing data with theoretical models of wave formation and behavior, Munk settled on a maximum wave height of about 25 feet and a recommended deck height of 32 feet above the water. With a wide range of "expert" opinions from which to choose, companies designed their platforms based on their willingness to take risks and their sense of the odds against a 25-year storm hitting their particular location during the life of their particular field. The safe consensus in these early years hovered around a maximum wave height of about 29 feet in the shallow waters of the Gulf, with a frequency of perhaps once every 40 to 50 years.

A series of relatively weak, small hurricanes in 1947–1952 quickly called this consensus into question. A small but intense hurricane offshore Freeport, Texas, in October 1949 severely damaged a platform; the post-mortem suggested waves as high as 40 feet had buffeted the platform. The observed wave damage to several platforms in these years led to estimates of waves in the 22–29 foot range in each case. Once every 50 years, indeed. Observations also showed more clearly than had been previously understood that the key problem was to keep these mammoth waves from cresting on the deck. During the Freeport storm, a platform with a deck 26 feet above the ocean suffered damages that cost its owner more than $200,000 in losses while a nearby platform with a 33-foot deck showed no damage (Farley 1950; Willey 1953). The owner of the damaged platform came away convinced that a relatively small investment to build a slightly higher deck would have been justified to avoid the very high costs of cleaning up a damaged platform and the loss of production and revenues from shut-down time when oil could not be produced.

The California Company (Calco, a subsidiary of Standard Oil of California) had a particularly dangerous encounter with the first hurricane of this era, and its leaders responded by greatly improving safety standards. In early September 1948, a hurricane rose quickly offshore Louisiana, without sufficient warning for the evacuation of all offshore workers. The hurricane hit Calco's operations off Grand Isle, Louisiana, placing more than 50 men in harm's way. Twenty-five of them huddled aboard a converted LST tender placed under tow to try to reach safe harbor. Unable to make much headway, the captain of the tug towing the LST decided to cut his lines, leave the LST adrift, and take his tug to safety. Meanwhile a derrick barge with 30 men aboard also bounced about in the rough seas after a rescue boat sent for it ran aground. Hours later tugs finally managed to control both vessels and bring them to safety, with the men aboard "wet, but unhurt." Those involved in this incident came away determined to make changes to avoid risks to workers and to minimize the damages that the hurricane had done to Calco's platforms (Besse 2000).

With such concerns in mind, Calco went back to the drawing board, applying significantly higher estimates of maximum wave heights and forces in its designs. In the words of Paul Besse, one of the engineers at Calco who took the lead in redesigning its offshore facilities, "That certainly elevated every platform that Chevron put in from that day forward." The company also elevated the decks of two platforms already installed in the Gulf, staking claim to leadership in the offshore industry in moving decks up higher to avoid wave damage in severe storms. Seeking better information with which to design platforms, Besse found little, since "there had never been a time when anyone was crazy enough to try to build a platform in the open ocean and place men and equipment on it….We had to go on theory, and the hurricane…caused Chevron to start thinking about placing wave measuring equipment on a platform offshore" (Besse 2000)

Others agreed that it was time to obtain better measurements of wave heights. After Chevron installed three separate pilings in the Gulf with devices to measure wave heights in 1954, Humble Oil helped analyze the data obtained. The companies then calculated new design criteria for severe hurricanes in Texas and Louisiana. A. H. Glenn used these calculations along with wind and wave measurements from onshore and from ships to generate for the industry a new estimate of projected hundred-year storm conditions in the Gulf and other locations around the world. Calco and Humble, later joined by Shell, became the offshore industry's leading advocates for using such data to adopt higher, safer standards for platform construction and deck placement. Humble's leading offshore engineer, Arthur Guy, expressed the philosophy behind this new attitude with a simple sentence: "Error is cheap." These large companies took the view that the costs of potential for damage far outweighed the relatively small costs of building safer platforms. Better safe than sorry—and less expensive in the long run (Dunn 1996).

The election of Dwight Eisenhower and the end of the stalemate in offshore leasing in 1953 unleashed a burst of activity in the Gulf. At that time, there were already approximately 70 separate platforms in waters up to 70 feet in the Gulf (Toler 1953). Both numbers increased dramatically from 1953 until the economic downturn in the Gulf in the late 1950s. In this building boom, the offshore industry created a fully developed "Gulf of Mexico system" for exploring and producing oil.

At the heart of this approach was the development of mobile drilling rigs that could explore for oil in different locations, leaving production of oil for permanent platforms. The mobile drilling industry evolved quickly and in several competing directions at once, as entrepreneurs created companies to develop and exploit various technologies for drilling at sea. Submersible rigs, jack-up rigs, drilling ships, and semi-submersible drilling rigs evolved side-by-side in the 1950s and 1960s. Each type rig had characteristics that made it attractive for certain water depths and locations, and all were used to find oil in the Gulf and in other regions from the 1950s forward. These drilling rigs had one common characteristic that made them vulnerable to severe storms: they were designed to drill oil wells, not to move gracefully through the ocean. Most proved awkward to control and use in the open sea, and numerous accidents resulted.[7]

Such accidents highlighted a key problem facing offshore operators in these early years: uncertainty over insurance. Hedging risks with insurance made good business sense, but underwriters shied away given the "perils beyond their (the offshore operators') reasonable control and not heretofore encountered in their land operations." Yet after deciding that risky offshore work might not yet be insurable, insurance companies examined more closely their existing policies and found that they were already liable for hundred of millions of dollars under policies covering such things as damage to vessels, explosions, and injuries to workers. The lull in activity during the tidelands controversy afforded these companies the opportunity to begin to sort out the key questions facing them? Were

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[7] There is a well-developed historical literature on mobile drilling vessels. See Veldman and Lagers (1997) pp. 49-58.

mobile drilling rigs vessels or drilling rigs? Should their workers be considered seamen or drillers? Was a blow-out of an oil well in the ocean the same as an explosion at sea? Providing legally binding answers to such questions was the first step in providing adequate coverage for offshore operations (Pike 1949).

In comparison to the mobile drilling rigs, underwriters had less trouble in insuring the permanent platforms most companies built to provide a safe, sturdy foundation for long-term development. By the mid-1950s, these platforms were much-improved versions of those first built by Magnolia, Superior, and Humble in the late 1940s. The Gulf of Mexico system of this era came to be dominated by "piled jackets," large metal structures constructed in specialized fabrication yards onshore, transported by purpose-built barges, installed using specialized equipment, and then pinned to the ocean floor by piles driven down through the jacket into the ocean floor. Once the piles had been driven, prefabricated decks could be welded onto the jacket. Fabrication onshore produced a stronger, more uniformly built frame; the time spent on construction in the rough, unpredictable conditions out in the open sea could be minimized. The completed structure was self-contained, including quarters for work crews (Willey 1953).

Transportation and communication improvements allowed these platforms to be supplied more easily, while also assuring that the crews could be evacuated in the event of a storm. Fleets of purpose-built supply boats owned and operated by emerging firms such as ODECO quickly replaced the shrimp boats and war-surplus boats that had provided much offshore transportation in the earliest years in the Gulf. These boats were faster, stronger, and more comfortable, and they were equipped with modern communications. But they still required long hours in the water to ferry men and supplies back and forth from platform to shore (LaBorde 1998).

For safety and convenience, it was only a matter of time before local entrepreneurs developed helicopter service out to the rigs. By the early 1950s, Humble had contracted with a local company to lease helicopter service to platforms far out in the Gulf. The first entrant into this new business was PHI (Petroleum Helicopters Incorporated), which grew quickly in the 1950s and operated a fleet of 33 helicopters as of 1958. Once oil companies made the investment in helicopter landing pads out on the platforms and drilling rigs, the industry had a greatly improved capacity to respond to an emergency. When a hurricane threatened, the skies filled with helicopters ferrying men to safety onshore (Persinos 1999; Anonymous 1957a, 1960). Such transportation improvements became the offshore industry's first line of defense against hurricanes. If loss of life could be avoided, then the industry could learn to live with property damage as it gained a greater understanding of how to protect its facilities from major storms.

Effective evacuations, however, required more accurate and more up-to-date weather forecasting. To monitor the path of hurricanes, many companies subscribed to a well-developed forecasting service that kept in touch with their offshore facilities via advanced communications equipment. The U.S. Weather Service simply could not deliver the quality of forecast information available through New Orleans-based Glenn and Associates, which provided frequent detailed reports on wind, weather, and waves in areas of the Gulf containing offshore operations. This private weather service supplemented government data with its own long-range radar system and with the four daily observations submitted from the rigs of subscriber companies. The companies could have personal consultations with meteorologists if in doubt about storms. In this era before satellite observations, the offshore industry had far superior information about storms than was available to others; its special needs gradually led to the improvement of forecasting in general (Anonymous 1949b).

An overview of the response of this system of operations when faced with a hurricane comes from an article in the Humble Way, the employee magazine of Humble Oil. In this case, the weather forecasting service warned the company of a gathering storm that might ultimately pass over one of its major facilities. Careful monitoring of the storm convinced management to prepare for the worst. Workers then cleared the decks of the small platform in use at the site, storing some materials in the tender vessel, which was then battened down and moved away from the platform using winches on the mooring system. After anchoring the tender, workers evacuated in ships. Once the storm had passed with little damage, the workers returned and the platform was back in production the next day (Anonymous 1956a).

Humble was, of course, a major company with well-built platforms and well-developed safety procedures. The storm that threatened its facility was relatively small and did not score a direct hit. In 1956 and 1957, Humble and the rest of the companies in the Gulf had a more demanding test, as two fairly large hurricanes passed through areas with numerous offshore platforms.

The first was Hurricane Flossie, which moved through clusters of facilities offshore near the western edge of Louisiana in September of 1956. Labeled the “first real hurricane test” for offshore operators since drilling activity began in 1947, Flossie unleashed 110-mile-per-hour winds and 15 to 20-foot waves that caused the shutdown of several hundred offshore producing wells and many drilling rigs for two to three days. Although costs from downtime exceeded actual damages, this minimal hurricane did teach operators several valuable lessons.

The first lesson reflected the attitudes produced by a decade of relatively mild weather. Again, as in 1948, nearly 50 men “rode out” the storm on tenders and other vessels. After a Calco tender vessel had been torn from its anchor, 25 crewmen fighting to survive in the high seas floated serenely in the eye of the storm for a while before 100 mile per hour winds returned from the opposite direction and their struggle began anew. The companies and the men involved took a calculated risk that they would be safe. After noting that Flossie was only half as forceful as hurricanes that could hit the area, one trade journal, World Oil, echoed the arguments of operators who “say more attention should be given to complete evacuation, doing away entirely with the calculated risk.” The industry took justifiable pride in its lack of fatalities in hurricanes, a record not exactly guaranteed by asking workers to ride out storms in clumsy converted LSTs (Anonymous 1956b; Lambert 1956).

Numerous tenders broke their mooring chains or moved off their anchors during Flossie. One of Humble’s tenders suffered breaks in six of eight mooring chains and swung around into the adjoining platform, causing some $200,000 in damage. Other companies reported problems with damaged risers, the conduits for the pipe from the platform to the ocean bottom. Yet despite such problems, all in all, the reports on Flossie stressed the effectiveness of existing designs and safety procedures, with the oft-repeated caveat that this was not a major storm. One respected trade magazine writer gave an optimistic interpretation of the lesson of Flossie: “The greatest fears of the offshore oil operators have been dispelled by the arrival of Hurricane Flossie." This "full-blown hurricane" had shown conclusively that the industry's "engineering estimates were correct" (Bailey 1958; Calvert [Gulf] 1957).

Nine months later, Hurricane Audrey, the first major hurricane to skirt Louisiana's "offshore alley," inflicted expensive damage, reminding the industry that it still had not experienced the effects of the direct hit of a major storm. In June of 1957, this storm arose quickly in the Bay of Campeche, took a straight path up toward the Texas-Louisiana state line, and slammed ashore at Cameron killing 400 to 500 people. It is remembered in the region as the deadliest hurricane since the Galveston storm of 1900, and it remains the sixth deadliest hurricane in U.S. history. Yet damage offshore was relatively minor. One mobile drilling rig sank in the storm and four tenders suffered damage when they pulled loose from their moorings and ran aground. Estimated damage to all offshore facilities reached about $16 million (Anonymous 1957c, 1957e).

What registered most clearly in the harsh aftermath of the storm was that the offshore industry had fared dramatically better than the communities along the coast. After helping clean up the carnage in Cameron, the industry reflected that "forethought minimized hurricane damage to offshore installations." On the key issue, the industry's record remained spotless: not a single life was lost offshore during Audrey. Two offshore workers reportedly died, but only after they had been evacuated from a platform to an interior location and then chose to return to Cameron to try to protect their homes. In its overview of the "scars" left by Audrey, one of the major offshore trade journals concluded that the "the industry has scored an overwhelming though costly victory" (Anonymous 1957c).

The industry could not be quite so optimistic concerning the performance of mobile drilling rigs. In quick succession in 1956 and 1957, five mobile rigs capsized—four in the GOM and one off Qatar in the Middle East. Some were in rough waters; one was at dock being readied for sea. These five disasters caused more than $7 million in damages, with 13 fatalities in the four accidents in the GOM. The first imperative of mobile drilling rig design was the effective drilling of oil wells once on locations, but all had to be seaworthy enough to be towed in calm conditions. Although these "ungainly monsters of the sea" had been designed "to float within a reasonable degree of safety," they continued to experience difficulties from rough seas and high winds (Calvert 1957b).

In September of 1957 still another hurricane, Bertha, moved up the Gulf and inland near Cameron, sinking one drilling tender and driving another aground. The industry had been put on notice by nature, not once, but three times in a single year. It responded by raising new questions about the origins and properties of hurricanes. The focal point of investigations was a newly formed API committee, the Advisory Committee on Fundamental Research on Weather Forecasting. Staffed by industry experts who had the resources to fund research by academics and consultants, this new committee tackled fundamental issues that had long eluded explanation. What caused hurricanes to form and could their paths and intensity be forecast with greater certainty?

To address such issues, the API committee engaged the services of Herbert Riehl, a professor of meteorology at the University of Chicago, to prepare a "think piece" on what was known about hurricanes and what sorts of research were needed to advance knowledge. In the years from 1956 through 1962, the committee explored these issues with the best available theoretical ideas about hurricane formation and motion and the creative use of data supplied by A. H. Glenn on past hurricanes and potential hurricanes that did not develop. The committee, like the oil industry as a whole in these years, made use of rudimentary computers. Computer analysis helped the committee improve the art and science of hindcasting, giving the designers of offshore equipment useful information on which to base design criteria. In 1962 the API decided to sponsor no more research on hurricanes and the committee went out of existence. Its last publication reminded the reader of the great economic value of research that could predict the path of hurricanes, but apparently those who funded the work of the API could not see concrete results coming from the work of this advisory committee.

The offshore industry had its hands full with many other things. The push out to produce oil in the deeper waters of the Gulf reached the 100 foot mark in 1957 and then quickly moved on out to 225 feet in 1965 and more than 300 feet in 1969. More than a thousand platforms had been built in the Gulf by the mid-1960s. The technology of exploration and production, as well as that of deep water pipelines, moved forward by leaps and bounds, enabling the industry to increase offshore production in the GOM to more than 2 million barrels a day by the late 1960s. At the same time, the Gulf of Mexico system was being improved to operate effectively in deeper water in the Gulf, it was also being adapted for work offshore in the Middle East, in earthquake-prone California, and the in the powerful ice floes of the Cook Inlet in Alaska (Pratt *et al.* 1997). As the offshore industry tackled this array of challenging technical problems, there was a sense that the hurricane problem had been contained, if not solved, by research, measurements, and experience (Riehl 1957; Parks and Riehl 1963).

In these heady years, the stakes grew higher for those working offshore, since the costs of development tended sharply upward as water depths increased. Yet despite this growing economic incentive to build sturdier platforms, many companies refused to depart from traditional practices. Despite a growing consensus on the basic oceanographic issues—wave, wind, and soil mechanics—the "design criteria used by various major oil companies differed by more than 200% for the same wave height considerations" (Lee 1963). On the key issue of deck height, common practices ranged from the use of the 1950s standard of 28–32 feet above mean Gulf level all the way up past the 50-foot range by safety-conscious companies such as Calco. Higher meant safer and more expensive, and each company placed a bet on the right combination of safety and cost for the particular location and water depth of each particular project.

In 1964 through 1969, a series of devastating hurricanes called these bets. Hilda (October 1964) and Betsy (1965) both measured as "100-year" storms; then four years later in August 1969, Hurricane Camille, labeled a "400-year storm," roared through the western Gulf. These three major storms in rapid succession showed conclusively that hindcasters had underestimated the potential frequency and power of severe hurricanes.

Hilda was not the largest hurricane to hit the GOM in the post-war years, but it did more damage to the offshore industry than any previous storm. In late September of 1964 Hilda spun into the Gulf and grew into a dangerous storm, with winds estimated as high as 150 miles per hour. As it moved over cooler waters toward landfall in central Louisiana, the storm lost force while slowly moving through offshore facilities valued at more than $350 million. In the words of one executive from a company that suffered severe damage, “Instead of spreading out over a big area…, she seemed to gather her energy into one tight mass and moved in and really tore things up” (Hurricane Hilda 1964). When the sun came out after the storm, clean-up crews returning to the evacuated platforms found stunning devastation. Losses reached more than $100 million, with 13 platforms destroyed and 5 more damaged beyond repair. Hilda had delivered a jolt of reality to an industry grown complacent about the power of major hurricanes (Anonymous 1965a).

One response was a meeting of concerned offshore operators at the Roosevelt Hotel in New Orleans in November of 1965. Sixty-four people attended, including representatives of most of the major oil companies active in the Gulf, the major contractors, gas transmission companies with pipelines in the Gulf, oceanographic consultants, and several university researchers. No organization called the conference; it came about because Hilda scared individuals into action. Those who had previously been satisfied to go it alone in designing offshore platforms now looked about for help in understanding what had happened and what needed to be done to avoid future catastrophes. Griff Lee, who had been active in offshore design and construction with a major oil company (Humble) and a major contractor (McDermott) since World War II, described the meeting as “a turning point for the industry. Before then, it had almost been every man for himself. This put together a cooperative spirit” (Hurricane Hilda 1964; Hurricane Andrew 1992). In some ways, the meeting resembled an old-fashioned Southern Baptist revival meeting, with admissions of sin followed by a call to accept a higher calling-and higher decks.

The meeting began with a somewhat apologetic speech by A. H. Glenn, the leading weather forecaster and hindcaster employed by the offshore industry. After reviewing the history of Hilda’s development, Glenn addressed a question on everyone’s mind: what was the practical meaning of the phase “25-year storm”? Hilda, labeled a 100-year storm, differed from previous post-war hurricanes more because of its path and its slow lateral speed than because of the force of its winds or waves. As Glenn lectured the audience about the problems of defining a 25-year or a 100-year wave and the distinctions between a 100-year storm and a 100-year wave, many in the room must have wondered why they had paid so much for so long for forecasts and hindcasts and why they had ever been so confident that hurricane conditions could be accurately predicted (Hurricane Hilda 1964).

When Glenn sat down, the group confessional began. Representatives of individual companies summarized the amount of damage they had suffered and then described in great engineering detail how the damage had affected the various parts of their platforms. These reports had a somber tone, as those who had ordered platforms and those who had built them traded notes about how Hilda had mangled their handiwork.

Near the end of the meeting Griff Lee took the floor to review “the complete failure” of a major platform that his company, McDermott, had recently built for Union Oil. Lee included a pointed reminder that McDermott had used A. H. Glenn’s predictions of the forces generated by a 25-year storm in designing the platform. An examination of the wreckage made it clear that Glenn’s estimates had been much too low. Working from severely flawed design data, the company had produced a severely flawed design with a lower deck that, at least in retrospect, had no realistic chance of surviving the fury of Hilda's waves.

The analysis of the problems with the design of this destroyed platform had a hard practical edge, since its twin had been loaded on a barge awaiting installation at a nearby site when Hilda hit. Lee gave the audience a classic account of engineering on the run, relating how McDermott had carefully studied the destroyed platform to make "some reasonable modifications of the (twin) structure," which it then installed. This was the ultimate wave tank test, using a real hurricane in the real GOM to test design assumptions. With strengthening near the ocean floor, stronger deck legs, and a higher deck, the one-time twin took its place as an only child out in the Gulf, near where the destroyed platform had once stood (Hurricane Hilda 1964).

After summarizing the overall destruction of Hilda, Lee concluded with a call for those gathered to admit their sins and change their ways. He noted that all but one of the platforms destroyed by Hilda had been designed to meet the projected forces of a 25-year storm. This meant, in effect, that they had been "designed with the owner accepting a risk." The prevailing attitude was "that the 25-year storm was only going to occur once in the whole GOM every 25 years, and if I'm lucky it will be over by your platform, not by mine" (Hurricane Andrew 1992). In a speech subsequently repeated many times at industry gatherings, he admonished the group to cut through the uncertainty about wind and wave forces by moving toward design criteria based on the forces generated by a 100-year storm. This meant strengthening platforms, with emphasis on raising the decks, since Hilda had provided striking evidence of the dangers to platforms when crashing waves "get into the decks." Two practical incentives pushed those present to heed Lee's call for action. The first was economic; the costs of clean-ups and repairs were quite high compared to the incremental costs of building stronger platforms. The second was a matter of engineering pride; good engineers did not like waste and inefficiency, and the images of platforms crumpled over into the Gulf were not ones they cared to see again (Hurricane Hilda 1964).

Unfortunately, they saw many more less than a year later in September of 1965, when Hurricane Betsy emerged in the Atlantic, crossed Florida, and moved through the eastern coast of Louisiana in an area with more than $2 billion in offshore investments. The storm destroyed eight more platforms and damaged others. In the massive damage caused by Betsy, one event came to symbolize the dangers of hurricanes. "Maverick," a state-of-the art jack-up drilling rig owned by George H.W. Bush's Zapata Corporation and at work on a project for Calco when Betsy struck, simply disappeared. So did a platform previously installed by Shell in the waters off the mouth of the Mississippi River. The future president received a check for $5.7 million from a New Orleans underwriter who had placed the insurance for the rig with Lloyd's of London. The offshore industry as a whole received another unmistakable warning that it had not correctly understood the risks posed by major hurricanes (Anonymous 1965b).

Insurance could ease the financial pain only if insurers continued to accept the extreme risks of providing coverage for mobile drilling rigs. "Maverick's" destruction was only the latest in a line of accidents involving such rigs, and underwriters had begun to revisit the question of whether this segment of the offshore industry might be uninsurable. A representative of John L. Wortham & Son, a major Houston-based insurance company, acknowledged that the "tremendous risks" required "extra efforts" from insurers. Others in the underwriting business continued to debate the basic issue of whether a mobile drilling rig should be insured as a vessel or as a drilling rig, its workers as "landlubbers or seamen." The compromise gradually struck was to take greater care for making the rigs safer as they were towed to the drilling site by having inspections of them by experienced naval architects while they were under construction and then having qualified naval engineers aboard while they were under tow. This compromise satisfied Lloyd's and others, and an insurance crisis was avoided (Kuhlman 1956; Griffin 1959).

Insurance covered some of the losses from accidents, but better design and construction that prevented accidents was obviously cheaper and more efficient. The devastation of Hilda and Betsy finally convinced the offshore industry to reevaluate its traditional approach to the threats posed by hurricanes. Greater cooperation was needed to define better design standards. The conference after Hurricane Hilda was followed by another conference after Hurricane Betsy, which had dramatically reinforced the calls of Griff Lee and others for change. At Houston's Rice Hotel in November of 1966, representatives of the offshore industry met to create what became the API's Offshore Committee. Under the auspices of the industry's major trade association, this committee gradually became a permanent focal point of efforts to define uniform standards that would limit future damage from hurricanes (Lee 1996).

Basic research and measurement of wind, waves, and soil continued, at times in cooperative efforts and at times within individual companies. Shell Oil led the way in the gathering data on wave heights with a project that placed sophisticated measuring devices on a string of large platforms in the Gulf. These devices could provide real measures to confirm the theoretical models of maximum wave heights during severe storms.

Or, as it happened, they could show finally and conclusively that the maximum waves from hurricanes had been consistently and grossly underestimated. During Hurricane Camille in August of 1969 Shell measured waves 70 to 75 feet high. These figures stunned offshore veterans who remembered early predictions by "experts" that waves in the Gulf would "seldom if ever, exceed 20 feet." Of course, twenty years of experience and the movement into deeper water had replaced such early guesses with higher and higher figures. But 70 feet made a mockery of the common wisdom about wave heights. Before Camille ripped apart the region around Biloxi, Mississippi, this monstrous Category 5 hurricane passed through a heavily developed offshore region south of New Orleans. Initial estimates of $100 million in property damages raised questions about what the toll might have been had the storm taken a track 100 miles to the west through the heart of offshore alley. But the "quality," as well as the quantity, of damage drew as much attention as the astonishing reality of a 70-foot wave in the Gulf. Included in the platforms destroyed were three modern ones installed by Shell, the generally acknowledged leader in offshore design. One of these was only five months old and was at the time the world's record deepwater platform (Anonymous n.d. Offshore).

Suddenly, more than thirty years after the first successful offshore venture in the GOM, Camille had washed up a new design problem. The giant new platform lost by Shell had been designed to withstand 100-year waves, but a mudslide caused by the storm, not wave forces alone, had toppled the structure, which had come to rest on its side some 100 feet away from its original site. Before

1969, shifting ocean sediments caused by earthquakes had been known to break telephone cables on the ocean floor, and as early as 1950, oceanographic consultants had studied the possibility that unburied offshore pipelines might move during hurricanes. But before Camille, platform designers had not appreciated that, under certain conditions, mudslides might pose catastrophic threats to platforms. The soil analysis routinely conducted for platform construction simply had not examined this possibility (Reid 1951; Bea 1971; Focht 2001).

Shell's failed platform was in 300 feet of water in "South Block 70," located offshore from the mouth of the Mississippi River. In retrospect, it was not surprising that the ocean bottom in a region covered by sediments deposited by a large river would be soft and relatively unsettled. Under extreme hurricane conditions—Camille had 200 mile per hour winds to go with its 70-foot waves—such sands could behave almost like a liquid. Shell's studies of the failed platform's site revealed a phenomenon not previously observed by the offshore industry. Camille had dramatically altered the contours of the GOM in South Block 70, lowering the ocean floor and, in effect, placing standing platforms into deeper water. While this was perhaps the most cost efficient way imaginable to establish a new world's record for platform water depth, it was not easily absorbed into the design criteria for new platforms (Bea 1971).

The process for finding ways to design platforms to withstand mudslides now began, taking a somewhat accelerated form of the process previously used to try to design for maximum wave forces without a full understanding of the maximum height of waves. First came the careful post-mortem of the platform that had been swept away in Camille and another one nearby that had been displaced. The information from these studies was placed in the context of the scant existing scientific literature on the frequency and intensity of mudslides. From this starting point, research was undertaken to fill in the wide gaps in information about mudslides. As this research moved forward, preliminary engineering analysis of the forces exerted by mudslides could begin. Design criteria gradually emerged from this analysis, as did the realization that in extreme hurricanes some areas of the Gulf simply might not support platforms built with existing technology.

By 1970 the process of adaptation to hurricanes had reached a turning point. The offshore industry had pushed ahead for a quarter of a century, solving engineering problems on the run when necessary by using the best available estimates of hurricane-generated forces and then adapting these standards after they were called into question by additional research or by damage caused by hurricanes. Three major hurricanes in the 1960s removed much of the uncertainty about the power of severe storms in the Gulf, and the offshore industry responded by taking a hard, collective look at its traditional assumptions.

They did so within two important new venues for cooperation among oil companies, construction companies, and consultants. After its establishment in 1966, the API's Offshore Committee quickly grew into an effective instrument for defining, publicizing, and modifying the best possible standards for offshore operations. The definition of industry standards had been an important part of the work of the API, which was ideally suited to bring together experts from various areas of the industry to share information about best practices. The Offshore Committee simply extended this tradition to matters concerning standards of safety and design offshore. The sharing of basic research on various aspects of offshore operations went forward after 1969 at the Offshore Technology

Conference (OTC), an annual meeting where industry specialists gathered to present papers about their research. Both researchers and standard-setters could take advantage of the growing power and availability of better computers.

Peter Marshall, a Shell engineer who entered the offshore industry in 1962, summarized the difference between the early days and the years after the coming of computer-assisted design: “Intuitive design and an entrepreneurial spirit gave way to computers and an era of no surprises.” Marshall summarized the key change in attitude with the simple declaration that “we were less afraid of failure then.” He lamented the passing of the days when offshore engineers had been given greater latitude to do their jobs more creatively while accepting more risk.

Marshall was even able to joke about his own strange experience with failure. He designed a platform installed in 1965 in 283 feet of water, earning the record for water depth. Two days after its installation, almost before he could brag about his efforts, the platform suffered severe damage during Hurricane Betsy. Examination of the platform revealed pieces of the “Bluewater 1.” When built by Shell in the early 1960s, this semi-submersible had been an epoch-defining technological break-through in offshore drilling. Hurricane Flossie had capsized the vessel in 1964. As a new owner readied it to return to work the next year, Hurricane Betsy displayed a stormy sense of irony by sending it careening into its former company’s record-holding platform (Marshall 2002).

Such events make good stories, at least after the passage of a few decades. But do they also illustrate the folly of “entrepreneurial engineering”? Looking back at the formative years in the GOM, several things stand out. Fortunately, the emphasis on good forecasting and early evacuation meant that few people died or were seriously injured offshore in hurricanes.[8] The scanty accounts that exist suggest pollution from storm-related damage was not extreme. With risks managed through insurance and improvements in designs, property damages were not high enough to stop the movement into deeper waters. All in all, taking “calculated risks” and then fixing mistakes exposed by hurricanes on the run allowed the offshore industry to push through its ignorance and develop much needed domestic oil and natural gas reserves.

Looking back on this process from the perspective of fifty years of work on offshore structures, Griff Lee offers a sobering appraisal that suggests how little the industry knew as it plunged into the GOM: “In light of today’s data, the early load estimates were off (too low) by a factor of ten.” A factor of ten would seem to be well past the threshold where the brave become the foolhardy. But in the America offshore oil industry of the post-World War II era, this distinction was blurred by a combination of unusually good weather, extraordinary technical innovations, and the systematic efforts of good engineers and work forces to recognize and fix problems exposed by one of the strongest, most unpredictable forces in nature, the hurricane.

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[8] Overall, the offshore industry had more serious safety problems in such areas as the development of deep water diving and blow-outs of offshore wells, especially in the early years, when mobile drilling rigs also presented problems in rough seas.

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Joseph Pratt is the Cullen Chair of History and Business at the University of Houston. He received his Ph.D. in history from Johns Hopkins University and also has taught at the Harvard Business School, University of California-Berkeley, and Texas A&M. A leading authority on the history of the petroleum industry who has appeared in oil history documentaries such as *The Prize*, Dr. Pratt is the author or coauthor of numerous books on energy companies, such as (Amoco and Brown & Root), as well as on Houston-based law firms and financial institutions.

REACHING THE PUBLIC WITH PUBLIC HISTORY

Robert Carriker, History and Geography Department, University of Louisiana at Lafayette

PUBLIC HISTORY

Public history (sometimes referred to as applied history) is an umbrella term that pertains to areas of historical inquiry and methodology that target a non-academic audience. Public history is commonly thought of as simply “history outside the classroom.” Traditionally, the work of historians takes the form of monographs, erudite professional papers or articles, and lectures to captive classes of college students. Essentially, the audience of the conventional historian is rather narrow and largely consists of students and interested colleagues. Public historians apply the training, research, analytical, and interpretive skills of the discipline of history to create products/deliverables more accessible, useful, and understandable to a broad public audience. This allows historians to widen their impact and permits their learned perspectives to enhance a number of fields that historians have traditionally acceded to other professions. For example, public historians work in:

- Historic Preservation—Here public historians labor to document and interpret historic buildings, structures, sites, places, and objects.
- Museums—Public historians in museums create educational exhibits with innovative interpretive aides. They also incorporate material culture into those exhibits and work to conserve and preserve historical artifacts.
- Businesses—In businesses such as at the Tabasco Company, public historians organize and interpret a company’s history, making it accessible and useful for internal reports, exhibits, marketing, and/or corporate morale.
- Heritage Tourism—A growing field, especially in Louisiana, public historians can direct and create tourist related services for the traveling public in search of educational, meaningful, and entertaining experiences.
- Archives—At many institutions, from universities to corporations, archivists organize and make historical documents and other materials accessible.
- Applied Research—In a myriad of capacities public historians draw upon their research and analytical skills to provide research and documentation on any number of projects. From historic land use patterns for environmental research to projects such as this one: studying the impact of the oil industry for the Minerals Management Service (MMS).

Sometimes, but not always, the work of public historians requires them to seek ways to present their historical findings to the public at large. This is often the case in museum work, heritage tourism, historic preservation, and some business applications of history. In such cases, stepping away from the traditional role of the historian often mandates that the pubic historian hone and utilize some unique skills or tools:

- Material Culture and Oral History—Conventional historians do not usually work with the materials of history or treat human subjects as sources.

- Brevity—Keeping their audience in mind, public historians must concern themselves with writing styles that are conducive to public tastes and expectations.

- The Media—Public historians must be willing and able to use local media outlets to promote their products and their research to tap the public for support and/or intellectual contributions.

- The Public—Simply put, conventional historians rarely condone working with and for the public.

USING A PUBLIC HISTORY APPROACH IN AN ORAL/OIL HISTORY PROJECT

By using a public history approach, this project serves to define and explain the impact of the oil industry in and around the hub city of Lafayette, Louisiana. Our first client is the MMS; the product they will receive is an analytical report. However, we are also committed to providing a useful product for the general public, including the people who participate in the study. Although there are numerous ways to reach the public with public history, we have chosen to combine two public history approaches to accomplish our goal.

- Oral History—Although this is a research methodology utilized by various disciplines (anthropology/sociology and folklore, for example), oral history is, buy its very nature, apropos to public history research. Not only does oral history allow us to gather historical information that does not exists in written sources, but it also presents wonderful opportunities to create products for the public. Toward that end, we have chosen to reach the public through public history by creating an educational web page built upon our collected oral histories. This immediately calls upon a public history approach to a research problem dealing with recent advances in audio technology that improve and compliment the capturing of oral history interviews. Without even considering reel-to-reel tape recorders, audiocassettes are fast becoming antiquated technology (many would say they already have become so). In their place, digital audio recorders have gained popularity allowing a greater versatility, better sound quality, and a more stable medium. Add to this the options with up-and-coming software for digital audio transcription, and digital audio becomes far superior to previous technologies. Similar to digital audio, and especially of interest to the public historian, is digital video. This has the benefits of coupling digital audio with video that provides innumerable ways to reach the public with the collected research. As a researcher, the downside to this is that the learning curve is significant and the time, skills, and equipment needed to work with digital products are more costly. In the end the benefits of reaching the public and providing a more useful product to the client far outweigh the costs. As public historians we chose this technology not for its simplicity but for its versatility because the field demands versatility in methodology so that enhanced products can result.

- Web Exhibit—http://www.louisiana.edu/Academic/LiberalArts/HiGe/OCS/exhibit.htm. In conjunction with our decision to utilize digital video was the understanding that this format would allow us the opportunity to create a truly functional product for the public and that is the educational web page we are crafting: *Life from the Oil Patch: The Acadiana Story* (Figure 3A.1). Our focus is on the impact of the oil industry on the region in and around Lafayette and we are taking all of the primary research being collected from this project and turning it into a practical and didactic site for the people of this region, this state, and beyond.

    - *Life from the Oil Patch: The Acadiana Story*—The educational web page is organized both chronologically and thematically. Using a simple toolbar on the right of the page, the viewer can first go to the *Acadian Oil Timeline* that serves as a cursory outline and summary, highlighting the history of the oil industry in this region. The next three sections of the site are arranged chronologically: *1900–1940*; *1940–1960*; and *1960–1990*. These sections include subsections that allow us the opportunity to discuss different themes that have come up in the interviews. The strength of these sections is the inclusion of demonstrative audio and video clips as well as photographs. Essentially, we are allowing the interview subjects to tell the story. Moving down the toolbar, under *Interviewees* one finds a comprehensive list with photos of the interview subjects and under *Interviewers* there is information about the UL Lafayette team.

Robert Carriker received his doctorate in history from Arizona State University and is currently Associate Professor of History and Director of Public History Studies at the University of Louisiana at Lafayette. In addition to studying the impact of the oil industry on South Louisiana, his research has included experimental New Deal communities in the West, rural communities in Louisiana, and environmental land use studies in Arizona and Montana. Dr. Carriker also assists with a National Endowment for the Humanities summer seminar on Lewis and Clark for secondary school teachers.

OFFSHORE HISTORY PROJECT: WHERE DO WE GO FROM HERE?

Allan G. Pulsipher, Louisiana State University

The Offshore History Project is an unusual initiative by a federal agency. It was not inspired by Congressional criticism, legislation, or any of the other external forces that too frequently drive the research agenda of federal agencies. The project is a consequence of Minerals Management Service (MMS) leadership's awareness of the value of a comprehensive, accessible, objective history of the industry it regulates both for its own staff and for the interested, concerned, public.

The earlier presentations demonstrate that the project is off to a strong start. It is producing information and ideas that will interest scholars, past and current participants in the offshore oil and gas industry, leaders in coastal communities, and managers, planners and analysts in the Minerals Management Service.

The papers presented mirror the objectives and plan of the project. A basic premise of the project is that the history of this unusual and frequently changing industry needs to be written comprehensively. Our goal is to record and reflect not only the activities of the entrepreneurs and engineers that took the industry offshore, but also that of the workers who participated in the effort and the communities it affected. Although other aspects of the story, such as the development of the managerial and regulatory role of state and the federal governments, including MMS, and the impact of the industry on the development of ports and related infrastructure were not emphasized at the meeting, they also will be explored, as will other aspects of the story, as the project proceeds.

A diversity of disciplines and analytical perspectives has been built into the project. Business historians, applied anthropologists, regional and industrial economists and geographers, public historians, and environmental sociologists are collaborating; they all bring their own tool kit of information and methods.

Sharing tools and blending perspectives is an aspect of the project that interests academics, and it is beginning to happen. The oral histories, life stories, and personal or family photographs that are being collected in the field interviews are a potentially rich new source for all of the collaborators, not just those doing the interviewing. A classification and retrieval system is being organized that will make all the interviews and related materials available to all those working on the project. It will constitute a unique legacy available to all after the project is finished.

Although the precise nature of the final report is still in the design/creation process, it will follow the thematic, conceptual, and methodological lines previewed in the papers delivered at this meeting. As suggested by the video presentation prepared by the University of Arizona, and the presentation by Professor Carriker, an important component of the project is education and outreach. More effort will be directed toward these ends in the next phase of the project.

The team, in consultation with our partners at MMS, will continue to refine the research plan, find ways to reach our target audiences, and complete our plans to leave an archival legacy which will facilitate work by others after the project is completed.

Allan G. Pulsipher is the Executive Director and Marathon Oil Company Professor of Energy Policy in the Center for Energy Studies and a Professor in the Department for Environmental Studies at Louisiana State University. He has been with the Center for Energy Studies since 1990. Prior to coming to LSU, he worked as the Chief Economist for the Congressional, Monitored Retrievable Storage Review Commission; the Chief Economist of the Tennessee Valley Authority; a Program Officer with the Ford Foundation's Division of Resources and the Environment; as a Senior Staff Economist with the President's Council of Economic Advisers; and on the faculties of Southern Illinois and Texas A&M Universities. Dr. Pulsipher has a B.A. from the University of Colorado and a Ph.D. from Tulane University, both in economics.

SESSION 3B

COASTAL STUDIES

Co-Chairs: Susan Childs, Minerals Management Service
Mary Boatman, Minerals Management Service

Date: January 16, 2003

OUTER CONTINENTAL SHELF PIPELINES CROSSING THE LOUISIANA COASTAL ZONE: A GEOGRAPHIC INFORMATION SYSTEM APPROACH

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INTRODUCTION

This is a study of the transmission pipelines in the Louisiana Coastal Zone (LCZ) that originate in the Outer Continental Shelf (OCS) area of the Gulf of Mexico (Figure 3B.1). The Louisiana Geological Survey has developed a substantial, though incomplete, digital mapping system of onshore Louisiana pipelines. In this study, these LGS data were adapted to the format maintained by the Mineral Management Service, and spatially corrected to result in compatible GIS data for the OCS-related pipelines in the LCZ. The related onshore pipeline termini that occur in the LCZ were characterized as part of the study. As a result of this collaborative project, the pipeline databases in both MMS and LGS organizations have been enhanced. Properly utilized, these GIS databases will prove to be valuable in governmental regulatory (permitting) activities as well as emergency planning and response coordination.

BACKGROUND

Geographic Information System (GIS) technology provides MMS with a powerful tool for analysis of transportation, environmental impact, and emergency response issues. However, such analysis awaits completion of an accurate, large-scale digital pipeline GIS as the basis for much important derivative research. Therefore, MMS is required to acquire information on the existing onshore oil and gas infrastructure, which services the OCS offshore industry. In addition, MMS must document the routes of OCS-related pipelines ashore to either (1) the northern Louisiana Coastal Zone (LCZ) boundary, (2) neighboring states, (3) tanker terminals, or (4) refineries, and to characterize those termini.

The Louisiana Geological Survey (LGS) has an ongoing program to gather accurate, large-scale maps and engineering diagrams directly from the pipeline operators to create a reliable, large-scale digital pipeline GIS. Prior to this project, a large number of these source maps remained uncontrolled, schematic, small-scale, and otherwise problematic. These maps were unsuitable for GIS database entry without extensive source research, geo-referencing, and/or field investigation tasks beyond the scope of the original project for which these data were acquired.

In this project, LGS compiled these problematical pipeline maps and prepared them for inclusion in the statewide pipeline GIS as well as for further consideration within this study. In addition, the LGS tracked the OCS-originating pipelines into the onshore pipeline network, investigated their termini within the Louisiana Coastal Zone (LCZ), and developed a GIS data layer of the results.

METHODOLOGY

This project has allowed the MMS to make use of the Louisiana pipeline GIS data currently being developed by the Louisiana Geological Survey. When the project began, these data were geospatial linear features with graphic text labels. LGS also had 118 source maps from pipeline operators that contained inadequate geospatial control information. Geospatial control was first established on the 118 uncontrolled, operator-supplied, source maps in the early period of the project. Geospatial control was also established on an additional 96 newly acquired pipeline maps, which were then were digitized and compiled. A total of 214 source maps submitted to LGS from 15 pipeline companies were investigated in this project.

- Task 1 of the project was to evaluate these inadequate source maps and to research the best techniques for establishing geospatial control.

- Task 2 was establishment of geospatial control on all 118 in-house source maps. Seven different techniques were employed as needed, depending on characteristics of the source map.

- Task 3 involved digitization of the 118 in-house source maps plus 96 new maps, compilation of a digital mosaic, and merger of the digital mosaic with the digital LGS pipeline data.

- Task 4 was to investigate the LGS pipelines and the MMS pipelines around the LCZ. All LGS pipelines crossing the LCZ and interconnecting with MMS pipelines were identified and edge-matched with the MMS pipelines. The database for the pipeline linear features was populated with information from the operator's source maps, using the MMS prescribed, database definition. The pipeline linear features were then segmented. ArcView GIS 3.1/3.2 was used for all of Task 4.

- Task 5 was an investigation of the pipeline termini in the LCZ. All pipelines transporting materials between the OCS and the LCZ were traced by studying the operator's source maps and the results from the GPS field surveying. During field investigations, Global Position System (GPS) positions of the pipeline termini were collected using a Magellan Mark Pro X DGPS receiver. The pipeline attribute data were collected through field investigations, trade directories, and telephone contacts. These OCS pipeline termini in the LCZ include tanker terminals, refineries, points where pipelines enter neighboring states, and points where pipelines cross the northern coastal-zone boundary. Attribute data of the pipeline termini includes termini identification codes, operator's names, locations, parishes, mailing addresses, contact phone numbers, and fax numbers depending on availability. The GPS data were downloaded into a PC workstation, converted into ArcView GIS shapefiles; then, the attribute data tables were populated. The LGS pipeline exit points on both LA/TX and LA/MS boundaries and the LCZ northern border were also identified, geocoded, and included in the pipeline termini ArcView shapefile. Data on tanker terminals and refineries are compiled and reported. Only those pipelines originating in the OCS areas and entering the LCZ that have been reported to either the LGS and or the MMS by pipeline operators were traced and reported in this study.

RESULTS

A seamless GIS coverage of OCS pipelines across the state/federal boundary is the resulting product. Geodetic control was established for 118 uncontrolled, operator-supplied source maps. A total of 214 source maps from 15 companies were digitized and compiled into the LGS digital pipeline system. These LGS pipeline data were merged with the MMS/OCS pipeline data to meet the MMS database definition and format specifications. All edgematching adjustments were made under MMS advisement.

The LGS pipeline attribute data, derived from 124 source maps submitted by pipeline operators, were entered into the database in ArcView GIS 3.1/3.2. All OCS-related pipelines were traced from their origins in the OCS to terminus. Locations of the pipeline termini were determined, collected and verified by GPS field surveying, and transformed into an ArcView GIS shapefile. See Figure 3B.2 for a graphic depiction of the GIS data. The findings of this project are listed below:

Pipelines:

- One hundred ninety-one of the OCS pipelines pass through the federal/Louisiana boundary. One hundred fifty of these pipelines pass through the federal/Louisiana boundary and apparently do not connect with LGS pipelines. It remains uncertain if they connect with any onshore pipelines due to incomplete pipeline data for Louisiana. Forty-one of the 191 have been digitally connected to onshore, LGS pipelines. This accounts for 21% of the total number of OCS pipelines reaching the federal/state boundary.

- One OCS/LGS pipeline crosses the Louisiana Coastal Zone and exits at the Texas/Louisiana boundary.

- One OCS/LGS pipeline crosses the Louisiana Coastal Zone and exits at the Mississippi/ Louisiana boundary.

- Twenty-one OCS/LGS pipelines cross the Louisiana Coastal Zone and exit at the Louisiana Coastal Zone northern boundary.

- Nineteen OCS/LGS pipelines enter the Louisiana Coastal Zone and terminate at facilities therein.

- Seven OCS/LGS onshore pipelines pass through the federal/Louisiana boundary and cannot be paired with any OCS pipelines.

Facility types:

- Refineries: 4
- Tanker Terminals: 15

DELIVERABLES

The project deliverables include a final report, a technical summary, GIS data, digital map series for, and a slide presentation, all on a CD-Rom. The final report, entitled "Outer Continental Shelf Pipelines Crossing the Louisiana Coastal Zone: A Geographic Information System Approach," along with the map series in hard copy form accompanies the CD-ROM.

CONCLUSIONS

In this study, the Louisiana Geological Survey (LGS) and the Minerals Management Service (MMS) of the U.S. Department of the Interior have pooled resources to produce compatible public domain pipeline data for a number of the pipelines in the Louisiana Coastal Zone. These data should prove mutually beneficial to both state and federal governments. LGS has established an effective methodology for developing OCS-related pipeline GIS data for the Louisiana Coastal Zone (LCZ), by combining GIS data from these two public organizations and contributing an additional research effort. Due to an incomplete collection of operator source maps, the OCS pipeline GIS data produced, as a deliverable for this project, is not a complete inventory of the OCS-related pipelines that pass through the LCZ. With the current methodology established, future additions to these data should prove to be more efficient.

All of the pipelines represented with the LGS Pipeline GIS that are within the LCZ and cross the Louisiana's state/federal boundary, have been combined with all 191 of the pipelines represented in the MMS Pipeline GIS that cross the Louisiana's state-federal boundary into the LCZ. These combined pipeline data have been edgematched to produce the resulting 198 OCS-related pipelines in the LCZ. Wherever possible, these pipelines have been traced to their termini within the LCZ. The pipeline and pipeline termini data, described above, constitute the deliverable GIS data for this study. FGDC compliant metadata files can be found on the accompanying CD-ROM, along with the deliverable GIS data.

There are 150 pipelines in the MMS data crossing the boundary into the LCZ that could not be matched with pipelines in the LGS data. There are seven pipelines in the LGS data, crossing the state/federal boundary into federal waters that could not be matched with pipelines in the MMS data.

Assuming that that the MMS GIS of pipelines in the federal waters near Louisiana are complete, the deliverable MMS/OCS pipeline GIS for the LCZ is approximately 21.5% complete. However, the fact that there are seven LGS pipelines with no matches in the MMS data indicates that there might be other pipelines missing from the MMS data. If this is the case, this estimate of completeness should be lower. When these seven LGS pipelines are included the estimate of completion is 20.7%. Considering that the LGS pipeline GIS data are not yet complete for the LCZ, the percentage of completion could be further reduced slightly.

Pipeline operators will continue to submit pipeline data to the LGS, in its capacity as the Louisiana Repository of the National Pipeline Mapping System. The remaining pipeline data, yet to be submitted, could provide the missing data needed to complete this MMS/OCS pipeline GIS for the LCZ, over the next couple of years.

RECOMMENDATIONS

Throughout the extensive studies of modern environmental impacts in Louisiana’s Coastal Zone, pipelines have often been implicated as a significant contributor. Unfortunately, no comprehensive, accurate record of pipeline routes exists for the LCZ. Documenting the complex network of pipeline systems is an essential step towards researching and understanding the roles that pipelines have played in the deterioration of Louisiana’s Coastal Zone.

The accompanying pipeline GIS database for the LCZ is a substantial initial step toward developing a comprehensive oil and gas pipeline GIS for the Louisiana Coastal Zone. This collaboration of effort will prove to be a substantial benefit, not only to the collaborating organizations, but also to the entire pipeline community. However, further work is needed to complete the compilation of a comprehensive pipeline GIS for the LCZ. Unfortunately, approximately 50% of the pipeline operator’s source maps have not yet been provided to state or federal governments. The LGS is currently collaborating with the U. S. Department of Transportation, Office of Pipeline Safety, in the development of the National Pipeline Mapping System, through the year 2003. This project is providing major additions to the LGS pipeline GIS for Louisiana.

Future completion and maintenance of the pipeline GIS for the LCZ will require a collaborative effort of federal, state and local governmental agencies, public universities, and the pipeline industry. Only in an atmosphere of cooperation among these groups, could the completion of an accurate pipeline GIS for the Louisiana Coastal Zone be coordinated within the next few years and maintained through future years.

The authors recommend the following.

1) Louisiana pipeline regulators at DNR should facilitate the acquisition of pipeline operator source maps from those operators, in Louisiana, who have not yet submitted information to state or federal agencies. This would be a major contribution.

2) The MMS should fund a follow-up study, to research and document the remaining OCS-related pipelines and terminus facilities that have been revealed as undocumented by this study.

3) A viable program for continued maintenance of these pipeline GIS data should be designed and implemented within the existing framework of the governments of the state of Louisiana and the United States of America, with cooperation from companies that operate or construct pipelines in the Louisiana Coastal Zone.

R. Hampton Peele, a mapping scientist, is the GIS Coordinator for the Louisiana Geological Survey, Cartographic Section at Louisiana State University. His current and resent research includes the design and supervision of the GIS development process for hurricane impact studies of New Orleans for the LSU Hurricane Center; the surface geology of the Louisiana Continental Shelf for MMS; the

Louisiana Public Land Survey System for DNR; the surface geology of Louisiana for LGS; the Pipeline Infrastructure of Louisiana for the National Pipeline Mapping System–DOT/OPS; coastal permit and mineral lease records for DNR; thematic data layers of the 2000 revision of the Official Map of Louisiana for DOTD; digital compilation of high-resolution Louisiana parish boundaries for LOSCO; development of the GIS digital data library for LGS; and GIS network system administration for LGS. He received a Masters of Natural Sciences from Louisiana State University in 1997.

John Snead, a cartographer, is a graduate of LSU, where he now manages an advanced cartographic unit at the Louisiana Geological Survey. The LGS Cartographic Section is involved in contract mapping, technical support of research programs, and digital and traditional publishing. Dr. Snead has twenty-four years of diversified practical experience in field investigations, map production, geographic information systems, computer graphics, and electronic publishing. His published work includes over 360 large, multicolored maps and atlas plates. Snead has received international map design awards, the Society for Technical Communication Award of Merit, as well as the Distinguished Service Award for the Advancement of Spatial Analysis in Louisiana.

Weiwen Feng is a Geographic Information Systems Specialist with Louisiana Geological Survey at Louisiana State University. He worked in the fields of environmental geology, marine engineering geology, coastal geology for over eight years before he studied geography at Louisiana State University in 1996. He earned a master's degree of science in GIS & mapping science from LSU in 1998, just prior to becoming a full-time GIS specialist for LGS. Recently, he has been working on many research projects such as pipeline mapping crossings of the State of Louisiana highways, waterways, and the Louisiana Coastal Zones. He is also working on his Ph.D. thesis project on spatial analysis and projecting of the AIDS epidemic in the United States, a social behavioral modeling approach.

OUTER CONTINENTAL SHELF PIPELINES CANALS: A GEOGRAPHIC INFORMATION SYSTEM ASSESSMENT OF CHANGES TO COASTAL HABITATS

Jimmy Johnston, John Barras, and Steve Hartley,
U.S. Geological Survey, National Wetlands Research Center

Results from the Minerals Management Service USGS National Wetland Research Center's current study of coastal wetland impacts from pipeline construction and associated widening of canals and utilizing USGS habitat data are summarized below for Louisiana and Texas.

LOUISIANA

The total length of Outer Continental Shelf (OCS) pipelines (included in the Louisiana study area) from offshore or the three-mile state/federal boundary to the inland coastal zone boundary for Louisiana was approximately 15,400 km (9570 mi). Of that total, approximately 8000 km (4971 mi) or over half of these pipelines crossed wetland (marsh) or upland habitat as opposed to water bodies. Sources of OCS pipeline data were Penn Well Mapsearch, Minerals Management Service, National Pipeline Mapping System and the Geological Survey of Louisiana pipeline datasets. Additionally, based on USGS 1978 habitat data, approximately 56% of pipelines crossed marsh habitat and 44% crossed upland habitat (personal observation James B. Johnston and John Barras, USGS NWRC, Lafayette, LA). USGS land loss data from 1956 to 2002 indicated that, the total amount of land loss attributed to OCS pipelines was 34,400 ha (85,002 acres), within a 300 m (984 ft) buffer for each OCS pipeline. This number represents .04 km^2 (4 ha/10 acres) per linear km of pipeline installed. When one divides 34,400 ha by the 46-year period (1956–2002), the loss per year is 746 ha (1843 acres) for the 8000 km (4971 mi) of OCS pipeline or 11.9% of total land loss in the entire Louisiana pipeline study area. Note that from 1990 to 2002 (based on the preliminary data by USGS) the total pipeline land loss for the study area was approximately 25 km^2 (10 mi^2) or 6178 acres/yr, which represents a dramatic decline from the 1956–1978 and 1978–1990 analysis (Table 3B.1). Many of these pipelines were installed prior to the implementation of the National Environmental Policy Act of 1969 and more recently, the State of Louisiana's Coastal Permit Program in 1981. Additionally, given the width of the buffer—300 m (984 ft) vs actual pipeline width, which may be a 31 to 61 m (100 to 200 ft) wide—an unknown portion of water increase is attributed to other factors unrelated to OCS pipelines. To address this increase, selected OCS pipelines are being studied in greater detail to ascertain direct and secondary impacts to the extent possible. The information from that analysis will be included in future NEPA documents.

TEXAS

The total length of OCS pipelines (included in the Texas study area) from offshore of the three-mile state/federal boundary to the inland coastal zone boundary for Texas was approximately 978 km (608 mi). Of that total, approximately 182 km (113 mi) or over half of these pipelines crossed wetland (marsh) or upland habitat as opposed to water bodies. Sources of OCS pipeline data were Penn Well Mapsearch, Minerals Management Service, Texas General Land Office and the Texas Railroad Commission pipeline datasets. Additionally, based on USGS 1992 habitat data, approximately 6%

Table 3B.1. OCS Louisiana study area pipeline landloss (300 m buffer) trend summary (increase in water area by time period). (Preliminary results from Minerals Management Service USGS NWRC current coastal wetland pipeline impact study).

Time Period	**Years Total**	**Mi^2 Total**	**Hectare Total**	**Acre Total**	**Mi^2/Ha/Ac/Per Year**
1956–1978	22	101	26158	64640	4.60/1191/2944
1978–1990	12	22	5698	14080	1.80/466/1152
1990–2002	12	10	2590	6400	0.82/212/525
1956–2002	46	133	34447	85120	2.88/746/1843

of pipelines crossed marsh habitat and 12% crossed upland habitat. Using USGS land loss data from 1956 to 1992, the total amount of land loss attributed to OCS pipelines was 453 ha (1119 acres), within a 300 m (984 ft) buffer for each OCS pipeline. When one divides 453 ha by the 36-year period (1956–1992), the loss per year is 13 ha (31 acres) for the 182 km (113 mi) of OCS pipeline study area.

James B. Johnston received his Ph.D. in 1973 in biology from the University of Southern Mississippi. As the Chief, Spatial (Habitat) Analysis, Dr. Johnston seeks ways to improve responsiveness and efficiency of decision making by establishing partnerships among government agencies and the private sector to protect and restore natural resources. He also applies state-of-the-art technologies to monitor habitat changes, implements innovative research technologies to address resource issues, and establishes educational and public outreach programs.

COASTAL LAND LOSS AND WAVE-SURGE PREDICTIONS DURING HURRICANES IN COASTAL LOUISIANA: IMPLICATIONS FOR THE OIL AND GAS INDUSTRY

Gregory W. Stone, Louisiana State University

The potential negative impact of hurricane-generated storm surge and wave energy on the oil and gas infrastructure located in coastal Louisiana is enormous. This can be attributed to: (1) the extent and number of facilities located there; and (2) the fact that barrier islands and marshes have drastically diminished during recent history and are predicted to continue doing so in the absence of implementing well designed, large-scale restoration plans. It is the primary objective of this pilot study to evaluate, using state-of-the-art numerical hydrodynamic models, how the loss of barrier islands and wetlands affects storm surge and wave energy along a portion of the south-central Louisiana coast.

Using a Hurricane Planetary Boundary model, a storm surge model (ADCIRC) and wave model (SWAN) to stimulate a category 3 hurricane, the resultant data indicate that the vast majority of the study site underwent a considerable increase in combined surge and wave height during the interval 1950–1990s. This is an important period in time in that it represents the actual physical breakdown of the coast, to which the increase in surge and wave height can be directly attributed. Thus, the study and the conclusion provide a highly unique data set demonstrating that the deterioration of coastal south-central Louisiana has likely resulted in an increase in surge and wave height during this 40-year time period. The magnitude of increase is typically 8–10 ft although change >12 ft is readily apparent along the marsh shorelines and barriers (Figure 3B.3).

Over the approximate 30-year period between 1990s and 2020, the model forecast results also indicate that a significant increase in surge and wave height will occur throughout much of the study site (Figure 3B.4). Increases are widespread in the study area with the largest occurring at Fourchon, Timbalier islands, and in particular, Isles Dernieres and the adjacent marshes. At these locations, increasing values range from 10 to >12 ft. Throughout the marsh north of Terrebonne Bay, values increase from 6 ft, although in several location increases between 10 and >12 ft were computed.

The data presented here have very important implications for the oil and gas infrastructure located in the study site (Figure 3B.5). The data suggest that in the absence of large-scale barrier and marsh restoration, the current infrastructure will experience increasing surge levels and increasing wave energy if the anticipated coastal erosion is permitted to occur. The data dramatically illustrate that nearly the entire infrastructure is potentially exposed to increased surge and wave heights over time. It also important to note that this conclusion pertains to tropical storms and weaker hurricanes that historically are known to have a high frequency of landfall along the Louisiana coast.

Gregory W. Stone is a Professor in the Coastal Studies Institute and Department of Oceanography and Coastal Sciences at Louisiana State University. He earned his doctorate at the University of Maryland. His doctoral research concentrated on the late Holocene evolution and morphosedimentarty dynamics of the northeast Gulf of Mexico coast. His current research interests are nearshore and inner-shelf coastal processes and sediment transport during fair weather and severe storms conditions. He also directs a large coastal ocean observations system (Wave Current Surge Information System) off the Louisiana coast in which he and colleagues are further developing a computer and physical measurements workbench for numerical model skill assessment and development. He serves as scientific advisor to the National Park Service (Gulf Islands National Seashore) and as Deputy Editor-in-Chief of the Journal of Coastal Research. He has worked extensively on the impacts of mining large scale sand bodies off the Louisiana coast, a multi-year program funded by MMS.

ENVIRONMENTAL SENSITIVITY INDEX (ESI) SHORELINE CLASSIFICATION USING NEW REMOTE SENSING DATA AND TECHNIQUES

DeWitt Braud, Department of Geography and Anthropology, Louisiana State University
Scott Zengel and Chris Locke, Research Planning, Inc., Columbia, South Carolina

INTRODUCTION

Environmental Sensitivity Index (ESI) mapping refers to a shoreline classification and sensitivity ranking system that has been a vital component of oil spill contingency planning and marine environmental assessment programs nationwide for 25 years (Halls *et al.* 1997). The U.S. Minerals Management Service (MMS) currently uses ESI data and the ESI classification scheme (Table 3B.2) for environmental assessment studies related to OCS activities. ESI data are also a valuable input data layer commonly used in oil spill simulation models, such as the Spill Impact Modeling and Assessment Package (SIMAP) developed by Applied Science Associates (ASA).

Table 3B.2. Environmental Sensitivity Index (ESI) shoreline classes and definitions (LSU *et al.* 1996; MMS *et al.* 2001).

ESI Shoreline Type	Definition
1A	Exposed vertical rocky shorelines (not present in Louisiana)
1B	Exposed solid man-made structures (e.g., seawall, bulkhead, etc.)
2A	Exposed wave-cut platforms in mud
2B	Exposed scarps or steep slopes in mud
3A	Fine to medium-grained sand beaches
3B	Scarps and steep slopes in sand
4	Coarse-grained sand beaches
5	Mixed sand and shell beaches
6A	Shell beaches
6B	Exposed riprap
7	Exposed tidal flats
8A	Sheltered scarps in mud
8B	Sheltered solid man-made structures (e.g., seawall, bulkhead, etc.)
8C	Sheltered riprap
8D	Vegetated steeply sloping bluffs
9A	Sheltered tidal flats
9B	Vegetated low banks (non-wetland)
10A	Salt-brackish marshes (including intermediate marshes)
10B	Freshwater marshes
10C	Swamps (forested wetlands)
10D	Scrub-shrub wetlands (including mangroves)

Traditional ESI data development includes interpretation of aerial photographs and mapped observations by coastal habitat specialists during over-flights. This method has been applied successfully to the majority of the U.S. coastline. The complex, rapidly changing shoreline of Louisiana, however, has made ESI mapping extremely difficult to impossible using traditional techniques. As a result, a coast-wide ESI shoreline classification has never been developed for Louisiana. This represents a major information gap, as oil spill risk and environmental consequences in Louisiana are great.

ESI classification efforts in Louisiana in the late-1980s relied on remotely sensed imagery with spatial resolution of 20–30 meters (Jensen *et al.* 1990). Although a useful land-use/land cover classification was achieved, the detail associated with the linear nature of shoreline features could not be resolved, and a true ESI shoreline classification was not possible. More recently, the barrier island beaches and other outer-coast features of Louisiana were classified using traditional ESI methods, as part of the Gulf-Wide Information System (G-WIS) project (MMS *et al.* 2001; Zengel and Hanifen 2001; Zengel *et al*. 2002). This effort was possible due to the relatively simple configuration of the outer-coast. Beyond this, most of the Louisiana coast remains unclassified and cannot reasonably be completed using traditional methods. Newer, higher-resolution satellite imagery offers the best opportunity for coast-wide ESI shoreline mapping and classification in Louisiana and other similar areas with highly complex, rapidly changing shorelines. We propose to develop automated remote sensing classification procedures to support ESI mapping efforts in Louisiana and elsewhere. Procedures developed during this project will improve and support continued ESI mapping efforts in coastal Louisiana. ESI data developed during this project will directly support MMS OCS environmental assessments and oil spill modeling efforts.

PROPOSED PROJECT & METHODS

The proposed project will develop repeatable ESI classification procedures for use with newer, high spatial resolution remote sensing products such as the IKONOS satellite sensor system. The project will include seven phases. Archived IKONOS satellite imagery will be acquired for a study area in coastal Louisiana and pre-processed prior to classification. A digital shoreline or land-water interface will be developed from the imagery using automated techniques. Fieldwork will be undertaken to develop training sites for the various ESI shoreline classes. The imagery will be classified using appropriate remote sensing techniques. Following the classification, additional fieldwork will be conducted to provide both a quantitative and qualitative accuracy assessment of the classified imagery. Draft and final reports will be produced describing the shoreline development and ESI classification procedures, results of the accuracy assessment, the final data products, and future needs and directions. Final data products will include a digital shoreline, ESI coverages in Arc/Info format, and FGDC-compliant metadata for each layer.

RELEVANCE

This project will develop procedures and data that will help fill a major gap in coastal shoreline, wetlands, and barrier island environmental data sets used by MMS, several state of Louisiana departments and offices, and various other organizations concerned with coastal and marine resource issues and oil spills. Methods developed during this project will improve and expand ESI mapping efforts in Louisiana and other Gulf states in the future. Such efforts might be undertaken in phases by several cooperating agencies and organizations, as additional funding and imagery become available with time. Although the entire coast of Louisiana is not covered in the scope of this project, focus on a study area of high priority to MMS will result in key environmental data that will contribute significantly to OCS-related environmental assessment and oil spill modeling efforts in the region and will provide a direction for future efforts in the complex and dynamic Louisiana coastal region.

DeWitt Braud is an instructor and Director of the Remote Sensing Laboratory in the Department of Geography and Anthropology at Louisiana State University. He received an M.A. from Michigan State University. His research interests are remote sensing and GIS applications.

Christopher Locke is a GIS and Remote Sensing Analyst at Research Planning Inc., where he has been employed since 1996. He took a two-year hiatus from his job at RPI to get his master's degree in geography and geographic information processing from the University of South Carolina (1999).

Scott Zengel is a Senior Ecologist at Research Planning Inc., where he has been employed since 1994. He received his master's degree from the University of Florida (1993) in environmental engineering sciences (systems ecology/wetlands ecology). Mr. Zengel is currently working on his Ph.D. from Clemson University through a joint project with the Congaree Swamp National Monument, where he is monitoring feral hog impacts on the forest community.

GULF OF MEXICO ACTIVITIES AT THE NOAA NATIONAL COASTAL DATA DEVELOPMENT CENTER

Jeff Jenner, NOAA-NESDIS, National Coastal Data Development Center

INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) is responsible for environmental prediction, assessment, and the conservation and management of coastal and oceanic resources. NOAA's National Coastal Data Development Center (NCDDC), located at Stennis Space Center, Mississippi, provides access to coastal data to support environmental forecasts, scientific analyses, and formulation of public policy. Much of this data is stored at geographically distributed repositories in a variety of formats. NCDDC works closely with many federal, state and local agencies, academic institutions, and the private sector to create a unified, long-term database of coastal data sets. NCDDC focuses its resources on data for high priority, multi-jurisdiction coastal problems through partnership projects. Current partnership projects include the Coastal Risk Atlas, the Harmful Algal Blooms Observing System (HABSOS), the Integrated Ocean Observing System, Marine Invasive Species, Fish Habitat and Homeland Security.

INFORMATION TECHNOLOGY

NCDDC employs established and emerging technologies to catalog coastal data and to create a virtual data system that links the distributed network of data repositories. The web-based data portal (http://www.ncddc.noaa.gov) allows text and map-based searches of the NCDDC metadata catalog. The data portal uses "gateways" to geographically-distributed web sites and databases to bring data from multiple sources to a single user interface (Figure 3B.6). A gateway is a software adapter that connects the NCDDC data portal to a remote data server.

NCDDC staff and data providers can interface with the NCDDC metadata catalog using the NCDDC custom metadata management tool, Metadata Enterprise Resource Management Aid. "MERMAid" is an object-oriented software suite (based on open source code) that allows metadata entry, ingest, validation, cataloging, and output. MERMAid uses the Federal Geographic Data Committee (FGDC) metadata content standards. The object-oriented structure is easily adaptable to custom extended metadata elements and other metadata profiles, such as the biological and shoreline profiles. The tool currently supports the basic FGDC standard and the biological profile. It is now being tested and upgraded and should be available for data providers to use in late Spring 2003.

NCDDC is developing and implementing advanced data management capabilities, such as full text metadata searches, geographic data visualization (using GIS), dynamic metadata creation, and geodatabases.

LIAISON OFFICERS

Regional Liaison Officers (Figure 3B.7) help link customers and data providers with NCDDC products and services. They also help oceanographic data providers meet the requirements of data submission to NOAA's National Oceanographic Data Center.

GULF OF MEXICO ACTIVITIES

The Gulf of Mexico Liaison Officer (LO) is currently focused on identifying data and data sources for the partnership projects, documenting the data with metadata and ensuring its quality, and coordinating the development of gateways to state and federal data repositories. In partnership with the NOAA National Marine Fisheries Service (NMFS), the Gulf of Mexico LO recently completed two significant projects: 1) metadata for the SEAMAP database trawl surveys and access to the database through the NCDDC portal, and 2) metadata for and quality assurance of a compilation of Gulf of Mexico data relevant to studying the effects of shrimp trawling on benthic habitats, which was produced by the NMFS Galveston Laboratory. The latter set includes Gulf-wide data from NMFS, NOAA's National Ocean Service, Minerals Management Service, Florida Marine Research Institute, Texas Parks and Wildlife Department, and several other federal, state, and academic organizations.

NCDDC scientific project managers have played key roles in several Gulf-wide, coastal data-related activities. Harmful Algal Blooms Observing System (HABSOS) project manager has helped marine scientists and public health officials from the five Gulf states assemble, check, access, and display HAB data for a three-year case study. The Coastal Risk Atlas (CRA) project team identified and provided access to data from the Mississippi coast for use in the NOAA Coastal Services Center's Community Vulnerability Assessment Tool. NCDDC recently hosted a workshop to begin the process of federating data from independent coastal observing systems in the Gulf, working toward a demonstration of regional coastal data integration for the sustained and Integrated Ocean Observing System (IOOS). Fish Habitat project scientists have identified and are arranging for access to Gulf-wide and estuary-specific data sets for pilot studies with a long-term goal of supporting ecosystem-based fisheries management.

Jeff Jenner is the Gulf of Mexico Liaison Officer for NOAA's National Coastal Data Development Center (NCDDC), which is located at the Stennis Space Center, Mississippi. He serves coastal data providers and customers throughout the five Gulf states and is primarily responsible for regional data discovery, quality assurance, documentation (metadata), and coordination with NCDDC technical staff members. Mr. Jenner holds degrees in engineering from Florida Institute of Technology and Stanford University, with significant graduate course work in physical oceanography and marine science. Prior to joining NOAA in 2001, Mr. Jenner spent ten years in civilian and military space flight space programs working for McDonnell Douglas, Lockheed, and NASA, then six years in NASA scientific and commercial remote sensing programs. From 1995 to 1997, he was the Michael J. Smith Professor of Space Systems at the Naval Postgraduate School in Monterey, California.

THE ASSOCIATION OF SALINITY PATTERN AND LANDSCAPE CONFIGURATION WITH OCS OIL AND GAS NAVIGATIONAL CANALS IN COASTAL LOUISIANA: A PROPOSED STUDY

Gregory D. Steyer, USGS National Wetlands Research Center
Charles E. Sasser, Coastal Ecology Institute, Louisiana State University

We propose 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 and water level data to determine changes in those variables relative to pre- and post-navigational canal construction and subsequent deepening events; and (3) relating salinity and water level 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. Hydrologic field studies will be conducted where necessary to enable completion of analyses, identifying salinity pathways into marshes. The spatial and temporal dynamics of the study area habitat will be evaluated by marsh type, geomorphic setting, water body configuration classification, canal density, and connectivity to develop likelihood of land change over time. These analyses will provide resource managers with new and useful information regarding potential impacts of waterways and navigation canals on marsh salinity regime and wetland landscape patterns.

Greg Steyer received his baccalaureate degree from the University of Maryland in 1985, his master's degree in 1988 from the University of Louisiana in Lafayette specializing in wetland ecology, and is currently a Ph.D. candidate at Louisiana State University in the Department of Oceanography and Coastal Studies. For the past 15 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 evaluating ecological indicators, determining success criteria, and developing adaptive management approaches for wetland restoration activities; integrating existing state and regional monitoring programs under unified experimental designs; and developing state and Gulf-wide databases and models for use in natural resource decision support.

SESSION 3D

BIOTECHNOLOGY

Chair: Susan Childs, Minerals Management Service

Date: January 16, 2003

EVALUATION OF OIL AND GAS PLATFORMS ON THE LOUISIANA CONTINENTAL SHELF FOR ORGANISMS WITH BIOTECHNOLOGY POTENTIAL

Lawrence J. Rouse, Jr., Department of Oceanography and Coastal Sciences and
Coastal Studies Institute, Louisiana State University

In 1998, President Clinton convened the National Ocean Conference (NOC) in Monterey, California. The report of this conference, Turning to the Sea: America's Ocean Future, identified biotechnology as a high-priority issue for the nation. The report identifies a lack of information about baseline conditions of the marine environment which makes it difficult to assess the environmental impacts of biotechnology, listing among its key recommendations:

- Increase support for sustainable harvesting and testing of marine compounds by both government agencies and commercial pharmaceutical companies as possible treatments for AIDS, inflammatory or infectious diseases, and cancers; and

In response to the Minerals Management Service's recognition that offshore oil and gas platforms may serve as a harvestable source of organisms with pharmaceutical or other commercial application, this proposal will address the NOC report's recommendations. Our initial effort is to answer the following questions:

- What organisms make up the biofouling communities on the platforms?
- Are any of these organisms potential sources of pharmaceuticals or other natural products?
- How do the organisms populate the platforms?

What is the distribution and relative abundance of the organisms on a platform and how does this distribution vary between platforms and with depth and time?

The Investigators assembled for this project have expertise in a number of organisms that are potential sources of useful natural products. Our effort, therefore, focuses on a specific set of organisms. The team of scientists and their expertise includes:

Dr. Fred Rainey	Bacteria
Drs. Russell Chapman and Suzanne Fredericq	Algae
Dr. Michael Hellberg	Bryozoans
Dr. Barun Sen Gupta	Benthic foraminifers
Dr. Laurie Anderson	Molluscs
Dr. Dave Foltz	Genetic analysis

Dr. Larry Rouse is the project director and oversees the collection of samples from the offshore platforms.

The original sampling scheme was to obtain samples at a number of oil and gas platforms west of the Mississippi River delta. The selected platforms are in a variety of water environments: blue, green, and brown water. At each platform, samples are to be acquired from an easternmost and a westernmost leg at or near the surface, 10 meters, and 20 meters. At each level, all the encrusting organisms in three 25 by 25 cm squares will be scraped off and stored in plastic bags. The samples will be sorted and preserved as appropriate. Laboratory analysis will identify the organisms by morphology and/or by DNA sequencing techniques.

The first data collection cruise was scheduled for the week of 4 June 2001. Unfortunately, Tropical Storm Allison also picked this week to venture into the region. High seas (up to 8 feet), wind, and rain prevented dive operations for most of the week. On Saturday, 9 June, we were able to acquire samples at one near shore platform (South Timbalier-23). An attempt to sample at a second platform that day was not possible because of high sea state. The seas did not set down on Sunday and the vessel had to return to Freeport, Texas. As a result, only one platform was sampled on that trip. A total of 11 scrapings and six bottom samples were collected at the ST-23 platform.

On 4 May 2002, a party of 15 boarded the MV Spree at Port Fourchon, LA for the second sample collection cruise of the project. In addition to the scientists and divers, the party included a journalist and an underwater photographer representing the Smithsonian Magazine. The object of the cruise was to gather samples of the encrusting organisms at five platforms on the Gulf of Mexico continental shelf offshore of southeastern Louisiana.

The MV Spree departed for the first platform on 4 May. The sea state on the morning of 4 May settled down, and the ship arrived at the first platform in the afternoon. Samples were collected at one platform on 4 May and at three platforms on 5 May. On 6 May the wind and current at the final platform created a situation that was deemed too dangerous for diving, and no samples were collected at that location. At all platforms sampled, scrapings and syringe samples were acquired at 10 and 20 m depths on two opposing legs. Surface or near surface scrapings were also collected at all platforms.

4 May 2002	GI 42-C	28° 59.947' N	89° 56.264' W	100 ft
5 May 2002	GI 82-A	28° 43.301'N	89° 57.916' W	170 ft
	GI 95-A	28° 30.962' N	90° 07.366' W	200 ft
	ST 67-H	28° 47.935' N	90° 24.889' W	61 ft
6 May 2002	ST 23	29° 01.267' N	90° 10.259' W	No Samples Collected

The cruise returned to Port Fourchon in the afternoon of 6 May 2002 with a very satisfied science party. In spite of only collecting at four of five platforms, the cruise and sample collection were considered to be a success.

The samples are being analyzed and some initial results are listed below. Full discussions of the results for the groups of organisms targeted in this study are reported in the other papers presented in this session.

Bacteria	A number of novel actinobacterial species with biotech potential have been isolated.
Algae	More than 50% of taxa identified have biotech potential. One macroalgae has been identified as the first record in the Gulf of Mexico.
Foraminifera	Thirty-six motile species and six sessile species have been identified. The sessile species found on the platforms are rare or absent on adjacent sea floor
Bryozoans	No bryostatin-producing *Bugulia neritina* were found.
Molluscs	Low diversity—dominated by byssate bivalves, esp. *Isognomon*.
Genetic Analysis	*Barbita candida* from 3 platforms have been examined and they have been found to have genetic homogeneity.

In the future we hope to expand this examination of the diversity of encrusting organisms to platforms east of the Mississippi River Delta and to the region off of the central Louisiana coast. We believe that it is important to understand the spatial and temporal variability of these encrusting organisms which inhabit this unique cluster of reefs in the northern Gulf of Mexico and how these organisms respond to the variation of salinity, temperature, and suspended sediment concentration that they experience.

This research was sponsored through the Coastal Marine Institute at Louisiana State University. The Coastal Marine Institute was formed as the result of a Cooperative Agreement between the Minerals Management Service and the university. The Minerals Management Service and the university each provided half of the support for this project. Special thanks must go to the divers who collected the samples for this project: Mark Miller and Chris Cleaver of LSU, Susan Childs, Greg Boland, Jack Irion, Les Dauterive, David Ball, and Terry Dempre of MMS.

Lawrence Rouse is the director of the Coastal Marine Institute at Louisiana State University. He is also an Associate Professor in the Coastal Studies Institute and the Department of Oceanography and Coastal Sciences. His research interests are in coastal and shelf circulation, estuarine-shelf exchange, and remote sensing analysis of these processes. Dr. Rouse received his Ph.D. in Physics from Louisiana State University in 1972.

ISOLATION OF NOVEL BACTERIAL SPECIES FROM OIL AND GAS PLATFORMS

Fred A. Rainey, Louisiana State University

Over the past 30 years, efforts in the exploration of the potential of marine biotechnology have increased and funding has been made available through various federal agencies. In spite of these efforts and considering the extensive biological and chemical diversity seen in the Earth's oceans only a small number of the natural products discovered in marine life forms have been taken to a point of application/production. Fewer still have resulted in the expected economic development follow on. The reasons for this have been identified and discussed in the marine biotechnological community. Solutions to these problems are now emerging with advances in technology and the genomics revolution. These advances have enabled us to better identify and understand the extent of biodiversity in the marine environment. It is now clear that this diversity is more extensive than envisaged and represents a resource to be explored for natural products and their biotechnological potential. The application of novel culture methodologies has enabled us to recover a much greater diversity of microorganisms in recent years than had been recovered in the past 50 years of marine microbiology.

CURRENT KNOWLEDGE OF BACTERIAL DIVERSITY

Bacterial diversity can be placed in two general categories (i) cultured diversity and (ii) uncultured diversity. The cultured diversity consists of organisms that can be grown in culture separate from their environment of origin either on solid media or in liquid culture. Such organisms once obtained from the environment of origin reside in culture collections. Such culture collections can be large service collections like the American Type Culture Collection (ATCC) or the Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH (DSMZ) or smaller individual laboratory collections in universities or research institutions. The uncultured diversity is the diversity that is in the environment and can also be referred to as the as yet uncultured diversity. Our knowledge of this diversity comes from 16S rRNA gene sequences that have been recovered from environmental samples using culture-independent molecular biological approaches. The gene sequences that are recovered can be placed within the tree of life and so provide a taxonomic placement for an organism that was present in the original environment but not actually isolated or cultured. Such data provide us with information on the diversity of the organisms within that sample and show that there are a large number of organisms present in the environment for which we have no cultured representatives of closely related individuals. Our knowledge of bacterial diversity as compared to other life forms like the plants and insects is rather limited in that we only have 5000 validly described species. We know a little more about the phylogenetic diversity of the bacteria through analyses of the 20,000 16S rRNA gene sequences of cultured organisms that are present in the public databases. It is the 16S rRNA gene sequences that have been recovered from various environments that give us a real insight into the extent of bacterial diversity and indicate that the cultured component is just the tip of the iceberg. From the 30,000 or so environmental 16S rRNA gene sequences that exist within the databases we can conclude that a large number of phylogenetic lineages exist for which we have no cultured representatives and that our knowledge of bacterial diversity based on cultured organisms is less than complete.

INABILITY TO CULTURE ALL OF THE MICROBIAL DIVERSITY

Going to the marine environment to cultivate new organisms has two problems. First, as discussed above, the degree of diversity that was recovered was not fully realized until molecular sequence data techniques came on line. It is now possible to determine the identity to at least the genus level of any bacterial or archaeal culture using 16S rRNA gene sequence data. Due to the extensive database of 16S rRNA gene sequences that exists, comparison of the determined sequence data also allows one to determine whether the organism is novel and at what taxonomic level that novelty resides. The rRNA genes and other house keeping genes of eukaryotic species, e.g., marine algae are also of great use in determining the identity or novelty of collected specimens. Second, the actual technique of enrichment, isolation and subsequent cultivation of any microorganism has for decades resulted in the repeated recovery of the same types of microorganisms and given us a false sense of taxonomic diversity in the marine environment. The insight into the true diversity in the environment has led to an upsurge in isolation studies. New methodologies and the redesign of culture media and culture conditions have yielded a menu of new marine microbial taxa in recent years.

CULTURING APPROACH TAKEN IN THIS STUDY

To obtain as diverse a collection of bacterial strains as possible, we have carried out serial dilution plating on a variety of artificial culture media containing antibiotics. Media containing both high and low levels of organic nutrients have been employed. Some samples were pretreated by heating at 50°C for 10 min to select for spore-forming organisms preferably within the actinobacterial group. The diversity within the isolates obtained was determined using ARDRA and representatives were selected for 16S rRNA sequence determination and comparison.

DIVERSITY OF THE BACTERIAL CULTURES OBTAINED

Over 300 bacterial isolates were obtained and maintained in pure culture. All of these strains have been preserved at -80°C and are available for further study. The isolates obtained were found to be diverse in appearance as observed by the appearance of their colonies when grown on solid media. Many of the isolates are pigmented in the yellow to red to brown range and, in addition, some excrete extra-cellular pigments into the culture medium. Approximately one-third of the isolates had partial 16S rRNA gene sequences determined and their taxonomic affiliation determined. The majority of the isolates obtained from the enrichment cultures used to select for actinobacterial strains were in fact members of the class Actinobacteria. They fell into the genera *Streptomyces*, *Micromonospora*, *Agromyces* (first marine isolate) and *Kocuria*. Based on the 16S rRNA gene sequence similarity values obtained, many of these isolates represent new species of these previously described genera. Using non-selective media, the isolation studies yielded numerous taxa from other lineages within the Bacteria that represent novel species.

WHY ARE THESE ORGANISMS IMPORTANT?

The bacterial strains isolated in this study represent a resource that can be further investigated for the discovery of bioactive molecules. This is especially true for the actinobacterial strains which are a major source of bioactive molecules. Between 1985 and 2000 actinobacterial species remained the major source of newly described microbial metabolites. Examples of anti-microbials produced from actinobacterial species include: Beta-lactams eg. Cephamycins, Monbactams, Macrolide; antibacterials eg. Erythromycin, Clindamycin; Glycopeptide antibiotics eg. Vancomycin, Streptomycin, Gentomycin and Antifungals eg. Nystatin. This valuable resource in the form of a strain collection needs further characterization and should be screened for bioactive compounds. There are two ways to do this: either by cooperating with industrial partner or by adding expertise to our research team.

GOVERNOR'S BIOTECH INITIATIVE

In the Fall of 2002 the BOR requested proposals through the Governor's Biotech Initiative. A proposal was submitted by Fred A. Rainey, Harold Silverman, Steven C. Hand, Luigi Marzilli and Lawrence J. Rouse of the colleges of Basic Science and the Coast and the Environment at LSU Baton Rouge Campus. The proposal was entitled: Moving an established marine biotechnology program to the next level: natural product screening and development. This proposal was funded and will support a faculty position in the area of natural products science and/or environmental genomics. The person who will fill this position is expected to add the required expertise to the current research group that will allow us to further investigate the biotechnological potential of these bacterial isolates.

Fred A. Rainey received his B.Sc. (Honors) from the University of Warwick, England, in microbiology and microbial technology in1988 and his D. Phil. from the University of Waikato, Hamilton, New Zealand, in 1991. Dr. Rainey is currently an Associate Professor in the Department of Biological Sciences at LSU. His main interests are in the areas of microbial diversity and bacterial systematics.

MACROALGAE AND PLATFORMS IN THE GULF OF MEXICO

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Russell L. Chapman and Debra A. Waters, Louisiana State University

The more than 3000 standing oil and gas platforms in the northwestern Gulf of Mexico (GOM) provide habitat for a significant community of marine organisms. As part of a larger study, we are examining the macroalgae collected from four GOM platforms in May 2002 to determine species diversity, relative abundance, and vertical, horizontal, and seasonal distribution.

The May 2002 cruise visited four platforms where algae were collected (see Figure 3D.1):

- G1-42C
- El Paso G1-82-A
- VASTAR G1-95A
- EXXON ST 68H South Timbalier

These sites were selected to follow a horizontal gradient that will allow comparison of near-shore and outer-shelf areas.

A zonation of algal communities in the intertidal was visible at all stations and consisted of barnacles and small blades of green algae, mainly *Ulva fasciata* and several species of *Enteromorpha.*

At each site, divers sampled the east-west legs of the platform. To analyze the influence of the water column on the macroalgal community, each leg was sampled whenever possible at 20 m, 10 m, and at surface level. An effort was made at each site to collect from the higher intertidal zone. At each depth, three samples were collected using a pneumatic chisel and a specially designed collection funnel that deposited the scraping directly into the collection bags. The air-powered chisel scraped sections 8 cm wide by 25 cm long.

After sample bags were carried on board, the algal component was selected with forceps or spatulas and transferred to labeled bags. The thalli were sorted as follows:

- 48 sample bags fixed in 90% EtOH for algal identification, curation on semi-permanent microscope slides, and DNA extraction and molecular study;
- 14 sample bags of algae kept alive in a cool chamber in seawater for further culture studies in the laboratory at University of Louisiana at Lafayette (ULL). Cultures at ULL are maintained at 18C with a light:dark regime of 16:8 hrs in a Percival Scientific benchtop plant growth chamber Model E-30B in seawater enriched with Alga/Gro (Carolina Biological Supply Co.).

A collection of isolates in a culture chamber is being kept in seawater medium for further detailed studies. DNA studies for ongoing molecular systematic analysis have been initiated on some samples using the following methods:

For the DNA extraction, a small portion of the algal sample was ground in liquid nitrogen with a mortar and pestle. DNeasy Plant Mini Kit from QIAGEN was used following the manufacturer's protocol.

For gene amplification, 2 µl of the resulting extraction was used as template for a 50 µl PCR consisting of 10 µl 5M betaine, 6 µl 10X PCR buffer (Perkin Elmer Corp.), 6 µl 25 mM MgCl2 solution, 8 µl of 500 mM dNTP stock, 2 µl each of the appropriate primers at 10 mM, and 0.3-0.5 µl Amplitaq® DNA Polymerase. Amplification conditions for rbcL consisted of 4 minutes at 96°C for denaturation, followed by 30 cycles of 60 seconds at 94°C, 60 seconds at either 45°C or 42°C, and 90 seconds at 72°C, with a final 10 minute extension cycle at 72°C, and soak cycle at 4°C. The amplification reactions were performed on a PE GeneAmp PCR system 9700 or 2400.

For automated gene sequencing, amplification products were cleaned of excess primer, enzyme, and dNTPs by PEG precipitation (Hillis *et al.* 1996). The sequences were determined over both strands using an ABI Prism 3100 Genetic Analyzer (PE Applied Biosystems, Foster City, CA) with the ABI Prism BigDye Terminator Cycle Sequencing Ready Reaction Kit (Perkin-Elmer, Foster City, CA, USA). Reaction mixtures comprised 4 µl Terminator Ready reaction mix with 4 µl 2.5X buffer or 8µl Terminator Ready reaction mix, 1-2 µl template, 3.2 pmol primer, and deionized water q.s. up to a total volume of 20 µl. The cycle sequencing reactions were performed on a PE GeneAmp PCR system 9700 or 2400 for 25 cycles (96°C for 10 seconds, rapid thermal ramp to 50°C, 50°C for 5 sec., rapid thermal ramp to 60°C, 60°C for 4 min, rapid thermal ramp to 4°C). Resulting products were then purified using Centri-Sep spin columns (Princeton Separations P/N CS-901) following the manufacturer's instructions.

RESULTS

A total of 24 taxa have been identified from the samples (Table 3D.1 provides a preliminary list of algae). The number of taxa by division/class is as follows

- Chlorophyta: 7
- Rhodophyta: 12
- Phaeophyceae: 2
- Cyanophyta: 3

The macroalgae collected from the platforms are known to occur in the northwestern GOM with the exception of one red algal species, *Antithamnionella breviramosa.* It is is reported here for the first time from the GOM; it was previously known from Pacific Mexico, eastern Australia, the Solomon Islands, North Carolina, and Brazil.

Three of the species and seven of the genera collected have been identified as having medical or other biotechnological uses:

Table 3D.1. Preliminary list of algae. Taxa in bold have been reported as being of biotechnological use.

Chlorophyta:
- ***Bryopsis** pennata* Lamouroux
- ***Chaetomorpha** aerea* (Dillwyn) Kützing
- ***Cladophora*** sp.
- ***Enteromorpha*** spp.
- *Entocladia viridis* Reinke
- ***Ulva fasciata*** Delile
- *Ulvella lens* P. Crouan & H. Crouan

Rhodophyta:
- *Acrochaetium hypneae* Børgesen
- *Acrochaetium microscopicum* (Nageli ex Kützing) Nägeli
- *Antithamnionella breviramosa* (Dawson) Wollaston in Womersley & Bailey*
- *Callithamniella tingitana* (Schousboe ex Bornet) Feldman-Mazoyer
- ***Centroceras clavulatum*** (C. Agardh in Kunth) Montagne in Durieu de Maisonneuve
- ***Ceramium** flaccidum* (Kützing) Ardisson
- *Erythrotrichia carnea* (Dillwyn) J. Agardh
- ***Gelidium pusillum*** (Stachouse) Le Jolis
- *Herposiphonia secunda* (C. Agardh) Ambronn f. *tenella* (C. Agardh) Wynne
- ***Jania** capillacea* Harvey
- *Kylinia crassipe*s (Børgesen) Kylin
- *Sahlingia subintegra* (Rosenvinge) Kornmann

Phaeophyceae:
- *Kuetzingiella elaschistaeformis* (Heydrich) Balakkrishnan & Kinkar
- *Sphacelaria rigidula* Kützing

Cyanobacteria
- *Gloeocapsa* sp.
- *Oscillatoria acuminata* Gomont
- *Spirulina* sp.

* First report from the Gulf of Mexico

- Agar Producer: *Gelidium* spp.
- Antibacterial: *Cladophora* spp., *Centroceras clavulatum*, *Gelidium* spp.
- Antifungal: *Bryopsis* spp., *Cladophora* spp., *Centroceras clavulatum*, *Gelidium pusillum*, *Jania* spp.
- Antiherpetic: *Chaetomorpha* spp., *Cladophora* spp., *Eneromorpha* spp., *Ulva fasciata, Centroceras clavulatum*
- Anti-inflammatory: *Gelidium* spp.
- Anti-influenza: *Ceramium* spp., *Gelidium* spp.
- Antitumoral: *Bryopsis* spp., *Chaetomorpha* spp., *Enteromorpha* spp.
- Antiviral: *Bryopsis*, *Chaetomorpha* spp., *Cladophora* spp., *Enteromorpha* spp., *Ulva fasciata, Centroceras clavulatum*, *Gelidium* spp.
- Differentiation of Leukemia or Melanoma Cells: *Ceramium* spp., *Gelidium* spp.
- Diuretic: *Enteromorpha* spp.

Additionally, studies have shown that agar produced from red algae have antirheumatic properties and alginates from brown algae (Phaeophyceae) have been studied for spinal chord, bone, and nerve regeneration; dermal repair, and as mucoadhesives. *Spirulina* (Cyanophyta) is sold as a nutritional additive.

Figure 3D.2 shows the vertical distribution of the algae commonly collected at the platforms.

Numerous microscope slides of the algal samples have been made and digital images of the samples taken. A digital data bank of algae has been initiated, and the website for the project can be found at http://chapmanlab.lsu.edu/lab_mainpage/algae_project.html. This website also has an extensive list of literature on medical and biotechnological uses of algae and algae products.

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PUBLICATIONS

López-Bautista, J.M., S. Fredericq, R.L. Chapman, and D.A. Waters. 2002. Biodiversity and potential use of marine macroalgae from the offshore oil platforms in the Gulf of Mexico. Proceedings of Botany 2002 & Annual Meeting Phycological Society of America, Madison, WI, 4-7 August. P. 89.

PRESENTATIONS

López-Bautista, J.M., S. Fredericq, R.L. Chapman, and D.A. Waters. 2002. Biodiversity and potential use of marine macroalgae from the offshore oil platforms in the Gulf of Mexico. Poster presentation at the Scientific Meeting Botany 2002 and the Phycological Society of America, Madison WI, 2-8 August 2002.

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CRYPTIC SPECIES AND CRYPTIC ENDOSYMBIONTS IN THE BRYOZOAN *BUGULA NERITINA*

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Natural marine products may eventually provide many useful medicines, however to date the only marine compound to enter phase II clinical trials is bryostatin 1. Bryostatin 1 was initially isolated from the bryozoan *Bugula neritina*, but is now known to be produced by symbiotic bacteria found within this animal (Anthoni *et al*. 1990). Bryostatin 1 combats the growth of cultured cancer cells (Hornung *et al*. 1992) and has shown some promise aiding patients suffering from non-Hodgkin's lymphoma and lymphocytic leukemia (Varterasian *et al*. 2000).

Bryostatin 1 has yet to be synthesized in the lab. Isolating gram qualities of bryostatin 1 requires over 10,000 gallons for wet bryozoans as starting material (Schaufelberger *et al*. 1991), the equivalent of perhaps millions of colonies. Aside from the direct impact that collecting such quantities of *B. neritina* from natural populations, the collateral damage done to other benthic species could be very great. Large sources of *B. neritina* that could be harvested from artificial substrate thus might serve a medical need while sparing natural communities from damage.

Bugula neritina is a common member of temperate fouling communities worldwide. Along the Atlantic and Gulf coasts of North America, *B. neritina* is common on natural and artificial hard substrates (Osman 1977). Significantly, *B. neritina* has been reported as a dominant member of the fouling communities on the legs of shelf oil platforms in the Gulf of Mexico (GOM) (Gallaway *et al*. 1981). Whether these platforms could serve as a source of bryostatin 1, however, remains unknown because recent studies reveal that individuals identified morphologically as *B. neritina* actually belong to at least two cryptic species, only one of which harbors the symbiont that produces bryostatin 1 (Davidson and Haygood 1999).

We set out to determine whether the *Bugula neritina* growing on shelf oil platforms might serve as a source of the putative chemotheraputic agent bryostatin 1 using DNA sequences. Davidson and Haygood (1999) found diagnostic base pair changes in a region of mitochondrial cytochrome c oxidase I (COI) between deep water (>9 m) and shallow water *B. neritina* taken from southern California. D genotypes also harbored a different bacterial symbiont, recognizable by a diagnostic small subunit rRNA (SSU) sequence. Most importantly, only the deep water (D) genotype produced bryostatin 1. Some shallow water samples from northern California and North Carolina also harbored D genotypes, produced bryostatin 1, and had the D symbiont. No bryozoan samples had been sampled previously.

We sampled colonies of *B. neritina* from one Louisiana oil platform: South Terrebonne platform ST67H, LA. We sampled from four other populations south of Cape Hatteras ('Southern' populations: Beaufort, NC, Mosquito Lagoon, Cedar Key, and Turkey Point, FL). We also sampled 10 individuals from each of two 'Northern' populations ('Northern' populations: Indian River, DE and Waterford, CT). In addition, we sampled colonies of two other *Bugula* species: B. stolonifera (from Delaware and Woods Hole, MA), and two colonies of *B. turrita* (from Woods Hole).

We amplified diagnostic regions of DNA from *B. neritina* (COI) and *Candidatus* Endobugula sertula (SSU) using the polymerase chain reaction. We used some primers that had previously been developed for this purpose (Folmer *et al*. 1994; Haygood and Davidson 1997), along with additional primers for the bacterial SSU of our own design (McGovern and Hellberg, 2003). SSU amplification required a two-step process of initial amplification using general primers, followed by a secondary amplification with more specific primers (see McGovern and Hellberg 2003). Amplicons that would not yield unambiguous direct sequences were cloned. We obtained sequence from a minimum of three such clones per individual bryozoan colony. The resulting sequences were analyzed using neighbor-joining, maximum parsimony, and maximum likelihood analyses.

COI sequences from the ‘Southern’ populations of *B. neritina*, including the South Terrebonne platform ST67H, were identical to one another. These sequences were also identical to those of Davidson and Haygood (1999) from Beaufort, NC over the 618 bp where they aligned. There was a deep divergence (11.5%), however, between these Southern/Shallow form sequences and those obtained from *B. neritina* populations in Delaware and Connecticut. As with the Southern form, these Northern populations were both fixed for the same haplotype. This Northern Atlantic form of *B. neritina* differs not only from the Shallow/Southern form, but also from two other species of *Bugula* found north of Cape Hatteras, *B. stolonifera* and *B. turrita*, and from the Pacific deep water form of *B. neritina* identified by Davidson and Haygood (1999).

All bacterial sequences obtained from the Southern populations of *B. neritina* are identical and cluster with Haygood and Davidson’s (1997) shallow-water *Endobugula sertula*. In contrast, the bacterial sequences obtained from *Bugula* found north of Cape Hatteras differ by from 5% to 11% from the *Endobugula* sequences from the Southern populations and by 0% to 10% from each other. The bacterial sequences from the Northern *Bugula* show no apparent correlation with either geography or host phylogeny. Whereas all Southern bryozoan colonies were associated with identical bacterial sequences, this is not the case for the Northern *B. neritina* or the other two *Bugula* species.

From these results we can draw several conclusions. First, *B. neritina* growing on the single Gulf platform we sampled clearly matched the shallow form of *B. neritina* found by Davidson and Haygood (1999); that is, the form that does not make bryostatin 1. In addition, natural substrate in the sampled regions of the Gulf and in the open Atlantic up to Cape Hatteras also harbor only the Shallow water form of *B. neritina*. Clearly then, these platforms cannot serve as a source of raw materials for extraction of this particular cytotoxin, although it is worth noting that the Shallow form provides other forms of bryostatin that may eventually prove valuable.

Second, intraspecific variation was nonexistent in our samples: all individuals of a given form were genetically identical. This could in theory be due to low mitochondrial DNA mutation rates, but this seems unlikely given the strong divergence between forms. The low levels of variation that we found, then, may indicate that neither form of *B. neritina* that we studied was native to the sampled ranges; these may be invasive species.

Finally, our data indicate that a previously unidentified cryptic species of *B. neritina* occurs north of Cape Hatteras. Interestingly, this Northern form does not appear to harbor any specific bacterial endosymbionts, as indicated by the great diversity of -proteobacteria they harbor, none of which are particularly close to *Endobugula*. In contrast, the Shallow/Southern form or the deep-water Californian form harbor just a single species of -proteobacteria. This lack of endosymbionts in the Northern form correlates with an important aspect of its ecology: unlike the Southern form, which appear to be unpalatable to fish, the northern form is not chemically protected (N. Lopanik, pers. comm.). Thus, detecting cryptic species using genetic techniques is not merely taxonomic bookkeeping: it can have critical consequences for those seeking to understand ecological relationships as well.

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EVALUATION OF OIL AND GAS PLATFORMS ON THE LOUISIANA CONTINENTAL SHELF FOR ORGANISMS WITH BIOTECHNOLOGY POTENTIAL: BENTHIC FORAMINIFERA

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ABSTRACT

Both motile and sessile species of Foraminifera have been recovered from platform scrapings collected in 2001 and 2002 (Figure 3D.3). The motile species, also commonly present in adjacent soft substrate, include *Ammonia parkinsoniana, Buliminella morgani,* and *Nonionella basiloba.* The sessile species, atypical of soft substrates, include *Rosalina globularis, Planorbulina mediterranensis, Cibicides* sp., and *Patellina corrugata,* with the first three taxa showing great variations in shell morphology.

INTRODUCTION

Before the present study, there was no available knowledge of foraminiferal communities of petroleum platforms anywhere in the world. Hence, the focus of this benthic foraminiferal study is a species census. In addition, we aim to elucidate the foraminiferal zonation on platform legs (as indicated by diversity and dominance patterns) and find clues to colonization strategies.

MATERIAL AND METHODS

The samples include both scrapings and syringe samples taken from platform legs (ST 23, ST67H, and G182A) and control samples of seafloor sediment (from near the bases of ST23 and ST67H, the shallowest platforms). The samples were frozen immediately after collection. In the laboratory, they were preserved in ethanol (in room temperature), and micropaleontological laboratory techniques were applied. These included (1) the use of the Rose Bengal stain to distinguish between living and dead Foraminifera; (2) wet-sieving of scrapings through 2 mm, 1 mm, 0.5 mm, and 0.063 mm screens; (3) species identifications and counting under an optical microscope; (4) preparation of a species-distribution database; and, (5) species illustrations with a scanning electron microscope. At this time, the database (that would eventually include data from two additional platforms) is incomplete, and numerical analyses are yet to be performed.

RESULTS AND DISCUSSION

Our results show that some motile foraminiferal species inhabiting platforms have been recruited from soft-bottom natural substrates. However, we have also found sessile species that are rare or absent in soft substrates living in relative profusion on the platforms. The highlights of our present findings from three platforms are given in Table 3D.2.

Table 3D.2. Partial foraminiferal distribution data from three GOM platforms. Water depths (meters) are given in parentheses; names of species that have been found attached are in bold; asterisks indicate numerous individuals.

Common Species	Platform																
	ST23 (16)						ST67H (19)							GI82A (52)			
	W-Bottom-diver (16)	E-Bottom-grab (16)	W-20 (15)	E-20 (15)	W-10 (8)	E-10 (8)	E-Bottom-diver (19)	E-Bottom-grab (19)	W-20 (18)	E-20 (18)	W-10	E-10	W-0	W-20	E-20	W-10	W-0
Ammonia parkinsoniana	X*	X*	X*	X						X		X					
Nonionella basiloba	X*	X*	X*	X													
Buliminella morgani	X*	X	X*	X		X											
Elphidium sp.	X	X*	X			X					X						
Trochammina spp.			X*	X	X	X*					X	X				X	
?Nonion sp.			X*	X*						X		X					
Bolivina spp.	X	X	X*	X*	X*	X*			X*	X*	X*	X*	X	X*	X*	X*	X*
miliolids		X	X*	X*		X*	X	X	X*	X	X	X	X	X*	X	X*	X*
Rosalina globularis			X*	X*	X*	X*			X	X*	X*	X*	X*	X*	X*	X*	X*
***Cibicides* sp.**			X	X		X			X	X	X*	X		X*	X	X	X
Patellina corrugata			X*	X*		X			X	X	X	X	X*		X	X*	X
Cornuspira sp.			X*	X*					X*	X*	X	X	X*			X	X*
Planorbulina editerranensis						X					X	X		X*	X	X	X*
Hanzawaia concentrica	X						X*	X*	X	X	X	X					

The most conspicuous aspect of the foraminiferal distribution is the relative abundance of attached taxa such as *Planorbulina mediterranensis*, *Cibicides* sp., *Rosalina* sp., *Patellina corrugata*, and *Trochammina* spp. Apparently, the shell morphology of the first three species is partly controlled by the shape of the attachment surface and the mode of attachment; misshapen specimens and aberrant chamber arrangements are common. All five species are abundantly present at various sampling levels (~20 m, 10 m, and 0 m below sea surface). In contrast, motile species other than *Bolivina* spp. may be dominant only close to the platform base. At ST23, the foraminiferal community of the seafloor mud has many common elements (e.g., *Nonionella basiloba*, *Buliminella morgani*, *Bolivina spp., and Ammonia parkinsoniana*) with the platform community about a meter above. This similarity, however, is not as strong at ST67H, with only a few specimens of the abundant bottom species *Hanzawaia concentrica* being found on the platform legs. Overall, the abundance distribution of Foraminifera is extremely patchy, and our present data on populations are inadequate to draw any broad conclusions about foraminiferal species zonation on platform legs.

Many sessile species of Foraminifera secrete an organic film for attachment (e.g., Poag 1982), and are easily detached from the substrate by mechanical forces. Thus, many more samples need to be examined for a proper census of these species. Judging by the high diversity of motile species on natural reefs (e.g., Rose and Lidz 1977; Hallock 1999; Sen Gupta 1999), it is likely that continued work would reveal the presence of a large suite of motile species on GOM platforms, putatively feeding on bacteria, microscopic algae (including diatoms), and particulate organic debris (Goldstein 1999). Algal mats are likely to constitute a favored microhabitat for foraminiferal colonizers (as in the case of algal cover on reef rubble, see Hallock *et al.* 1986). The distribution of errant polychaetes (Gallaway and Lewbel 1982) suggests that other suitable microhabitats for Foraminifera would be depressions and crevices on the surface of the artificial reefs (i.e., on or between the surfaces of live or dead, shelled epifauna), which provide both food and shelter. These substrates, especially barnacle surfaces, are being carefully examined for both sessile and motile Foraminifera.

We postulate that foraminiferal colonization of platform legs would start with (1) migration of individuals from the surrounding seafloor, (2) settlement of benthic zygotes following the union of free-swimming gametes (or settlement of benthic gamonts produced by meiosis), (3) transport by motile invertebrates (e.g., mollusks, arthropods), or (4) accidental settlement of living individuals after the resuspension of physically disturbed seafloor sediment (Brunner and Biscaye 1997). A relevant question is the distance of migration between the natural habitat (provenance) of a species and the platform (artificial reef). Published data from the Flower Garden Bank, the nearest living coral reef (Poag and Tresslar 1981), show that many species present there are also present on the platforms, but these are all widespread species of GOM. The samples we have studied do not contain *Amphistegina*, the most typical reefal foraminifer of the Caribbean biogeographic province (including the Flower Garden Bank), but whether this genus can occur as a "displaced" taxon (i.e., at "some distance from their usual home range"), as is the case with several reef-type invertebrates of GOM platforms (Lewbel *et al.* 1987), is yet to be determined by examining platform samples from a wider geographic area.

A task of the 2000–2002 project was the search for agglutinated foraminiferal species, because such species hold promise as a source of bioadhesives for biotechnological and biomedical applications (Bowser *et al.* 1992; Bowser and Bernhard 1993). Several agglutinated species (e.g., *Trochammina* sp., *Bigenerina irregularis,* and *Spiroplectammina* sp.) have been found, but high densities of large specimens (>1 mm) that could be exploited to extract these bioadhesives have not been recovered. We plan to continue the search in the proposed second study, which is expected to include platforms outside of the Mississippi River plume.

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MOLLSCA FROM OIL AND GAS PLATFORMS ON THE LOUISIANA CONTINENTAL SHELF: A BIOTECHNOLOGY SURVEY

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INTRODUCTION

This report of results concerning Mollusca is part of a larger study evaluating oil and gas platforms on the Louisiana continental shelf for organisms with biotechnology potential (Task Order 17809). Dr. Larry Rouse is the project director, and co-principal investigators include Drs. Fred Rainey (Bacteria), Russell Chapman (Algae), Michael Hellberg (Bryozoa), Barun Sen Gupta (benthic Foraminifera), Laurie Anderson (Mollusca), and David Foltz (genetic analyses of Mollusca and Foraminifera).

The project was developed in response to MMS's recognition that offshore oil and gas platforms may serve as a harvestable source of organisms with pharmaceutical or other commercial applications. The project also addresses recommendations in the National Ocean Conference Report to (1) increase support for sustainable harvesting and testing of marine compounds by both government agencies and commercial pharmaceutical companies as possible treatments for AIDS, inflammatory or infectious diseases, and cancers; and (2) support research on the environmental effects of extracting marine organisms for biotechnology purposes.

In this initial effort, we are addressing three research questions: (1) what organisms make up the biofouling communities on platforms; (2) which, if any, of these organisms are potential sources of pharmaceuticals or other natural products; (3) what is the distribution and relative abundance of these organisms, and how does this distribution vary geographically, with depth, and over time?

FIELD COLLECTIONS

Five platforms in water depths ranging from 15-61 m were sampled over two years; ST23 in 2001 and the remaining platforms in 2002 (Figure 3D.4; Table 3D.3). At each platform, two legs (east vs. west) were sampled. The sampling goal was to take three replicate samples, each scraped from a 0.0625 m^2 area, at three water depths: 0, 10, and 20 m. If a platform was in water < 20 m deep, the deepest sample level was at 1 m above the sea floor. Wave conditions made sample collection difficult for 0-m samples, so that when sampling was possible, only one replicate was collected (Table 3D.4). In addition, due to time constraints, only two replicate samples were collected at the 10-m level on the east leg of ST23. Finally, one replicate from 10 m on the west leg of ST42C was collected but lost before reaching the lab.

SAMPLE PREPARATION

Samples scraped from platform legs were frozen in the field. Each sample was thawed in the lab and preserved in 95% ethanol. Large pieces (ca. > 4 mm) were stained with Rose Bengal and retained

Table 3D.3. Location and water depth of platforms.

Platform	Depth (ft (m))	Latitude	Longitude
ST23	50 (15)	29°01.267'N	90°10.259'W
ST67H	61 (19)	28°47.935'N	90°24.889'W
GI42C	100 (30)	28°59.947'N	89°56.264'W
GI82A	170 (52)	28°43.301'N	89°57.916'W

Table 3D.4. Sample replicates collected.

Platform	Leg	0 m	10 m	20 m
ST23	E	0	3	3
	W	0	2	3
ST67H	E	0	3	3
	W	1	3	3
ST42C	E	1	3	3
	W	0	2	3
GI82A	E	1	3	3
	W	1	3	3
GI95A	E	1	3	3
	W	1	3	3

in ethanol. Finer sediment and biota were screened using 63 micron, 0.5 mm, 1 mm, and 2 mm sieves, stained with Rose Bengal and preserved in ethanol. Molluscs were identified from the > 2 mm fraction of samples. To compare sampling levels, differences in the number of replicates per sampling level needed to be taken into account. However, because the "A" replicate of most sampling levels tended to have a larger volume of biotic material, one replicate per level was not chosen at random. Instead, abundance data per level was averaged across replicates.

RESULTS

The platforms sampled host a low diversity molluscan assemblage dominated by byssate bivalves (Figure 3D.5 and Figure 3D.6). Twenty-seven bivalve and gastropod species were identified, with *Isogonoom bicolor* and *Barbatia candida* making up about 90% of the total assemblage. Changes in relative abundance among platforms (Figure 3D.5) is in part caused by uneven sampling at the

0-m level. No 0-m samples were collected at ST23 and only one sample was collected at ST67H and GI42C (Table 3D.4). These platforms have a lower relative abundance of *I. bicolor*, a species that is most abundant at very shallow depths (Figure 3D.6, see also Galloway and Lewbel 1982). The high dominance of *I. bicolor* at GI82A and GI95A is caused by the presence of one 0-m replicate at each platform that contains hundreds of *I. bicolor*, which swamp out other taxa on relative abundance plots.

A similar pattern of change in relative abundance with sample depth can be detected for all platforms (Figure 3D.6). *Isognomon bicolor* dominates (nearly 100%) of 0-m samples. This species also dominates 10-m samples (> 60%), although *Barbatia candida* also is common (nearly 20%) at this level. *Lithophaga* spp. are rare in 0-m samples, but the abundance of these boring bivalves increases with depth and are especially common at platform ST23. *Chama macerophylla* is the fourth most abundant species identified, and although individuals are not numerically abundant, both living and dead valves of this species form an important substrate for other members of the encrusting community.

Bivalve composition is similar to that previously reported from platforms on the Louisiana and east Texas continental shelf (e.g., Fotheringham 1981; Gallaway and Lewbel 1982), where *Isognomon* was most common from 0-12 m, arcids were common from 3-12 m, and *Chama macerophylla* was reported between 1 and 20 m. However, previous reports indicate that oysters were common several meters below the water surface on nearshore platforms (Gallaway and Lwebel 1982). In the platforms examined for this study, three species of oysters were identified (*Ostrea equistris*, *Crassostrea virginica*, and *Lopha frons*) but none were numerically abundant.

The bivalves assemblage identified for this study also resembled those of shorelines with hard substrates in Texas and Mexico (Britton and Morton 1989). *Isognomon bicolor* is common in the midlittoral of jetties and other artificial shoreline structures. Communities of naturally hard shorelines in this region contain *I. bicolor* in areas exposed to wave energy, and *Barbatia candida* in sheltered areas.

BIOTECHNOLOGY SIGNIFICANCE

The molluscs collected in this study with the greatest biotechnology potential are those that produce bioadhesives. These taxa include the byssate bivalves *Isognomon* and *Barbatia*. The byssus is a bundle of proteinaceous threads secreted by a bivalve that attaches to a substrate by an adhesive plaque (Rzepecki and Waite 1991; Burzio *et al.* 1997). These adhesives are of biotechnology interest because they provide strong, durable adhesion to wet surfaces (Rzepecki and Waite 1991, 1995). In addition, some of the proteins in the adhesive can chelate metal ions (Martell 1982; Deming 1999). The most widely studied byssal protein is mussel adhesive protein (MAP) from *Mytilus edulis*. This compound is used as an attachment factor for cells and tissues in culture (Waite 1991; Deming 1999); as an immobilization agent for antigens, antibiotics, and enzymes (Burzio *et al.* 1997); and as an anticorrosive coat for metals and metal sequestering reagent (Burzio *et al.* 1997; Rzepecki and Waite 1995). Additional potential uses are as medical and dental adhesives and fillers; as microencapsulating agents; as sizing agents for textiles; and as water-resistant inks (Rzepecki and Waite 1995; Burzio *et al.* 1997).

Byssal composition is highly variable among taxa (Waite 1983). Therefore, an examination of other byssate bivalves (including those found on Louisiana platforms) may lead to the extraction of a new variety compounds with similar or new applications.

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POSSIBLE CRYPTIC SPECIES AND GENETIC VARIATION OF FOULING BIVALVES ON GULF OF MEXICO OIL PLATFORMS

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INTRODUCTION

Offshore oil platforms represent a unique, man-made hard substrate for fouling organisms in the northern Gulf of Mexico (GOM). Oil platforms in the northern GOM extend from coastal (shore to > 27 m depth), to offshore (27 to 64 m), to blue water (> 64 m), placing them in different water masses that are subject to different hydrodynamic regimes (Gallaway *et al.* 1981). Consequently, the larvae that colonize the platforms may originate from different sources, and dispersal among platforms may be limited. Therefore, the fouling organisms inhabiting platforms in different zones may be cryptic species or exhibit population structure due to a lack of gene flow. Molecular analyses of genetic structure within some nominal species representing diverse marine taxa have revealed heterogeneity suggestive of interspecific differences (Knowlton 1993, 2000). To date, there have been few studies investigating the taxonomic diversity of the fouling organisms inhabiting oil platforms (e.g., Howard *et al.* 1980; Gallaway *et al.* 1981; Gallaway and Lewbel 1982) and all have relied on morphological identifications. Prior to the present group of studies, none have explored the genetic variability of these organisms in order to confirm their taxonomic status or to evaluate their population structure; however, there have been two studies that examined the genetic diversity of harpacticoid copepods inhabiting the sediments around GOM oil platforms (Street and Montagna 1996; Gregg, Foltz, and Fleeger unpublished data).

Taxonomic and genetic heterogeneity of marine organisms must be anticipated prior to surveys for biotechnologically useful molecules and studies of ecological processes. The purpose of the present study was to examine the genetic variability of the bivalve community associated with GOM oil platforms in order to (1) determine whether there are cryptic species and (2) examine the genetic variation within and among platforms. To do this, we examined the variability in the mitochondrial cytochrome c oxidase subunit I (COX I) gene. Mitochondrial genes have been used extensively in studies of bivalves to discriminate cryptic species (e.g., O Foighil *et al.* 1996; Peek *et al.* 1997) and to determine population structure (e.g., Reeb and Avise 1990).

METHODS

Collection of Samples

Samples of attached bivalve mollusks were collected as described by Anderson (these proceedings) and stored in 70% ethanol until they were processed for genetic analysis. Processing consisted of dissecting the soft tissues from each individual and storing the tissues in TE buffer (10 mM Tris pH 8.0; 0.1 mM EDTA) at -20°C. The shells were retained as vouchers for further morphological examination.

Genetic Methods

A small (~ 2 mm^2) piece of soft tissue was removed from each bivalve. DNA was extracted from this tissue using the CTAB protocol described by Winnepenninckx *et al.* (1993). A 720-bp portion of the COX I gene was amplified by the polymerase chain reaction (PCR) using the universal primers developed by Folmer *et al.* (1994). The PCR was carried out by adding 1 µl of the DNA extract to 5 µl GeneReleaser (BioVentures, Inc.) in a 0.5-µl tube, then incubating the mixture in a thermal cycler using the profile recommended by the manufacturer. After incubation, a PCR master mix was added to each tube. Reactions were done at either a 25 or 50-µl final volume, and the final concentrations of the reagents were as follows: 1X Promega Reaction Buffer A; 2.5 mM MgCl2; 0.2 mM total dNTPs; 1 µM of both forward and reverse primers; 2 units Promega Taq polymerase. The PCR was done in a Perkin-Elmer DNA Thermal cycler under the following conditions: 1 cycle of 95°C for 3 min; 40 cycles of 95°C for 30 sec, 47°C for 45 sec, and 74°C for 1 min; 74°C for 7 min. Three µl of each PCR product was electrophoresed into a 2% agarose gel, stained with ethidium bromide, and viewed by UV transillumination.

The genetic variability of the COX I gene was determined by cutting with restriction enzymes and DNA sequencing. After the PCR, a portion of the amplicon was digested with the restriction enzyme Mse I (recognition sequence AATT; New England Biolabs) according to the manufacturer's protocol. The restriction fragments were then electrophoresed on 2% agarose gels, stained with ethidium bromide, and viewed by UV transillumination. DNA sequences were then obtained from randomly chosen individuals from within each restriction profile. The PCR products were purified using Exo-SAP IT (USB) following the manufacturer's protocols, then sequenced using the ABI-Prism Big-Dye cycle sequencing chemistry (Applied Biosystems). The sequencing reactions were scaled down to 10-µl reaction volumes, as described by Rocha-Olivares *et al.* (2001), and run on an ABI-377 Gene Analyzer (Applied Biosystems).

Data Analysis

The raw DNA sequence data were proofread and assembled into contigs using Sequencher 4.0 (Gene Codes). Previously published sequence data from bivalves in the family Arcidae (Marko 2002; Marko and Moran 2002) were downloaded from the GenBank database, http://www.ncbi.nlm.nih.gov/. The processed sequence data were then aligned using ClustalX (Thompson *et al.* 1997). Phylogenetic analysis was performed in MEGA 2.0 (Kumar *et al.* 2001) using the Neighbor-joining method (Saitou and Nei 1987) for tree construction with the Kimura-two-parameter model (Kimura 1980) of DNA evolution. The reliability of the phylogenetic tree was determined by the nonparametric bootstrap test (Felsenstein 1985).

Frequencies of the different COX I restriction profiles within and among platforms were used to determine the population structure by an Analysis of Molecular Variance (AMOVA, Excoffier *et al.* 1992) using Arlequin 2.0 (Schneider *et al.* 2000). There were two levels in the hierarchical design of the AMOVA including variability among platforms and the variability within platforms.

RESULTS

We plan to concentrate the genetic analysis on three taxa (Arcidae, *Isognomon* spp., and *Lithophaga* spp.) because they were the most abundant bivalve groups (272, 1687, and 225, respectively) and they showed morphological variability. To date, 105 bivalve mollusks from two taxa, the Arcidae and *Isognomon* spp., collected from three platforms (GI-42-C, GI-82-A, ST-67-H) have been processed for genetic analysis (Table 3D.5). RFLP and DNA sequence data have so far been collected only for the Arcidae, so the remainder of the results will only apply to this group.

Table 3D.5. Species of interest and progress of genetic analysis to date for attached bivalves collected from oil drilling platforms. Table includes the numbers (N) of three taxa collected from each platform as well as the numbers of individuals processed for genetic analysis. Ext: DNA extractions; PCR: polymerase chain reaction; RFLP: restriction digests; Seq: DNA sequence. Isog. = *Isognomon* spp.; Lith = *Lithophaga* spp.; Arcid. = Arcidae.

Platform	Isog. N	Ext	Lith. N	Arcid. N	Ext	PCR	RFLP	Seq
GI 42 C	189	12	55	102	49	34	34	7
GI 82 A	625	12	1	6	6	6	6	
ST 67 H	120		16	30	26	23	23	
ST 23	152		129	39				
GI 95 A	601		24	95				

Twenty DNA sequences from six species within the family Arcidae were downloaded from the GenBank database for comparison with DNA sequences of the Arcidae in the present study. These species included *Barbatia gradata*, *B. domingensis*, *B. reeveana*, *B. candida*, *Arca mutabilis*, and *A. imbricata*. Each species formed a separate clade in the phylogenetic analysis with high bootstrap support (100%) (Figure 3D.7). The seven DNA sequences from individuals in the present study all grouped within the same clade as *B. candida* suggesting that there are no cryptic species among the arcids from the one platform examined, so far. The average uncorrected distance for sequences within the *B. candida* clade, including the previously published sequences and the ones from the present study, was 0.011. The average uncorrected distance among sequences from only the present study was 0.006 with a maximum of 0.0075.

Restriction fragment profiles from 63 of the arcids collected at the platforms were analyzed to determine genetic variation and to find evidence of cryptic species. The restriction fragment length analysis revealed the presence of three haplotypes at the three platforms, which will be referred to as A, B, and C. DNA sequences have been obtained from individuals consisting of haplotypes A and B (A - Bc 9. 10, 19, 28; B - Bc 13, 32, 35; see Figure 3D.7) confirming that they are located within the *B. candida* lineage and are likely the same species; however, no sequence data have yet been collected to confirm the phylogenetic status of haplotype C. For the following analysis, we assumed that haplotype C also fell within the *B. candida* lineage.

Variation of the COX I gene for *B. candida* was determined by examining the frequencies of the three haplotypes at the three platforms. Haplotype B was most common with an average frequency of 0.643 followed by haplotype A (0.293) and haplotype C (0.063) (Table 3D.6). No significant population structure was detected using AMOVA (Fst = -0.044; p>0.9) with essentially all the variation found among individuals within platforms (104%) compared to between platforms (-4%). The negative estimate of Fst is likely a result of the true value being close to zero.

Table 3D.6. Genetic variation of *Barbatia candida* within and among platforms. Haplotypes were determined by RFLP analysis using the restriction enzyme Mse I. Numbers below the haplotype designations (A, B, and C) are the frequencies of these haplotypes at each platform. n = the number of individuals analyzed at each platform.

		Haplotypes		
Platform	**n**	**A**	**B**	**C**
GI 42 C	34	0.29	0.65	0.06
GI 82 A	6	0.33	0.67	0.00
ST 67 H	23	0.26	0.61	0.13

DISCUSSION

The genetic analysis of the Arcidae collected from the platforms GI-42-C, GI-82-A, and ST-67-H has shown no evidence of cryptic species or population structure. The RFLP and sequence data collected to date indicate that all of the individuals are *Barbatia candida*; however, the bivalves collected from platforms at the coastal station (ST-23) and the blue water station (GI-95-A) have yet to be processed. The Arcidae are known to show significant intraspecific morphological variation among populations in different habitats suggesting the potential for cryptic species (Marko and Jackson 2001). Processing data for more populations from differing habitats (i.e., coastal, offshore, and blue water) in the present study may reveal greater taxonomic heterogeneity within this group. The RFLP analysis suggested that there was no structuring of the arcid populations inhabiting the three platforms that have been processed so far. Bivalves in the family Arcidae disperse by means of planktotrophic larvae that may remain in the plankton for up to one to two weeks (Chanley and Andrews 1971). Given the closeness of the platforms, for which samples have been processed thus far, it is not surprising that gene flow among them is sufficient to homogenize the populations. Nonetheless, genetic discontinuities have been observed among geographically close bivalve populations when hydrographic barriers exist (e.g., Reeb and Avise 1990). Again, the further processing of samples from platforms located in differing hydrographic regimes may reveal restricted gene flow among populations.

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David Foltz received a Ph.D. in zoology from the University of Michigan in 1979. Since 1983, Dr. Foltz has been a faculty member at Louisiana State University, most recently as a professor in the Department of Biological Sciences. Research in his laboratory is concerned with the molecular population genetics, systematics and evolution of marine invertebrate species.

SESSION 3E

SOCIOECONOMIC ISSUES

Chair: Stephanie Gambino, Minerals Management Service
Co-Chair: Kristen Strellec, Minerals Management Service

Date: January 16, 2003

THE SUPPLY LOGISTICS OF FOUR OCS SERVICE BASES

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Several Gulf of Mexico (GOM) ports have emerged as important Outer Continental Shelf (OCS) logistics centers connecting the onshore supply network with the waterborne offshore segment. An analysis of activities at four major service bases (Port Fourchon, Morgan City, and Iberia, Louisiana and Galveston, Texas) is included in this report. In addition to cargo handling, ports also serve as industrial sites for large shipyards, equipment fabrication and repair, and value-added processing activities for both inputs and outputs of the OCS industry.

PORT FOURCHON

Because of its central location with easy access to the GOM and the availability of efficient port infrastructure, Port Fourchon has developed as the largest supply base for offshore services. The proximity to offshore installations in the Central Planning Area (CPA) and Eastern Planning Area (EPA) and the 300-foot wide navigational channel with a depth of 24 feet are considered to be distinct advantages.

The Demand for Port Services: Empirical Analysis and Forecasts

Using time-series data, demand relationships were estimated for truck traffic, inland barge traffic, and cargo tonnage at Port Fourchon during the 1990s when OCS activities grew at a rapid rate. The number of wells drilled (total number of wells and the number of exploratory wells) and the number of new pipeline miles approved were specified as independent variables in the regression models. The estimates derived from all models were statistically significant and consistent with economic theory. The demand for port services was forecast through 2010 using model results.

Truck Traffic Demand Estimates and Forecasts. During the period 1994 to 2001 truck traffic volumes at the port have increased from 87,000 to 211,000 trips per year indicating an annual growth rate of 13%. The empirical estimat indicated that truck traffic increased by 628 trips for every additional well drilled in the OCS. Truck traffic growth trends derived using model results projected an annual growth rate of 5%, or a 60% cumulative growth of current truck traffic by 2010.

Inland Barge Traffic Estimates and Forecasts. While barge traffic grew at a more modest rate of 4% during the period 1993 to 2001, forecasts indicated 2 to 3% annual growth through 2010 and a cumulative increase of 22%.

Port Tonnage Estimates and Forecasts. The tonnage at the port grew from 3.9 million to 27.2 million between 1992 and 2001, a phenomenal rate of increase of 24% a year. According to the model results, for every exploratory well drilled, 148,500 tons of cargo is generated at the port. The point forecast for port tonnage projected a total tonnage of 50 million in 2010-an annual growth rate of 7 to 8% and an overall increase of doubling the current volumes.

THE PORT OF MORGAN CITY

Morgan City, located at the intersection of several major waterways, is an important onshore supply base specializing mainly in shipbuilding and repair activities.

Empirical Analysis and Forecasts

Since the Atchafalaya River from Morgan City to the GOM is the port's main access channel providing the vital link for the delivery of offshore supply services, vessel traffic on this segment is hypothesized to represent the level of port services. The number of non self-propelled vessel trips was used as the dependent variable in the regression models estimating the demand for port services. The oil and gas industry variables used are similar to what was described for Port Fourchon.

Variable Relationships Between the Number of OCS Wells Drilled and Vessel Traffic. The three regression models specified with different categories of OCS wells as the explanatory variable provided statistically significant parameter estimates and high F-values for the models. The results indicated that for every development well and exploratory well drilled in the OCS, the number of non self-propelled vessel trips will increase by 40 and 13 vessel trips respectively.

Vessel Traffic Forecasts. The forecasts from regression models were compared with the forecasts of vessel trips derived from linear trend extrapolation. The projections derived from models were lower than the trend. For example, while the trend indicated 6900 vessel trips in 2010 with an annual growth rate of about 5%, the median forecast derived from using regression models was about 4.5% in annual growth.

PORT OF IBERIA

The Port of Iberia is located along the Commercial Canal approximately 7.5 miles north of the Gulf Intracoastal Waterway (GIWW), 9 miles north of Weeks Bay on the GOM and 4.5 miles southwest of the City of New Iberia. The location and configuration of the Port of Iberia are strongly influenced by OCS supply activities; the port specializes mainly in platform fabrication, repair, and maintenance.

Demand for Port Services

Since a comprehensive database for quantitative analysis was not available, a qualitative assessment of demand for services at the Port of Iberia was conducted. However, the demand generated by OCS activities and its effects on port planning were clearly evident from the following aspects:

- A survey conducted in 1999 in the port area indicated that 70.6% of the businesses are in some form connected to the offshore supply industry.

- Three distinct stages of port infrastructure investment are evident during the 1990s: projects to provide basic port infrastructure and amenities in the early 1990s; facility expansion projects in the mid 1990s; and projects with public and private sector cost sharing in the late 1990s.

- An analysis of the lease information indicated that the port has leased 279 acres of waterfront property to 47 tenants. With 55% of the land leased beyond 2005, the port is assured of a stable revenue stream for the next 10 to 15 years.

- The key financial indicators for the period 1992 to 2000 indicated favorable growth trends. While operating revenues of the port increased by 205%, operating expenses increased only by 35%, leading to an increase of net income by 170%. Total assets of the port grew by more than 125% during the period.

PORT OF GALVESTON

The Port of Galveston is located on Galveston Bay 9.3 miles inland from the GOM. Galveston's public port facilities are strategically located, providing easy access to the GOM and the inland waterways network. The Galveston Ship Channel, maintained at a minimum depth of 40 feet and 1200 feet minimum width, serves as the main access channel to the port.

Offshore Service Activities and Major Operators

Four major offshore service providers operate from the Port of Galveston.

1. Edison Chouest Offshore Service Center. The Port of Galveston entered into a lease agreement with Edison Chouest for the development of an offshore multi-service terminal in April 2000. The 100-acre site located on port land on Pelican Island is an indication of increase in demand for offshore services in the Western Planning Area (WPA). Edison Chouest plans to develop a multi-service facility known as C Port Galveston. Upon completion, the facility will create a centralized hub for goods and services required for deepwater offshore operations.

2. Deepsea Flexibles, Inc. The port signed a five-year lease agreement with Deepsea Flexibles Inc., in 1999. The firm specializes in the manufacture of flexible pipes for the offshore oil and gas industry.

3. Marine Repair Facility at Pier 14. This facility, operated by Smith-Hamm, Inc. is engaged in repair and maintenance of vessels and offshore rigs.

4. Pelican Island Marine Repair Facility. First Wave/Newpark Shipbuilding-Pelican Island, Inc. is the operator of this 110-acre vessel repair and maintenance facility. The company operates a network of five yards offering repair and maintenance services, new construction and environmental services.

Growth Trends in OCS Services

The port-owned waterfront land at the Port of Galveston increased from about 299 acres in 1965 to about 850 acres in 2000, almost tripling the size of the port. However, the share of port-owned land leased for OCS activities has increased from 4% to 27% during the 1993–2000 period. Overall, the OCS service sector at the Port of Galveston has expanded its capacity during the last decade and is poised to serve the increasing demand for services in the WPA.

OCS SUPPLY SERVICE OUTLOOK

The offshore service activities performed at four GOM ports were examined in this report. After an initial period of market volatility and adjustments, the OCS supply bases have become relatively stable and all ports have embarked on ambitious long-term plans to improve the system. While Port Fourchon continues to invest on port infrastructure expansion, the port is actively involved in improving Louisiana Highway 1, the development of an airport, and deepening the Lafourche navigation channel. The Ports of Morgan City and Iberia are planning the deepening of access channels to the GOM. As observed above, OCS activities at the Port of Galveston have emerged as the major port activity. While expanding OCS activities provide tremendous economic opportunities to coastal communities, public infrastructure planning to accommodate orderly development remains a high priority. The information provided in this research report will be of interest to planning officials directing the regional development effort.

Jay Jayawardana is a research professor and associate director of the National Ports and Waterways Institute at the University of New Orleans. His major interests are in port planning and management, marine transportation, and policy analysis. Dr. Jayawardana was instrumental in developing an evaluation methodology for funding projects under the Louisiana Ports Construction and Development Priority Program. Under this Program, he has evaluated more than 250 intermodal projects for the Louisiana Department of Transportation and Development resulting in $300 million of private and public capital investment in the state port sector. Recently, he has assisted state agencies in Arkansas, Mississippi, and Missouri to plan similar port investment programs.

Anatoly Hochstein is Professor and Director of the National Ports and Waterways Institute, the University of New Orleans. He has a prominent career of over 25 years in the field of water transportation and is well recognized as one of the leading experts in ports/waterways planning. As the first Director of the Institute, Dr. Hochstein is charged with formulating a comprehensive program of research, advisory service, training, and education for the advancement of the maritime industry. His expertise encompasses diversified disciplines ranging from analysis of trade/shipping patterns and institutional and managerial frameworks to fleet operations and preliminary feasibility of structural and non-structural waterway improvements. Dr. Jayawardana has been responsible for a variety of critically important water transportation research projects worldwide, and thus has an intimate knowledge of the international maritime transportation industry, operating in different geographic and economic situations.

ENVIRONMENTAL JUSTICE CONSIDERATIONS IN LAFOURCHE PARISH, LOUISIANA

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Federal agencies must identify any adverse environmental or human health impacts resulting from their programs as a result of Executive Order 12898. Specifically, this executive order states that "each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing…disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority and low-income populations in the United States" (Executive Order 12898 1994). [In effect, this order requests that agencies develop and implement practices to assess/measure environmental justice impacts.] Toward that end, the Minerals Management Service (MMS) has contracted with Louisiana State University (LSU) researchers to develop a means to assess the differential effects of Outer Continental Shelf (OCS) mineral extraction and related support activities on minorities and low-income residents of Lafourche Parish, Louisiana.

Lafourche Parish offers an outstanding location to pilot a method for assessing environmental justice considerations linked to OCS activities. Port Fourchon, the principal staging area for Louisiana's OCS industry, is located near the southern, coastal tip of the parish. Most of the traffic providing supplies to the OCS industry travels along a single highway where the majority of the parish's 89,974 residents live. There is a sizable African-American and Native American population in the parish, along with Asian-Americans and Hispanics. Nearly 20% of the parish population was below the poverty level in 2000. Many local residents who are not directly involved in OCS activity are engaged in commercial fishing, hunting, or trapping in the parish's wetlands or maritime waters. Oil spills, transport accidents, or pipeline leaks could directly impact their livelihoods or the foodstuffs they consume. Although there has been considerable attention paid to environmental justice along Louisiana's chemical corridor, little attention has been paid to populations living within reach of OCS-related activity.

Environmental justice is a subset of a larger range of concerns labeled environmental equity. Environmental justice refers to the equitable treatment of minority and low-income populations under government rules, regulations, policies, laws, permitting, and enforcement actions. The environmental justice movement, at the most fundamental level, seeks to obtain and preserve equitable treatment of all citizens in terms of environmental issues. Environmental equity is a broader term that applies to the existence of disproportionate impacts of environmental disamenities to minority or low-income populations. Environmental inequities can occur despite equitable policies and their enforcement. Several important findings come from our research. First, there are inequities in the distribution of OCS-related activity and minority populations in Lafourche Parish. Other factors, such as income and percent elderly, as well as median rent and house values, were not as significant as race and ethnicity. There are clear distributional variations found across the parish, primarily between the northern and southern portions. In terms of OCS-related activity, much of the onshore support infrastructure, such as shipyards, supply bases and ports, are located in south Lafourche, where there is easy access to water transport. On the other hand, the onshore OCS-support facilities, such as pipelines, gas processing plants, and petroleum storage facilities, are much more geographically dispersed.

There is a corresponding north-south division in Lafourche Parish's minority population. South Lafourche, in addition to housing most of the OCS-related onshore infrastructure, is home to the much of the parish's Native-American population. This population historically settled in south Lafourche because of the easy access to waterways and open areas for hunting, fishing, and trapping. These same territories are also vital pathways for OCS-related activities. Conversely, north Lafourche is much more urbanized than south Lafourche. Thibodaux is the largest urban center in Lafourche Parish and is also home to a large portion of the parish's African-American population. This population historically has not settled in the wetlands and bayous of south Lafourche, opting instead to locate in various agricultural regions and urban centers. Asians and Hispanics, unlike both the Native-American and African-American populations, tend to be much more dispersed geographically, although they are largely concentrated along the Louisiana Highway 1 transportation corridor and in Thibodaux

Our results show that Native Americans, more so than any other population, are much more likely to live in close proximity to most OCS-related facilities, although there are some variations, particularly when considering the onshore OCS-related infrastructure. For example, Native Americans are the least likely to live in close proximity to petroleum storage facilities, which are located in the Port Fourchon area and in Thibodaux. Conversely, the African-American population is the least likely minority group to be found residing near the OCS-related infrastructure, due to that population's concentration in north Lafourche and Thibodaux.

This analysis presents only a snapshot of Lafourche Parish in the year 2000. Though inequities are indeed present, we have not analyzed the processes underlying this situation. In other words, we have attempted to establish the geographic relationship between OCS-related activity and vulnerable populations and not causality. Nonetheless, this research provides MMS and other agencies involved in the planning process with valuable information on the potential impacts of increasing OCS activity on various vulnerable populations. Though OCS-related activity has not targeted minority groups, some have the potential to be disproportionately effected.

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Scott Hemmerling is a Ph.D. student at Louisiana State University. He earned his B.S. from State University of New York, Buffalo, in 1992 and worked as an environmental consultant in upstate New York. Subsequently, he earned an M.S. in urban studies at the University of New Orleans. His dissertation research is on environmental justice in coastal Louisiana.

WHY THE DIFFERENCE? OCS OIL AND GAS AS NOXIOUS BURDEN IN PENSACOLA, FLORIDA, AND WELCOME OPPORTUNITY IN PANAMA CITY, FLORIDA

Patrick Moore, University of West Florida

This Minerals Management Service study focused on two Florida Panhandle Metropolitan Statistical Areas (MSA) containing deep-water ports: Pensacola and Panama City. Throughout the second half of the twentieth century, these two communities each faced specific challenges to their respective development. Stemming from their economic, geographic, and social structures, these cities made specific choices pertaining to the growth of their communities.

Historically isolated from external economic and political conditions, the Second World War transformed the two cities' social, political, and economic structures. As a result of federal spending during and after the war, the nature of these cities forever changed (Rice and Bernard 1983). Between 1940 and 2000, as a direct result of World War II and Cold-War federal programs, new infrastructure developments, tourism, and retirement migration, Florida's population increased by 743% (Rice and Bernard 1983). The two key communities of the Florida Panhandle also experienced similar change as the combined population grew 466% (U.S. Census Bureau 1995).

For Pensacola, military ties were always an integral part of the economy and population. After serving as an important military defensive site for Spain, France, Britain, and the United States (U.S), Pensacola was selected by the U.S. Navy in 1914 as the country's first naval aeronautical center (Bordelon *et al.* 1989). Serving as "The Cradle of Naval Aviation," Pensacola expanded its existing federal ties during and after the Second World War (U.S. Navy 1999). With the largest and most diverse economy in the Panhandle, Pensacola capitalized on this period of growth, as its population grew 294% between 1940 and 2000 (U.S. Census Bureau 1995).

While Panama City based its early economy on tourism, World War II military activity caused the town's population to double between 1940 and 1950 (Smith 2000). The U.S. Navy's site for mine and countermeasure-warfare testing, naval-ship research, and amphibious training later became Tyndall Air Force Base (Bay County 1992). Because of these federal operations and, later, from a renewed and growing tourism economy, between 1940 and 2000 the population in the Panama City MSA grew 617% from 20,686 to 148,217 residents (U.S. Census Bureau 1995).

Because of the heavy reliance on federal monies as the staples of these two economies, the populations made specific choices about growth within their respective towns. Despite their similar origins, during the last half century the two towns gradually separated in their views toward growth and their acceptance of, or resistance toward, economic development from tourism, industry, and OCS-related activities. Based upon material research, focus groups, and oral history interviews, the findings illustrate the differences between the two communities and indicate the reasons behind the populations' views and choices.

For the Pensacola MSA, which contains the city of Pensacola as well as Gulf Breeze, Pensacola Beach, Milton, and Pace, the population has generally adopted limited-growth policies toward development of new industry and tourism and no-growth policies toward OCS activities. Stemming heavily from the federally-supported economy, many residents see few benefits in encouraging development that will arguably have a negative impact on quality of life issues including traffic, taxation rates, property values, congestion, and pollution. Although many recognize the potential benefits associated with growth, including improved services and resources, many do not believe that these outweigh the associated potential burdens. While these attitudes have dictated the MSA's development, issues associated with OCS activities incur an even greater resistance. Familiar with the impact of gas and oil operations on Gulf Coast communities west of Pensacola from Mobile, Alabama to Galveston, Texas, the potential environmental consequences heavily outweigh any possible benefits. As one respondent suggested, residents, faced with a potential change to their quality-of-life perspectives, overwhelmingly support a "not in my backyard kind of philosophy" (Cochran 2002).

During the first several decades after WWII, Panama City generally adopted similar no-growth positions to that of Pensacola. For the beach-front area that experienced little direct federal funding, tourism revenues provided the staple of the economy. Faced with increasing differences between no-growth proponents in Panama City and pro-growth supporters along the beach, in 1970 the differences led to the incorporation of Panama City Beach (Smith 2000). From this point, the support of development by Panama City Beach led to constantly increasing growth, revenues, and economic influence. At the same time, Panama City maintained their limited- and no-growth policies and ultimately witnessed diminishing political authority within in the MSA. With respect to OCS activities, respondents within Panama City Beach believe that increased oil and gas activities would be a welcome benefit to the economy, but Panama City maintains control over the port facilities, limiting any significant development.

For Pensacola, the potential for OSC activities faces heavy resistance. Because of the community's no-growth attitudes, resistance to oil and gas development stems not only from concern over environmental damages to the pristine white-sand beaches but also (and in many respects to a greater extent) from the desire to maintain the existing social, economic, and political structures within the city. Although there is a growing minority pro-growth voice within the community, these respondents recognize that even with support of OSC activities the community would see few long-term benefits (Luke 2002). Because of the limited existing infrastructure in Pensacola, the majority of oil and gas related jobs and revenues will unquestionably benefit better-equipped port cities to the west such as Mobile and beyond. The combinations of these factors leave few supporters on either side of OSC activities within Pensacola.

The Panama City MSA, in contrast, faces a less galvanized population in respect to growth and development. While a significant contingent in Panama City proper resists the development of OCS activities, the pro-growth base in Panama City Beach views the potential of gas and oil related industry as a potentially new and important revenue source for the region. Unlike Pensacola, whose western neighbors maintain the resources for OSC development, Panama City sees its competition as the port cities farther east and south along the Florida Gulf of Mexico Coast. While some concern exists about the potential environmental impact on the tourism base, most believe that the economic benefits would likely outweigh these improbable burdens.

Despite the dissimilarity between the two MSA's in terms of growth attitudes, the role of the federal government has led to the creation of an intriguing coastal anomaly. Stemming from the strong military economic infrastructure between Panama City and Pensacola, including the coastal areas of Destin, Fort Walton Beach, and Mary Esther, little of the overall economic activity is water-based, including shipping or OSC activity. Beyond recreational-based tourism and a nominal fishing industry, the vast majority of the Florida Panhandle economy is land-based. Even with the presence of the U.S. Navy at N.A.S. Pensacola (as the majority of other military installations are Air Force), as the "Cradle of Naval Aviation," this too is almost exclusively land-based with no major naval vessels using the facilities as its home port. Unquestionably, the influence of the federal government dictated the use of the region and influenced the choices—past, present, and future—of the resident populations.

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Patrick Moore is an Assistant Professor of History and the Director of the Public History Program at the University of West Florida. Dr. Moore specializes in Cold War and policy history. In addition to MMS projects, his projects and publications include studies of the influence of the federal government through military and Department of Energy operations on community structures. Other projects include studies for the Soil Conservation Service, the United States Navy, and most recently a monograph for NASA's Kennedy Space Center on the history of Public Affairs and their ties to press and visitor operations. In an effort better to communicate and "use" historical knowledge and findings, He has collaborated with University of West Florida Institute for Human and Machine Cognition in developing History Concept Mapping models for the preservation and interpretation of history and the past.

ECONOMIC EFFECTS OF CHANGES IN CRUDE OIL PRICE AND PETROLEUM PRODUCTION FROM STATE OFFSHORE WATERS IN LOUISIANA

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INTRODUCTION

Most studies of national economies have concluded that changes in oil price affect macroeconomic aggregates and hence, the growth of economies. The effects of oil price changes on the national economy are generally understood; however, the impacts of such changes on state or sub-regional economies are less fully examined. Few studies (Brown and Hill 1988; Brown and Yucel 1995; Yucel and Guo 1994) have studied the impact of world oil price declines or increases on state economic performance. Most of these studies, unlike national studies, tend to show that rising oil prices stimulate economic growth in oil-exporting states and retard growth in oil-importing states. The converse is true for declining oil prices.

Changes in oil price do affect revenue and income of communities in nations where the oil and gas industry looms large in the economy. For most oil producing regions, oil-tax revenue is a major source of fiscal revenue. Thus, a decline or increase in firm's profits can influence this tax base significantly. Further, an increase in oil price can induce cost-cutting measures by firms, with labor inputs the most easily affected. To get to equilibrium following an energy price increase, firms cut output, employment, and wages; thus, household income is negatively affected.

This study was motivated by Mineral Management Service's (MMS) desire to undertake additional socioeconomic studies on the economic impact of the oil and gas industry on communities around its jurisdictional mandate. The focus on Louisiana in this study is motivated by the fact that the economic and social life in the state, especially in the coastal communities, is tied to the exploration and production (E&P) activities of the oil and gas industry operating in the region. Apart from providing direct jobs, E&P operators in the state also generate severance tax revenues plus royalty and cash bonus payments for state leases. Louisiana has been a leader in petroleum exploration, development, and production among oil producing states. It is the third leading producer of natural gas and fourth leading producer of crude oil in the United States (U.S.). Moreover, if production activities in the federal Outer Continental Shelf (OCS) are included, then the state is the second and third leading producer of gas and oil, respectively, (http://www.lmoga.com/industryoverview.html). However, in more recent years, a larger proportion of oil and gas production in Louisiana comes mostly from the federal OCS area, outside the tax jurisdiction of the state.

DATA AND DESCRIPTION

Oil and gas production data were obtained from the Center for Energy Studies' (CES) oil and gas database. The oil price series used is the crude oil producer price index deflated by the all commodities price index series, both available from the U.S. Bureau of Labor Statistics. Data on employment levels for Louisiana was taken from the U.S. Bureau of Economic Analysis (BEA). The

BEA also provides a reliable source for the following series: Louisiana personal income and revenue; U.S. real gross domestic product (GDP), GDP implicit deflator and interest rates (measured as the Federal Reserve's three-month treasury bill rate). All data are annual series spanning the period 1969 to 1998. A brief *raison d'etre* of selecting revenue, employment, and personnel as key economic performance indicators are given below:

- Revenue: Louisiana currently derives about 14.2% of its total tax revenue from oil and gas industry activities in the state; this is a far cry from what it used to be in the 1980s, when the proportion of total tax revenue from the oil and gas industry was between 25–30%.
- Employment: A lot of people in Louisiana are employed directly or indirectly in the oil and gas sector; hence, any unusual developments in the sector will reflect on the state's welfare; unemployment levels is one such closely watched variable.
- Personal Income: Apart from the substantial number of jobs in produced by the oil and related sectors, wages in the oil sectors are often higher than other sectors; thus, overall personal income levels in the states may be affected by downturns or booms in the oil sector.

Figures 3E.1 through 3E.5 display the trends in crude oil price, state offshore oil production in Louisiana waters, employment, personal income, and revenue over time. Clearly, the trend in oil price shows three distinct patterns of growth over the period examined: a period of slow growth in the early 1970s and a period of gradual decline in the mid to late 1980s and in the 1990s. In between these periods were a period of sharp increase and a sharp decline. Surprisingly, oil production from state offshore waters in Louisiana has been declining since the early 1970s. This pattern of production even in the periods of rising oil price is likely to be as a result of a combination of factors including slow diffusion and adoption of new completion technology, basin maturity, well completion rate, and different price formation and expectation by economic agents over the period. Of course the shift in focus of E&P to the federal OCS and other emerging frontiers may equally have been a factor

The three key macroeconomic variables we selected have generally trended upward as expected. However, it is interesting to note that employment appears to have undergone some distinctive adjustment in the 1980s when oil price was particularly high and was accompanied by general recession in the U.S. A summary of the data used presented in Table 3E.1.

STUDY METHODOLOGY

A vector auto-regression (VAR) approach is used to examine the effects of price changes and production on aggregate economic indicators in Louisiana. The VAR is commonly used for forecasting systems of interrelated time series and for analyzing the dynamic impact of random disturbance on the system of variables. In this formulation, every endogenous variable is modeled as being dependent on its own lag(s), and on other endogenous variables and their lags. Exogenous variables may also be included.

Table 3E.1. Summary statistics of the data employed.

	RCPPI	PROD	RLAPI	RLAREV	RGDP	TRBR	LAEMP
Mean	56.96225	32.94452	43.69815	5.965803	5614.567	6.723222	1.906032
Median	51.65565	25.96980	45.95101	5.735367	5318.750	6.185000	1.966935
Maximum	111.8367	72.06320	62.59143	8.793051	8515.700	14.02500	2.369388
Minimum	28.69775	10.06149	25.21061	3.500994	3571.400	2.997500	1.429470
Std. Dev.	20.53012	17.24180	10.71933	1.582245	1460.688	2.504792	0.264646
Skewness	1.157421	1.249315	-0.215878	0.210916	0.315068	1.020208	-0.379893
Kurtosis	3.462524	3.402055	2.066761	2.000067	1.945754	3.852844	2.286749
Jarque-Bera	6.965525	8.006004	1.321686	1.472259	1.885630	6.113297	1.357500
Probability	0.030722	0.018261	0.516416	0.478964	0.389530	0.047045	0.507251
Sum	1708.868	988.3356	1310.944	178.9741	168437.0	201.6967	57.18097
Sum Sq. Dev.	12223.09	8621.106	3332.220	72.60147	61874657	181.9455	2.031088
Obs	30	30	30	30	30	30	30

where:

RCPPI = real oil price index
PROD = oil production in million bbl
RLAPI = real personal income in million $
RLAREV = real revenue in million $
RGDP =real gross domestic product in million $
TRBR = Treasury bill rate (in %)
LAEMP =employment levels in millions

Equation (1) depicts an example of the VAR model estimated to explain the interaction between Louisiana employment, oil production in the state offshore, and changes in crude oil price. Similar systems of equation are also formulated and estimated to evaluate the interaction between oil price, oil production, and state revenue, as well as the interaction between oil production, oil price, and personal income.

$$cppi = cons\tan t + \sum_{i=1}^{3} \beta_i^{cppi} prod_{t-i}^{ocs} + \sum_{i=1}^{3} \gamma_i^{cppi} cppi_{t-i} + \sum_{i=1}^{3} \omega_i^{cppi} trb_{t-i}$$

$$+ \sum_{i=1}^{3} \varphi_i^{cppi} gdp_{t-i} + \sum_{i=1}^{3} \delta_i^{cppi} laemp_{t-i}^{cppi} + \mu_t^{cppi}$$

$$prod^{OCS} = cons\tan t + \sum_{i=1}^{3} \alpha_i^{OCS} laemp_{t-i}^{ocs} + \sum_{i=1}^{3} \beta_i^{OCS} prod_{t-i}^{ocs} + \sum_{i=1}^{3} \gamma_i^{OCS} cppi_{t-i} +$$

$$\sum_{i=1}^{3} \omega_i^{OCS} trb_{t-i} + \sum_{i=1}^{3} \varphi_i^{OCS} gdp_{t-i} + \mu_t^{OCS}$$

$$laemp = cons\tan t + \sum_{i=1}^{3} \alpha_i^{emp} laemp_{t-i}^{emp} + \sum_{i=1}^{3} \beta_i^{emp} prod_{t-i}^{ocs} + \sum_{i=1}^{3} \gamma_i^{emp} cppi_{t-i}$$

$$+ \sum_{i=1}^{3} \varphi_i^{emp} gdp_{t-i} + \sum_{i=1}^{3} \delta_i^{emp} tbr_{t-i}^{emp} + \mu_t^{emp}$$

Equation (1)

where:

cppi = log of crude oil price index
prod = log of oil production in the offshore waters of Louisiana
trb = the U.S. three-month Treasury bill rate in levels
gdp = log of U.S. real gross domestic product
laemp = Louisiana employment levels

EMPIRICAL RESULTS AND ANALYSIS

Variance Decomposition

The variance decomposition procedures provide a way to decompose the effect of a shock to its component sources. We estimated Equation (1) over the sample period and used the result to decompose the historical values of employment, personal income, and revenue. The decomposed values measure the percentage share of each particular shock (innovation to the one-step ahead forecast errors of a dependent variable). These values provide an indication of the relative magnitude or importance of individual shocks in determining the observed variations in each variable. Table 3E.2, Table 3E.3, and Table 3E.4 present some of our estimated results.

The results in Table 3E.2 show that most of the observed variation in employment in Louisiana is explained by employment's own internal dynamics. Although employment explains up to 80% of its own variation initially, by the third period (i.e., year) it has stabilized at only about 60%. The rest

Table 3E.2. Variance decomposition of Louisiana employment (LAEMP).

Period	S.E.	RCPPI	PROD	LAEMP
1	0.014042	19.53977	0.043355	80.41688
2	0.016670	38.74775	0.179632	61.07262
3	0.016909	38.93415	1.377332	59.68852
4	0.016922	38.94094	1.434458	59.62460
5	0.016925	38.94648	1.439996	59.61352
6	0.016926	38.94842	1.440647	59.61093
7	0.016926	38.94908	1.440854	59.61006
8	0.016926	38.94906	1.440923	59.61002
9	0.016926	38.94906	1.440924	59.61002
10	0.016926	38.94906	1.440924	59.61001

Table 3E.3. Variance decompositions of Louisiana personal income (RLAPI).

Period	S.E.	RCPPI	PROD	RLAPI
1	0.016444	6.941654	2.927364	90.13098
2	0.020302	23.01235	4.469333	72.51832
3	0.021216	24.29308	6.082681	69.62424
4	0.021494	24.42441	6.911991	68.66360
5	0.021581	24.40654	7.265357	68.32810
6	0.021609	24.38794	7.399870	68.21219
7	0.021618	24.37923	7.447516	68.17325
8	0.021620	24.37589	7.463587	68.16052
9	0.021621	24.37472	7.468825	68.15645
10	0.021621	24.37433	7.470490	68.15518

Table 3E.4. Variance decompositions of Louisiana revenue (RLAREV).

Period	S.E.	RCPPI	PROD	RLAREV
1	0.046219	13.47064	7.233741	79.29562
2	0.049089	12.42080	9.729911	77.84929
3	0.050865	13.47620	13.82770	72.69610
4	0.053710	14.01228	12.87557	73.11215
5	0.056304	13.64094	12.82049	73.53856
6	0.056459	13.56644	13.16931	73.26425
7	0.056754	13.99074	13.18369	72.82557
8	0.057501	13.83699	12.86506	73.29795
9	0.057660	13.79275	13.20571	73.00153
10	0.057675	13.79812	13.20718	72.99470

of the variation in employment is explained by oil price (up to 39% in the third period). Hence, oil price continues to play a very important role in shaping Louisiana employment within the context of oil production in state waters. However, oil production in state waters appears to have only a small effect on Louisiana's total employment level.

Table 3E.3 shows that crude oil price explains 90% of the variation in Louisiana personal income initially then stabilizing at about 68% in the fifth year. As expected, the impact of a change in oil price on Louisiana personal income is significant. It seems to account for as high as 24% of the observed variation in income by the third year. The effect of state offshore production on personal income subsequent to a change in price although bigger than that on employment, it is under 10% and statistically not significant.

In Table 3E.4, the decomposition results for revenue indicate that Louisiana revenue is responsible more for its own variation than employment and personal income are responsible for their variations (over 70.5% over time). The effects of oil price and state offshore production on revenue seem to be about the same (about 13%).

IMPULSE RESPONSE DYNAMICS

Impulse response function is another technique for characterizing the dynamic effects of an unexpected shock in a given economic system using VAR representation. The response function allows us to examine the dynamic paths of the effects of an exogenous shock of one variable on other variables and to further characterize the stability and duration of such effects. The persistence of such a shock reveals how fast it will take the system to return to equilibrium. The faster it takes a shock to dampen, the shorter the adjustment period (Brown and Yucel 1999).

Figures 3E.6 through 3E.8 display the impulse response subsequent to a one standard deviation shock to growth rate in oil price. The dashed lines indicate 95% confidence bounds for the response. The value on the x-axis indicates the forecast horizon and the y-axis represent the growth rate of the variable. As expected, employment rises in response to a one-time positive shock to price (Figure 3E.6). This response reaches its highest levels in the second period, about 0.8 above its initial equilibrium level. This response is also shown to be statistically significant during this period. Afterwards, employment declines gradually towards its long run equilibrium levels. However, the response after two years is insignificant, indicating a relatively quick adjustment of employment levels to price changes.

The dynamic response of Louisiana personal income to price and the subsequent state offshore oil production dynamics are displayed in Figure 3E.7. A positive shock to price initially leads to an expected positive response from personal income. However, the initial response is insignificant, indicating that the full significant response is not realized until production effect has been fully realized. Thus, personal income reaches its highest significant levels in the second period and remains significantly so for another six months as it declines towards equilibrium levels.

In Figure 3E.8, revenue response to oil price shocks is shown to be initially positive as expected. The response rate in revenue is clearly higher than the response rate for employment and personal income starting at about 2% in the first period. However, the succeeding lower levels of response are insignificant. An important observation for revenue response is that it shows a distinct cyclical pattern over time. The implication of this is that shocks to oil prices and the subsequent offshore production path may be more destabilizing to Louisiana fiscal plans than they are to employment or personal income. However, for the overall economy such destabilizing trends are not statistically significant, keeping in perspective the state offshore oil production path.

Although a positive response from all these macroeconomic aggregates to positive price shocks is expected, it is quite possible to observe negative responses along their time-paths. This is true for employment in the fourth to sixth periods, and for revenue in several periods after the first. The reason for this is that the VAR is constructed to include feedback responses from all other endogenous variables in the system. It is possible to examine these responses in terms of their cumulative pattern over time, so that the net effects are reflected for each variable. The results presented in Table 3E.5 are based on the cumulative response to a 20% shock in crude oil price. The cumulative responses of all the variables are positive over time, but they are not significant beyond the third period and fifth period for employment and personal income, respectively. On the other hand, the positive cumulative response is only statistically significant for revenue in the first year.

SUMMARY AND CONCLUSIONS

In this study, we estimated a 3-VAR model to analyze the impact of changing oil price and state offshore oil production on Louisiana economy. The main hypothesis is that the impact of oil price

Table 3E.5. Cumulative response to one standard deviation shock to price.

Macroeconomic Aggregate			
	Employment	**Personal Income**	**Revenue**
Accumulated Growth Rate	1.69	2.0	2.3
Peak Period	4	6	7
Macroeconomic Effect	25,155 jobs	$623.4 million	$99.36 million

One standard deviation shock to price growth equals about 20% growth rate.

on state economic aggregates would mostly be positive, keeping in perspective oil industry activities. From our results and analysis, when only considering state offshore oil production, we conclude that

- Changes in oil price still significantly affect economic performance and growth in Louisiana.
- A shock to oil price can significantly affect employment levels and personal income growth, but the effect of such a shock on revenue growth, seems to be currently less important beyond its initial effect.
- The effect of a price shock on revenue, though less significant, is still more potentially destabilizing than the effect of a price shock on personal income and employment, especially in the short run.
- A 20% shock to crude oil price can lead to about 25.2 thousand new jobs, add $623.4 million to personal income, and add $99.6 million to revenue at the corresponding peak periods.

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THE RELATIONSHIP OF CRIME TO OIL DEVELOPMENT IN THE COASTAL REGIONS OF LOUISIANA

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INTRODUCTION

This research focused on the question of the influence of cycles in the oil industry on levels of crime in the coastal parishes of Louisiana. This question is part of a line of discourse that has emerged through the application of the "boom town" analogy in the interpretation of the effects fluctuations in the oil economy may have had on communities. While some past research has shown a relationship between periods of rapid change ("boom-bust") in the oil and gas economy and homicide and suicide rates (e.g. Seydlitz, *et al.* 1993), much of the literature is anecdotal or is characterized by methodological problems. The theoretical reasoning associated with the expectation that boom and bust will create social problems such as higher crime is premised on the logic that consequences of rapid expansion and contraction are increasing relative deprivation, due to the uneven distribution of economic gain, and disruption or disorganization of community institutions, thus reducing the effectiveness of social control. To examine this general proposition, the present study involved qualitative and quantitative strategies to determine the impact of cycles in the oil industry and crime. We conducted guided conversations with key subjects, and developed a data set on crime patterns in oil-involved parishes in Louisiana's coastal region and in a comparison group of non-oil-involved counties over a 25-year period (1974–98). Here we focus on quantitative findings for violent crime only (assault, homicide, and robbery). The qualitative data suggest, at least in the perception of community participants, there is little if any relationship between flux in oil activity and crime. Analysis of the crime rates reveals a similar pattern, at least with regard to the crimes included here.

QUALITATIVE DATA

It is often suggested that the social and economic impact of the oil and gas industry has contributed to a number of social problems. Much of the evidence which suggests such a connection has been speculative, limited in scope, and inconclusive. One of the unique features of oil and gas extraction and other sorts of mining activity is its cycle of expansion and contraction. As noted, it has been suggested in the literature this pattern is analogous to that occurring boomtown communities. Our interviews with law enforcement and public officials find little to support the relationship between oil development and crime.

The qualitative data indicate two themes. The first theme respondents offered was that minor criminal episodes are part of a long standing tradition in these communities. Indeed, the boom/bust cycle itself is an understood and accepted part of the community having little to do with changes in crime. The following statement by a long-time police officer reflects this view:

> I see seafood docks, shrimpers, welders, carpenters…construction workers in general, they have always existed in a boom/bust economy, you recognize what it is that there is not a steady flow and you live like that—you make enough in the boom to make it through the down cycle…I guess if you don't know that and if you are a mind set to commit crime—then you will—but it seems a bit farfetched to me—most people experience boom bust times and never get involved in crime.

A local jail warden stated:

> The crime rate in this parish has been low and constant…we reflect national trends…oil goes up and down and crime is in no way related to that.

A second less typical theme expressed was the notion of a long standing conflict, suggested in the "boom town" literature, that are the fault of communities' old-timers who benefited from the need for labor and did so at the expense of the community. Our findings suggest this problem has been minor and never reached the level of seriousness suggested in the literature. For example, one respondent (a sheriff) stated:

> We had these labor dorms that the----ran… those guys made a fortune…they brought in the scum of the earth…that's the problem not oil…its those guys…in the last few years people have started recruiting skilled labor from foreign countries…these people are no problem…there is no relationship between oil and crime or the cycle of that activity…its just the labor supply…if you need unskilled labor and you also have to rely on some criminal who runs a labor camp then you have problems with that bunch…that was the problem not any boom/bust cycle…I cannot believe some of the crap that people brought into their own communities…those days are over and crime has never had anything to do with offshore drilling…criminals came in here when criminals were in charge of labor camps…and let me say that these workers did nothing bad just a pain in the ass nuisance.

A small town police officer's remarks were consistent:

> During the 70s/80s boom we had lots of low class characters coming in as labor—they had little work history; when bust hit they hung around; they created some minor problems. Last time we had labor coming in but they had a work history; they came to work—good people no problem; lots of them lived in trailers together; when things slowed down they found work in other places quickly; goes to show you that the boom bust cycle is not the problem and neither is oil.

Many responded that the comments regarding these labor camps were unfounded, and that they presented no problems.

Overall, the qualitative data indicates that the boomtown literature on crime and social problems may not be applicable to offshore oil. If one looks at the company/mining towns of the Southwest, the concept perhaps is applicable. The town disappears or nearly does. The demand for offshore oil never stopped. It has moved up and down, but the ideology is that it will return because the demand is always there. Oil like other industries or the jobs associated with it, has a varying demand. One learns to survive in it. Some scholars are guilty of looking to confirm the accepted notion of boom/bust rather than being open to evidence that may disapprove it.

QUANTITATIVE ANALYSIS

Following Seydlitz *et al.* (1994), we examine the parishes in Louisiana that are the most involved in oil and gas extraction. They identified these parishes based on the percentage of persons employed in oil and gas extract and the percentage of income of parish residents derived from oil and gas activities. To answer the question of the effect of the oil industry on crime in these political units, we used two strategies. First, for each parish we identified two United States (U.S.) counties with little or no petroleum involvement, but which had experienced similar growth patterns across the three census periods 1970, 1980, and 1990. Comparing variation in crime rates in the parishes with those of the counties across time was a first step in identifying whether there is uniqueness to crime patterns that may be associated with the oil/gas economy present in the Louisiana parishes, or whether the variation represents more general trends. Second, we examined the data using pooled time-series models that allowed us to correct for the possibility of distortion due to autocorrelation and to statistically control the effect of oil activity on crime.

When we plot the crime rates across time (1974–98) there are some differences between the parishes and comparison counties. For assault rates, the oil-involved parishes are consistently higher, with peaks in 1980 and 1992, but both rise across the period. Homicide rates are more unstable, particularly for the parishes (not unusual for a low frequency event) and there is a peak in 1981 in the parish rate. Robbery rates, like assault, showed a tendency to increase over the period with notable peaks above the control counties in 1983 and 1990. When we examined the annual mean differences, the t values did indicate the possibility of a significant association between the boom/bust years of the late 1970s and 80s and a rise in assault and homicide. The parish means for assault rates were significantly different (higher) in 1976–1985, as well as for homicide rates in 1981–1983. There were no significant differences for robbery. The critical question, however, is whether change in oil industry activity produced these differences, or if other, more general period effects and trends are creating the difference independent of oil activity.

While comparison of mean levels of assault and homicide suggests that change in oil activity may be tied to higher rates of assault and homicide, using pooled time-series models that correct for autocorrelation shows little relationship between change in the oil industry (measured by employment in it) and variation in these crime rates. In these models, we used annual employment in oil and gas extraction, annual population, and previous year’s crime rate as predictor variables for annual parish crime rate. For all three models (assault, homicide, and robbery) oil and gas employment fails to be a significant predictor of violent crime rates. The implications of these results is that an explanation of violent crime patterns is most likely found in exiting or emergent social structural features that are independent of cycles in oil activity, as some of our interview subjects implicitly recognized. This, however, would not preclude the possibility of such an influence on other forms of crime.

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SESSION 3F

ENVIRONMENTAL FATES AND EFFECTS OF DISCHARGES

Co-Chairs: Mary Boatman, Minerals Management Service
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SYNTHETIC BASED DRILLING FLUIDS: AN INTRODUCTION

Mary C. Boatman, Minerals Management Service

Synthetic based drilling fluids (SBF) are fluids whose continuous liquid phase is a synthetic organic compound. Some examples of the compounds used for the liquid phase are internal olefins, poly-alpha olefins and esters. The fluids were developed to replace the use of oil based fluids (OBF), which consisted of mineral oil or diesel. The discharge of OBF or the cuttings generated through the use of OBF is strictly prohibited because of the toxicity of some components of the fluids. The use of an organic liquid phase as opposed to the commonly used water phase is necessary to address problems of stuck pipe, deviated wells, and for deepwater wells. In deepwater environments, organic based fluids also help prevent the formation of hydrates and improve well control. Synthetic fluids also demonstrate a lower persistence in the environment and lower toxicity relative to OBF. Discharge of cuttings generated from drilling with the more environmentally friendly SBF is allowed.

Synthetic based drilling fluids (SBF) were first used in the Gulf of Mexico (GOM) in 1992. Generally, when using SBF, the upper few hundred feet of a well is drilled using conventional water based drilling fluids (WBF) and the lower part of the well is drilled with SBF. The discharge of the fluid is prohibited, and unused fluid is returned to the mud company for recycling. Discharge guidelines for cuttings generated from drilling with SBF are incorporated into the National Pollution Discharge Elimination System (NPDES) permits for facilities in the central and western GOM. The permission is predicated on the completion of a survey of the environmental effects.

The environmental concerns with using SBF are both spatial and temporal: the distribution on the seafloor of the discharged cuttings and the biodegradation of the cuttings. The Environmental Protection Agency evaluated the use of SBF and produced guidelines for their use in “Synthetic-Based Drilling Fluids in the Oil and Gas Extraction Point Source Category—Effluent Limitations Guidelines and New Source Performance Standards” (Federal Register, 22 January 2001). These guidelines were incorporated into the Region IV general permit on 16 February 2002.

The Minerals Management Service (MMS) has funded several studies to examine the fates and effects of SBF on the seafloor in the Gulf of Mexico. A literature review was completed in 2000 (MMS 2000-064). The MMS has joined with the Department of Energy and industry in sponsoring a study of the spatial and temporal distribution of discharges on the continental shelf and upper slope. The MMS is funding a study of the fates and effects of discharges at deepwater sites (1000 meters) from both drilling sites and production facilities. A laboratory study into the degradation rates of SBF under the conditions found in deepwater is also being funded by MMS. The results thus far from the three ongoing studies are presented in this session of the Information Transfer Meeting.

Mary C. Boatman, an Oceanographer with the Gulf of Mexico Region of the Minerals Management Service, has worked on several water quality issues for MMS, including the use of synthetic based drilling fluids. She received her Ph.D. in chemical oceanography from Texas A&M University.

EFFECTS OF OIL AND GAS EXPLORATION AND DEVELOPMENT AT SELECTED CONTINENTAL SLOPE SITES IN THE GULF OF MEXICO

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Continental Shelf Associates, Inc. and its subcontractors/consultants are conducting a multi-year study to assess the impacts of oil and gas exploration and development at four selected sites on the continental slope in the Gulf of Mexico (GOM). Two exploration sites were sampled before and after drilling, and three post-development sites were studied once, after drilling was completed. (Figure 3F.1). The two exploration sites, Garden Banks Area Block 516 and Viosca Knoll Area Block 916, were located in water depths of about 1000 m, and the two post-development sites, Mississippi Canyon Area Block 292 and Garden Banks Area Block 602, 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.

The program has two components: physical characterization and chemical/biological characterization. The objective of the physical characterization is to determine the physical impacts of the operations including 1) areal extent and accumulation of muds and cuttings; 2) physical modification/disturbance of the seabed due to anchors and their mooring systems; and 3) accumulation of debris due to operations. During the first cruise in Fall 2000, one exploration site, Viosca Knoll Area Block 916, was surveyed prior to drilling. At this site, data were collected with a deep-towed side-scan sonar and sub-bottom profiling system to prepare acoustic reflectivity maps. During the second cruise in Summer 2001, similar data were collected at the two post-development sites and at the Garden Banks Area Block 516 exploration site (post-drilling) with an autonomous underwater vehicle. Post-drilling data were not collected at Viosca Knoll Area Block 916 because the planned well was removed from the drilling schedule between the first and second cruise.

The objectives of the chemical/biological characterization are 1) to determine the extent of physical/chemical modification of sediments in the immediate area of the wellsites, compared to sediment conditions at reference sites (and before drilling in the case of exploration sites) and 2) to conduct limited biological collections to determine biological effects related to chemical and physical impacts. During the first cruise, pre-drilling sampling was conducted at the two exploration sites. During the second cruise, post-drilling sampling was conducted at the Garden Banks Area Block 516 exploration site and at the two post-development sites. Post-drilling data were not collected at Viosca Knoll Area Block 916 during the second cruise because the planned well was removed from the drilling schedule between the first and second cruise. This well was subsequently spudded in November 2001, and post-drilling sampling was conducted at this exploration site in August 2002.

During each cruise, box core samples were collected at 12 locations within 500 m of each exploration/development site, and two box cores were collected at each of six reference sites located at least 10 km from each exploration/development site. Sediment grain size, mineralogy, texture, radionuclides, metals, total organic carbon, and hydrocarbons were analyzed. Samples for pore water, redox chemistry, and sediment toxicity (10-day acute test) also were collected. Sediment profiling imagery transects were performed near each site and at two of the corresponding reference sites. The biological community was sampled using a box core, still photographs, and bottom traps. A number of biological parameters are being measured: 1) microbiotal activity, biomass, and community structure; 2) meiofauna taxonomy including harpacticoid taxonomy/genetic diversity/reproductive status and nematode feeding groups; and 3) megafaunal taxonomy and metal/hydrocarbon concentrations in tissues of selected animals.

An initial analysis of the geophysical, hydrocarbon, and macroinfauna data collected at Viosca Knoll Area Block 916, Mississippi Canyon Area Block 292, and Garden Banks Area Block 602 study sites revealed several preliminary conclusions:

- Based on interpretation of the side-scan sonar data collected around the three study sites, cuttings may occur up to 1000 m from a drilling site.
- Concentrations of SBM and total petroleum hydrocarbons (TPH) were measured in samples collected from box cores. SBM and TPH concentrations are highly correlated, and near-field SBM concentrations can exceed 10,000 μg/g.
- After drilling activities have occurred, annelids appear to dominate the near-field macroinfauna assemblage. In some instances, correlation between the abundances of macroinfauna and the concentration of SBM occurred.

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THE INFLUENCE OF SYNTHETIC-BASED MUDS ON SEDIMENT REDOX AND CONCENTRATIONS OF TOTAL ORGANIC CARBON AND TRACE METALS, INCLUDING METHYLMERCURY

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DEEP GULF OF MEXICO

As part of the MMS study of "Effects of Oil and Gas Exploration and Development at Selected Continental Slope Sites in the Gulf of Mexico," our group at Florida Institute of Technology is pursuing the following areas of investigation: 1) distribution of Al, As, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, V and Zn in surficial sediments (0–2 cm) and sediment cores, 2) sedimentation rates, 3) vertical distributions in sediment of dissolved oxygen, redox potential (Eh) and selected interstitial water parameters (e.g., ammonia, iron, manganese, sulfate, alkalinity), and 4) concentrations of As, Ba, Cd, Cr, Cu, Fe, Hg, Ni, Pb, V and Zn in samples of *Bathynomas giganteus* (a large isopod) and *Chaceon (Geryon) quinquedens* (a crab). The following four drilling sites were investigated: 1) Site GB516 (1036 m) was sampled twice, in both cases after drilling, 2) Site VK916 (1006 m) was sampled before and after exploratory drilling, 3) Site GB602 (1124 m) was sampled once post-development and 4) Site MC292 (1118 m) was sampled once post development (Figure 3F.2). Random samples were collected at multiple locations within 1000 m of the drilling sites (nearfield) and at >10 km from the drilling site (farfield). Samples also were collected at a few discrete, fixed nearfield locations. This presentation provides a broad overview of our results and interpretations to date.

Sedimentation rates based on vertical profiles for excess ^{210}Pb are 0.05 to 007 cm yr^{-1} for sites GB516, GB602 and VK916 (Figure 3F.2) and higher nearer the Mississippi River (site MC292) where the ^{137}Cs profile supported results for excess ^{210}Pb. At nearfield (NF) locations, maximum levels of Ba in sediment were 35% at GB516, 17% at VK916, 15% at GC602 and 15% at MC292, relative to levels of 0.1 to 0.2% at farfield (FF) stations. The distribution of Ba, from barite discharged with drilling muds, is very patchy in the NF zone. At site VK916, concentrations of Ba in the NF zone increased from an average of 0.11% to 3.6% for pre-drilling and post-drilling sample periods, respectively (Figure 3F.3). Concentrations of synthetic-based mud (SBM) do not correlate well with Ba because of differences in mud mixture, behavior after discharge and the occurrence of water-based muds (i.e., Ba and other components, but not SBM). Concentrations of Hg, Pb, As, Cd and other metals in sediments were not statistically different at NF versus FF stations at site VK916 for pre-drilling and post-drilling expeditions (Figure 3F.3). Overall, metal concentrations (excluding Ba) in the 134 NF sediments were within the range of values observed for FF stations in 87 to 100% of the samples, depending on the metal considered. A few instances of elevated levels of Hg (n = 10 at > 0.15 μg/g) and Pb (n = 17 at >40 μg/g) were observed, primarily at one discrete NF station.

Concentrations of metals in tissues from isopods (*Bathynomous giganteus*) and crabs (*Chaceon quinquedens*) showed large standard deviations and no significant differences between NF and FF samples. Concentrations of total Hg in isopods ranged from 0.6 to 15.7 µg/g (dry weight) with an average of 4.2 ± 3.9 µg/g (n = 22 from NF + FF). Further study of Hg in these lipid-rich organisms seems potentially valuable.

Vertical profiles for dissolved oxygen in the sediment were generated at 1-mm intervals and pH and Eh were measured at 2-cm intervals. In general, concentrations of dissolved oxygen decreased to zero at shallower depths in sediment from NF sites following drilling than at FF stations. The redox potential also tended to be lower (less oxidizing, more reducing) at NF sites, post development. For example, at site GB516, dissolved oxygen levels could be measured to a depth of ~3.5 cm in FF sediment relative to <0.5 cm in NF sediment (Figure 3F.4). In addition, Eh levels at the FF site were oxidizing (400 mV) relative to anoxic, highly reducing conditions (-150 mV) at some NF stations (Figure 3F.4).

To simplify comparisons among sites, the amount of dissolved oxygen in the sediment column was integrated as nmoles cm^{-2}. This integrated amount of dissolved oxygen in the sediment was lower at NF stations following development. For example, at site VK916, the mean, integrated amount of oxygen in the sediment column during the pre-development sampling was statistically the same at FF and NF stations (Figure 3F.5). Following development, the mean value remained the same at the FF stations and decreased at NF and discretionary (fixed) stations (DS) (Figure 3F.5).

Total Mercury and Methylmercury in Sediments Adjacent to Drilling Sites on the Upper Slope and Shelf in the Gulf of Mexico

As part of a separate study of the impact of synthetic-based muds on the shelf and upper slope, the distributions of total Hg and methylmercury (MeHg) in seabed sediments near six offshore drilling sites in the Gulf of Mexico were determined. The purpose of this study was to help ascertain whether drilling discharges lead to enhanced concentrations of MeHg in sediments near drilling sites. Three of the study sites are located on the outer continental shelf (MP299, MP288 and EI346) at water depths of 60 to 119 m, and three sites are located on the upper slope (MC496, EB946 and GC112) at water depths of 534 to 556 m (Figure 3F.6). Surface (0–2 cm) and subsurface (2–20 cm) sediments for this study were collected within the following three zones at each of six drilling sites: <100 m (nearfield), 100 to 250 m (midfield) and >3 km (farfield).

Concentrations of total Hg in sediment range from 11 to 92 ng/g (parts per billion, dry weight) for all farfield (FF) samples and 25 to 558 ng/g for all nearfield (NF) samples. Total Hg concentrations were significantly higher at NF stations than at FF stations for five of the six drilling sites due to inputs from drilling discharges. When total Hg levels in NF sediments exceed background levels, concentrations of Ba range from 2 to 28% (dry weight), relative to ambient Ba concentrations of about 0.05 to 0.15%. A strong linear relationship between Ba and total Hg, coupled with the high levels of Ba as barite ($BaSO_4$) in these sediments, support the contention that barite, a common additive to drilling mud, is the primary source for anthropogenic Hg in these sediments (Figure 3F.7a).

The relationship between concentrations of total Hg and Ba in sediments from NF stations at a given site can be used to estimate total Hg levels in the industrial barite used during drilling. Estimated average concentrations of total Hg in industrial barite at different sites, based on the Ba versus Hg relationships, range from about 400 to 1000 ng/g (e.g., site EI346 in Figure 3F.7a) and are consistent with regulations by the U.S. Environmental Protection Agency that permit total Hg levels in industrial barite of 1000 ng/g.

Concentrations of MeHg range from 0.11 to 1.05 ng/g for all FF sediments and <0.03 to 2.7 ng/g for all NF sediments. Mean concentrations (± standard deviation) for MeHg are 0.44 ± 0.27 for all FF stations (n = 62) and 0.45 ± 0.41 for all NF stations (n = 109). In contrast with results for total Hg, concentrations of MeHg in surficial (0–2 cm) sediment from all six drilling sites do not vary significantly between nearfield and farfield stations (e.g., Figure 3F.7b).

Graphs showing concentrations of total Hg versus MeHg are useful for comparing data from different sites. For example, at site EI346 (Figure 3F.8a) and site EW963, sediments with high levels of total Hg (i.e., 200–500 ng/g) have similar or lower levels of MeHg than found at background (FF) stations. Such observations show that despite 4 to 10 times higher levels of total Hg, concentrations of MeHg are not elevated and are often depleted relative to ambient sediments. These observations support the argument that excess Hg held in barite is not being converted to MeHg. However, results for site GC112 are somewhat ambiguous in that concentrations of MeHg are enhanced at several NF stations; however, the higher MeHg values are equivalent to ~3% or less of natural concentrations of total Hg at this site. Therefore, these anomalously high levels of MeHg could have either a natural or an anthropogenic source of Hg.

Considerable variability is observed in concentrations of MeHg at several sites. For example, MeHg concentrations range from <0.03 to 0.40 ng/g within one nearfield zone; whereas, they range from 0.35 to 2.7 ng/g within another nearfield zone. Observed variability in concentrations of MeHg is partly related to local variability in redox state in the top 10 cm of sediment. Low to non-detectable levels of MeHg are observed in nearfield stations where the redox potential (Eh) is <-100 mV (anoxic and highly reducing) in the presence of abundant total H_2S (>1 millimolar, mM). Higher values of MeHg are found in a few nearfield stations where levels of TOC are higher and where Eh values are about 0 mV (anoxic, moderately reducing). These observations are consistent with previous studies that suggest that optimum conditions for formation of methylmercury are in anoxic sediment with sulfide-poor interstitial water and sufficient levels of biodegradable organic matter and nutrients.

Concentrations of MeHg correlate positively with TOC in sediment from FF stations on the shelf (r = 0.63); however, no significant correlation was observed in FF sediments from the upper slope (r = 0.13) or the combined data set for FF sediments from the shelf and upper slope (r = 0.38). These trends for TOC versus MeHg in FF sediment show that TOC alone is not a key variable in determining how much MeHg is in sediment. When data for NF stations at sites MP299 and MP288 are added to the data for FF stations (Figure 3F.8b), the points overlap almost completely. At site EI346, sediment containing higher levels of TOC contains lower concentrations of MeHg (Figure 3F.8b). The lower levels of MeHg at higher concentrations of TOC in these sediments may be the result of higher levels of total H_2S (>1 mM) that inhibit methylation of Hg.

Levels of total Hg are 60 to 70% higher in ambient (FF) sediments from the upper slope versus the shelf and MeHg concentrations in ambient sediments from the upper slope (0.59 ± 0.26 ng/g) are double values of 0.28 ± 0.17 ng/g in shelf sediments. These trends in background concentrations of total Hg and MeHg from the shelf to the upper slope identify an interesting natural trend in the Gulf of Mexico.

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MODELING THE FATE OF SYNTHETIC DRILLING MUD BASE FLUIDS IN GULF OF MEXICO SEDIMENTS

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An important aspect of the assessment of deep-sea drilling operations in the Gulf of Mexico (GOM) is the environmental impact related to the discharge of cuttings contaminated with synthetic base fluids (SBF). SBF are added to drilling muds to lubricate the drill bit, control reservoir pressure, and bring rock chips, or cuttings, to the surface. They can be composed of linear alpha olefins, internal olefins, esters or parrafins, are released into the marine environment when cuttings are discharged.

Biodegradation of long-chain hydrocarbons such as can be found in SBF has been considered to occur only very slowly or not at all under anaerobic conditions. However, results of current studies using an anaerobic incubation of sediments from the shores of the GOM spiked with SBF and SBF surrogates have revealed that the many synthetic-based drilling fluids are biodegraded anaerobically. Thus, marine sediments may recover from contamination with synthetic-based fluids. The current questions are the following: how much time is required for biodegradation; what environmental factors control the rate of biodegradation; and will a complete removal of the synthetic-base fluids be realized.

Our research has two interconnected themes. We are investigating the ability of microbes in GOM sediment impacted by tailings discharge to biodegrade SBF under environmentally relevant conditions in terms of temperature and pressure. We are also developing a model, which incorporates microbial response, environmental conditions, and base fluid structure to estimate the response and recovery of impacted deep-sea sediments.

SBF BIODEGRADATION STUDIES

The anaerobic biodegradation of surrogate synthetic base fluids (SBF) is being examined using sea-floor sediments collected from GOM sites believed to be contaminated with drill cuttings. Sediments have been collected from depths ranging between 65 m and 1135 m. Duplication of sea-floor environmental conditions in the laboratory setting requires the use of pressure vessels to place the sediment under the same conditions of hydrostatic pressure evident at the depth of sampling. Currently, two stainless steel incubation vessels have been manufactured in our lab, and a third vessel is in the planning stages. The pressure vessels were made from 1-inch thick stainless steel tubes which were 10 inches tall and 10 inches internal diameter. Plates made of 1-inch stainless steel were made to fit over the top and bottom of the tubes. The end plates have an extended inner core, which holds two O-rings used to form an airtight seal with the inner wall of the stainless steel tube. The end plates are secured by 18 or 24 steel bolts, depending on the vessel. Once the end plates have been secured, water is pumped into the pressure vessel to raise the hydrostatic pressure to mimic conditions at the depth at which the sediment had been collected. The pressure vessels are incubated in a walk-in cool room at 4°C, which also mimics deep-sea conditions.

Heavy-duty polyethylene heat-seal bags are used to incubate the sediment inside the pressure vessels. The test compounds, which are surrogate of ester-based SBF (ethyl oleate) and olefin-based SBF (tetradecene), have been spiked into selected sediments to a final concentration of 2000 mg carbon/ kg dry sediment. Sediments were mixed with synthetic marine water (Forty Fathoms Crystal Sea Marine Mix), and a volume of sediment/marine water slurry equivalent to 30 g dry sediment is transferred into polyethylene bags, which are then heat-sealed. The control treatment consists of sediment free of any test substrate. The same sediment/marine water slurry used to fill the polyethylene bags was also transferred into 100 mL glass bottles, which were sealed airtight with rubber septa and crimp cap seals. The sediment in the glass bottles were incubated at atmospheric pressure in the 4°C incubator.

The two sediments currently under investigation are MP299NF and GC112NF, which were sampled at 66 and 535 m depths, respectively. Therefore, they required incubation pressures of 97 or 786 psi to mimic their in situ environments. At 4–6 week intervals, the pressure vessels were opened and 3 replicated bags from each treatment are chosen at random. Three of the sediment containing bottles were also sacrifice sampled at the same time. The sediment was analyzed for pore water sulfate levels and the concentration of the surrogate compounds, ethyl oleate, or tetradecene, remaining in the sediment. Results to date are shown for the MP299 (Figure 3F.9) and GC112 sediments (Figure 3F. 10).

The removal of sulfate from sediment pore water is used to monitor the activity of sulfate-reducing bacteria, which dominate anaerobic microbial activity in marine sediment. For sediments spiked with the surrogate ester-based SBF, ethyl oleate, a reduction in pore-water sulfate concentration coincided with the reduction in the amount of ethyl oleate remaining in the sediment. These results indicated that ethyl oleate is biodegraded under sulfate-reducing conditions. The results are similar whether the sediments were incubated under hydrostatic pressure in the bags or at atmospheric pressure in the bottles.

In contrast, sediments spiked with a surrogate olefin-based SBF showed no evidence of sulfate-reducing activity. These results are consistent with other studies performed in our lab using coastal GOM sediment which showed that olefin biodegradation under sulfate-reducing conditions occurs more slowly compared to the biodegradation of ester compounds. There was no change in the tetradecene concentrations in the sediment incubated in the glass bottles. However, tetradecene concentration was more variable in sediment incubated in polyethylene bags. A possible reaction between tetradecene and polyethylene may be occurring and may affect recovery efficiencies. A study currently in progress examines tetradecene sorption to polyethylene bags.

MATHEMATICAL MODEL DEVELOPMENT

Although the kinetic data is needed for use in modeling the fate of SBF in the GOM has yet to be generated, we have developed a mathematical framework to use for the model. The framework has been developed from the current body of literature that could be found concerning modeling microbial and physical processes in the environment. The model developed is not original in any of its aspects, but is a combination of modeling biodegradation processes as well as the diagenesis models that were developed for describing the natural processes in marine sediments. The combinations of these mathematical frameworks as well as the fact that we are including oxygen, sulfate, and carbon dioxide as electron acceptors and are able to use our mathematical framework to model all three processes in one environment makes the final framework a unique one.

MODELING FRAMEWORK

The model has been developed to predict the fate of SBF after the discharge of cuttings is completed and cuttings are uniformly settled on the sea bottom. The main mechanism of degradation of SBF base materials is through microbial degradation. Hydrocarbons are biodegraded mainly by oxidation; therefore, biodegradation of SBF base materials and other hydrocarbons is much more rapid in the presence of oxygen (aerobic) than when it is absent (anaerobic). The amount of oxygen in Gulf sediments is limited; in the first centimeters or even millimeters, all oxygen will be used by aerobes. This depletion of oxygen in the sediment will render them anaerobic. Sulfate is abundant in seawater (~29 mM; therefore, it will be the dominant terminal electron acceptor for microbial oxidation of SBF base chemicals in anoxic marine sediments. Once the sulfate in the sediments has been consumed, then methanogenesis will occur and CO_2 will become the dominant electron acceptor. To account for the different rates of SBF degradation with the three different electron acceptors that could be used in Gulf sediments, the model is divided into three zones; oxygen consumption zone, sulfate consumption zone, and CO_2 consumption zone. Michealis-Menten type kinetics limited both by hydrocarbon concentration and electron acceptor availability are used to describe the biological reactions.

In addition to the biodegradation parameters, the mathematical framework also takes into account resuspension, bioturbation, and diffusion of the electron acceptors into the sediment layers. Sediment mixing by organisms (bioturbation) and resuspension by bottom currents are two processes which dilute and disperse contaminants that initially settle on the seafloor. Others have found that the organisms responsible for bioturbation are effective to a depth of 5 centimeters. After 5 cm, bioturbation decreases exponentially and approaches to zero at about 10cm depth. Therefore, in our modeling it is assumed that first 5 centimeters are well mixed and pore water in cuttings is oxygen saturated. After that, the effect of bioturbation and resuspension is neglected.

MODEL ASSUMPTIONS

- Contaminant is SBF base chemical and it is non diffusible.
- Oxygen consumption layer is well mixed via organisms at first 5 centimeters.
- After 5 centimeters mixing is neglected.
- Initial concentration of SBF is uniform throughout region.
- There is no compaction in sediments.
- Only single component (hexadecane) mass transfer is currently used.
- A constant porosity of 0.924.

GOVERNING EQUATIONS

Biodegradation rate due to oxygen consumption:

$$r_{F,O} = -\left(\frac{k_1 X_1 F}{Y_1\left(K_{1,s} + F\right)}\right)\left(\frac{O}{K_{s,O} + O}\right) \tag{1}$$

where,X_1 = specific concentration of hydrocarbon utilizing aerobes, mg/g dry sediment

F = SBF Base chemical concentration, g/g sediment dry weight
k_1 = maximum specific growth rate, g/time
Y_1 = yield of growth of aerobic hydrocarbon degraders, g cells/g SBF
$K_{1,s}$ = half velocity coefficient, mg/g dry sediment
O = dissolved oxygen concentration, mg/L
$K_{s.o}$ = half saturation constant for oxygen limitation, mg/L

Rate of hydrocarbon degradation due to sulfate consumption:

$$r_{F,SO_4} = -\left(\frac{k_2 X_2 F}{Y_2\left(K_{2,s} + F\right)}\right)\left(\frac{S}{K_{s,SO_4} + S}\right)\left(\frac{K'_{O,SO_4}}{K'_{O,SO_4} + O}\right) \tag{2}$$

where, X_2 = specific concentration of hydrocarbon utilizing sulfate reducers, mg/g dry sediment

F = SBF Base chemical concentration, g/g sediment dry weight
k_2 = maximum specific growth rate, g/time
Y_2 = yield of growth of sulfate reducing hydrocarbon degraders, g/g
$K_{2,s}$ = half velocity coefficient, mg/g dry sediment
O = dissolved oxygen concentration, mg/L
S = sulfate concentration
$K_{s.SO4}$ = half saturation constant for sulfate limitation, mg/L
$K'_{O,\ SO4}$ = coefficient for oxygen inhibition of sulfate reducers, mg/L.

SBF degradation rate in methanogenic zone:

$$r_{F,CO2} = \left(\frac{k_3 X_3 F}{Y_3\left(K_{3,s} + F\right)}\right)\left(\frac{K'_{SO_4}}{K'_{SO_4} + S}\right)\left(\frac{K'_{O,CO_2}}{K'_{O,CO_2} + O}\right) \tag{3}$$

where, X_3 = specific concentration of hydrocarbon utilizing methanogens, mg/g dry sediment

F = SBF Base chemical concentration, g/g dry sediment
k_3 = maximum specific growth rate, g/time
Y_3 = yield of growth of methanogenic hydrocarbon degraders, g cells/g SBF
$K_{3,s}$ = half velocity coefficient, mg/g dry sediment
O = dissolved oxygen concentration, mg/L
K'_{SO4} = constant for sulfate inhibition of methanogenesis, mg/L
$K'_{O, CO2}$ = constant for oxygen inhibition of methanogenesis, mg/L

COMBINED FORMULA FOR ALL LAYERS

$$\frac{dF}{dt} = -\left(\frac{k_1X_1F}{Y_1(K_{1,s}+F)}\right)\left(\frac{O}{K_{s,O}+O}\right)-\left(\frac{k_2X_2F}{Y_2(K_{2,s}+F)}\right)\left(\frac{S}{K_{s,SO_4}+S}\right)\left(\frac{K'_{O,SO_4}}{K'_{O,SO_4}+O}\right)$$

$$\ldots\ldots\ldots-\left(\frac{k_3X_3F}{Y_3(K_{3,s}+F)}\right)\left(\frac{K'_{SO_4,CO_2}}{K'_{SO_4,CO_2}+S}\right)\left(\frac{K'_{O,CO_2}}{K'_{O,CO_2}+O}\right)-D_b\left(\frac{\partial^2F}{\partial z^2}\right) \qquad (4)$$

CALCULATIONS FOR PORE WATER SPECIES (OXYGEN AND SULFATE)

The amounts of oxygen and sulfate (main electron acceptors) in pore water are also influenced by mixing (resuspension and bioturbation), molecular diffusion and biodegradation. The rates of electron acceptor consumption have been estimated using microbial energetic calculations for energy and cell production from each electron acceptor when hexadecane is the hydrocarbon. These should be similar for most SBF.

The rate of oxygen consumption will be 12.25 times of rate of hexadecane consumption by aerobic organisms, the rate of sulfate consumption will be 6.125 times of rate of hexadecane consumption by sulfate reducing bacteria we assume CO_2 will be in excess.

Mass balance equation, $\frac{\partial C}{\partial t} = (\frac{D^\circ}{\theta^2}+D_b)\left(\frac{\partial^2 C}{\partial z^2}\right)+\sum \mathrm{Re}\,actions$ becomes for oxygen (O), and sulfate (S)

$$\frac{\partial O}{\partial t} = (\frac{D_O^\circ}{\theta^2}+D_b)\left(\frac{\partial^2 O}{\partial z^2}\right)-12.25*\left(\frac{k_1X_1F}{Y_1(K_{1,s}+F)}\right)\left(\frac{O}{K_{s,O}+O}\right) \qquad (5)$$

$$\frac{\partial S}{\partial t} = (\frac{D_S^\circ}{\theta^2}+D_b)\left(\frac{\partial^2 S}{\partial z^2}\right)-6.125*\left(\frac{k_2X_2F}{K_{2,s}+F}\right)\left(\frac{S}{K_{s,so4}+S}\right)\left(\frac{K'_{O,SO4}}{K'_{O,SO4}+O}\right) \qquad (6)$$

The values for X will be determined by measuring the specific populations in the sediments obtained during the study. The initial X will come from the far field (unimpacted) sediments and will be increased using a yield factor (Y, Table 3F.1) calculated using thermodynamic equations. The yield will also be corrected using experimental data. The model increases the X in each time period by the yield amount until it reaches a maximum (determined from experimental data).

Table 3F.1. Comparison of calculated versus observed yields for growth on hexadecane.

	Calculated yield (g cells/g hexadecane)	**Yield found in archives g cells/g hexadecane**
Oxygen	1.3965	0.3
Sulfate	0.1446	0.0327
CO_2	0.0637	

Solution for above partial equations:

$$\frac{\partial O(z,t)}{\partial t} = (\frac{D_o^{\circ}}{\theta^2} + D_b)\left(\frac{\partial^2 O(z,t)}{\partial z^2}\right) - 12.25 * \left(\frac{kXF(z,t)}{Y_1(K_s + F(z,t))}\right)\left(\frac{O(z,t)}{K_{s,O} + O(z,t)}\right) \tag{7}$$

With explicit differencing:

$$\frac{O_i^{k+1} - O_i^k}{\Delta t} = (\frac{D_o^{\circ}}{\theta^2} + D_b)\left(\frac{O_{i+1}^k - 2O_i^k + O_{i-1}^k}{\Delta z^2}\right) - 12.25 * \frac{k_1 XF_i^k}{Y_1(K_s + F_i^k)}\left(\frac{O_i^k}{K_{s,O} + O_i^k}\right) \tag{8}$$

and

$$O_i^{k+1} = O_i^k + \Delta t\left((\frac{D_o^{\circ}}{\theta^2} + D_b)\left(\frac{O_{i+1}^k - 2O_i^k + O_{i-1}^k}{\Delta z^2}\right) - 12.25 * \frac{k_1 XF_i^k}{Y_1(K_{1,s} + F_i^k)}\left(\frac{O_i^k}{K_{s,O} + O_i^k}\right)\right) \tag{9}$$

$$S_i^{k+1} = S_i^k + \Delta t\left((\frac{D_s^{\circ}}{\theta^2} + D_b)\left(\frac{S_{i+1}^k - 2S_i^k + S_{i-1}^k}{\Delta z^2}\right) - \left(6.125 * \frac{k_2 XF_i^k}{Y_2(K_{2,s} + F_i^k)}\left(\frac{S_i^k}{K_{s,S} + S_i^k}\right)\left(\frac{K'_{O,SO4}}{K'_{O,SO_4} + O_i^k}\right)\right)\right)$$

(10)

$$F_i^{k+1} = F_i^k + \Delta t \left(\begin{array}{l} -\left(\frac{k_1 X F_i^k}{Y_1 \left(K_{1,s} + F_i^k \right)} \right) \left(\frac{O_i^k}{K_{s,O} + O_i^k} \right) - \left(\frac{k_2 X F_i^k}{Y_2 \left(K_{2,s} + F \right)} \right) \left(\frac{S_i^k}{K_{s,SO_4} + S_i^k} \right) \left(\frac{K'_{O,SO_4}}{K'_{O,SO_4} + O_i^k} \right) \\ \ldots\ldots - \left(\frac{k_3 X F_i^k}{Y_3 \left(K_{3,s} + F_i^k \right)} \right) \left(\frac{K'_{SO_4,CO_2}}{K'_{SO_4,CO_2} + S_i^k} \right) \left(\frac{K'_{O,CO_2}}{K'_{O,CO_2} + O_i^k} \right) - D_b \left(\frac{F_{i+1}^k - 2F_i^k + F_{i-1}^k}{\partial z^2} \right) \end{array} \right) \tag{11}$$

Where Δt is the time step, C_i^k is the concentration at the grid point $x=x_i$ at time t_k (time at the k-th time step).

The equations have been coded into an excel spread sheet such that the input parameters can be changed independently and the results viewed in graphical format for use in predictions and in sensitivity analysis. The figures presented in the MMS ITT session are not included here due to space limitations.

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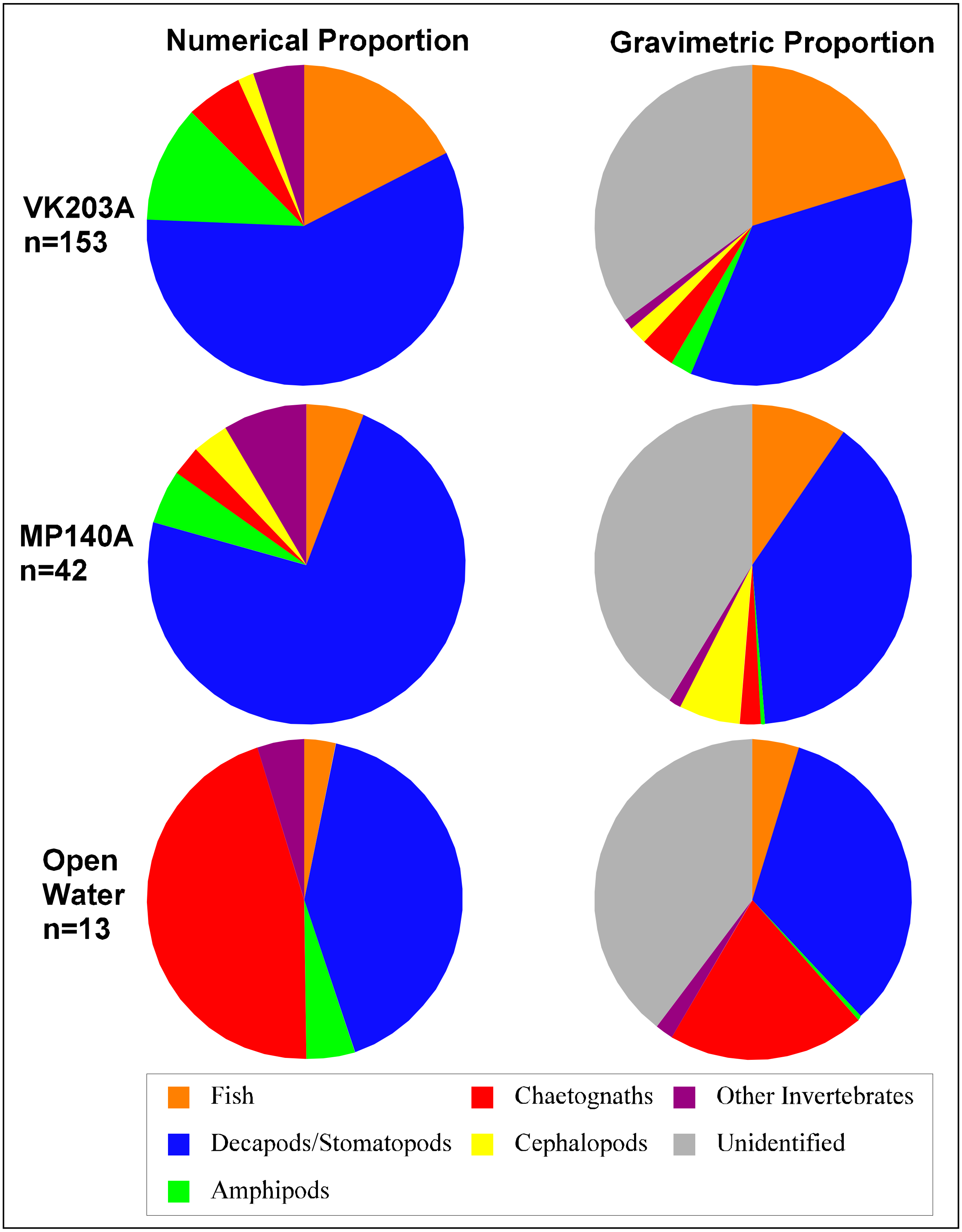


Figure 1A.1. Numerical proportion (left column) and gavimetric proportion (right column) for the prey items in the diets of blue runner from the summer 2000 sampling trips.

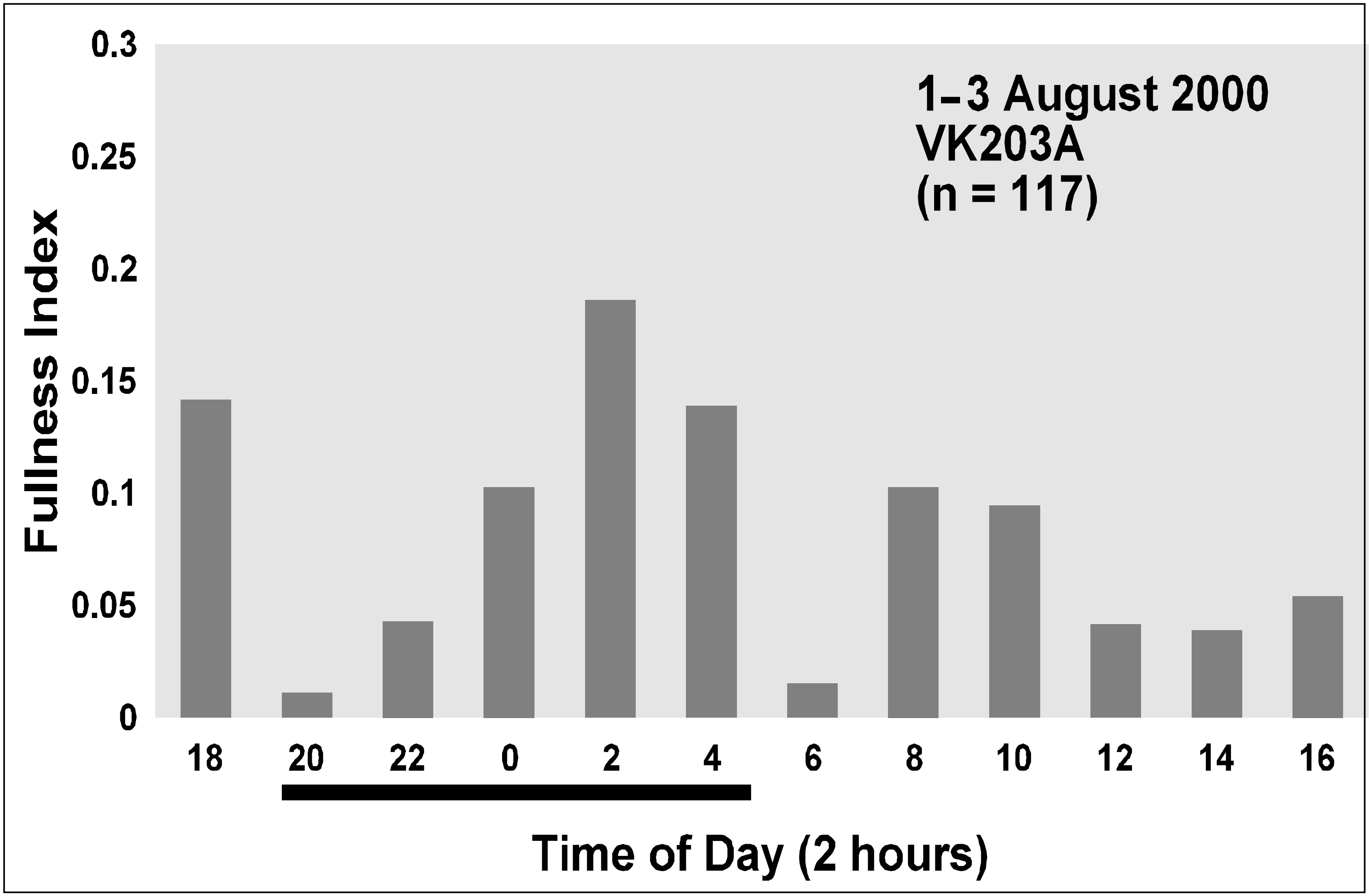


Figure 1A.2. Fullness value for blue runner collected during the diel sampling trip near the VK203A platform. The error bars are ± 1SE and the black bar along the x-axis indicates night.

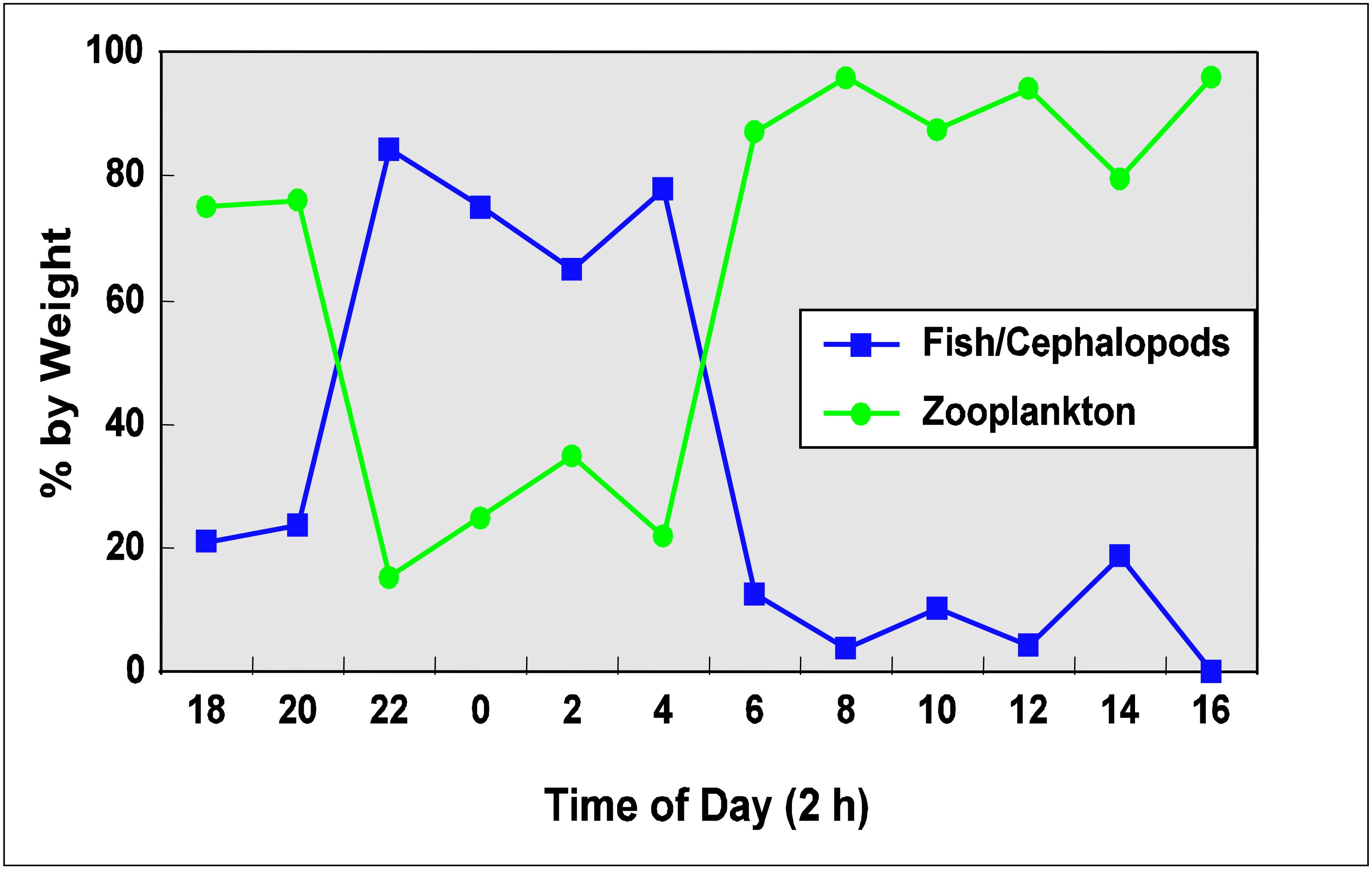


Figure 1A.3. The percent weight contribution of nektonic (Fish/Cephalopods) and planktonic (Zooplankton) forms during the diel sampling cruise.

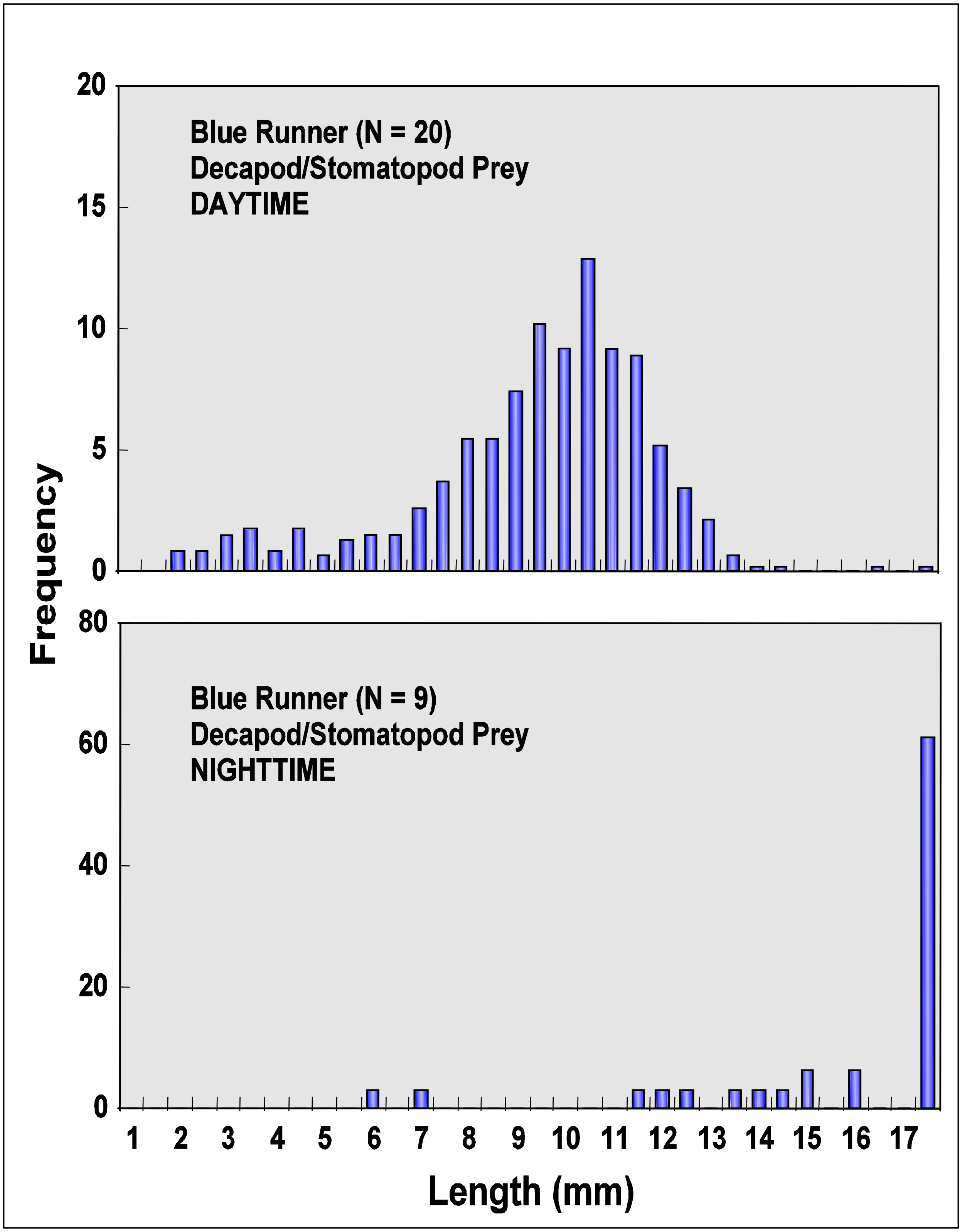


Figure 1A.4. Length frequency distribution for decapods/stomatopods consumed by blue runner during summer 2000 cruises during daytime (top) and nighttime (below). Note the y-axes are scaled differently.

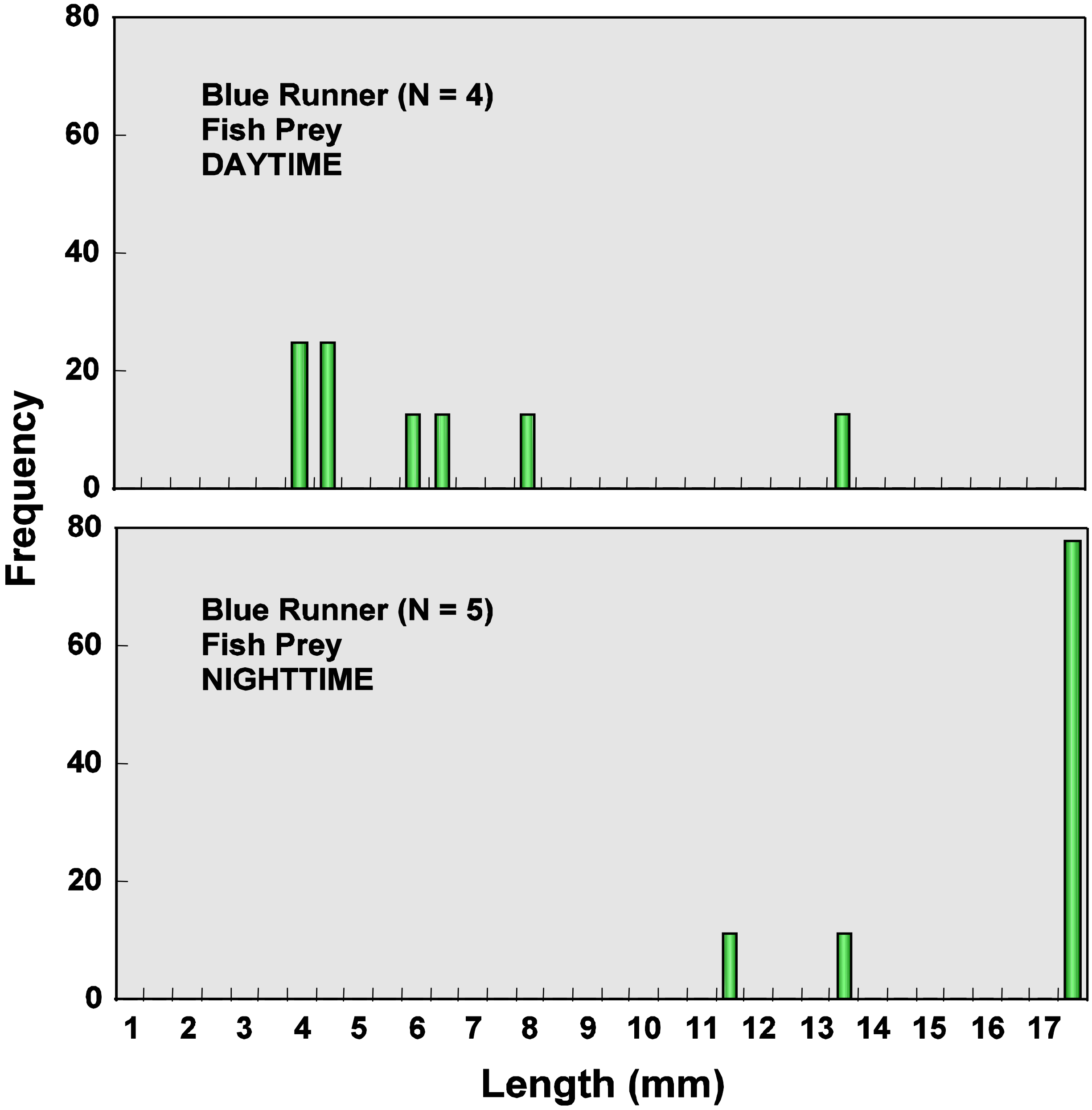


Figure 1A.5. Length frequency distribution for fish prey consumed by blue runner during summer 2000 cruises during daytime (top) and nighttime (below).

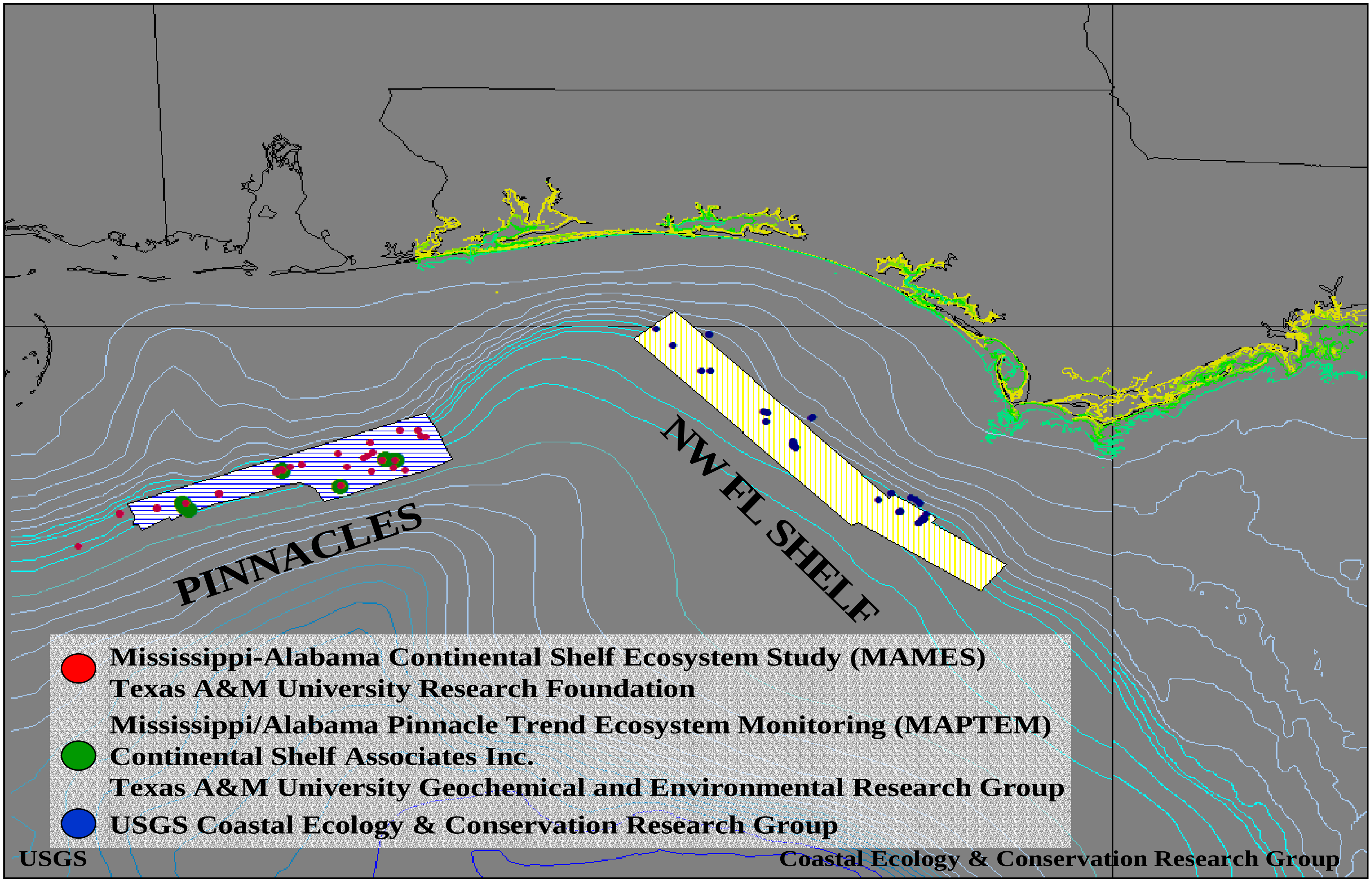


Figure 1A.6. A map depicting the current study areas on the NW Florida shelf and the location of the two studies performed in the Pinnacles (Mississippi/Alabama shelf). Boxes represent areas mapped by a high-resolution multibeam bathymetric system.

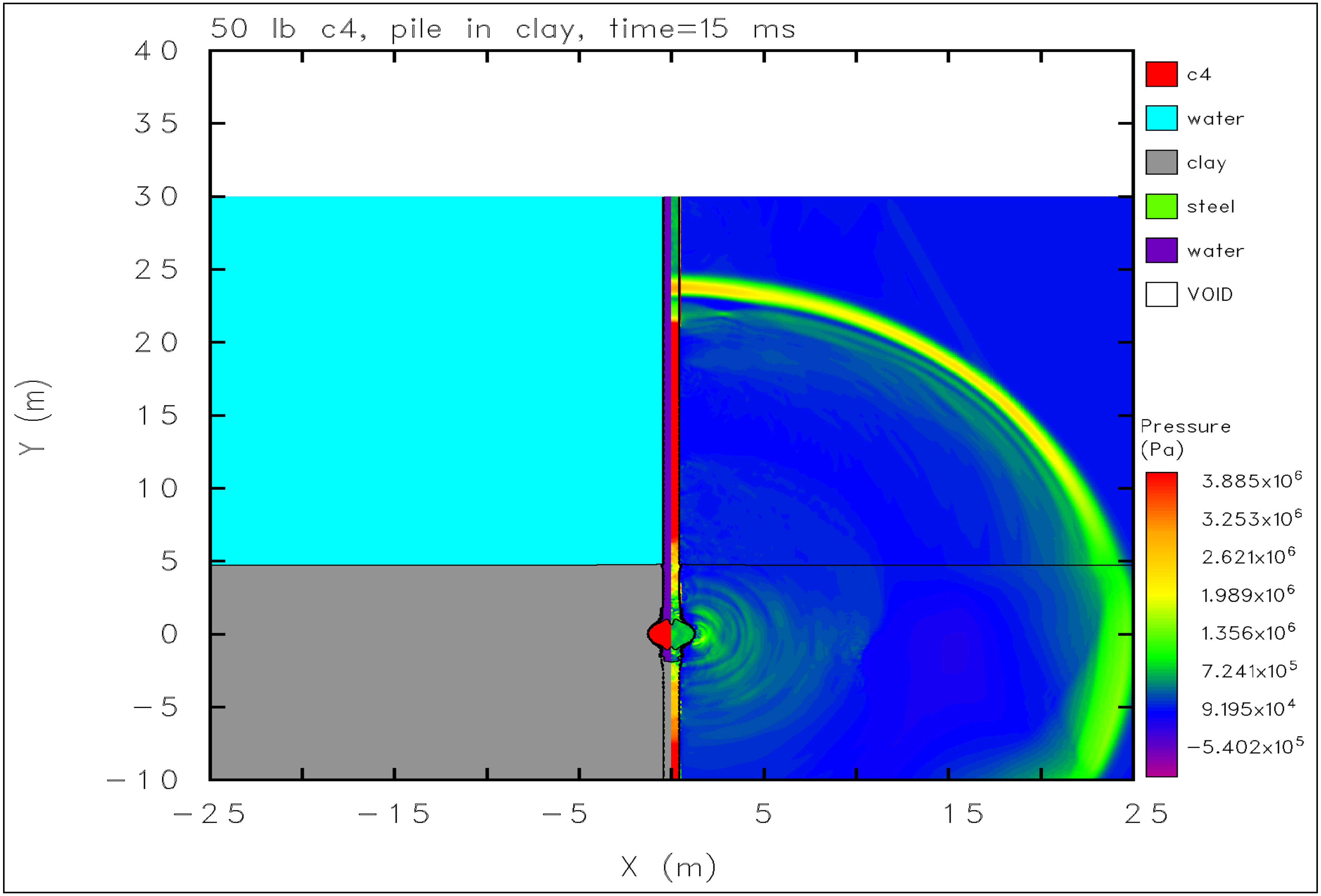


Figure 1B.1. Material and pressure field for 50 lb C-4 pile in clay calculation at 15 ms.

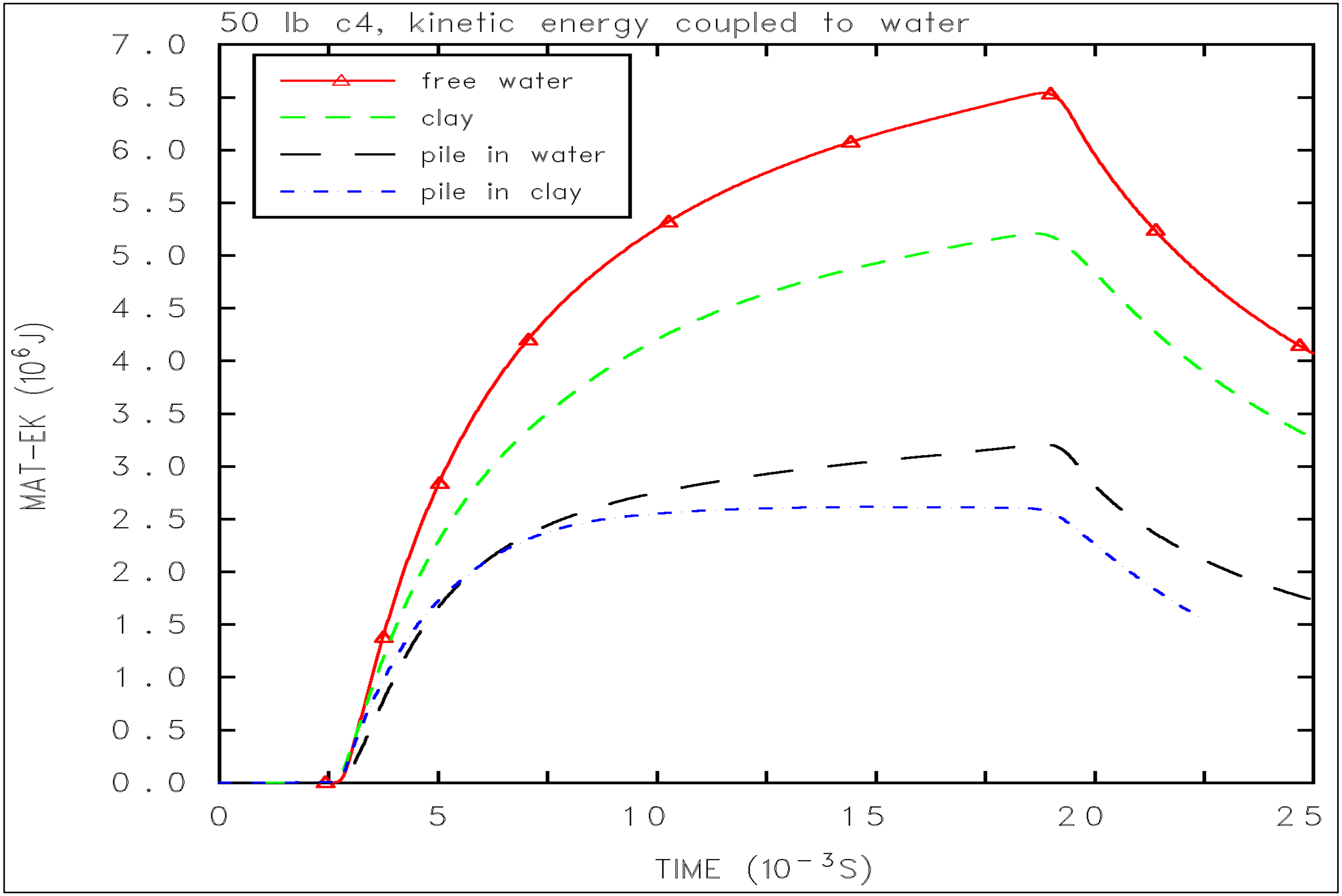


Figure 1B.2. Comparison of kinetic energy coupled into the water for baseline numerical simulations.

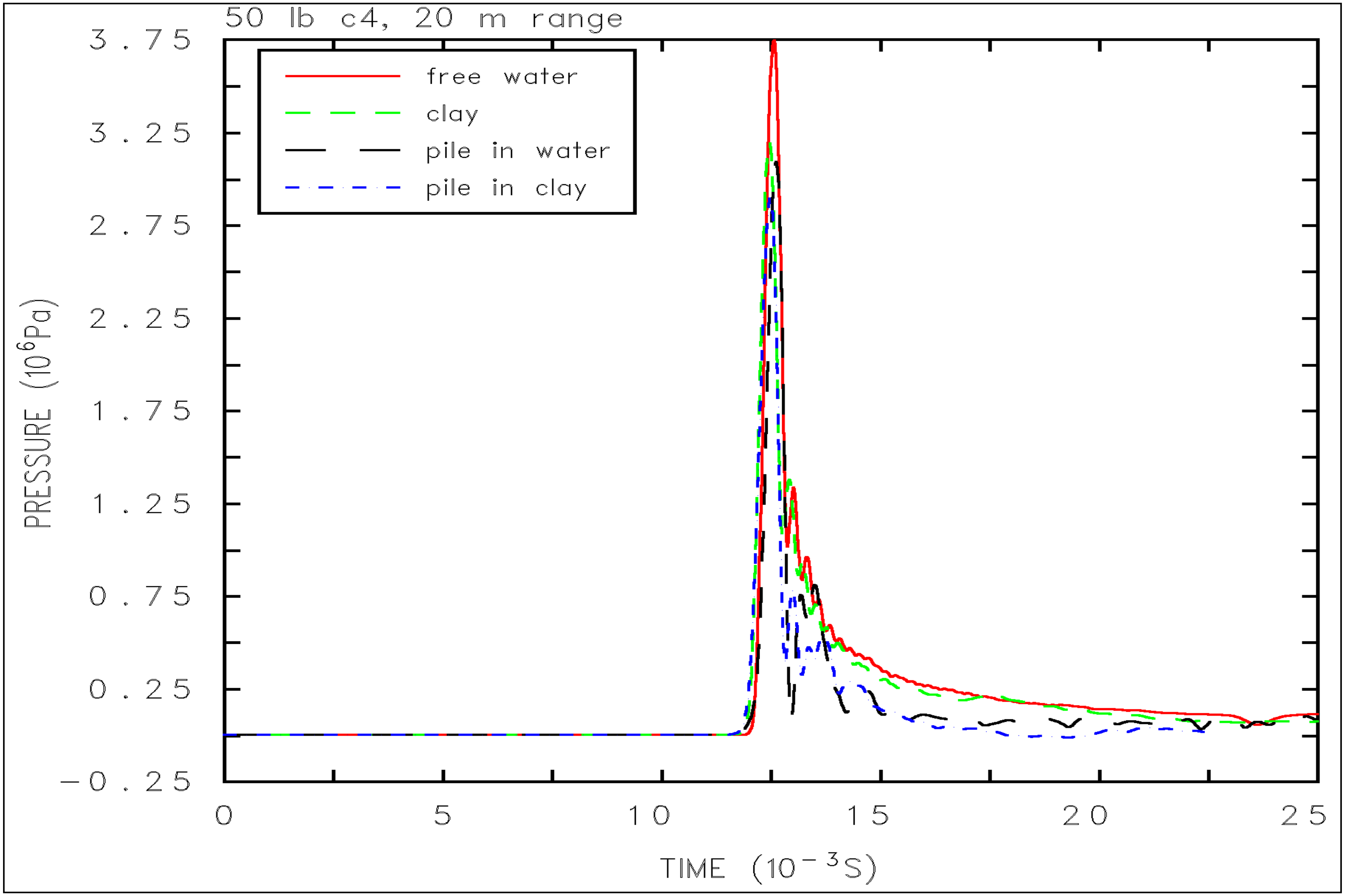


Figure 1B.3. Comparison of pressure time histories at the 20-meter range.

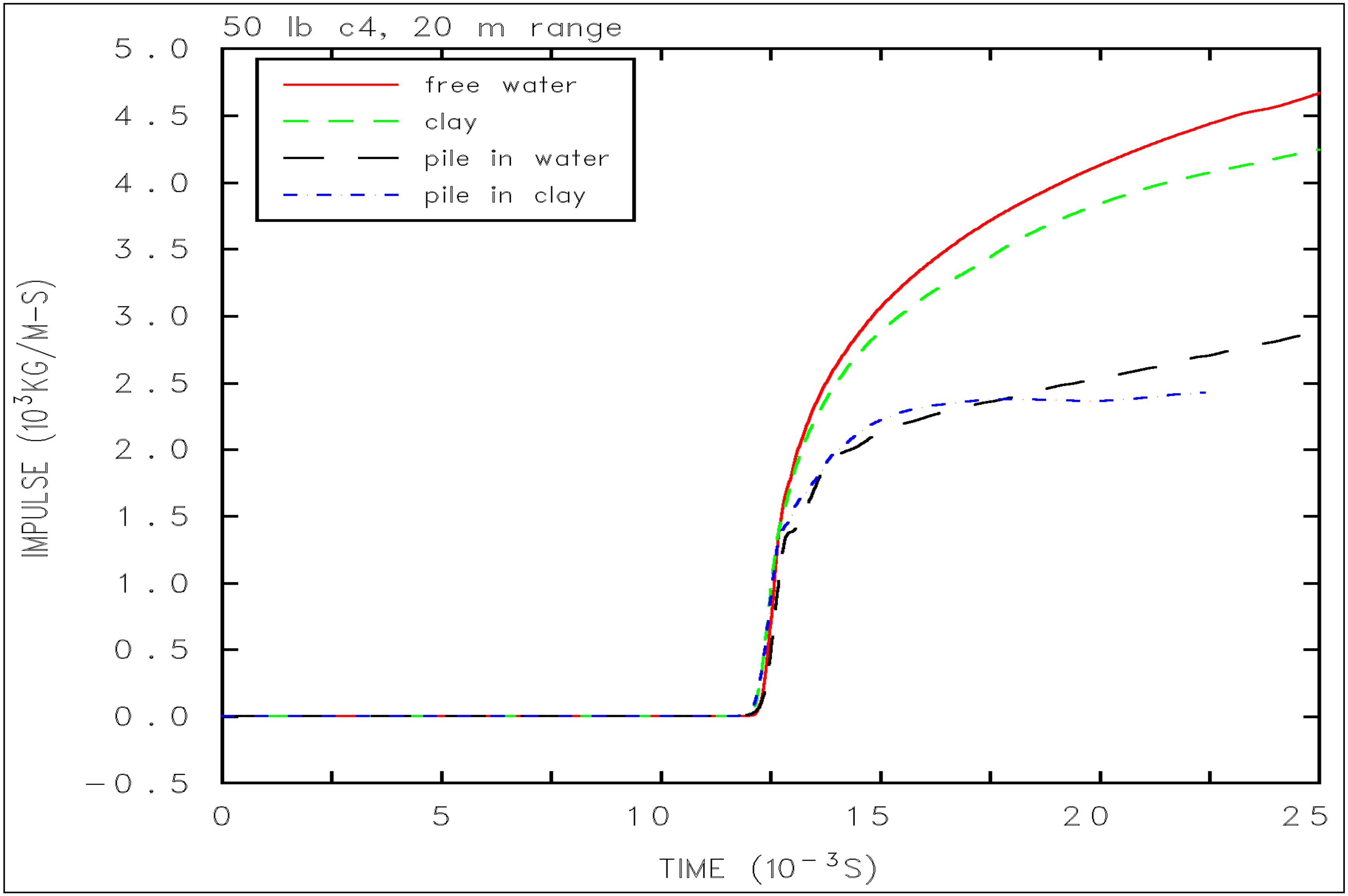


Figure 1B.4. Comparison of impulse time histories at the 20-meter range.

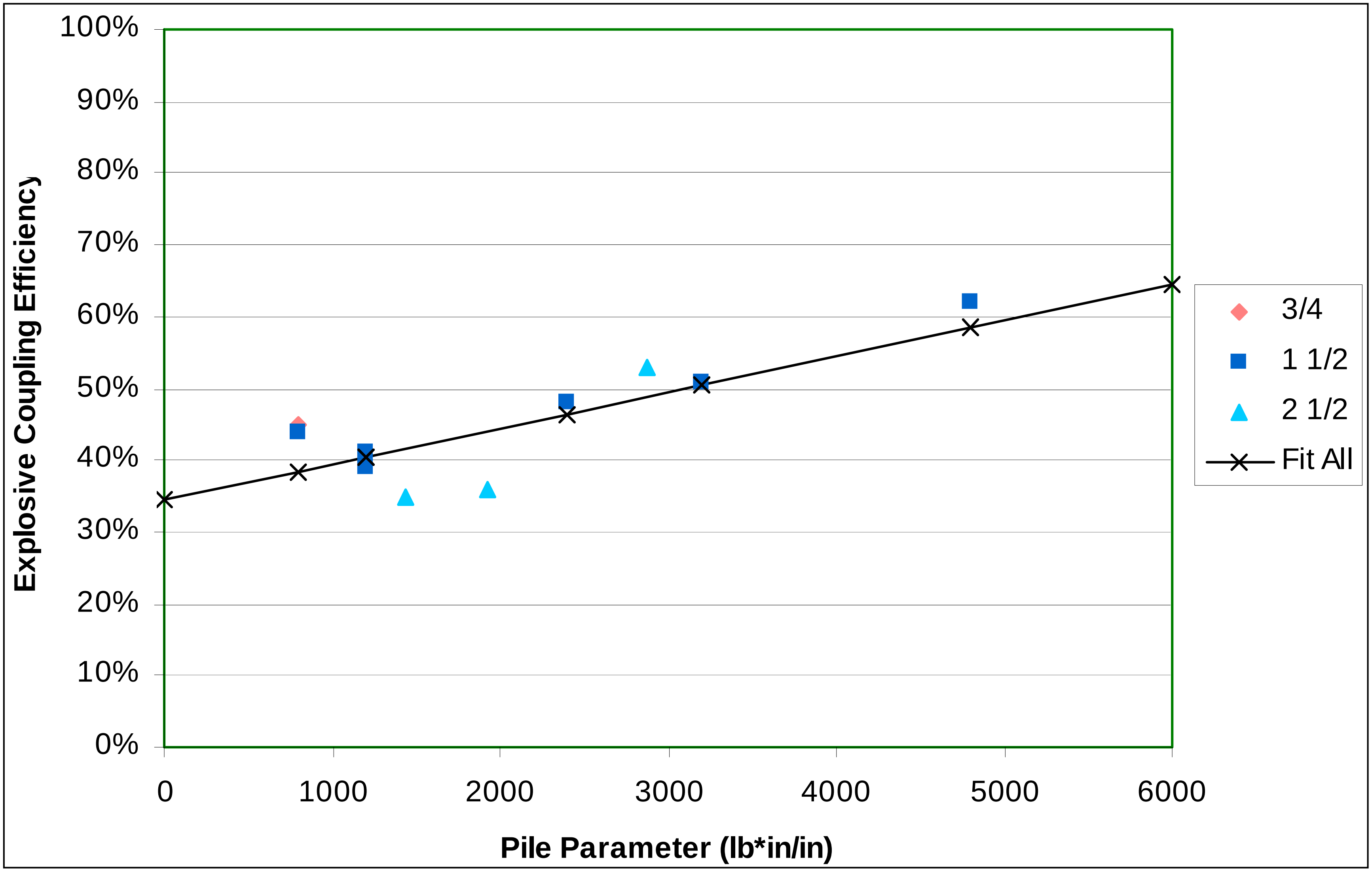


Figure 1B.5. Relationship between the explosive coupling efficiency and the pile parameter $\left(w \cdot \frac{d}{t}\right)$

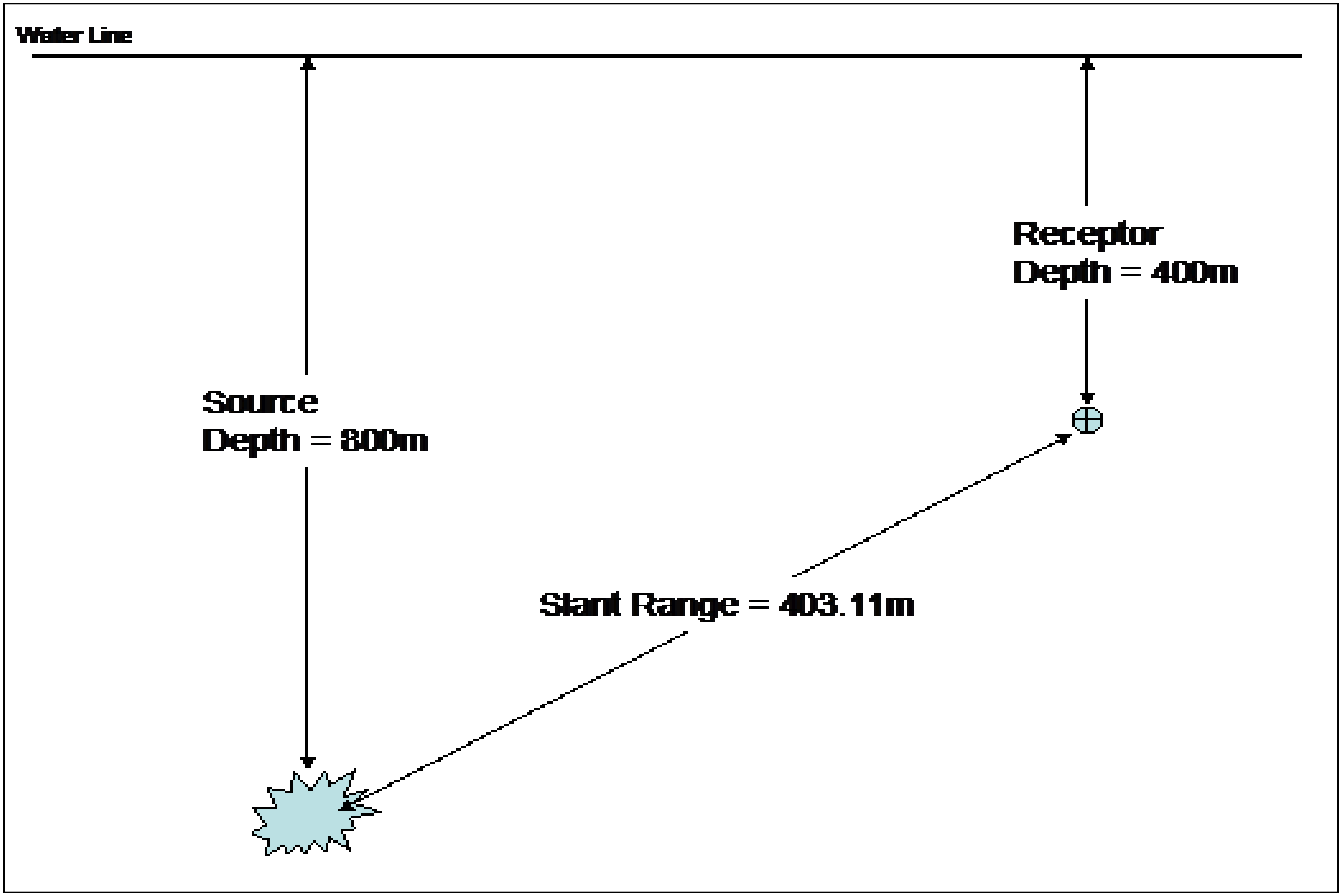


Figure 1B.6. Free water configuration used for comparison.

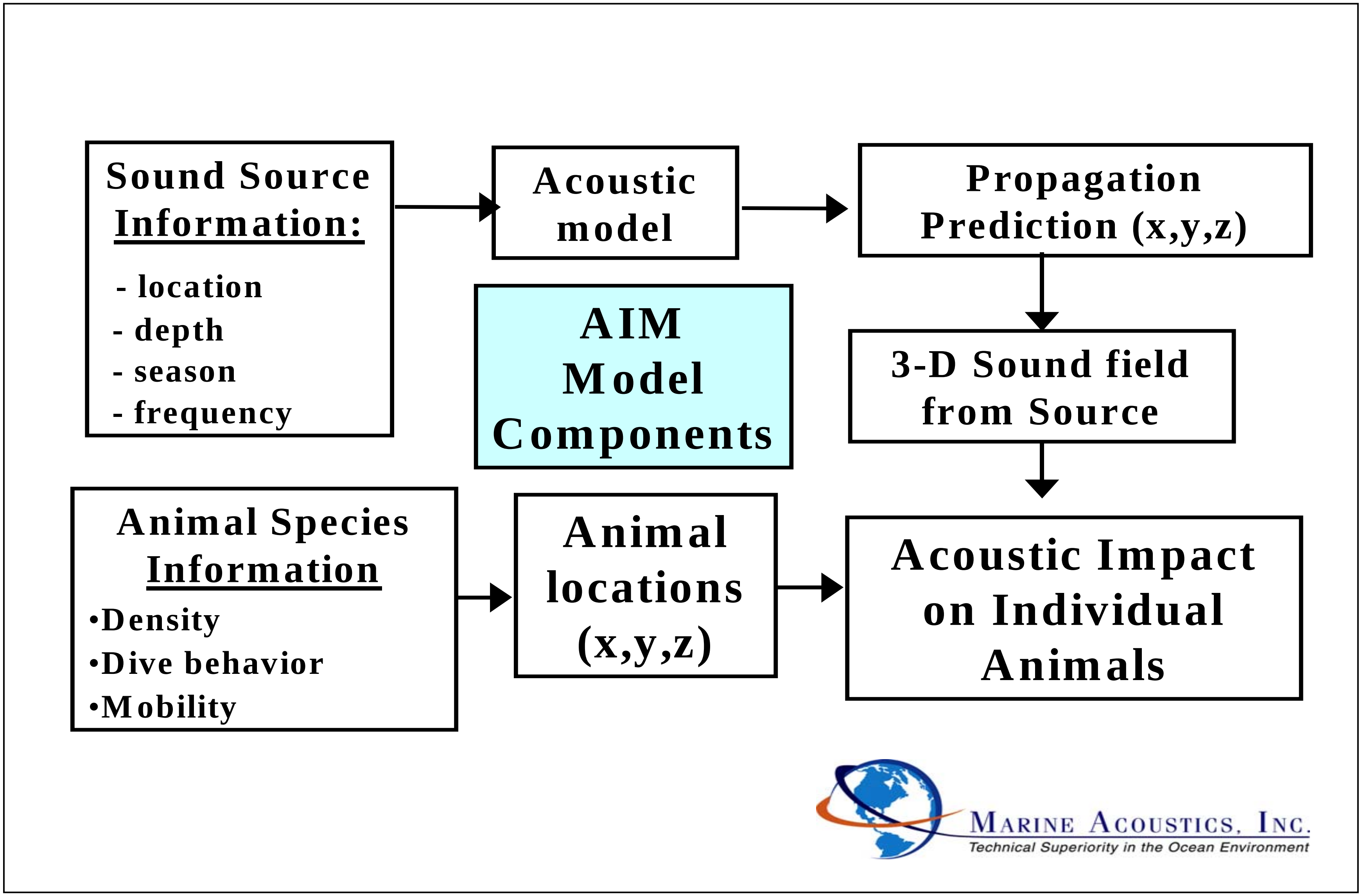
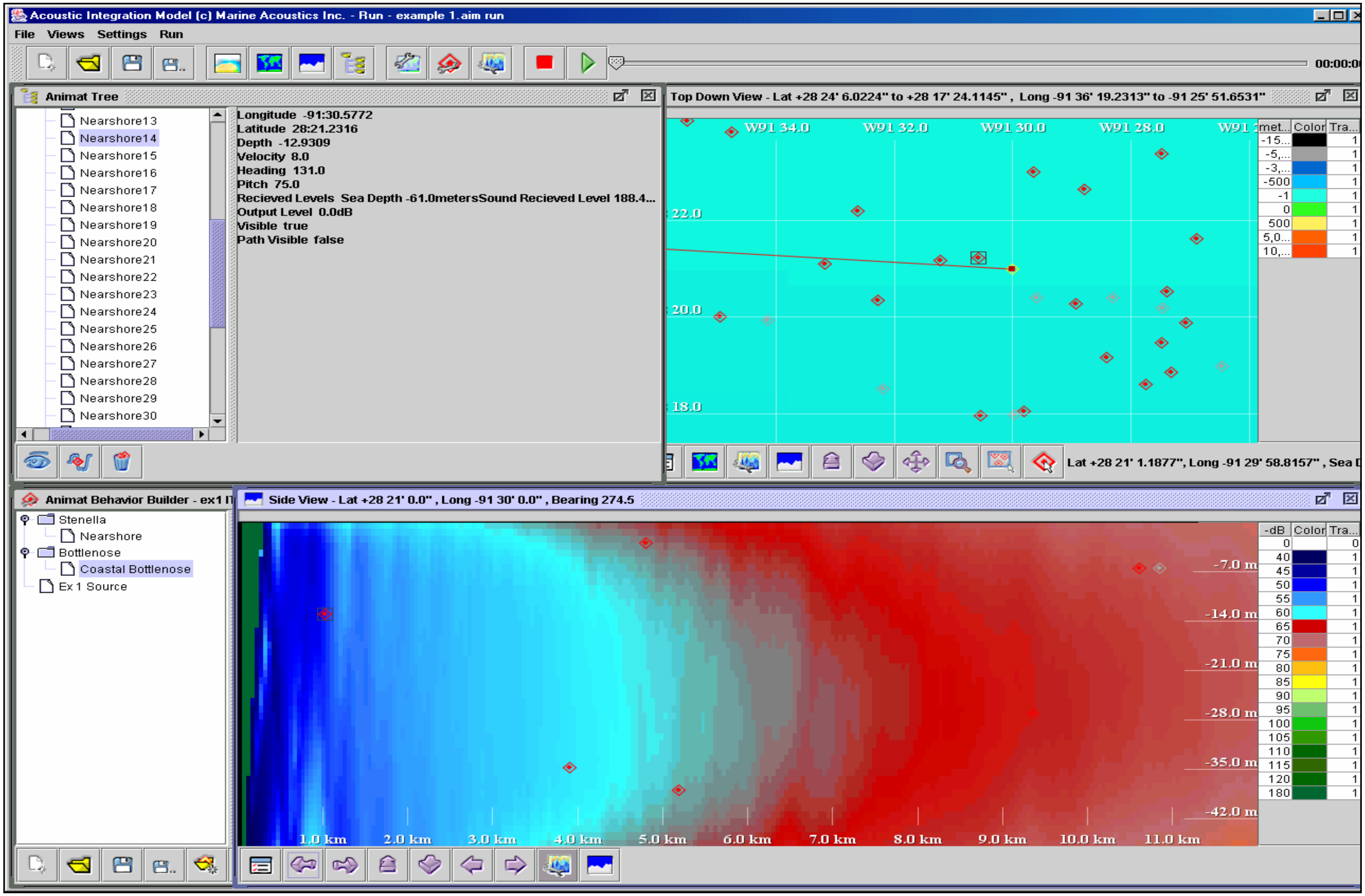


Figure 1B.7. The essential elements of the current version of the AIM model as applied to the acoustic impact assessment problem.



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Output Level 0.0dB
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Path Visible false

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-1	🟦	1
0	🟩	1
500	🟨	1
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10,...	🟥	1

-dB	Color	Tra...
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45	🟦	1
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55	🟦	1
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Figure 1B.8. Screen shot of the AIM modeling developed for Example #1.

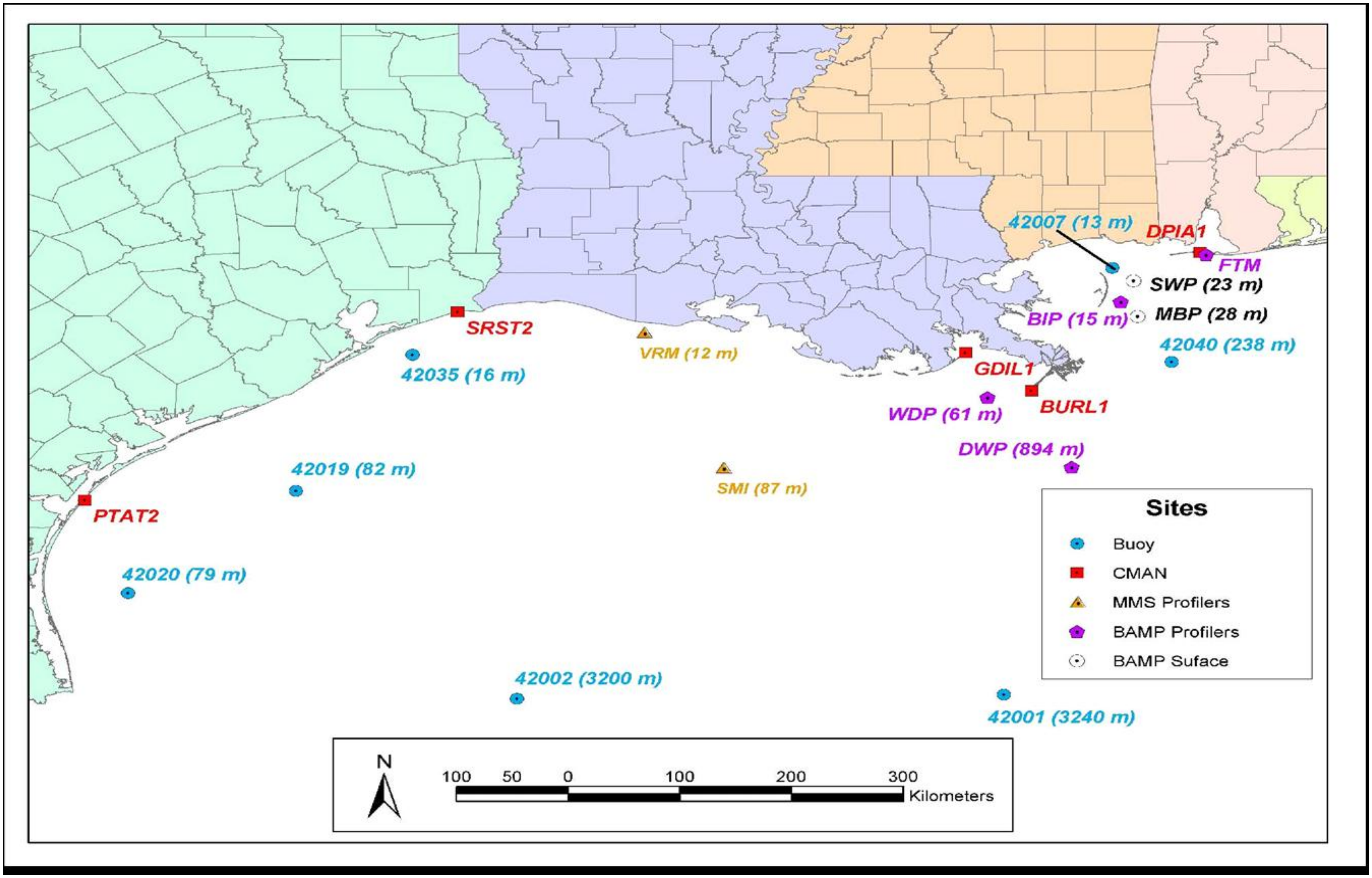


Figure 1C.1. Map of the MMS study region depicting locations of C-MAN, buoy, and radar wind profiler platform monitors. The water depths are provided in parenthesis.

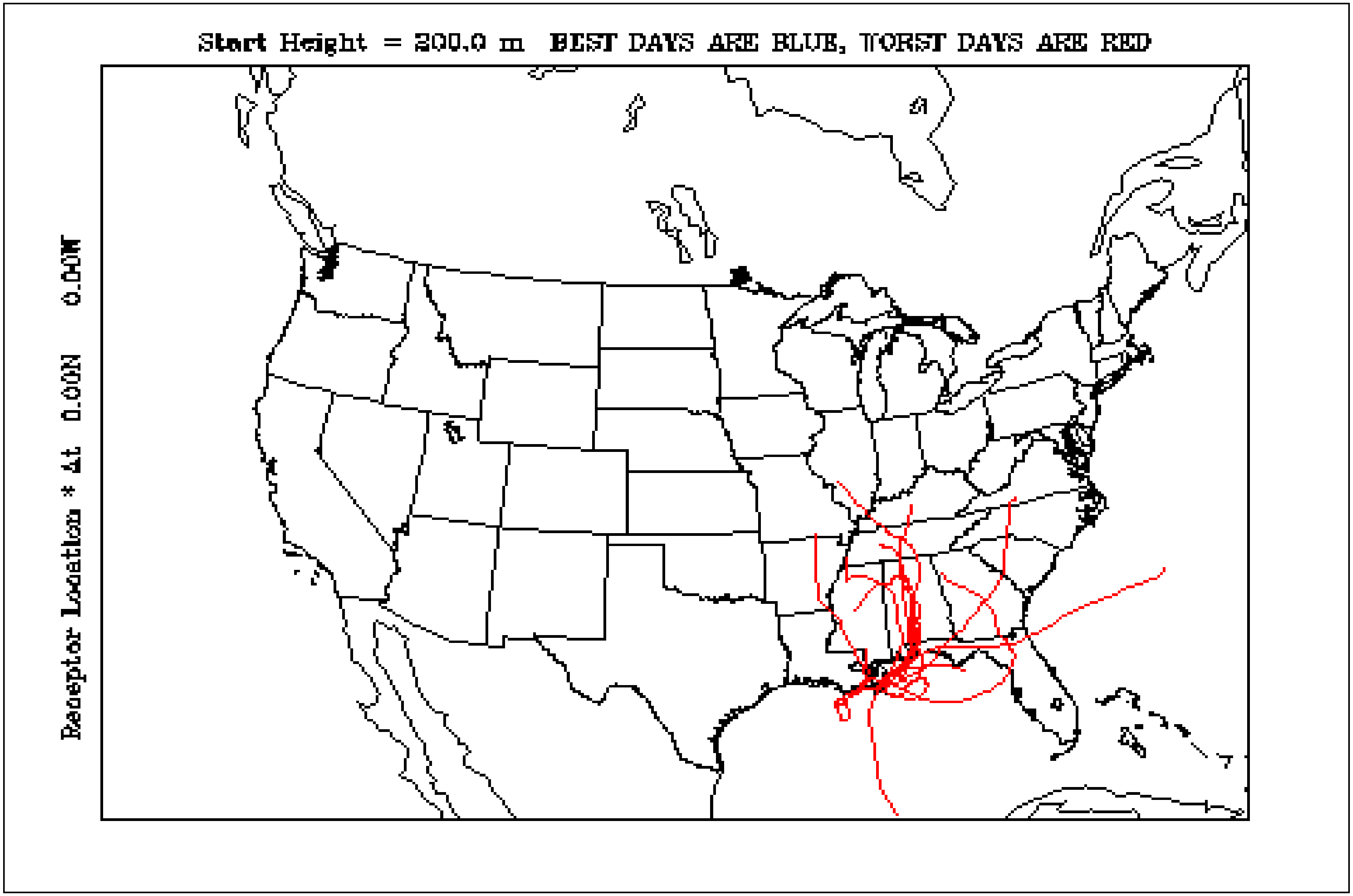


Figure 1C.2. 72-hour back trajectory cluster Analysis, BNWA at 9 CST and 200 m.

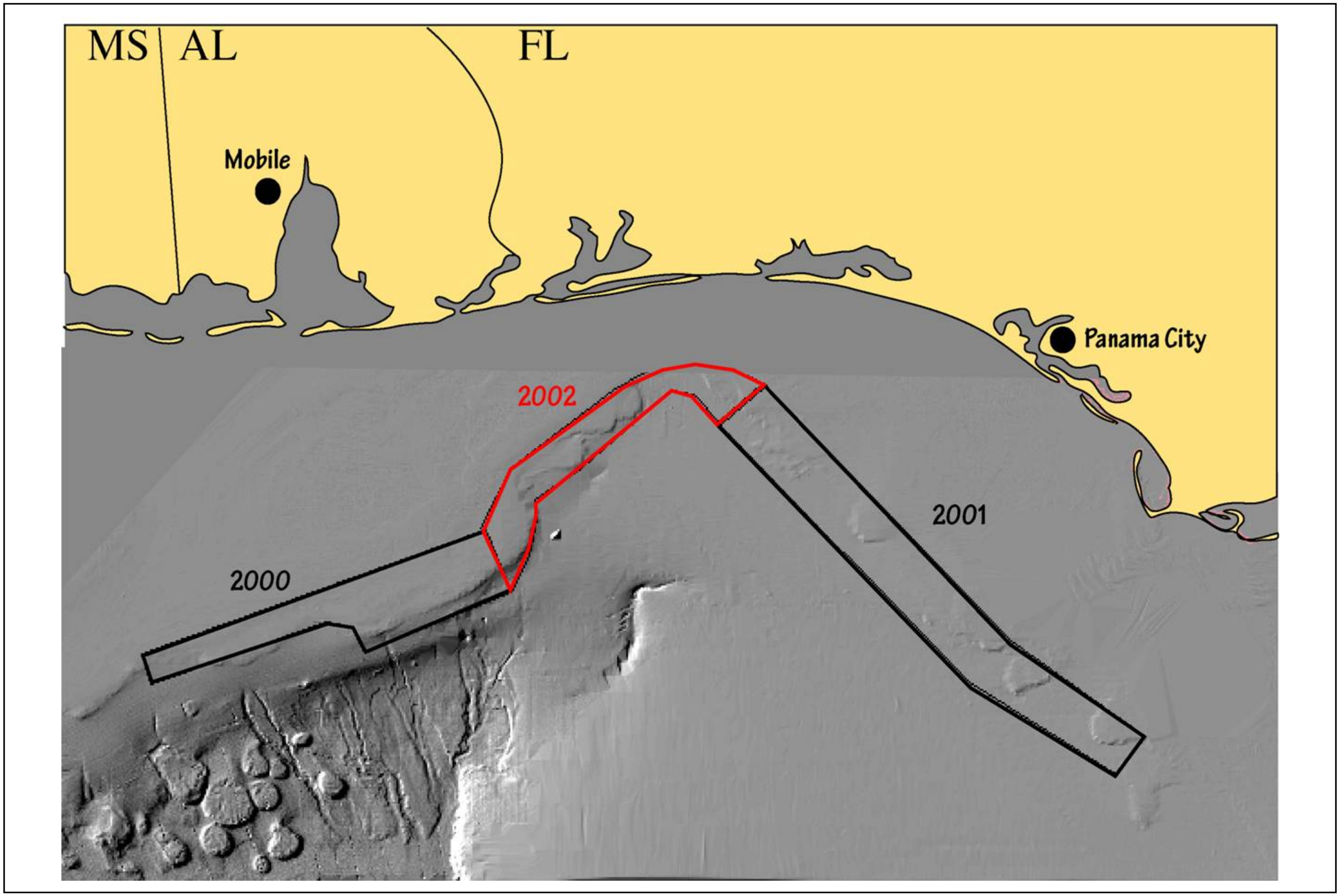


Figure 1D.1. Map showing the areas mapped with a high-resolution multibeam echosounder in 2000, 2001, and 2002.

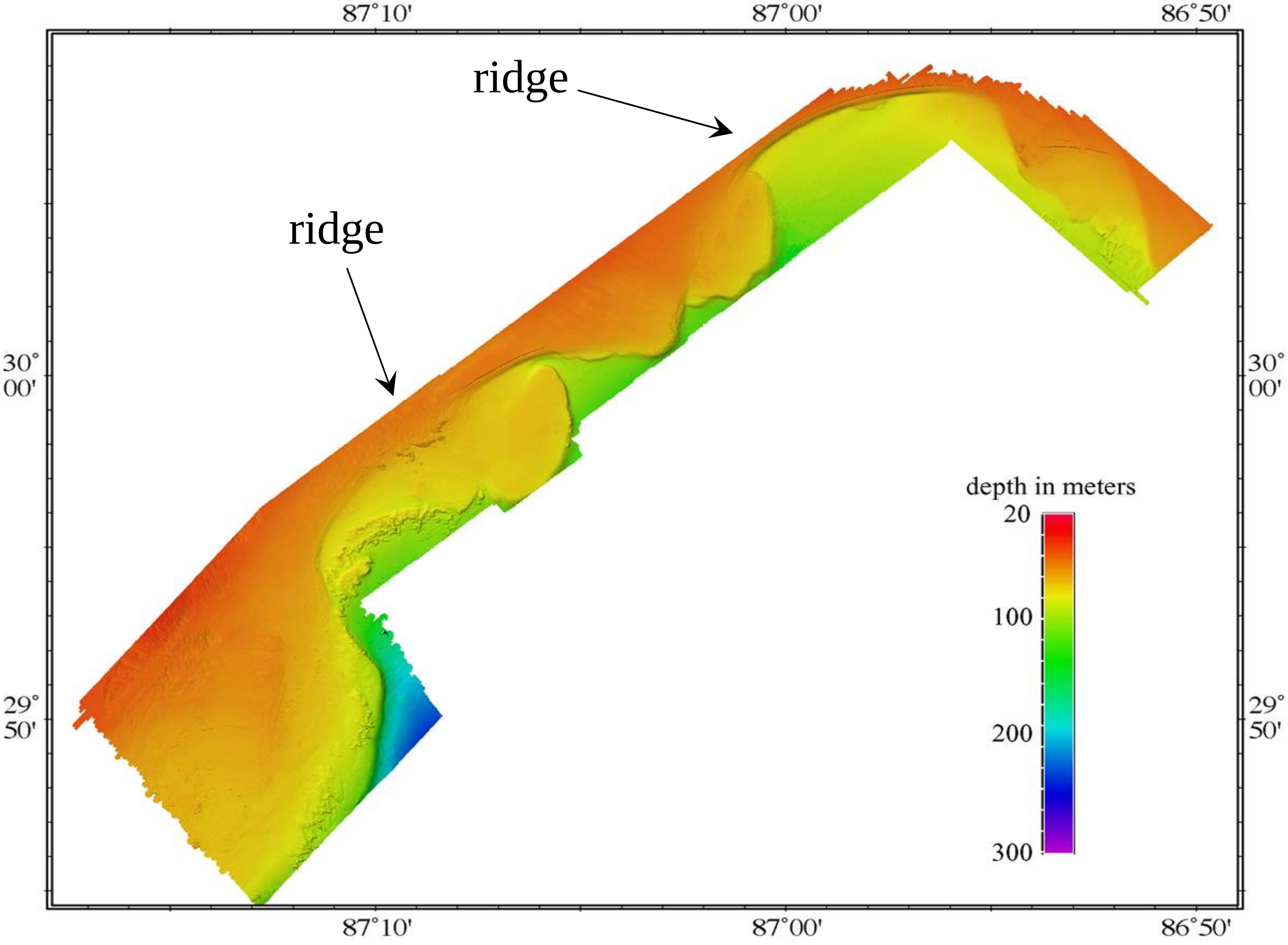


Figure 1D.2. Color shaded-relief map of the outer continental shelf west of DeSoto Canyon. Arrows point to ridges that resemble barrier islands.

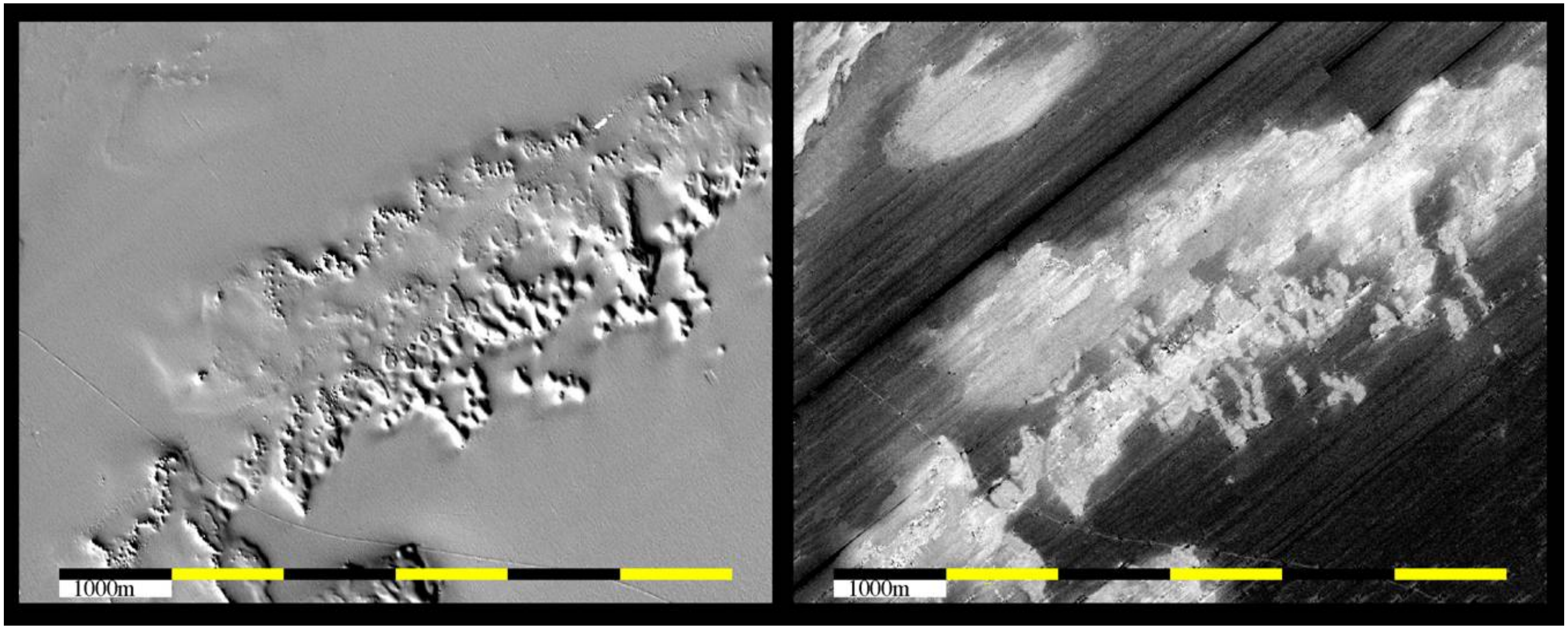


Figure 1D.3. Shaded bathymetry (left) and co-registered acoustic backscatter (right) of features that geomorpically resemble reefs. These features occur in water depths that range from 80 to 105 m. Light tones are higher acoustic backscatter.

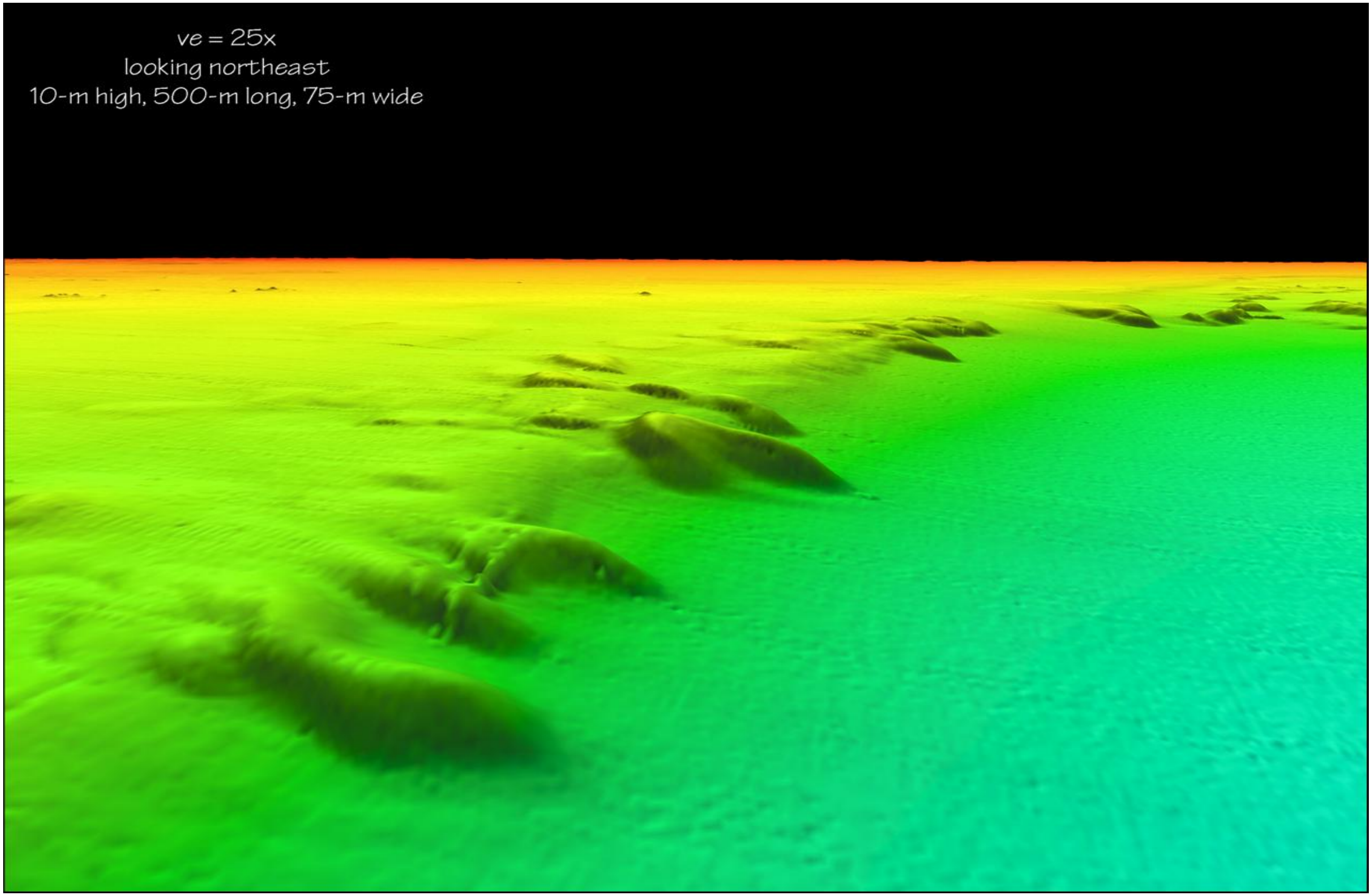


Figure 1D.4. Mounds that strike perpendicular to the contours. These features may be Oculina lithoherms.

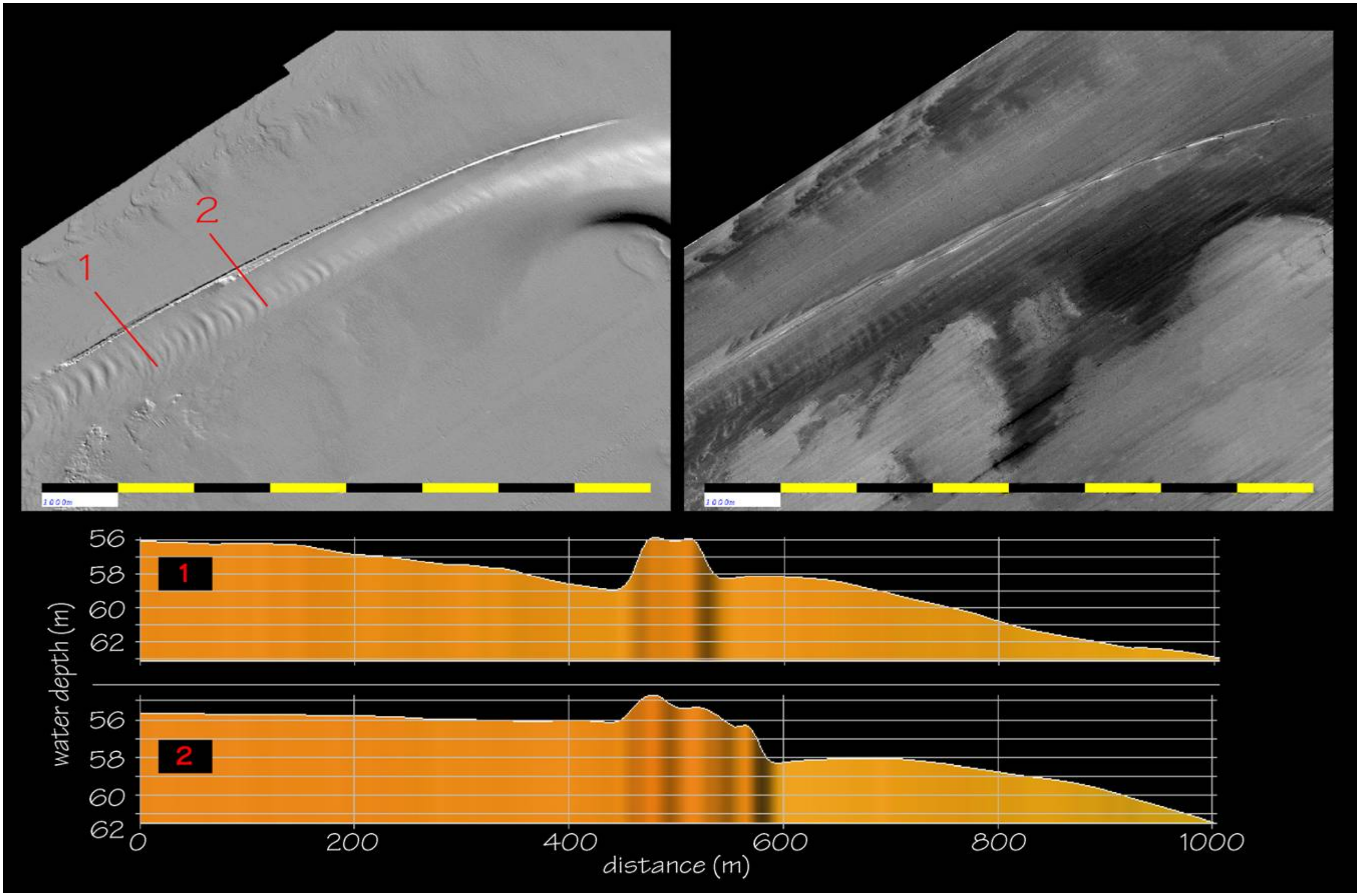


Figure 1D.5. Shaded bathymetry (upper left) and co-registered acoustic backscatter (upper right) of ridge system that resembles a barrier island. Lower panels are profiles across the ridge.

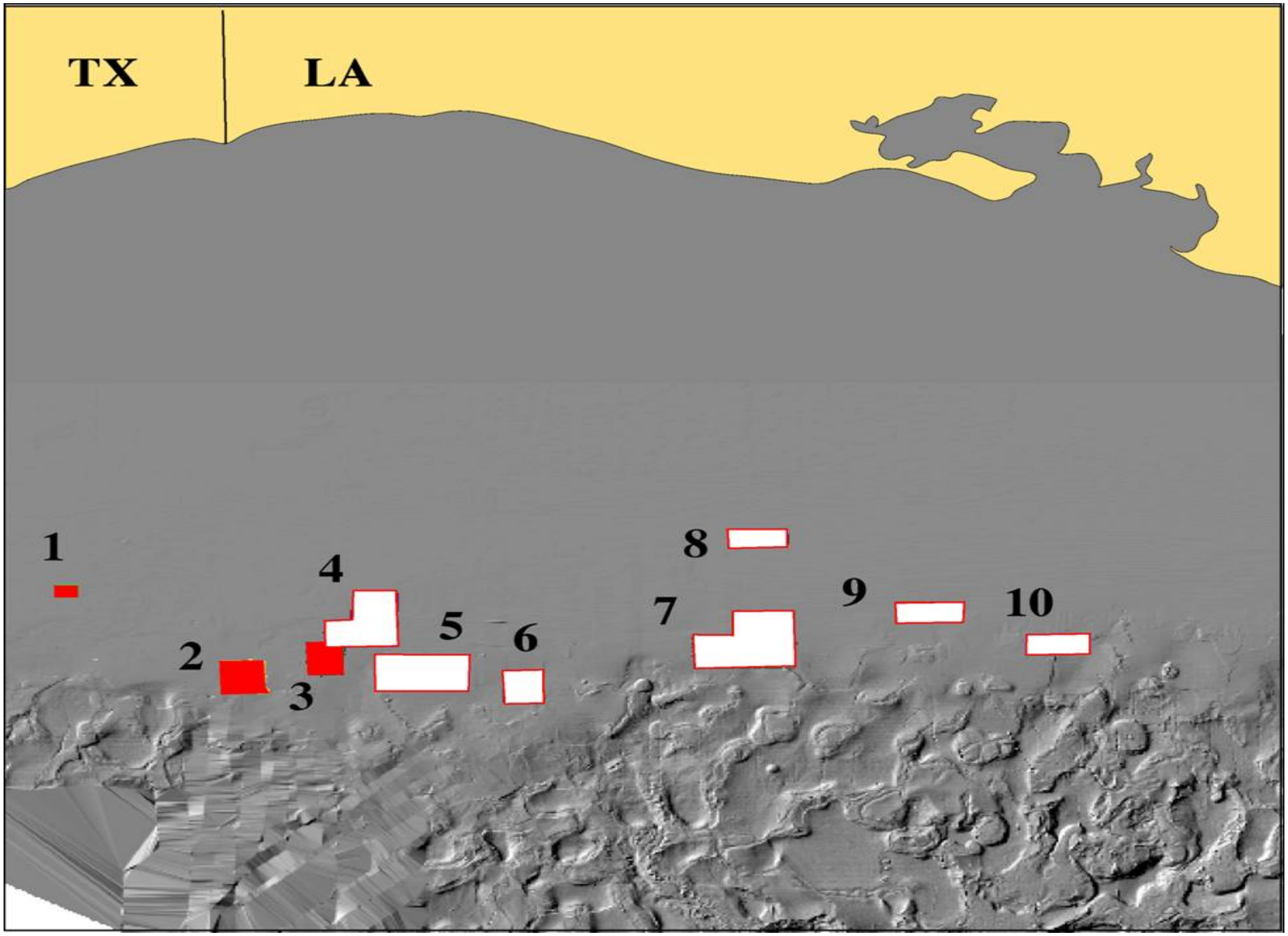


Figure 1D.6. Location map of areas mapped in 1998 (red) and 2002 (white). Areas include (1) Stetson Bank, (2) West Flower Garden Bank, (3) East Flower Garden Bank, (4) MacNeil Bank, (5) Rankin and Bright Banks, (6) Geyer Bank, (7) McGrail, Bouma, Rezak, and Sider Banks, (8) Sonnier Bank, (9) Alderdice Bank, and (10) Jakkula Bank.

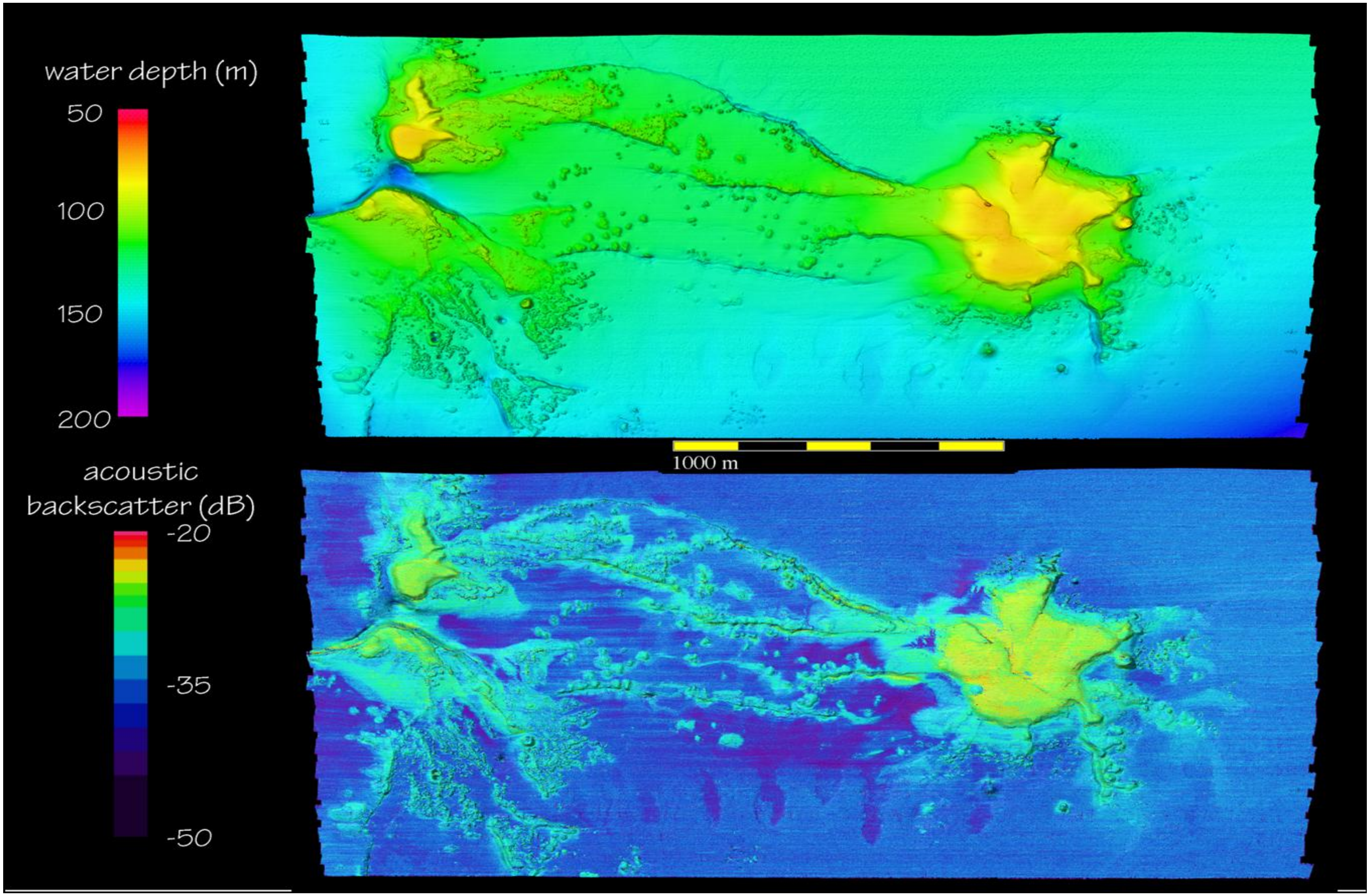


Figure 1D.7. Rankin #1, Rankin #2, and Bright Banks bathymetry (top) and acoustic backscatter (bottom).

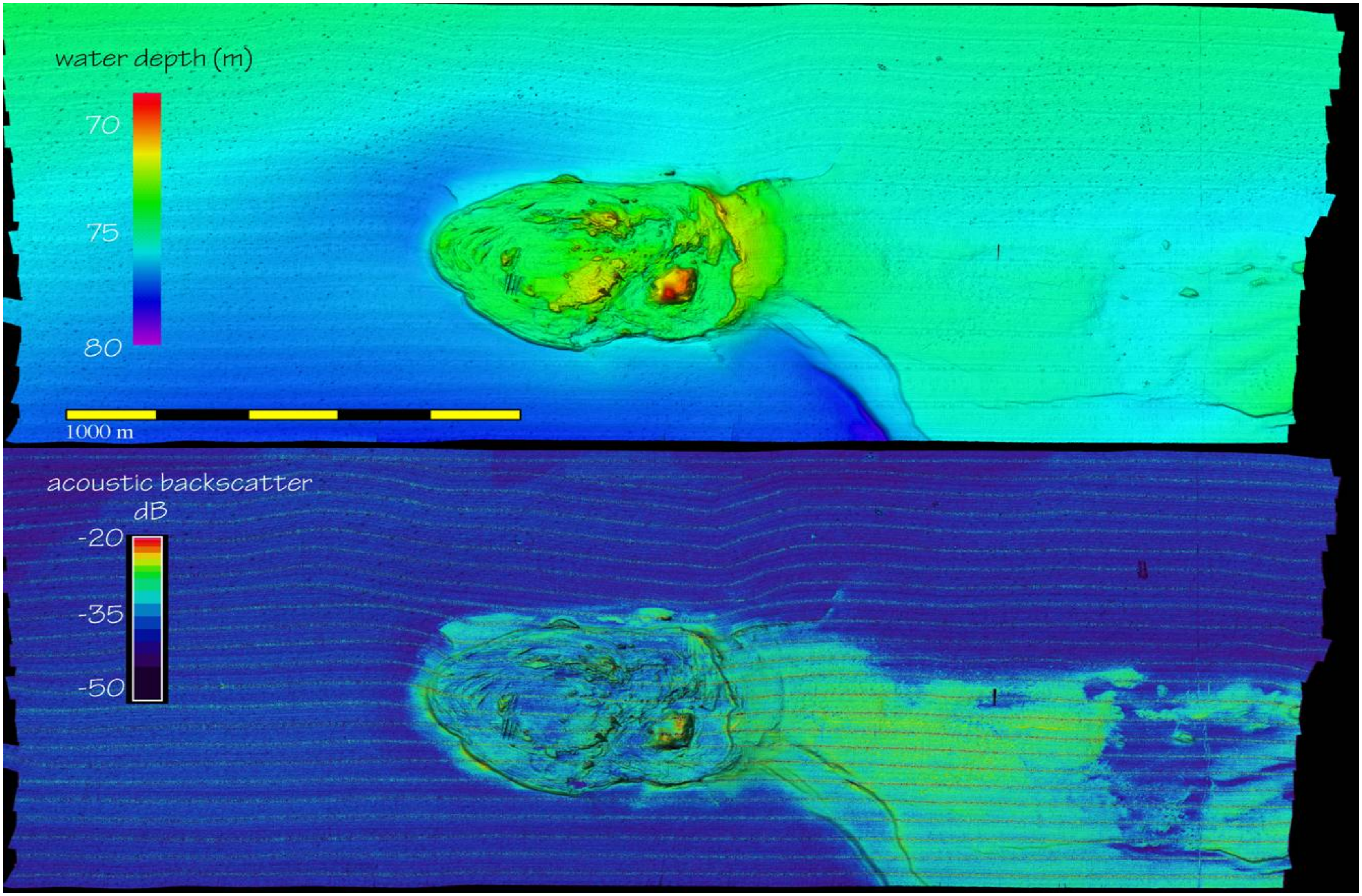


Figure 1D.8. Alderdice Bank bathymetry (top) and acoustic backscatter (bottom).

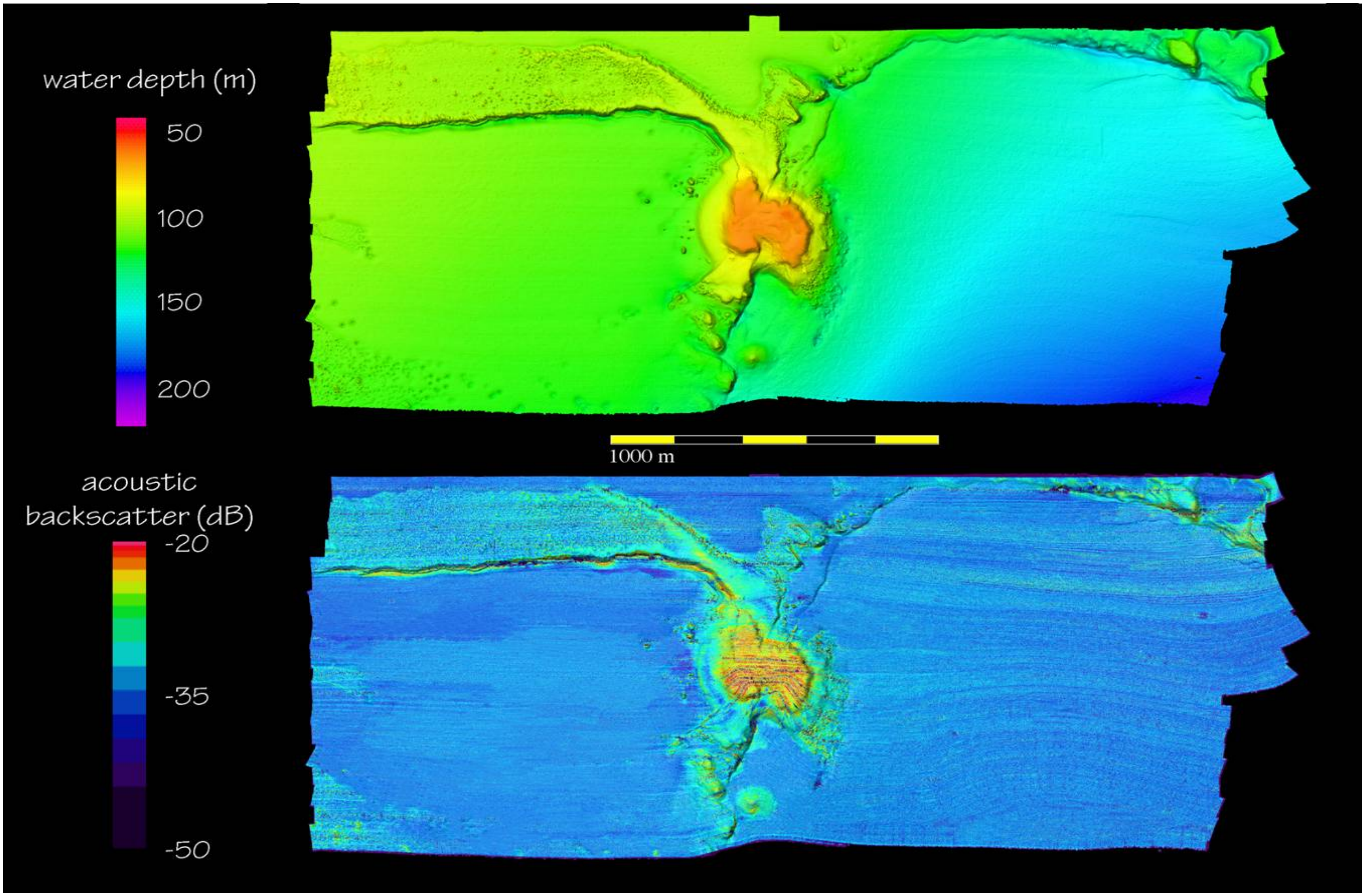


Figure 1D.9. Jakkula Bank bathymetry (top) and acoustic backscatter (bottom).

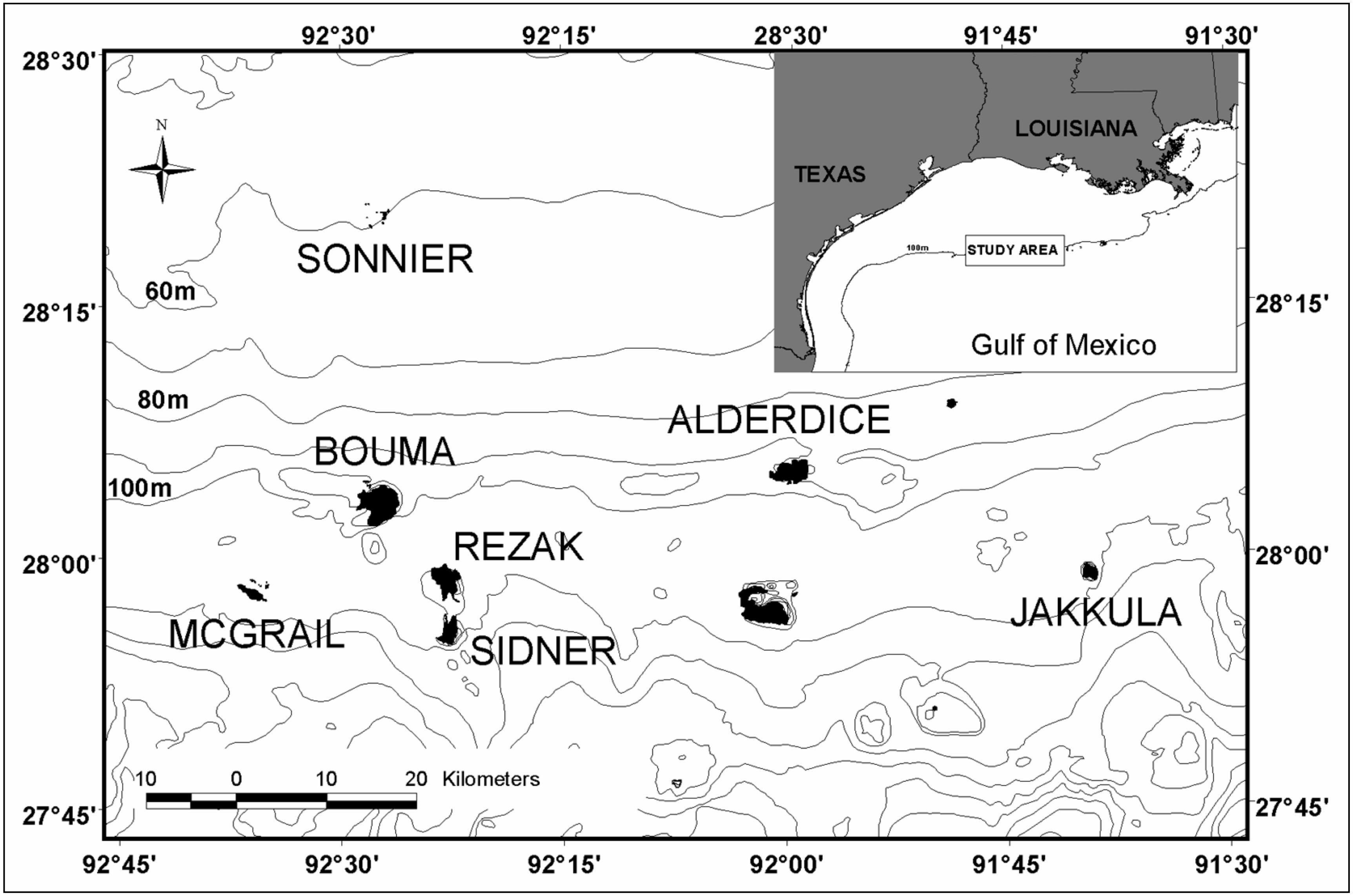


Figure 1D.10. Location of outer shelf banks surveyed during the 2002 SSE Mission.

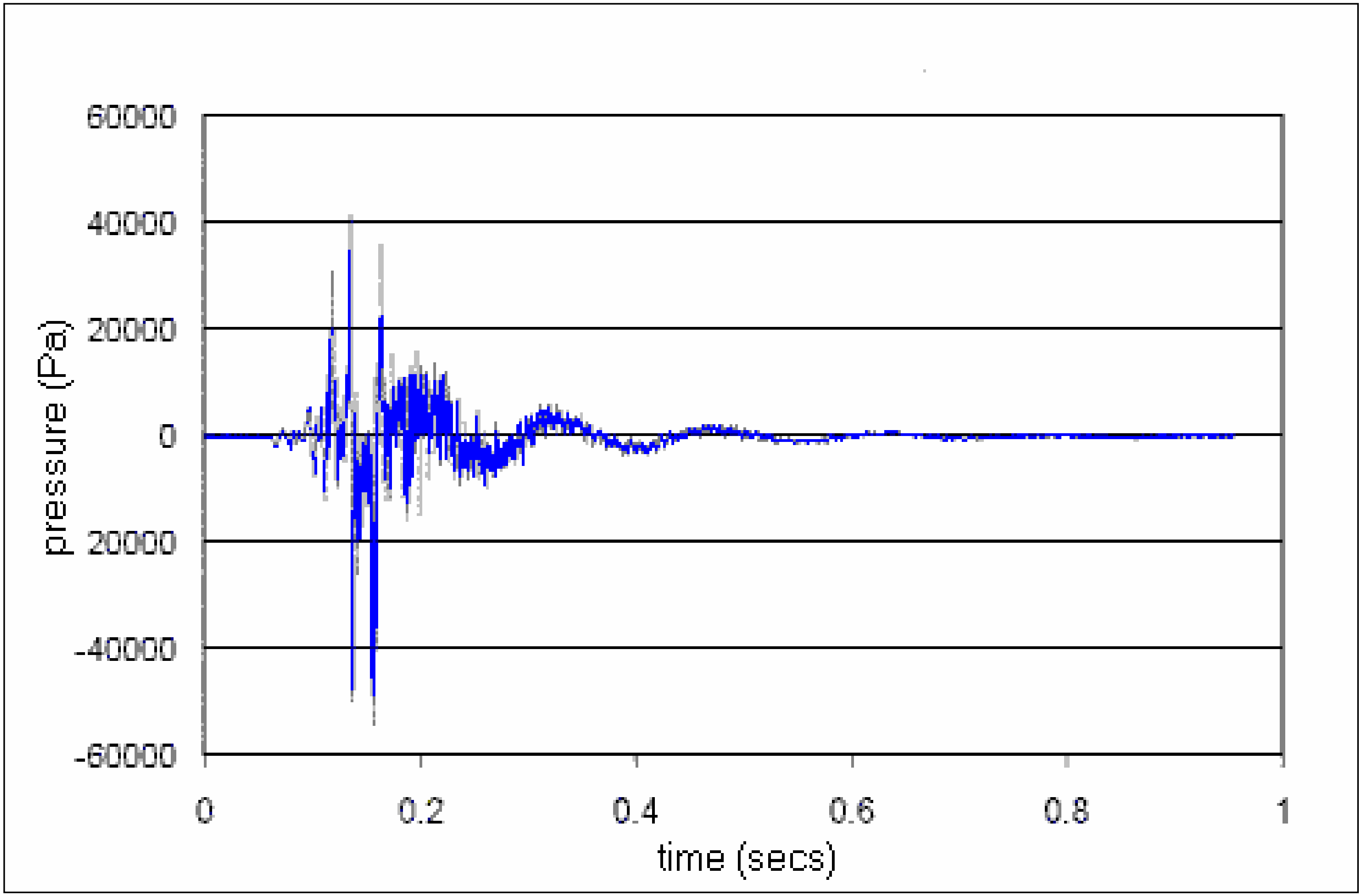


Figure 1E.1. A typical pressure time history recorded at 600 meters.

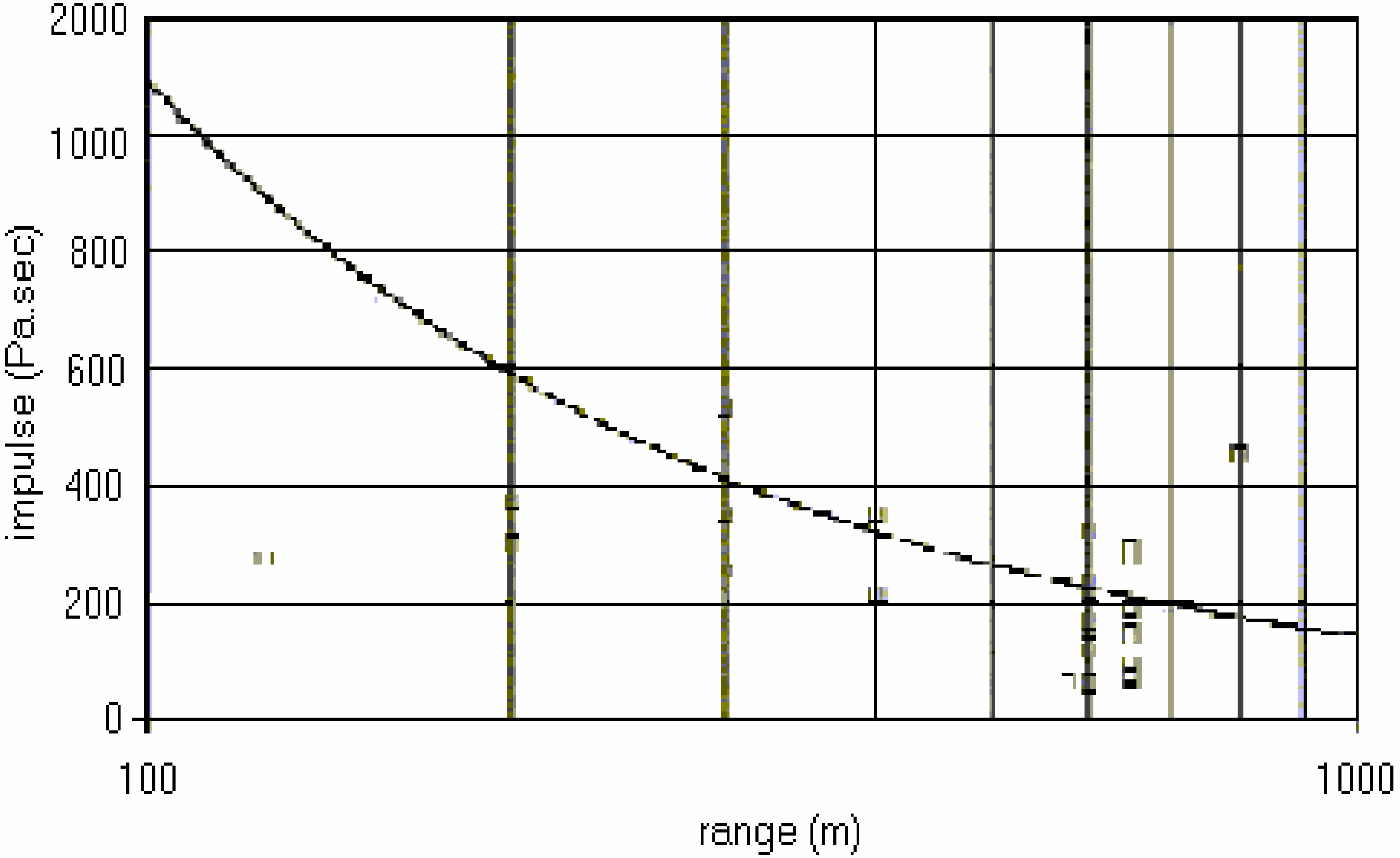


Figure 1E.2. Measured versus estimated peak pressure for unconfined charge, as a function of range.

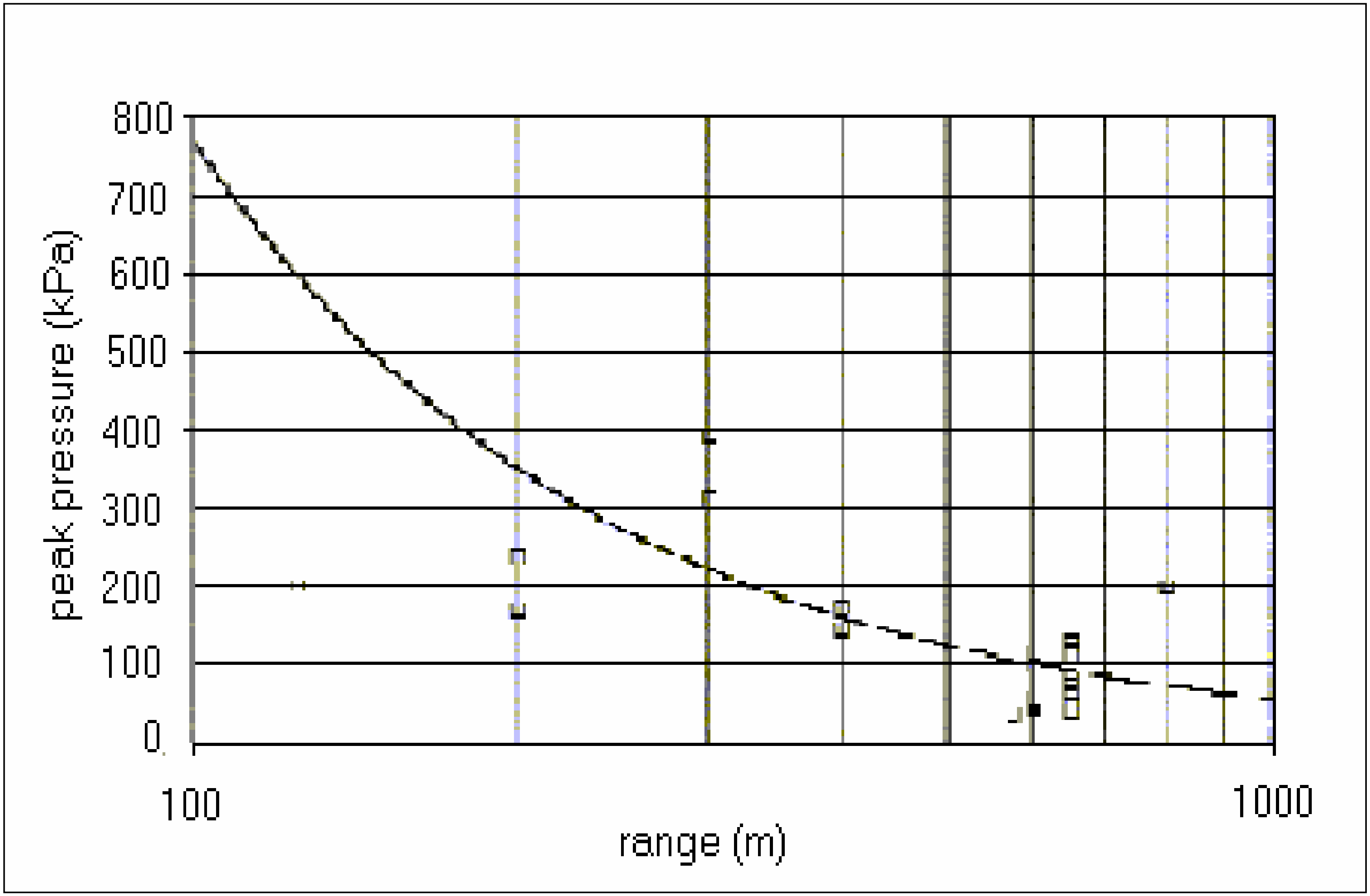


Figure 1E.3. Measured versus estimated impulse for unconfined charge, as a function of range.

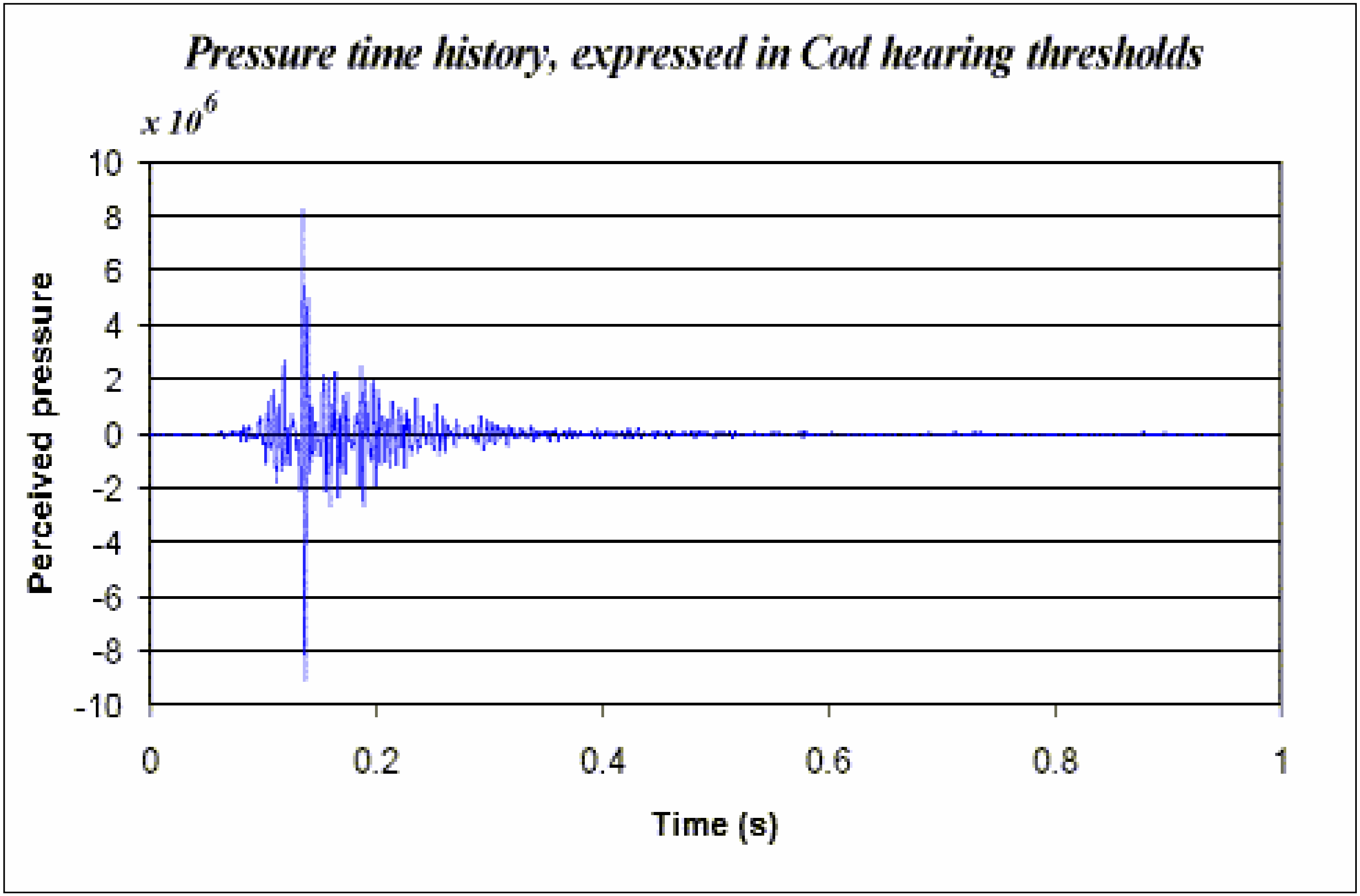


Figure 1E.4. A pressure time history expressed in units of hearing: Cod.

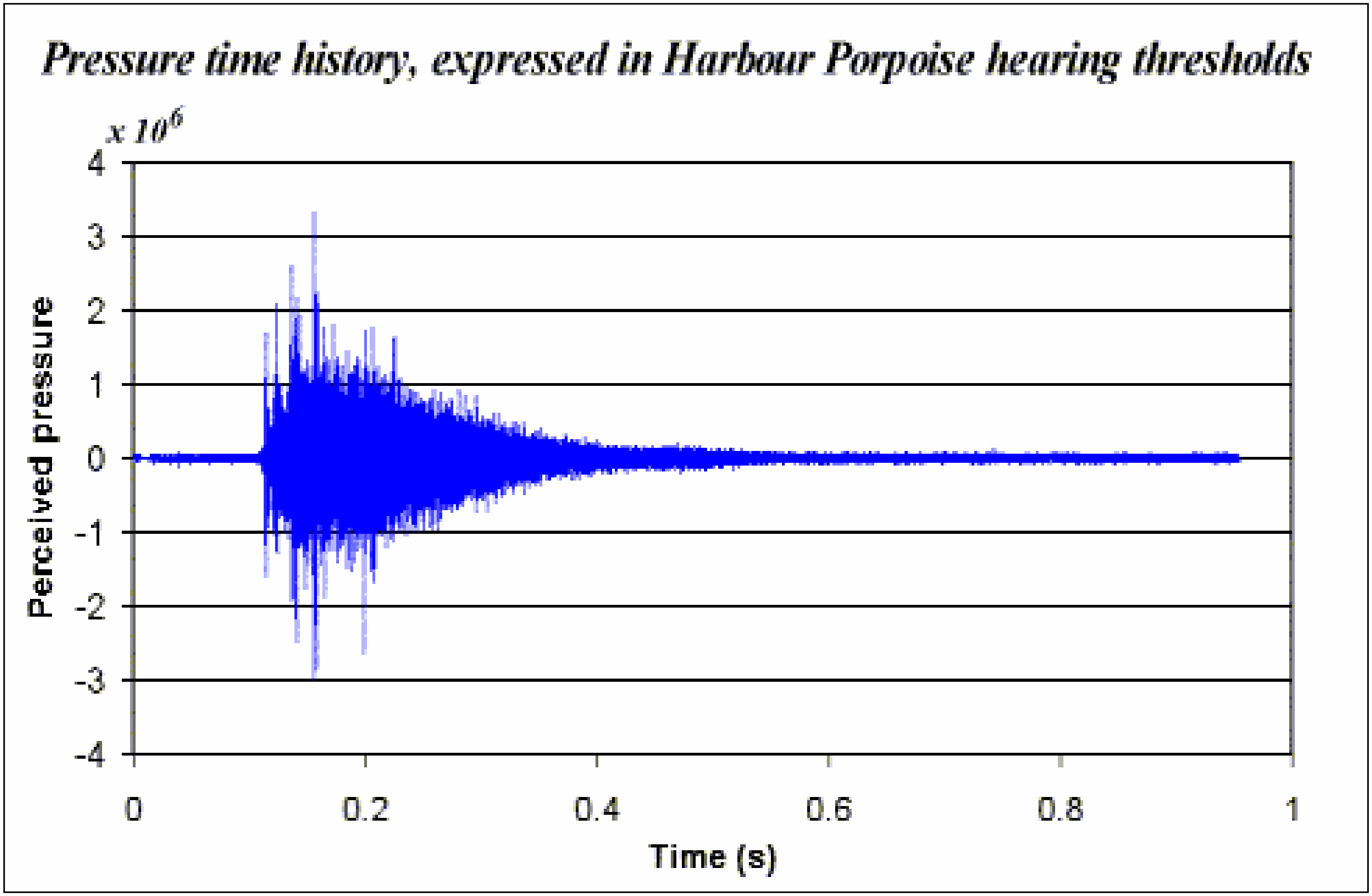


Figure 1E.5 A pressure time history expressed in units of hearing: Harbor Porpoise.

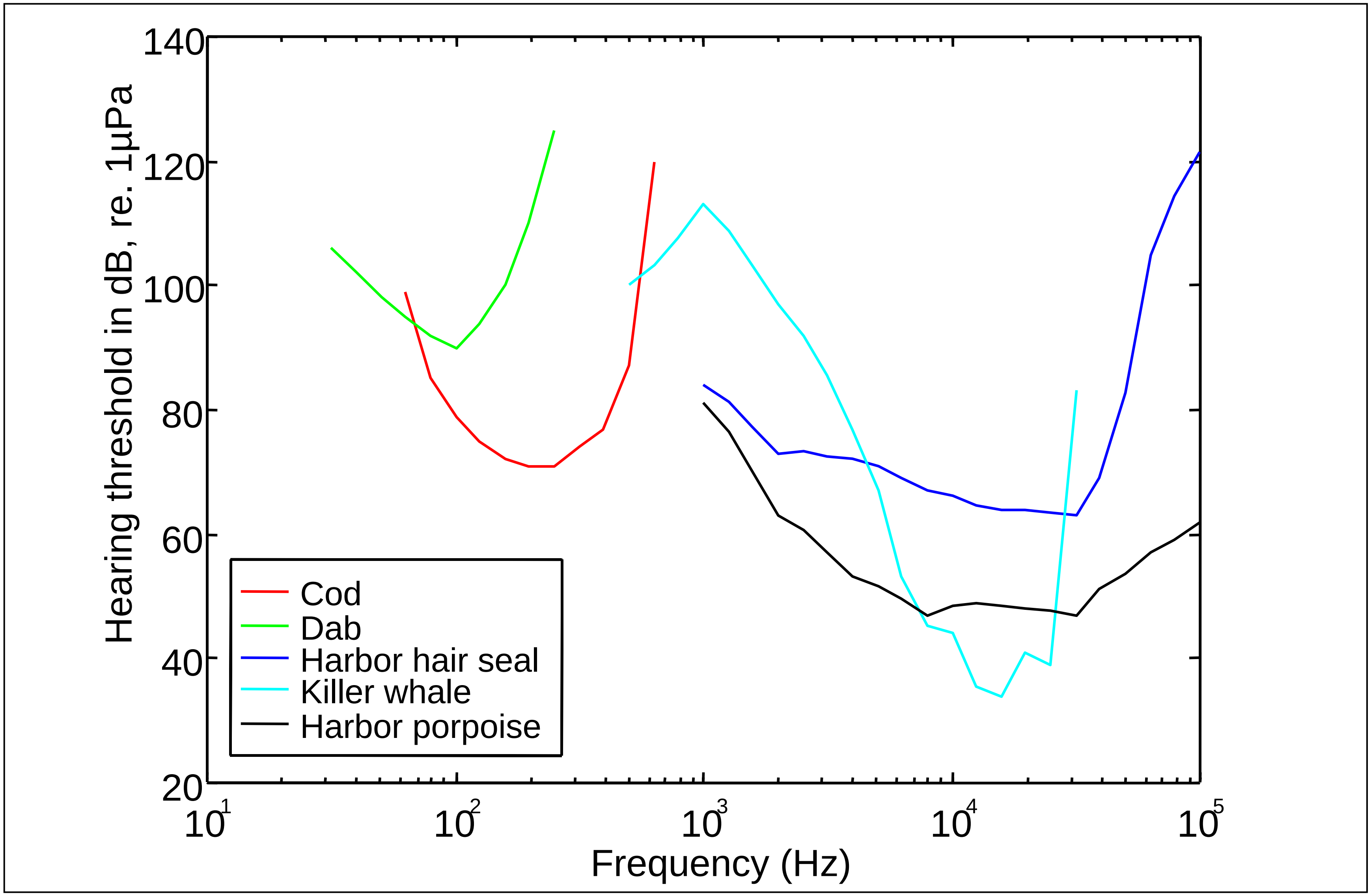


Figure 1E.6. Audiograms of various species, as used to generate dB_{ha} (Species) levels.

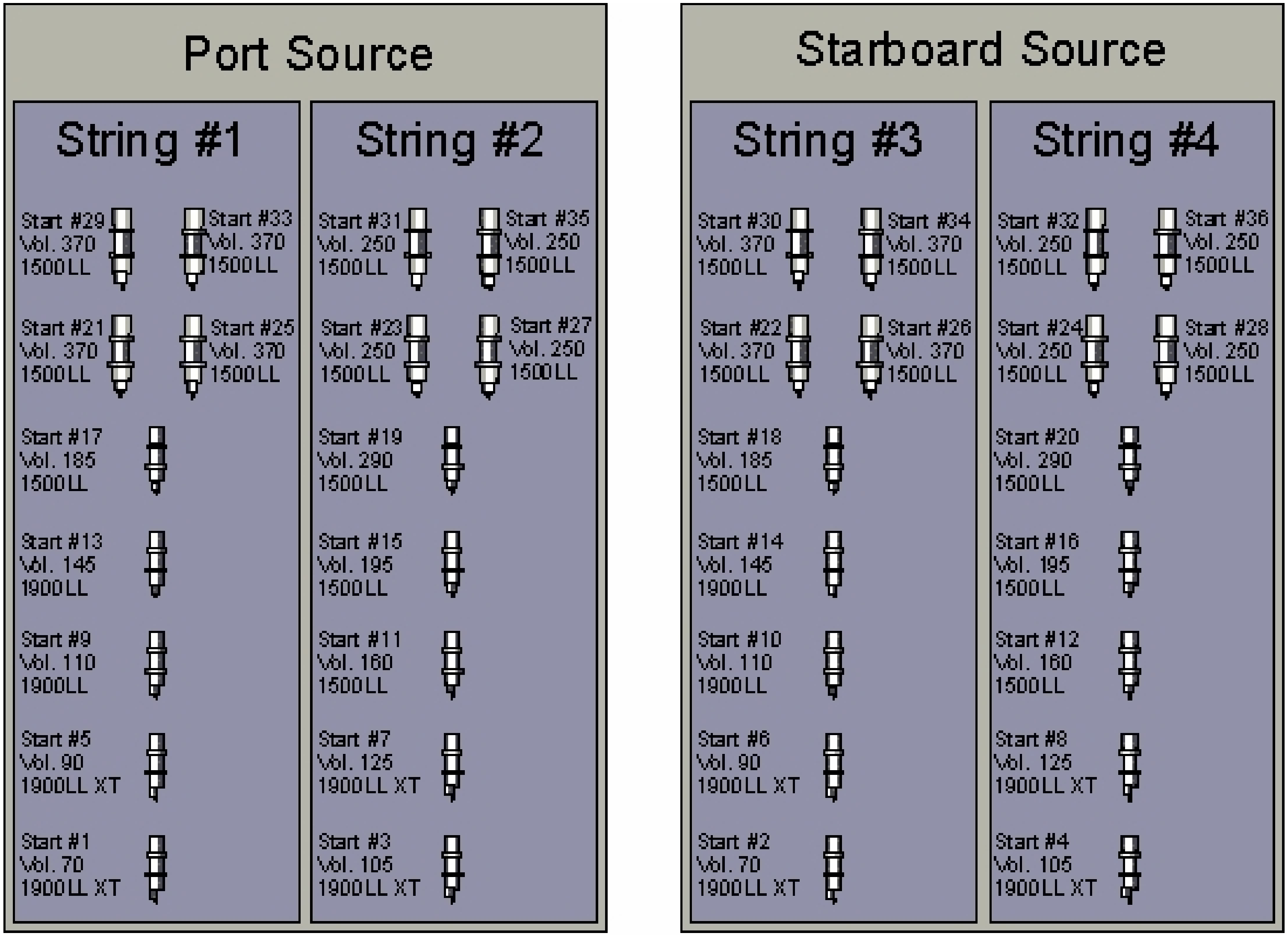


Figure 1E.7. A diagram illustrating the layout of airguns in the port and starboard airgun arrays.

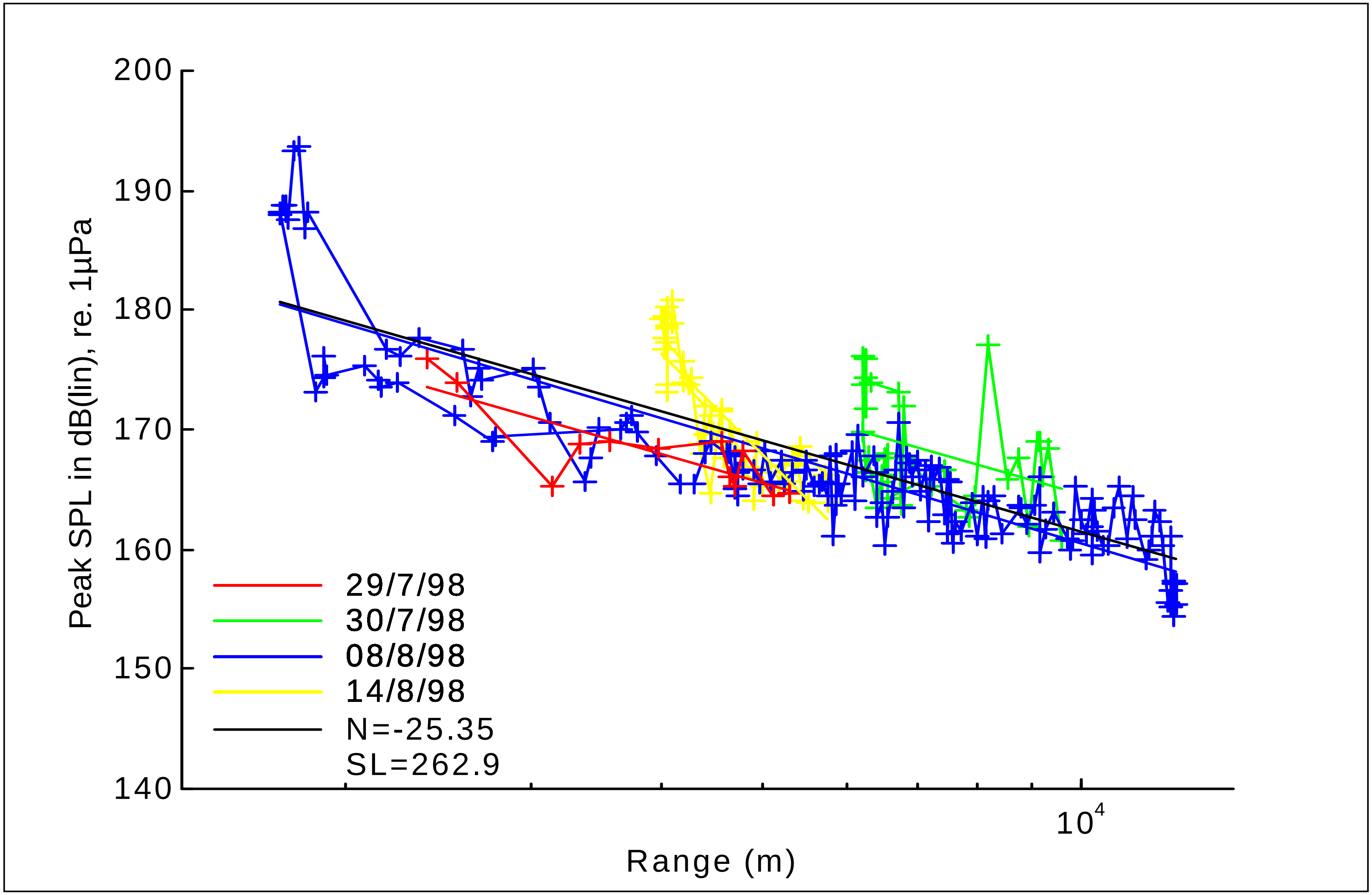


Figure 1E.8. Peak sound pressure level in dB(lin) re. 1µPa at 5 meters depth versus range, unweighted results.

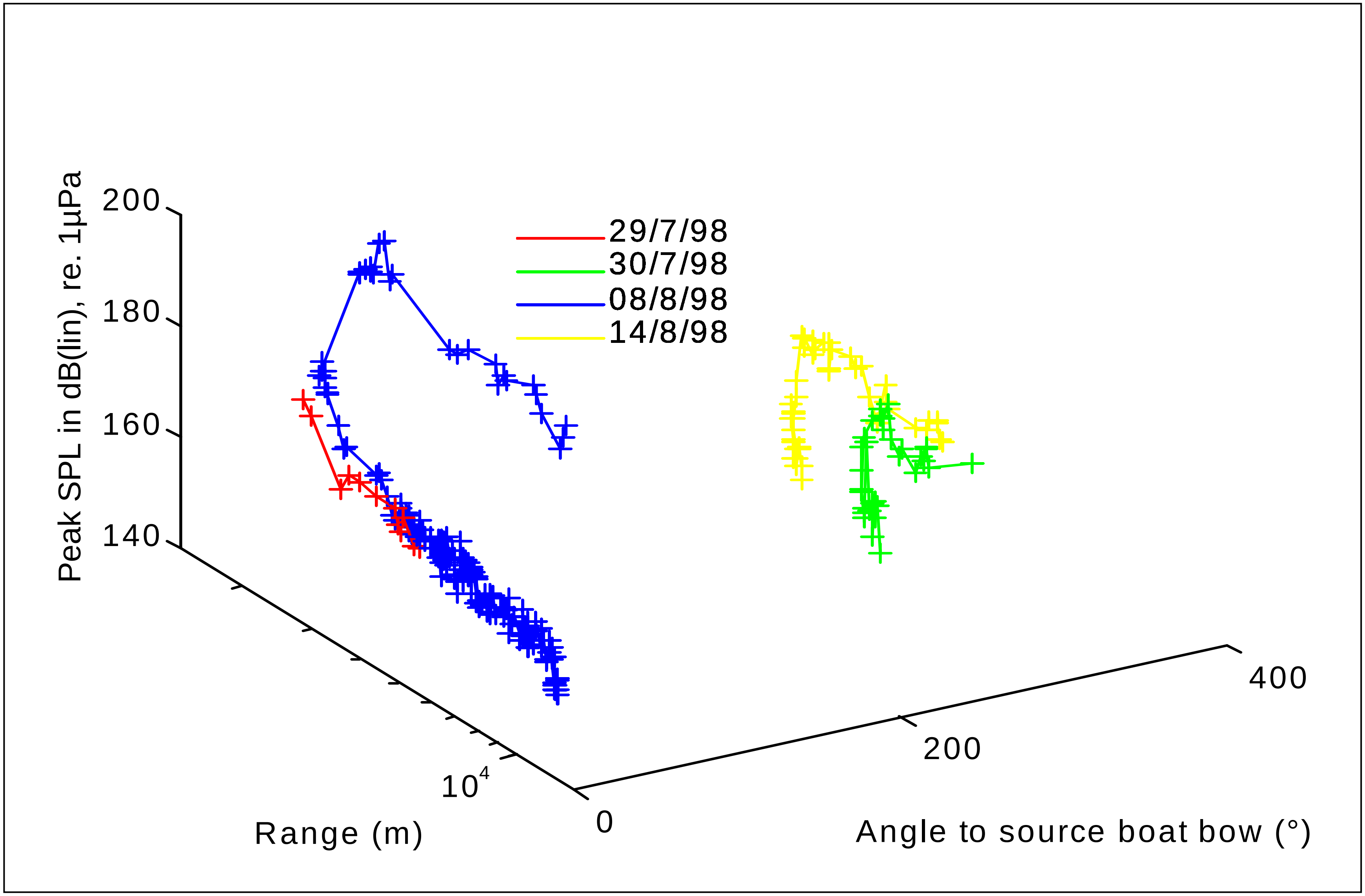


Figure 1E.9. Peak sound pressure level in dB(lin) re. 1µPa at 5 meters depth versus range, unweighted results, second view.

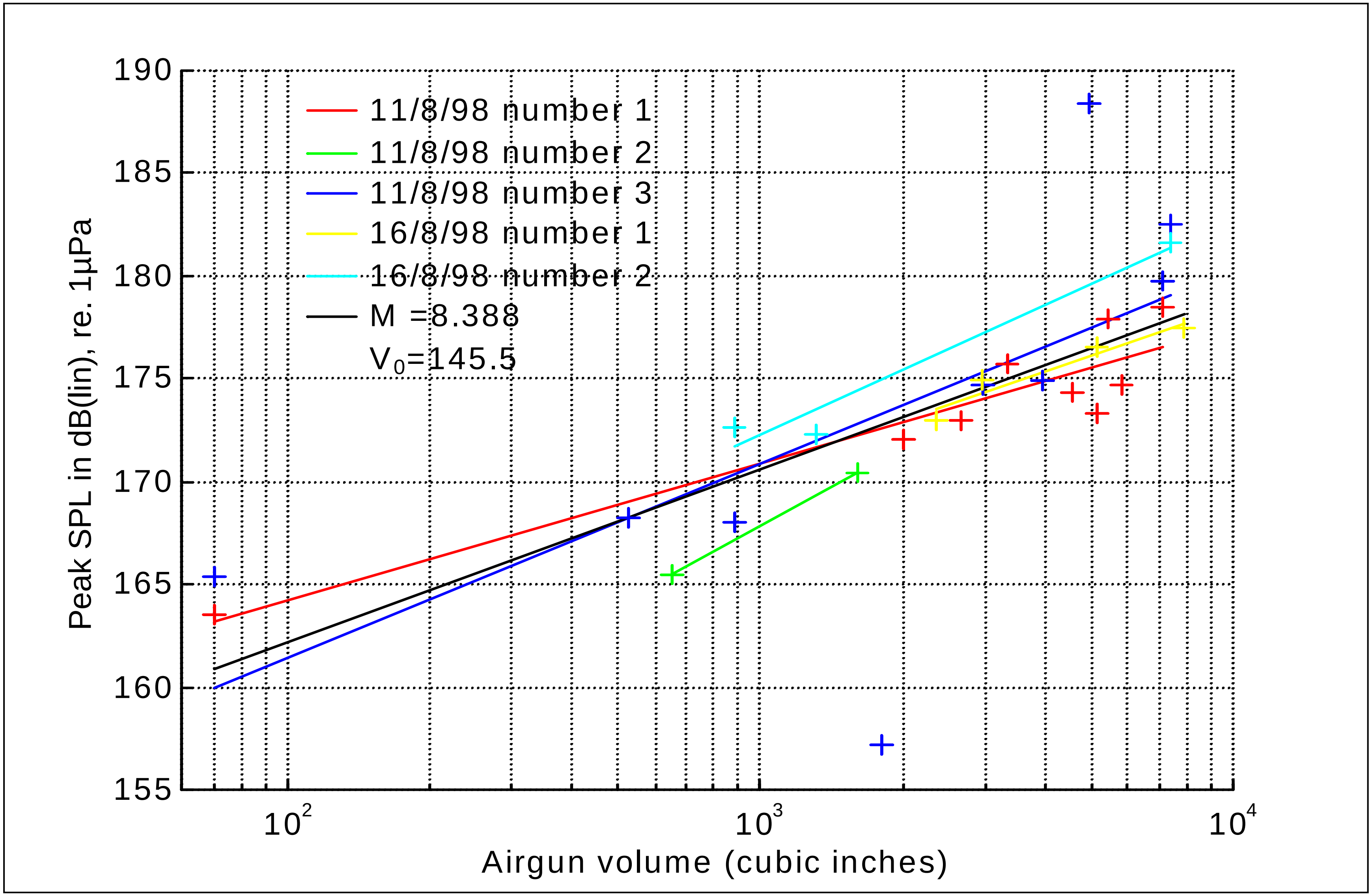


Figure 1E.10. Peak sound pressure level in dB(lin) re. 1µPa, measured at 5 meters depth versus compressed air volume discharged.

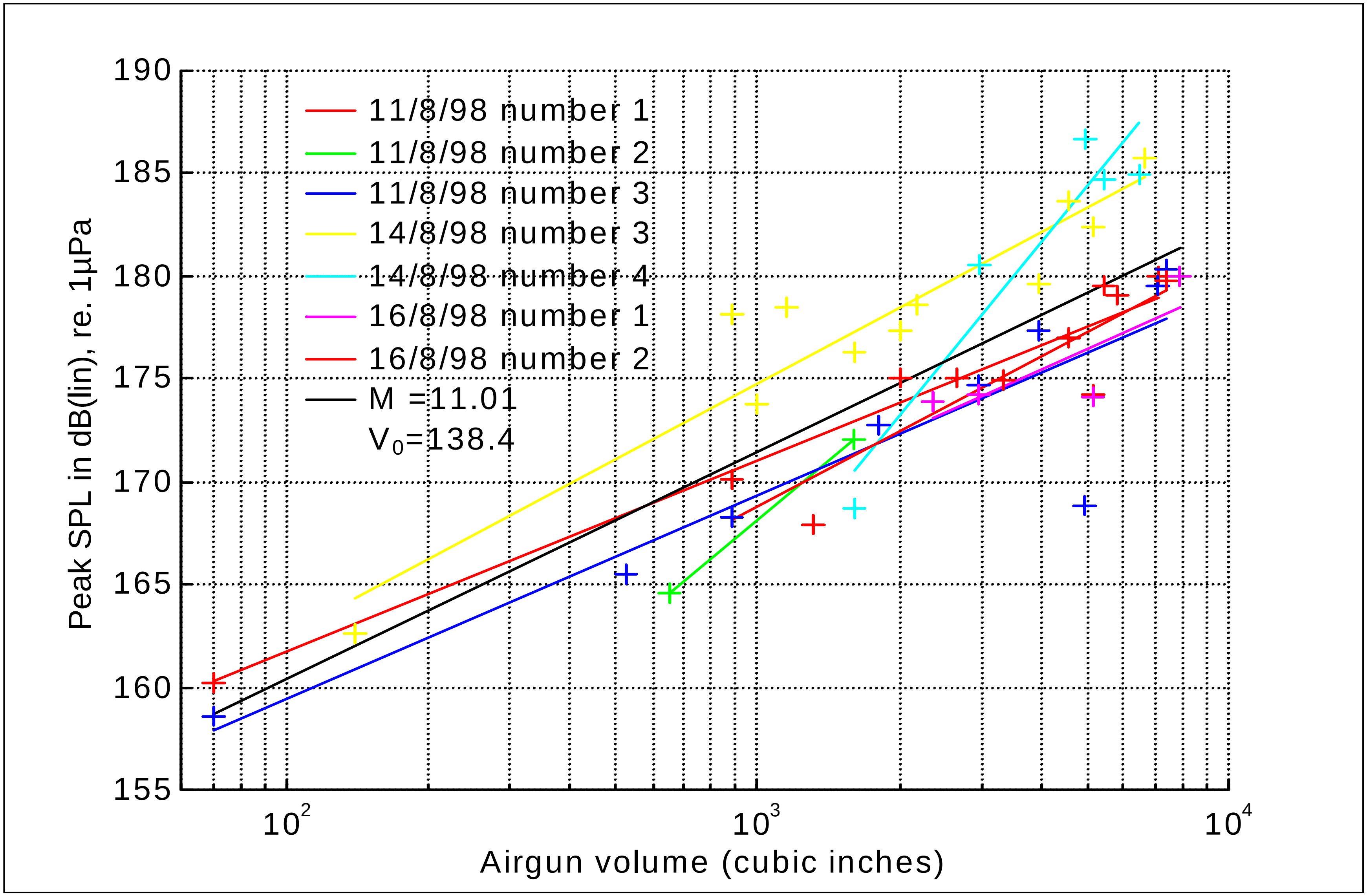


Figure 1E.11. Peak sound pressure level in dB(lin) re. 1μPa, measured at 20 meters depth versus compressed air volume discharged.

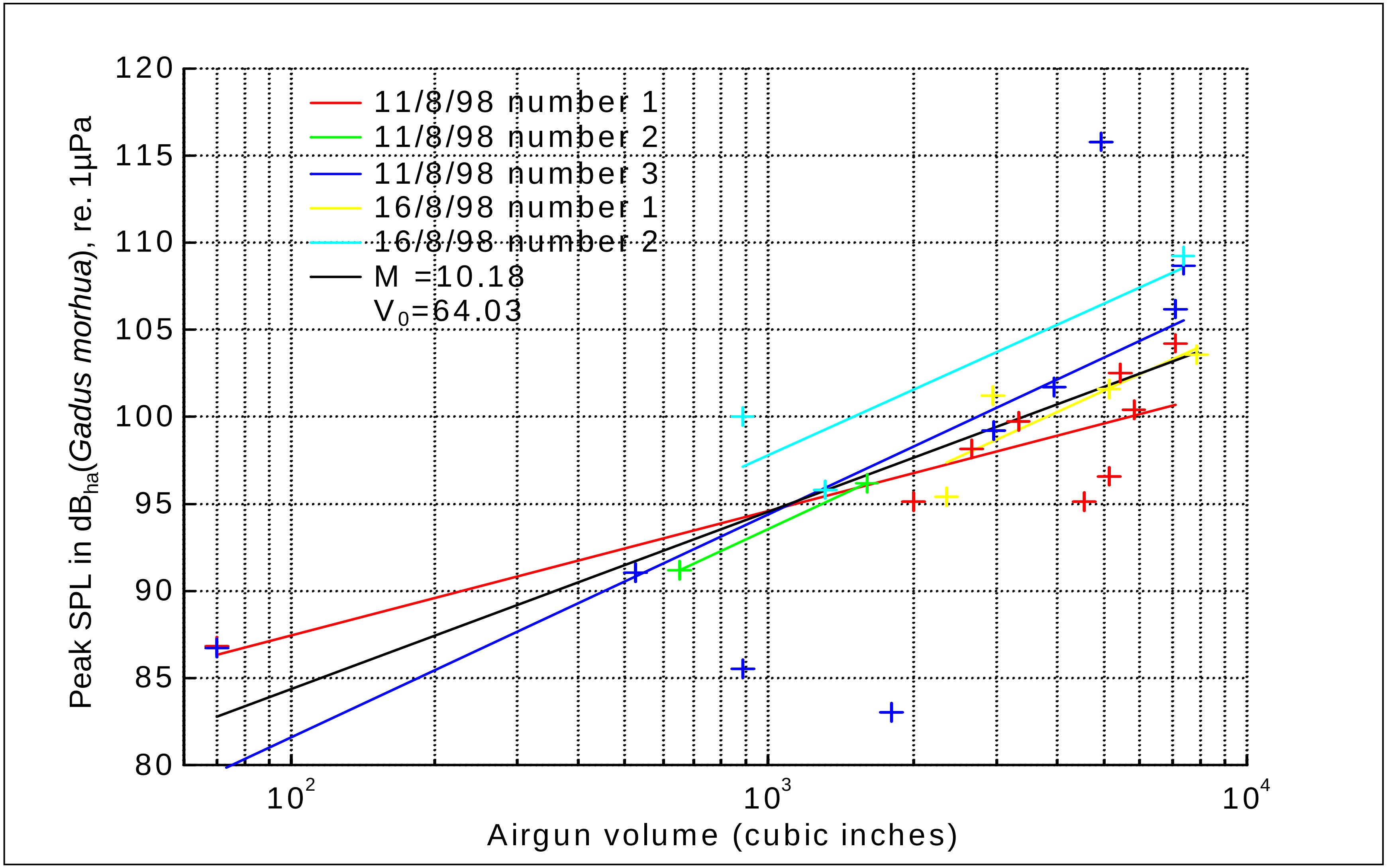


Figure 1E.12. Peak sound pressure level in dB$_{ha}$ (*Gadus morhua*) re. 1µPa for the cod, measured at 5 meters depth versus compressed air volume discharged.

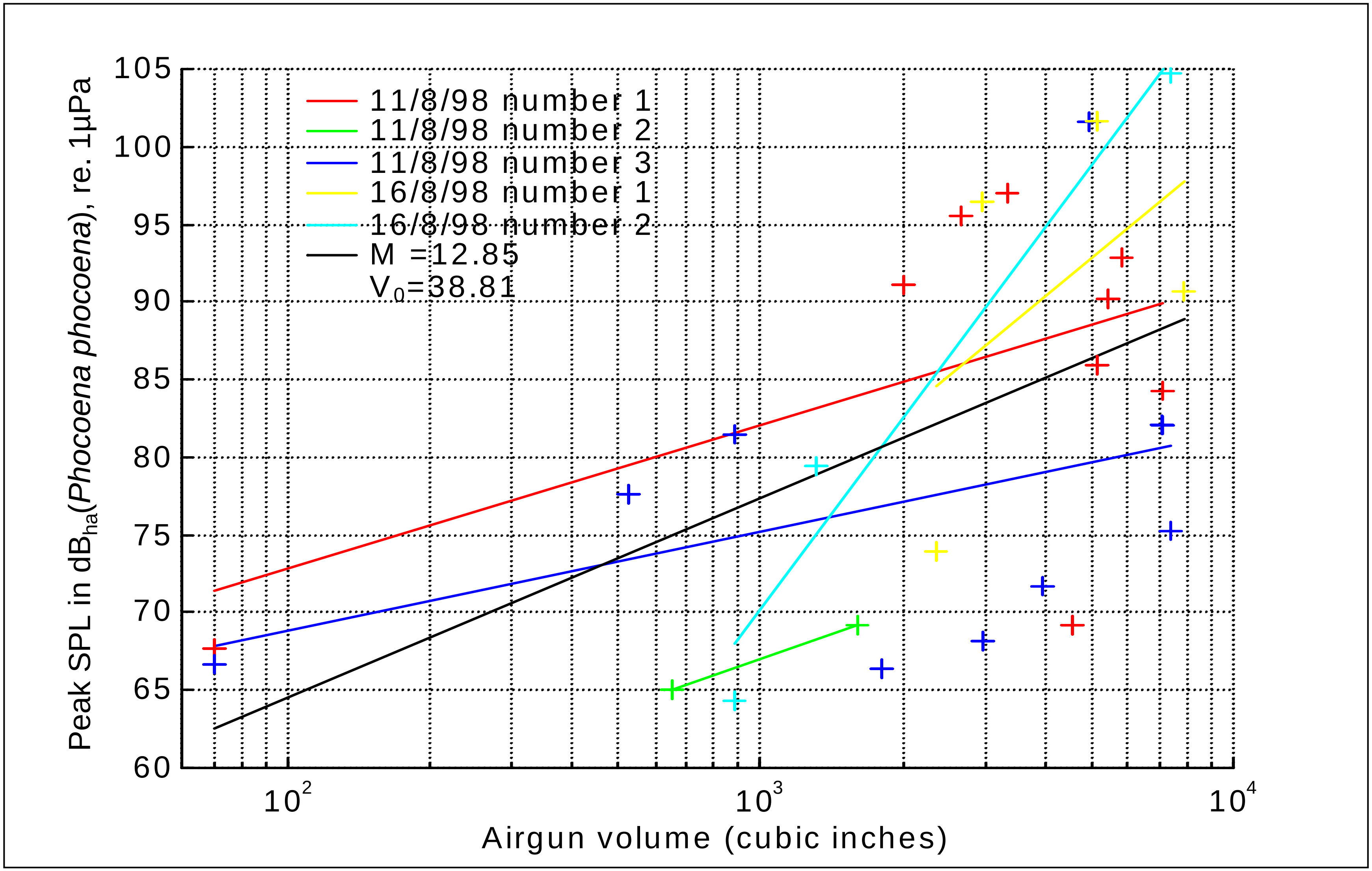


Figure 1E.13. Peak sound pressure level in dB$_{ha}$ (*Phocoena phocoena*) re. 1μPa for the harbor porpoise, measured at 5 meters depth versus compressed air volume discharged.

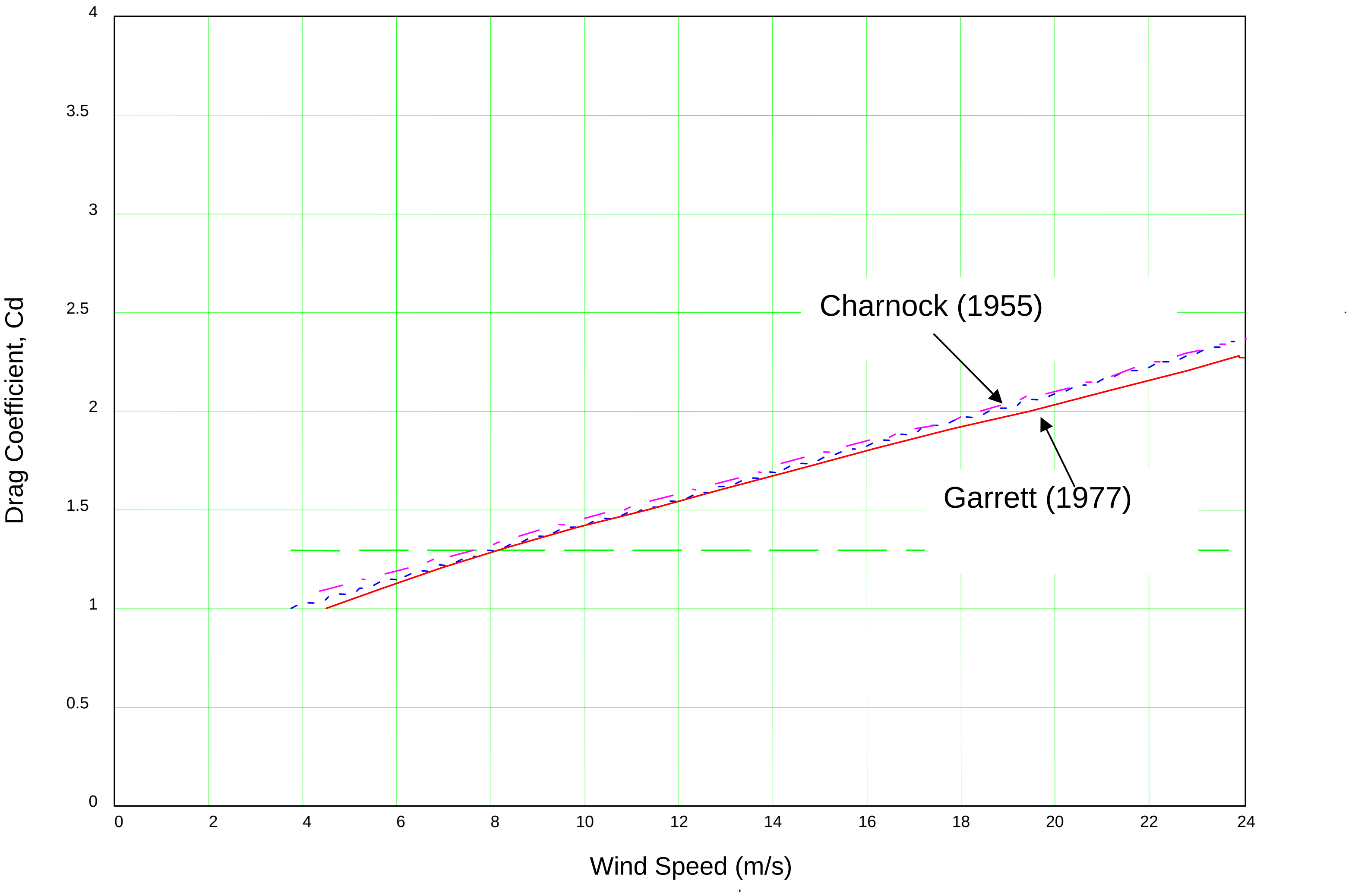


Figure 1F.1. Comparisons of drag coefficient versus wind speed.

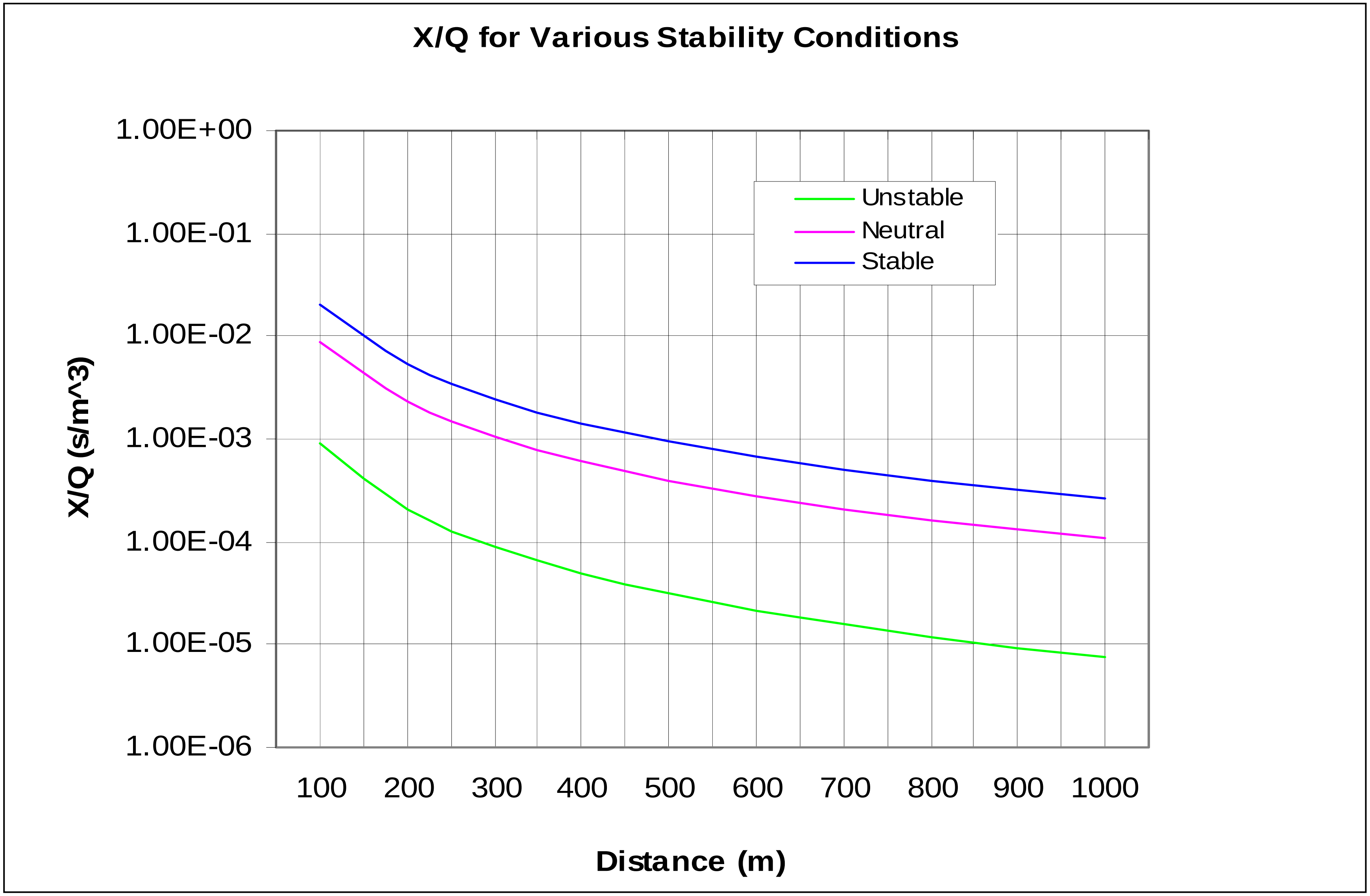


Figure 1F.2. X/Q versus plume downwind distances for various stability conditions.

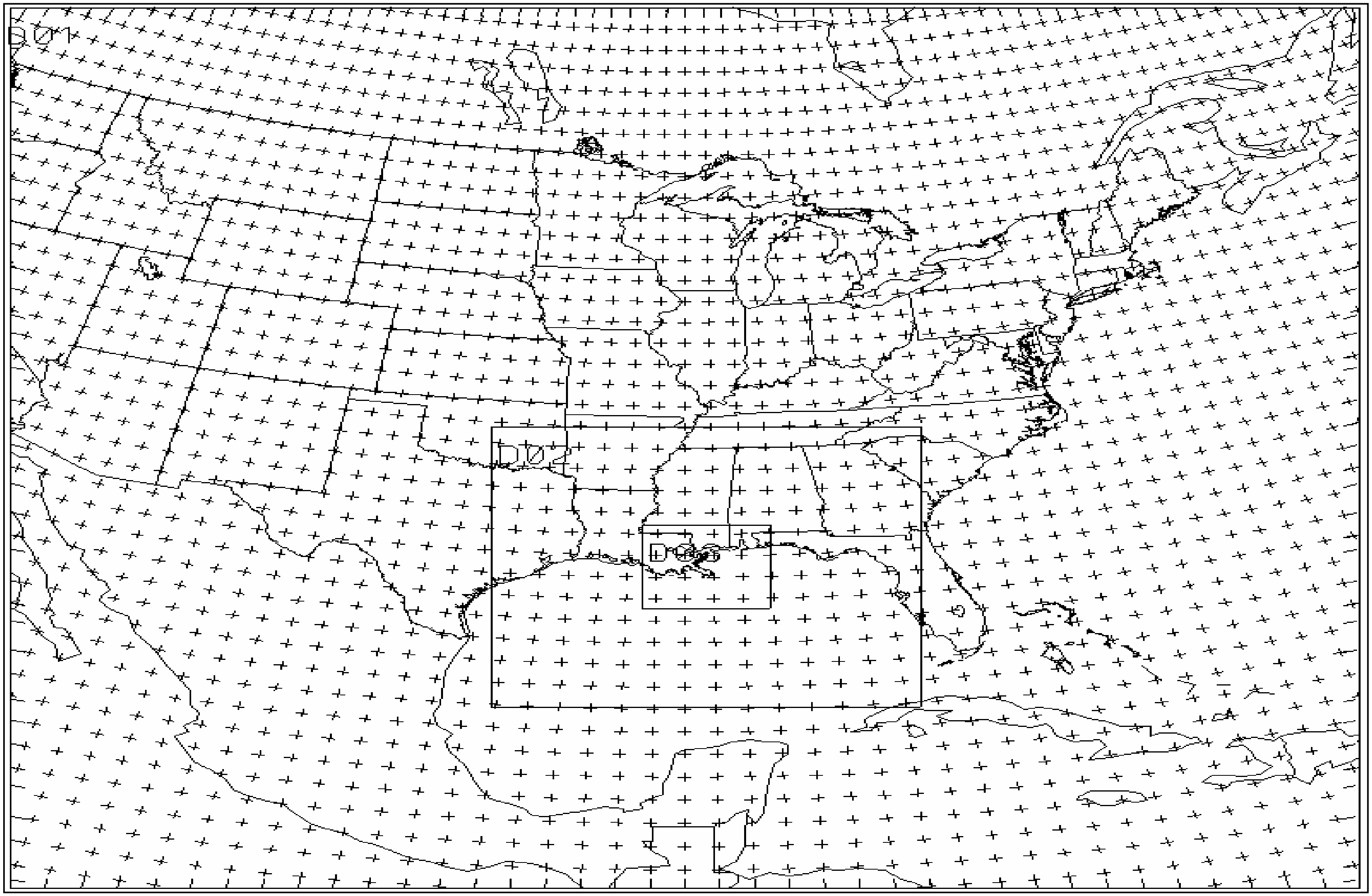


Figure 1F.3. 36-km, 12-km, and 4-km domains for MM5.

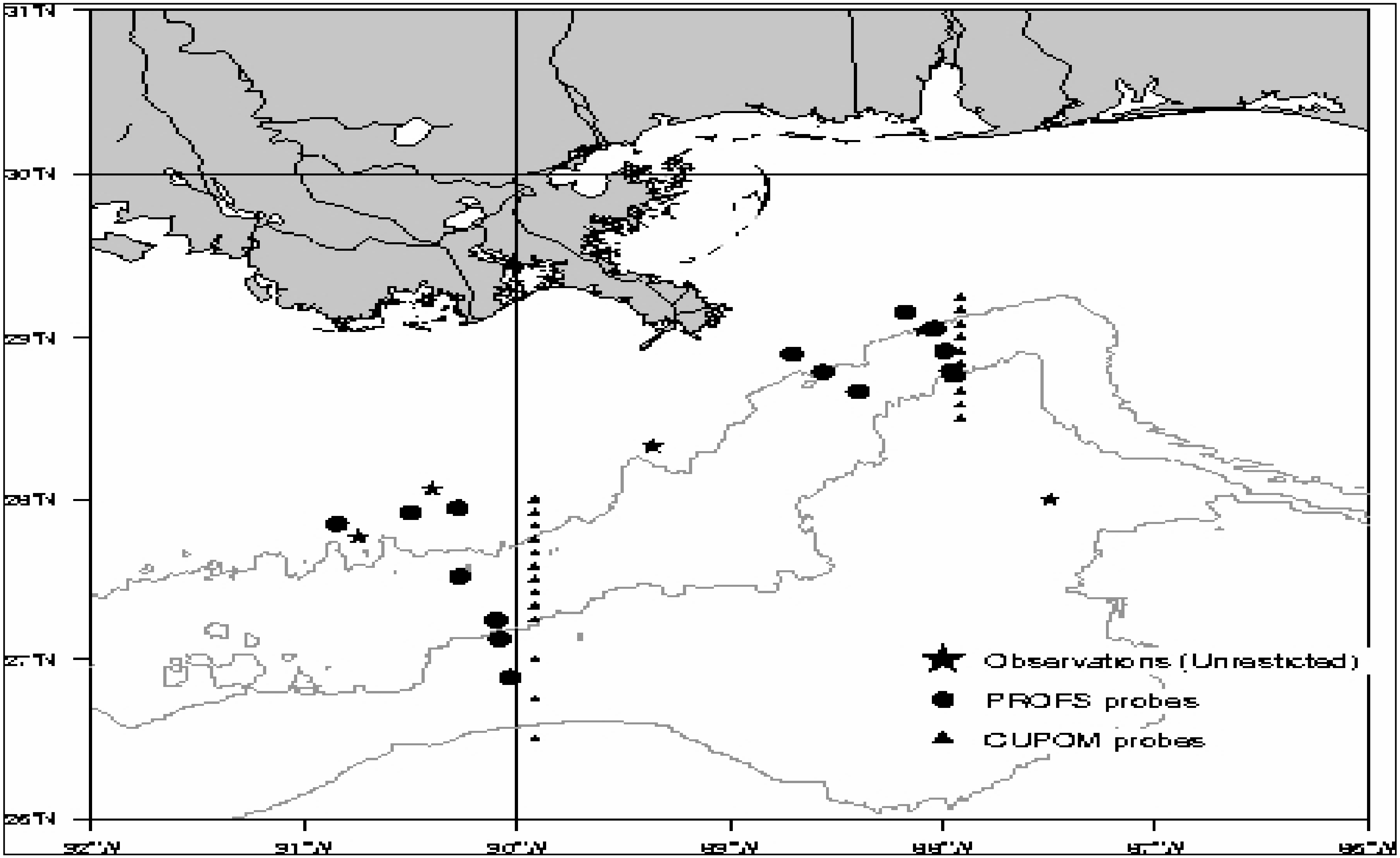


Figure 2B.1. Map of north-central Gulf of Mexico showing locations of candidate jets from public data (stars) and virtual mooring locations of CUPOM model (triangles) and PROFS model (circles). Bathymetric lines shown are for 1000, 2000, and 3000 m isobaths.

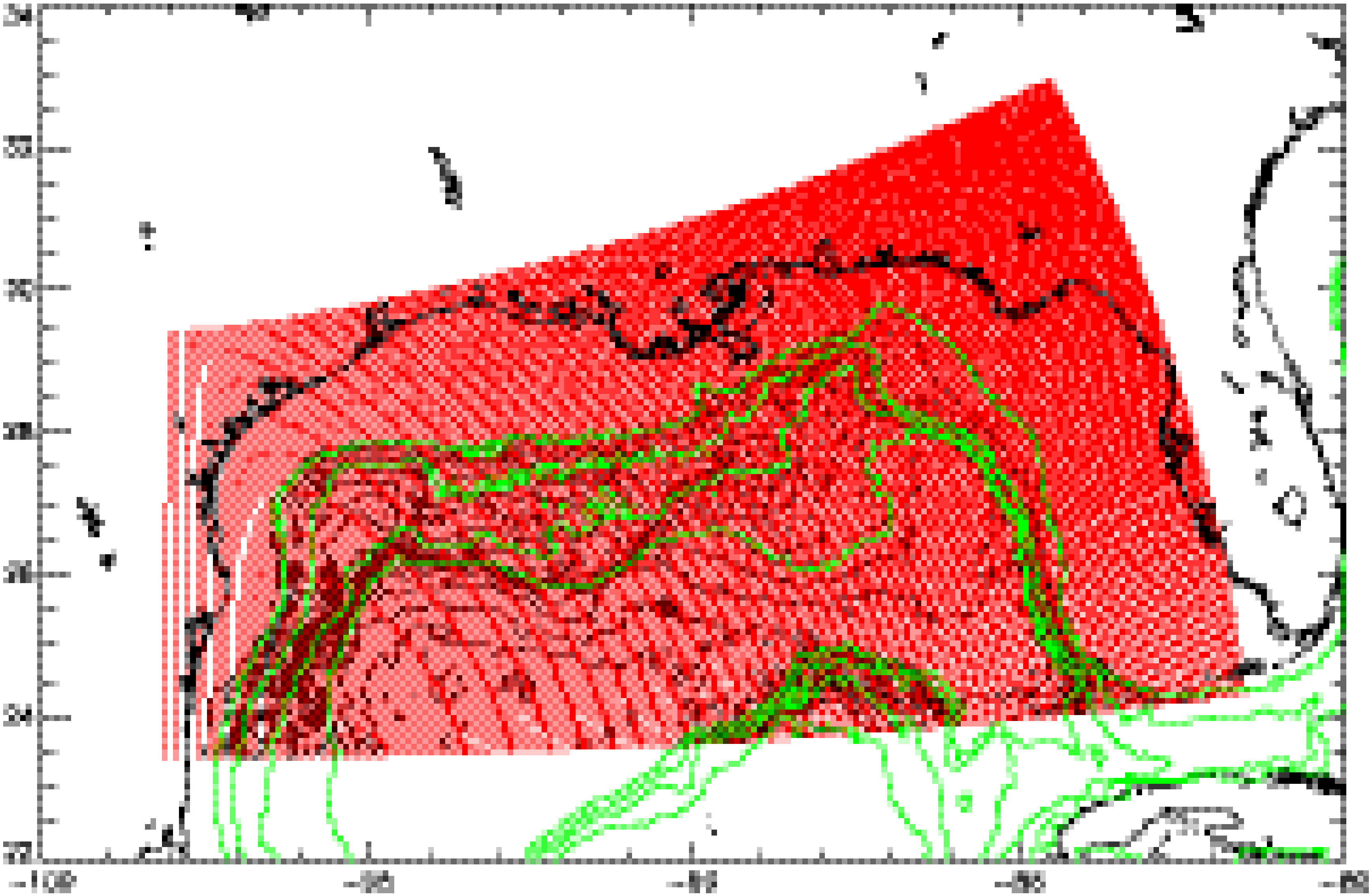


Figure 2B.2. The Gulf of Mexico subdomain of Leo Oey's PROFS FGS model. Grid is 240 x 289 x 25 shown in red, model bathymetry is shown in gray, Herring bathymetry in green and the GMT coastline.

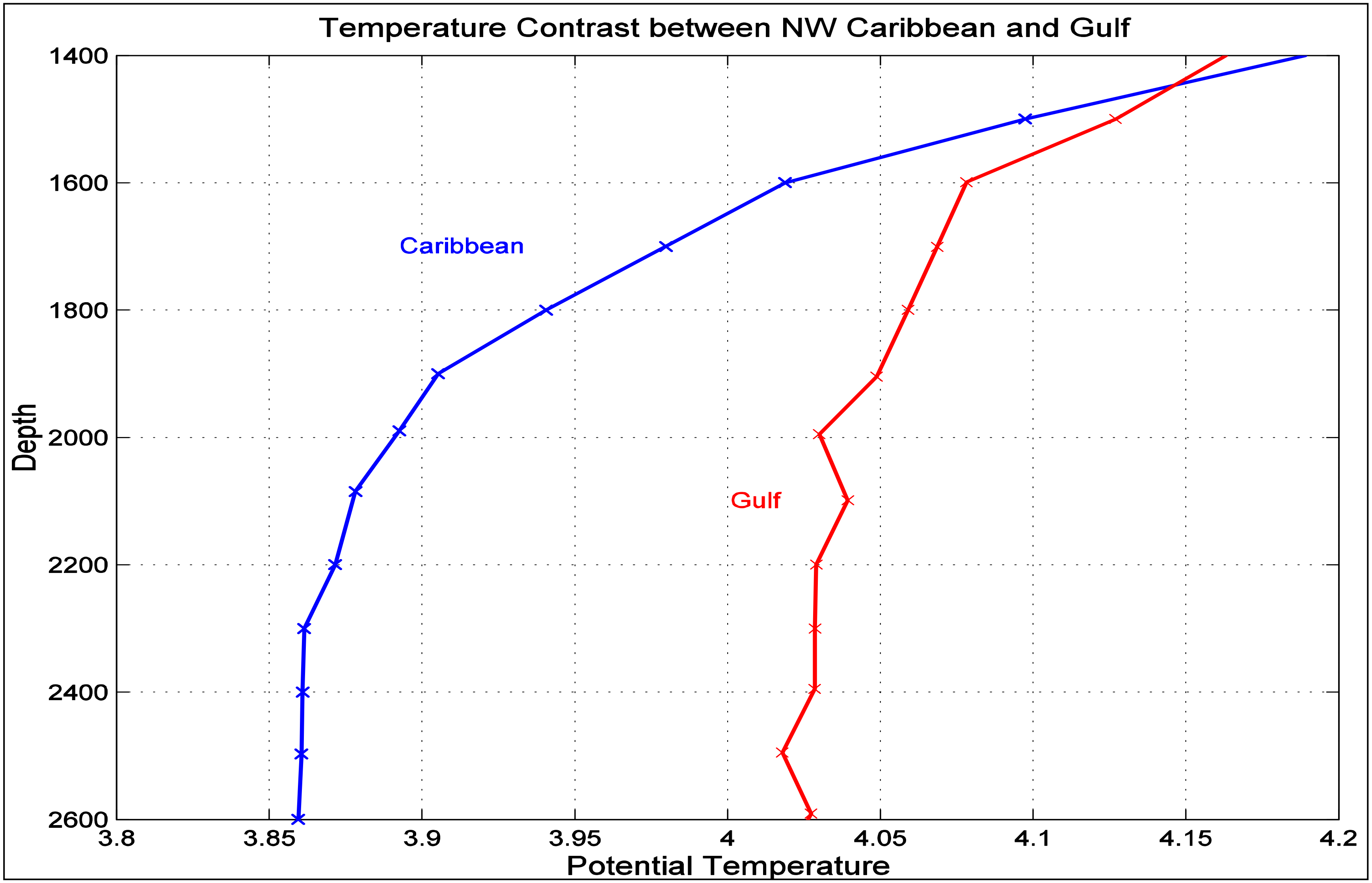


Figure 2B.3. The temperature contrast between the deep Gulf of Mexico and the northwest Caribbean Sea. These means are from the historical hydrographic data base. The uncertainties in the deep values are larger than the apparent irregularities.

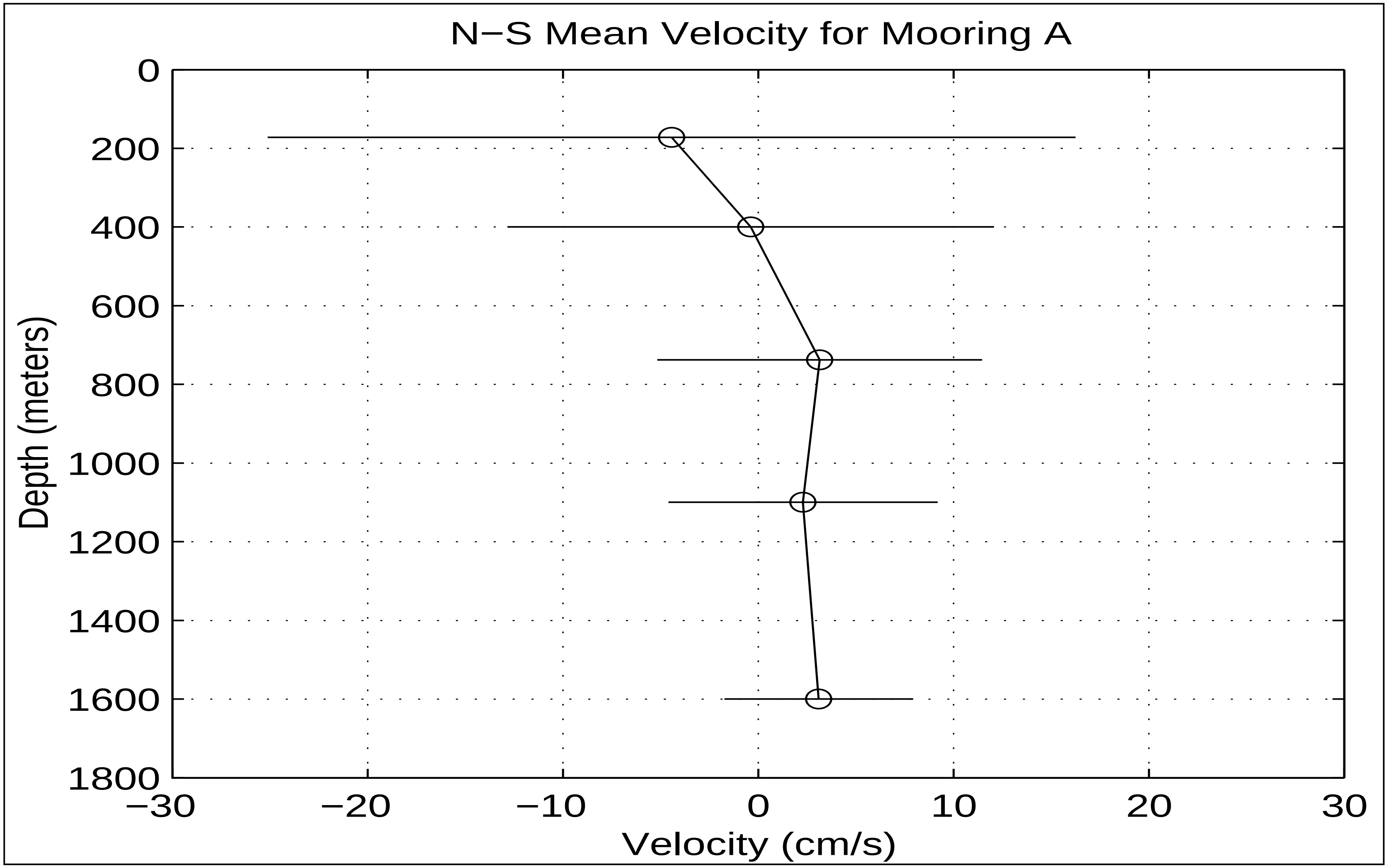


Figure 2B.4. Mean north-south velocity component at a mooring off the west coast of Florida; error bars show standard deviation of the velocity. Data from SAIC, Raleigh NC.

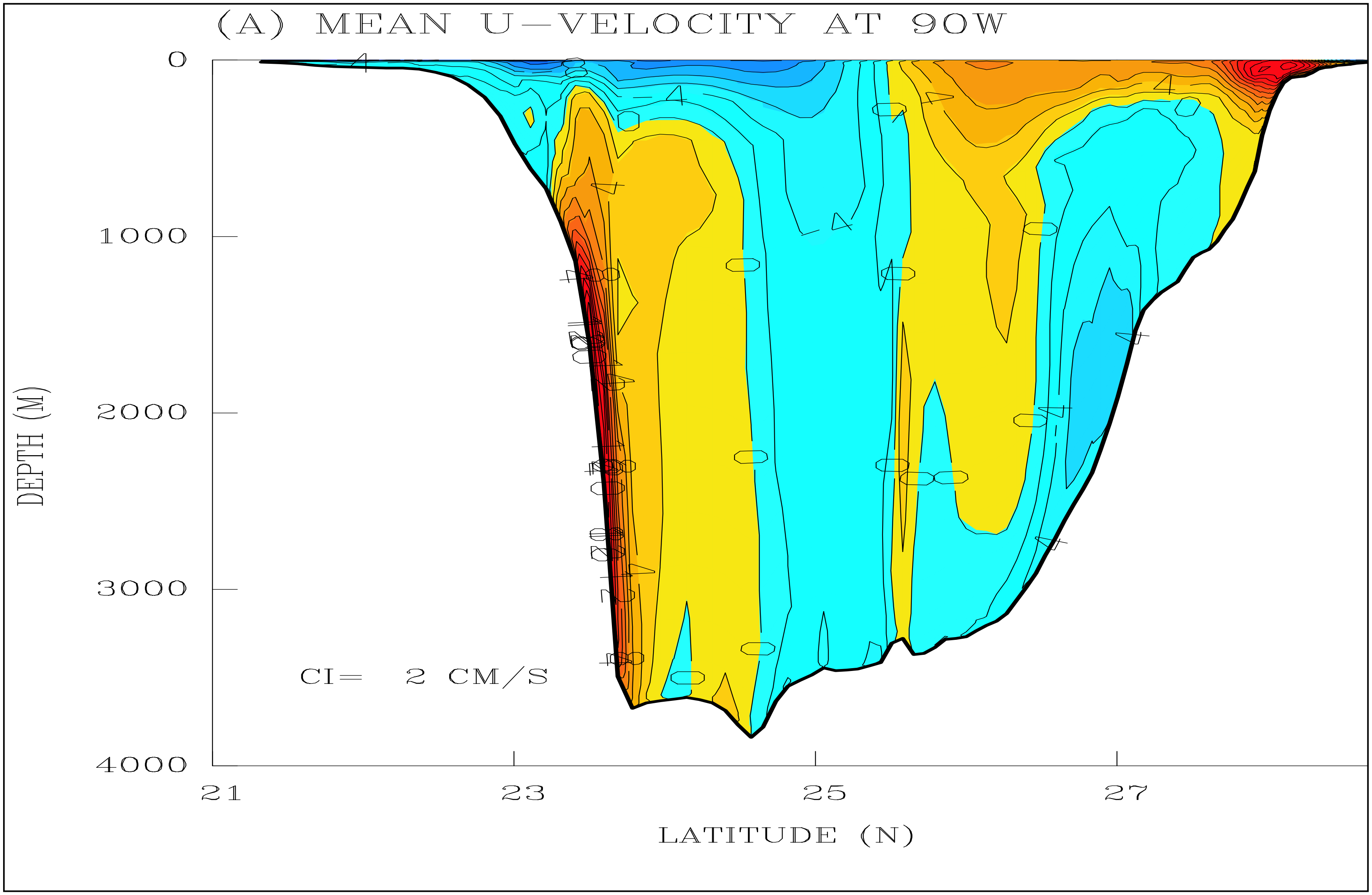


Figure 2B.5. The mean East-West velocity on a vertical section at 90° W; from Ezer-Oey Princeton Model.

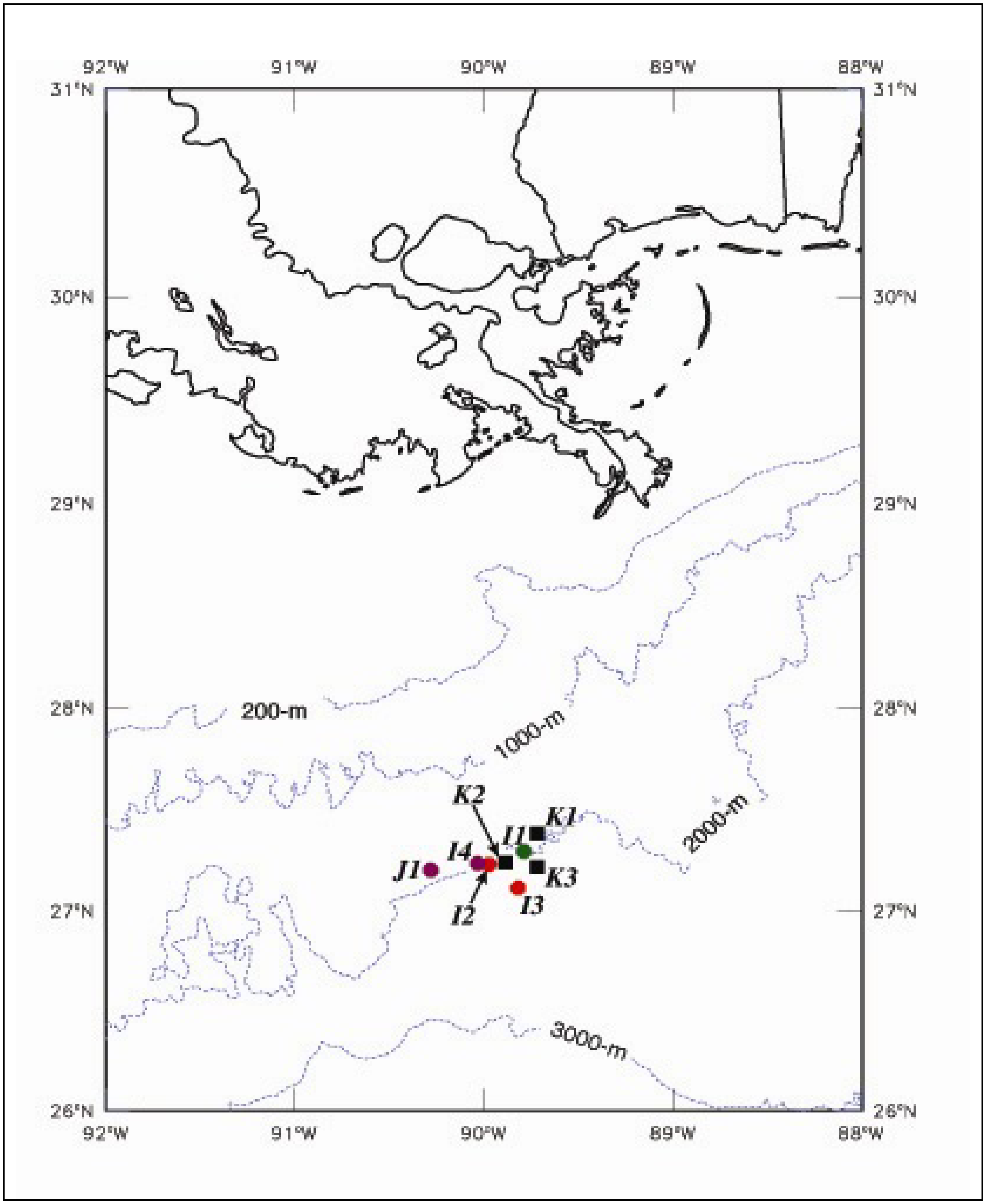


Figure 2B.6. Map of the deployment region in the northern Gulf of Mexico. Solid dots and squares are the positions of current meter moorings and bottom mounted PIES, respectively. Bottom moorings and red (main array) and purple. The full-depth mooring is green.

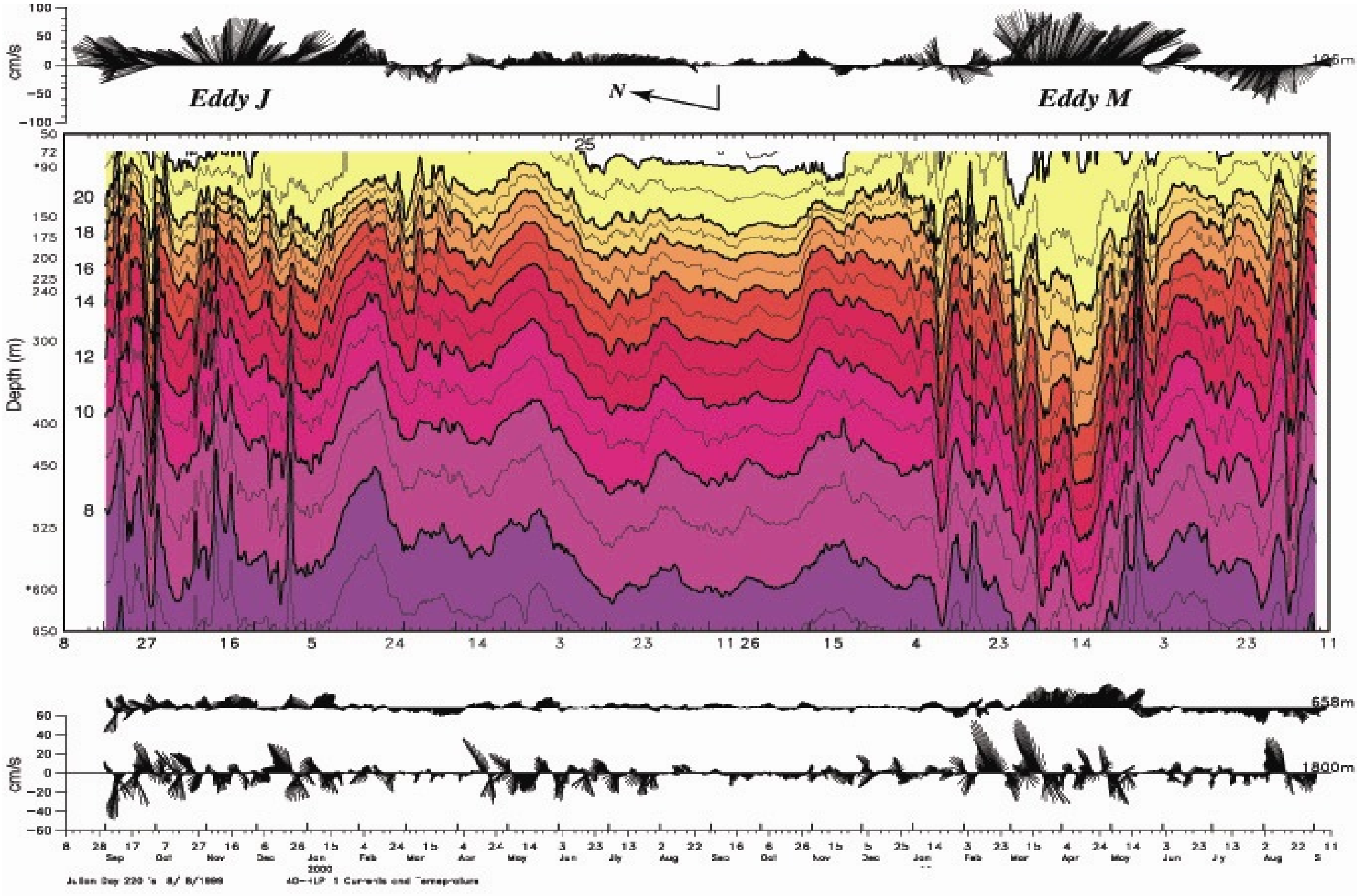


Figure 2B.7. 40-HLP current vectors and isotherm contours for selected depths from mooring I1.

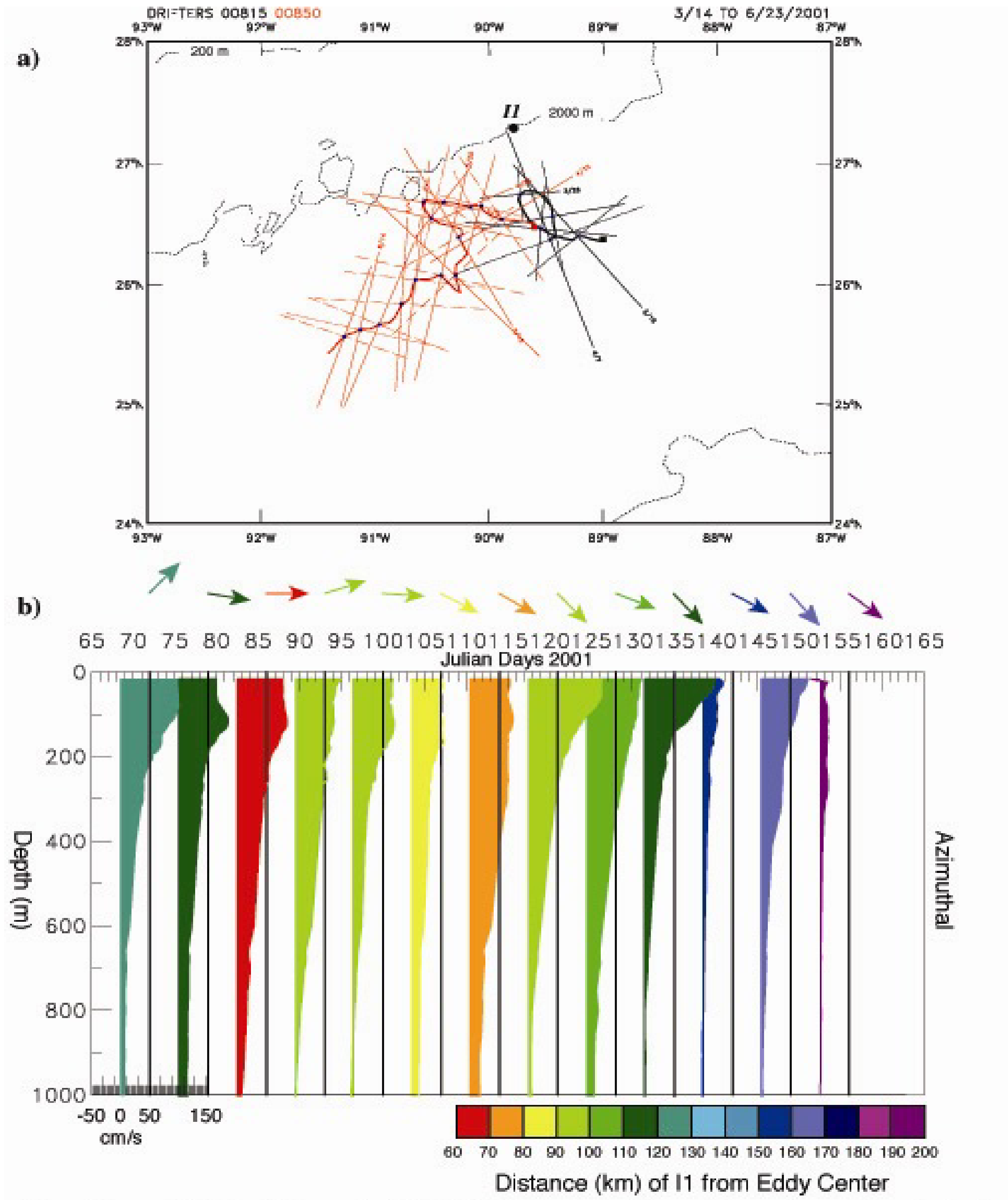


Figure 2B.8. (a) Paths of the center of eddy Millennium derived from a kinematic model analysis of smoothed drifter tracks (heavy lines); (b) Daily averaged azimuthal velocity component profiles, at I1, for eddy M on the given Julian days, 2001. The profiles are color coded according to distance from the eddy center. The vectors, above the plots, show the direction of the azimuthal component.

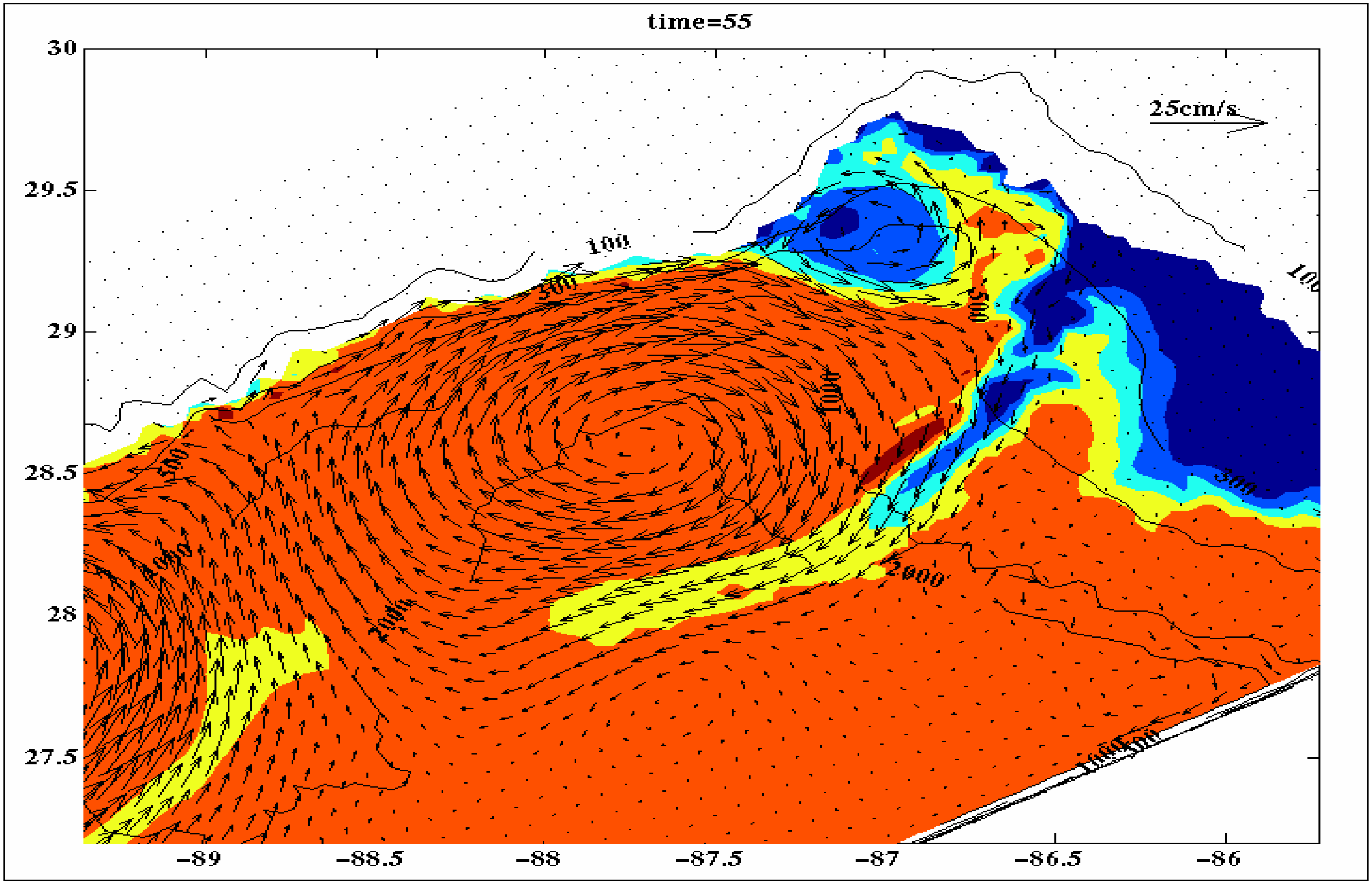


Figure 2B.9. Interaction of an anticyclone with the DeSoto Canyon. Color code is the passive tracer concentration along the σ-27 isopycnal surface, and vectors indicate velocities vertically averaged over the thermocline depth.

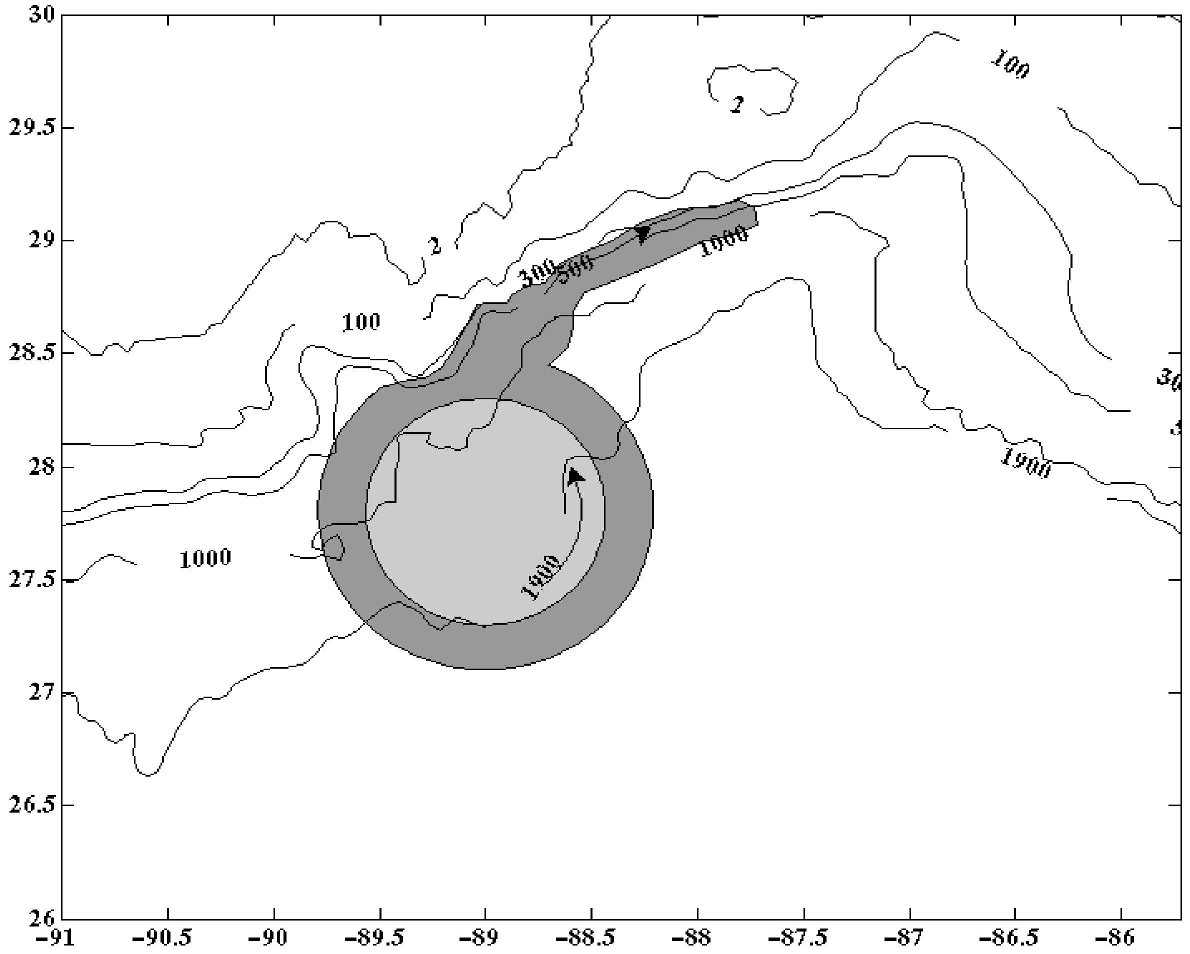


Figure 2B.10. Conceptual model of the eastward jet generation by a cyclone. Darker shading indicates a positive PV anomaly initially wrapped around the cyclone.

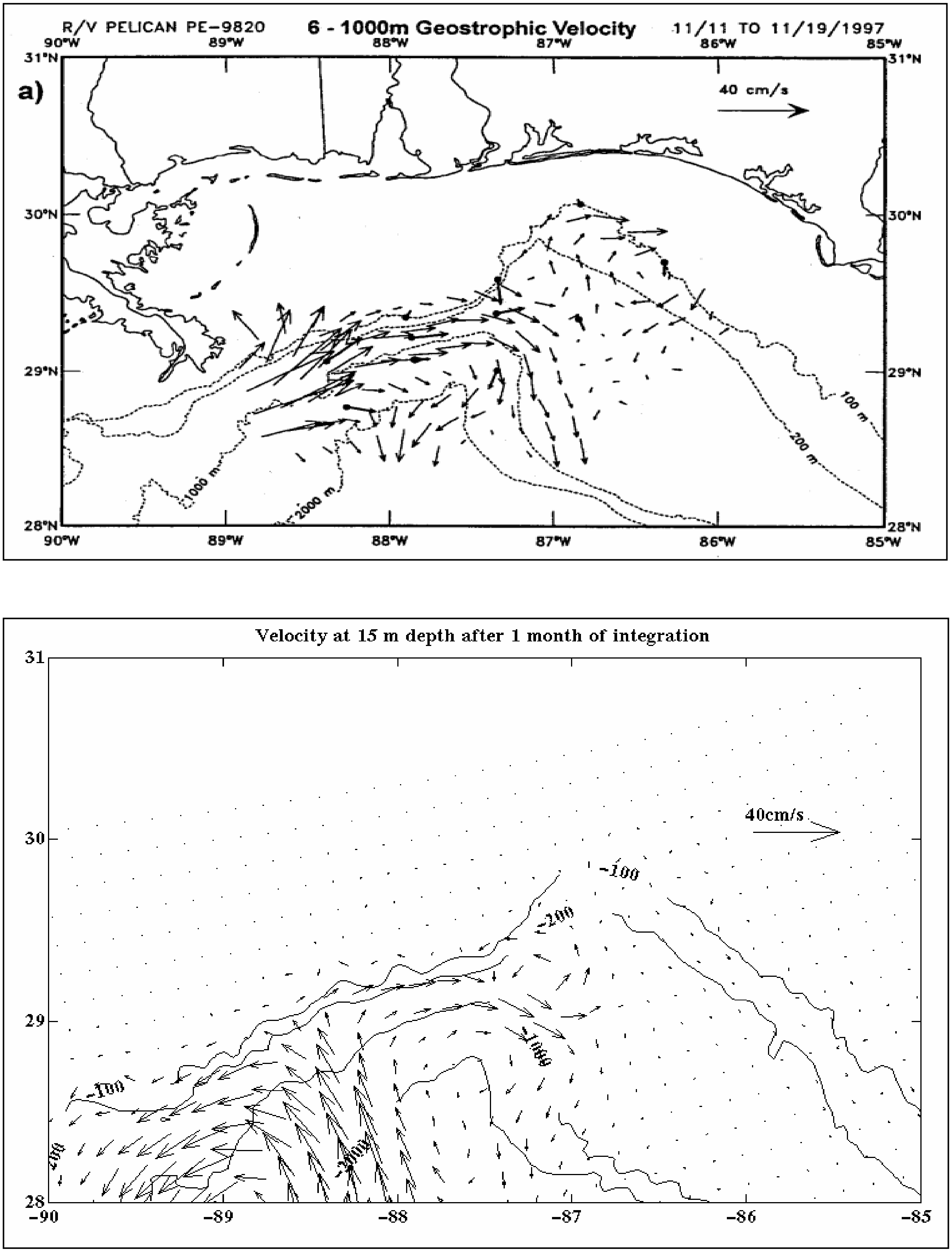


Figure 2B.11. Observed (upper panel) and simulated (lower panel) near-surface velocities.

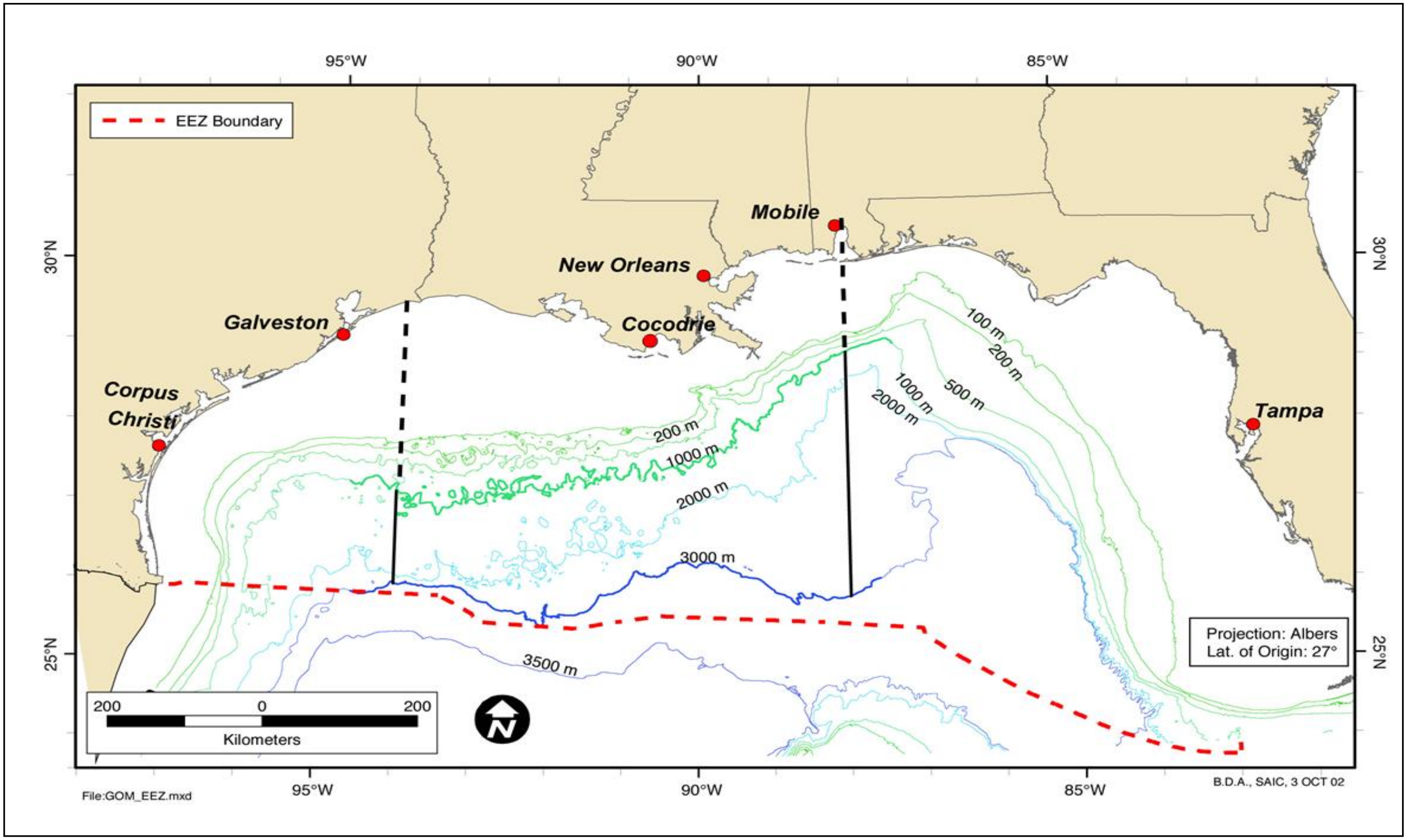


Figure 2B.12. Northern Gulf of Mexico study area, nominally between the vertical black lines and the 1000 m and 3000 m isobaths. The Sigsbee Escarpment begins in the east with the base at approximately 2000 m and deepens to approximately 3000 m in the western portion of the study area.

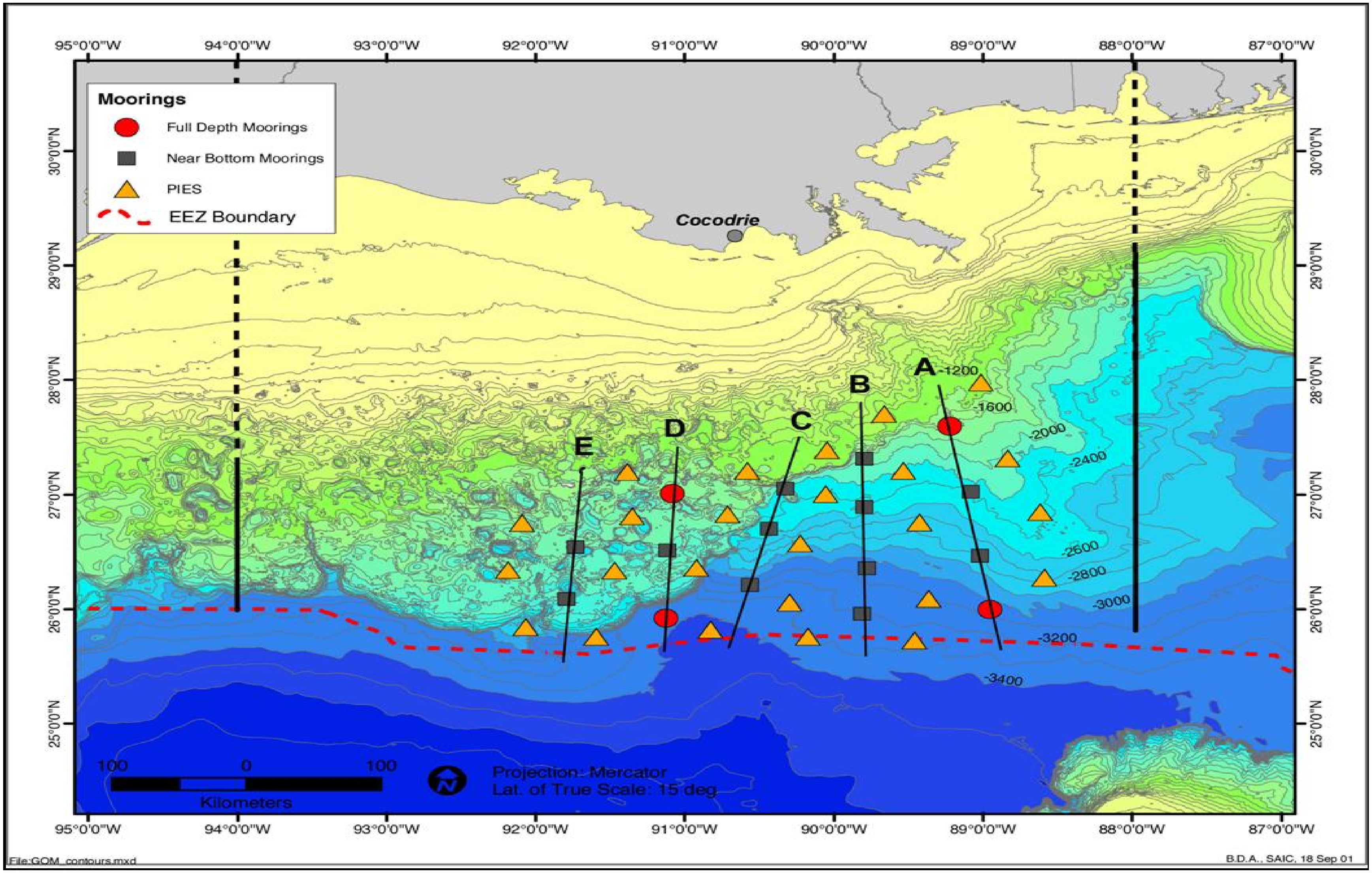


Figure 2B.13. Placement of PIES, full-depth and near-bottom moorings. Current mooring placement is such that each is within a polygon defined by PIES locations. The distribution of PIES and resulting profiles will provide a regional framework within which all current estimates can be viewed.

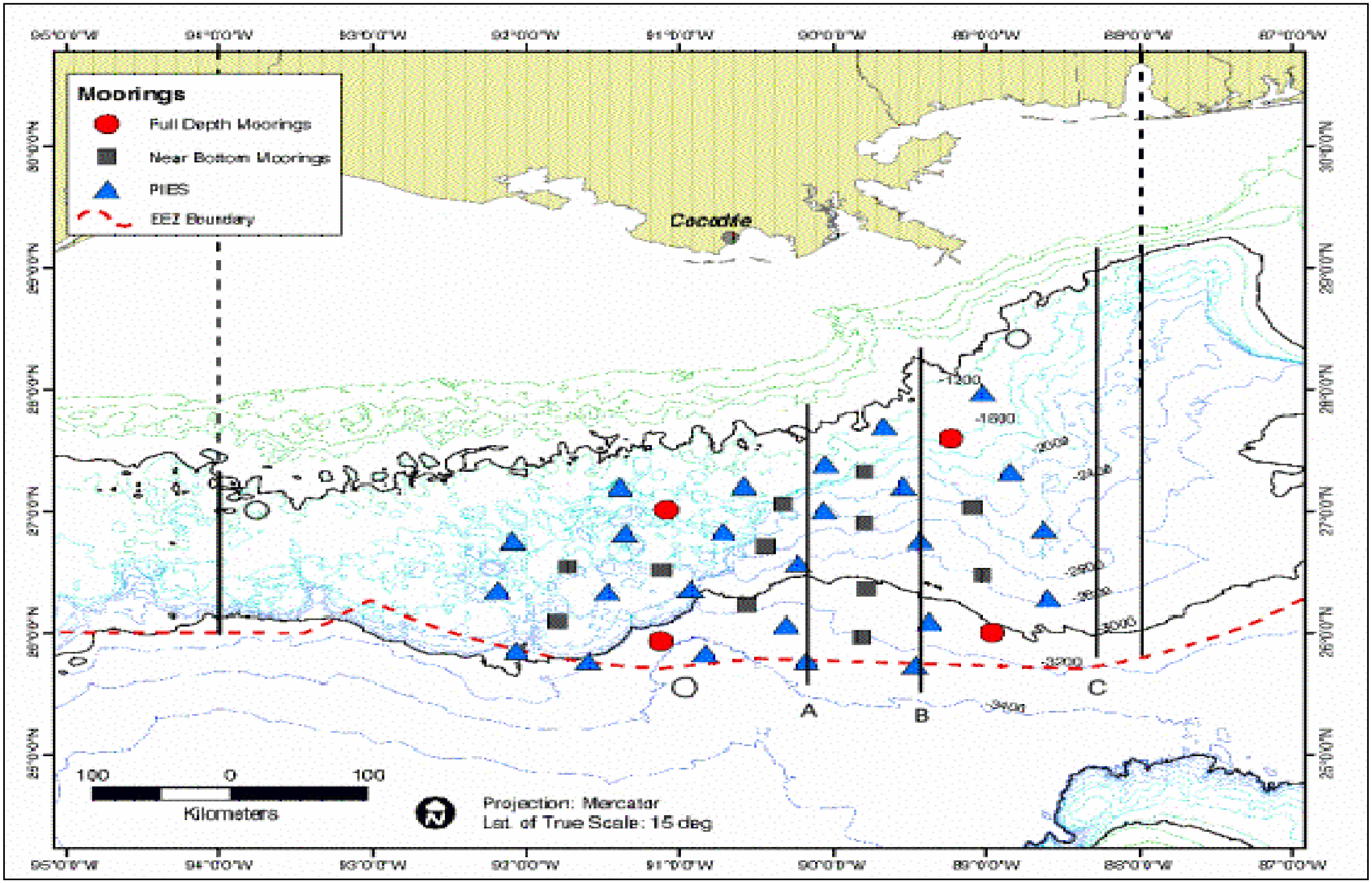


Figure 2B.14. Drifters will be deployed along Lines A, B, and C in the adjacent map. The expected direction of movement includes a westerly component, hence the positioning. The approximate location of the sound sources is shown by the open circles on the eastern, western and southern edge of the study area.

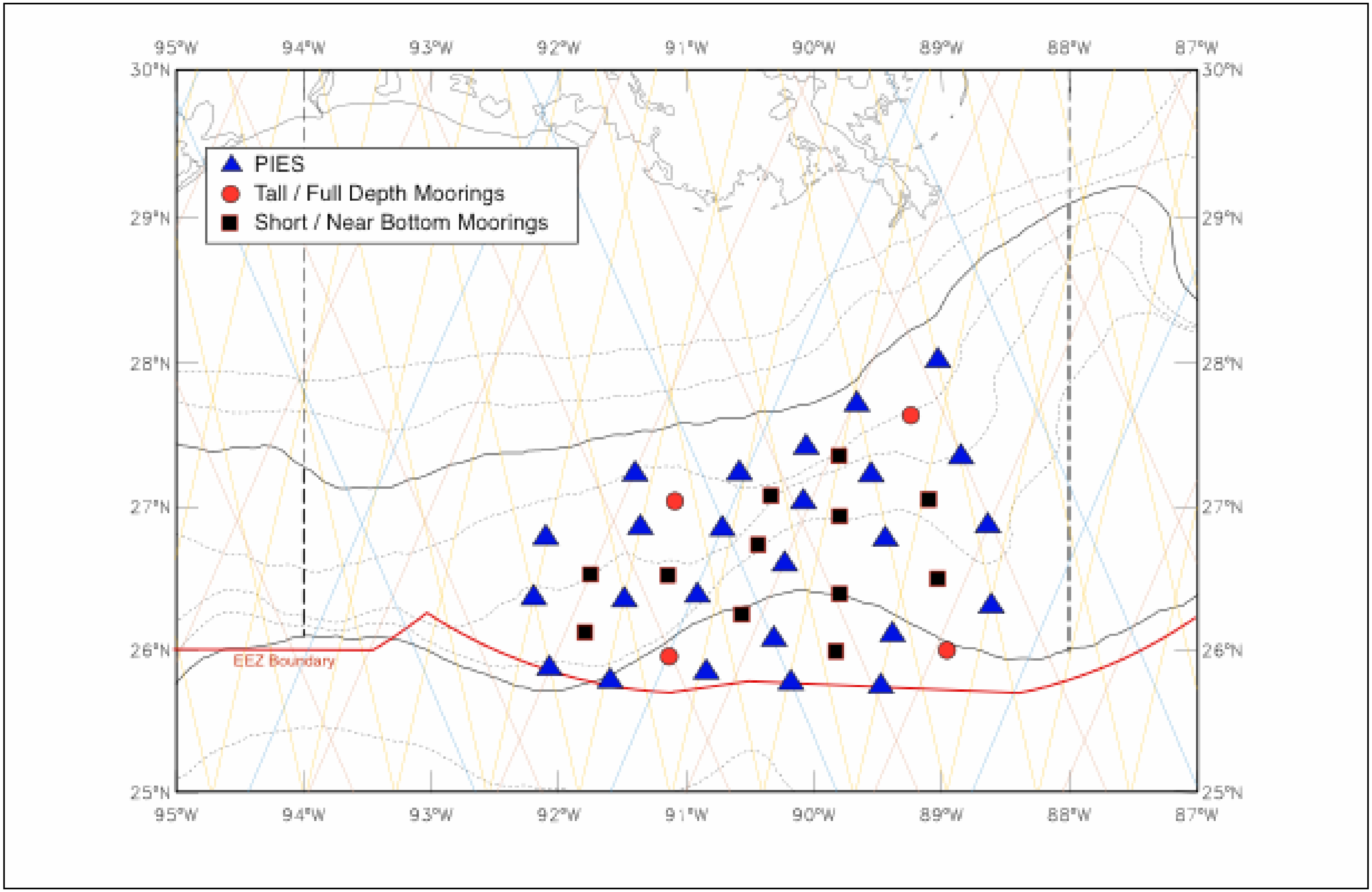


Figure 2B.15. Placement of PIES is such that many are located along ground tracks of satellite altimeters. This collocation will provide valuable paired data sets for evaluating ocean processes and altimetry mapping schemes.

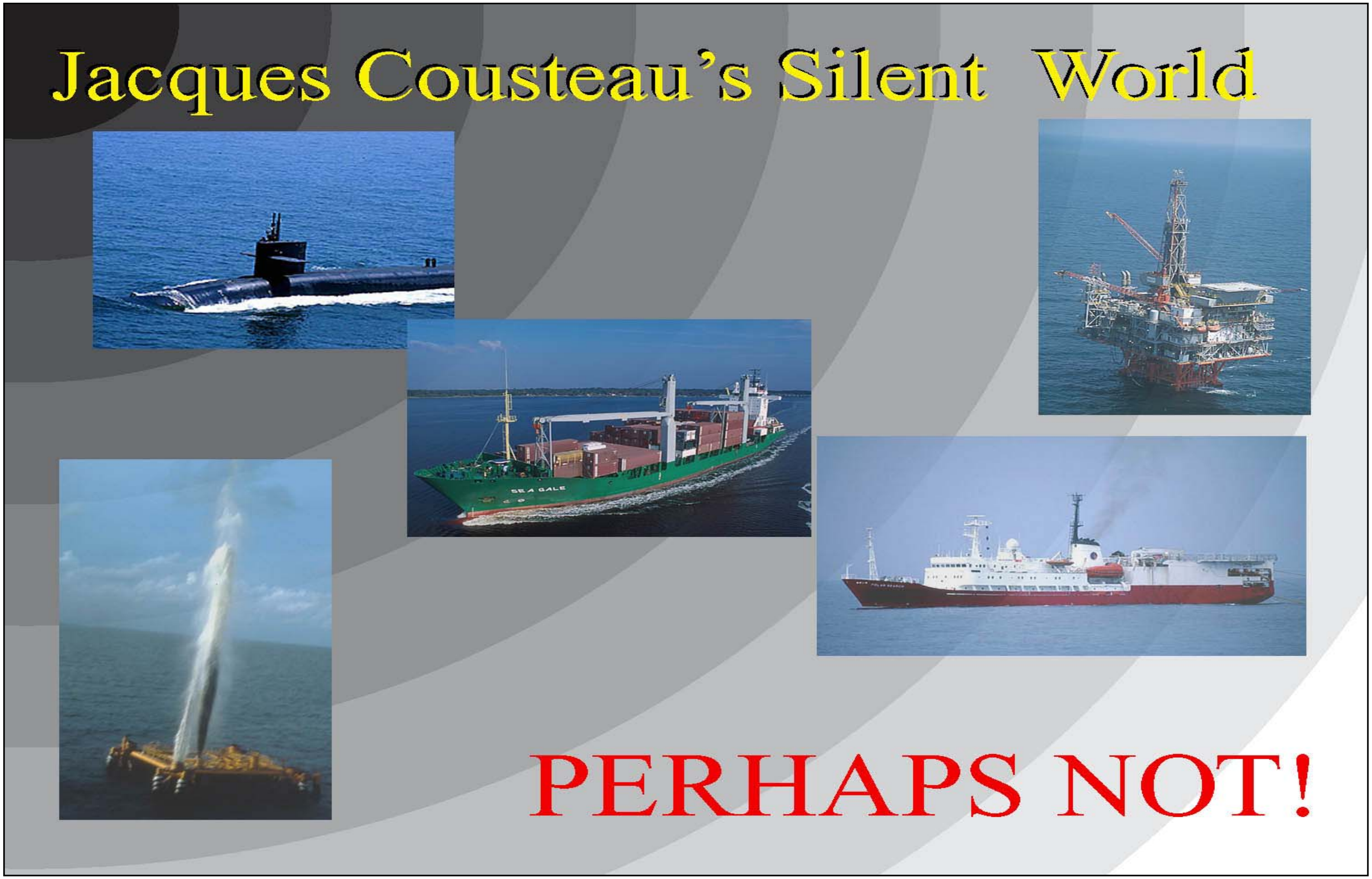
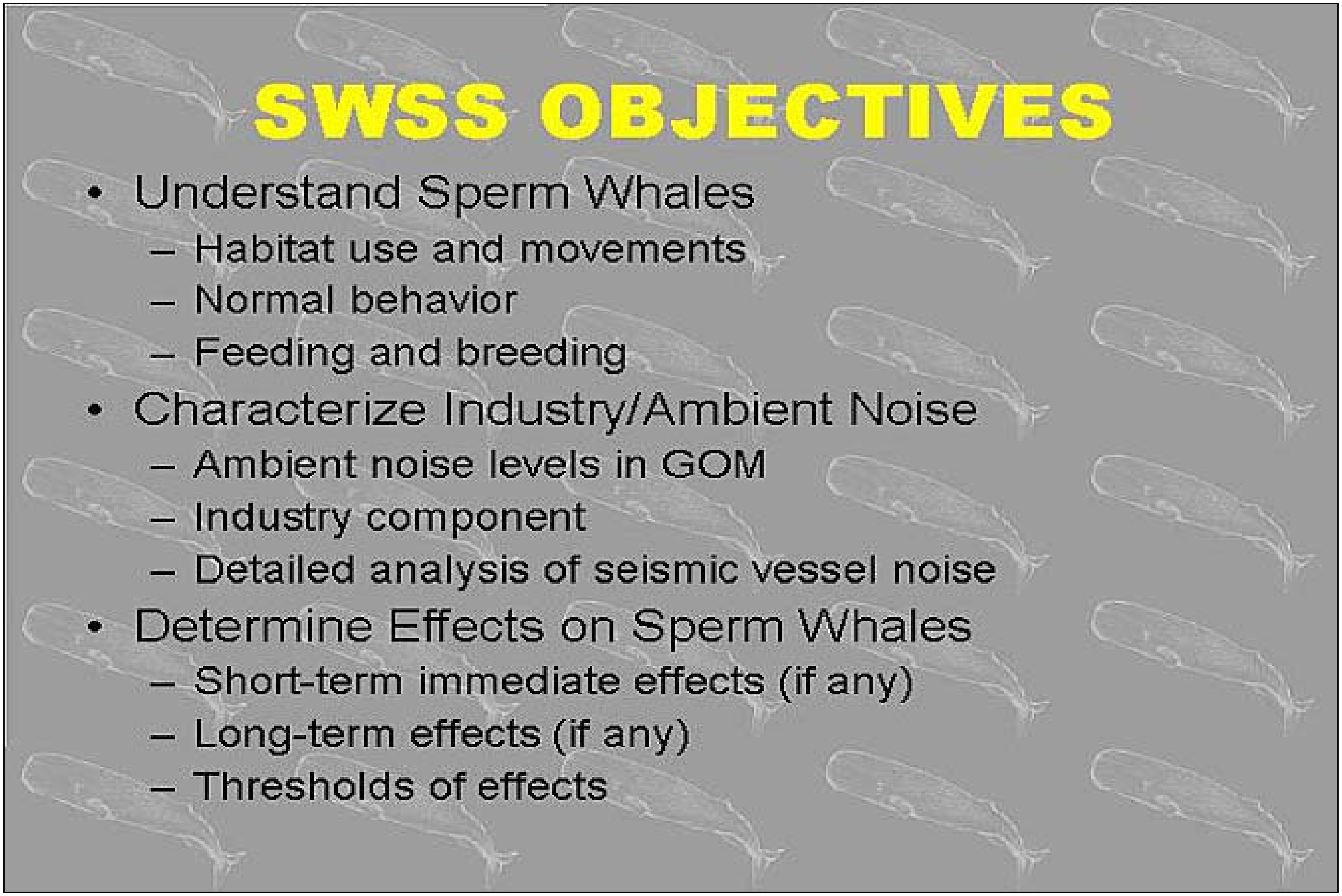


Figure 2C.1. Acoustic concerns in the Gulf of Mexico include military activities, commercial shipping, offshore drilling, seismic operations, and explosive removals of structures. Photos courtesy of MMS, Lawrence Smith, and Bill Lang.



SWSS OBJECTIVES

- Understand Sperm Whales
  - Habitat use and movements
  - Normal behavior
  - Feeding and breeding
- Characterize Industry/Ambient Noise
  - Ambient noise levels in GOM
  - Industry component
  - Detailed analysis of seismic vessel noise
- Determine Effects on Sperm Whales
  - Short-term immediate effects (if any)
  - Long-term effects (if any)
  - Thresholds of effects

Figure 2C.2. Broad objectives of the Sperm Whale Seismic Study (SWSS).

Figure 2C.3. Participants on the Sperm Whale Seismic Study (SWSS), year one, 2002, research.

Upper Left. July 2002 S-Tag Cruise on *Gyre.*
Front Row: Nathalie Jaquet, Mike Fredericks, Joel Ortega, Doug Biggs.
Second Row: Dan Lewer, Daniel Palacios, Terry Ketler, Sarah Tsoflias, Larry Glickman, Jonathan Gordon.
Third Row: Jamie McKee, Dan Engelhaupt, Will Rayment, Christopher Richter, Ladd Irvine, Reuben Hale.
Back Row: Ricardo Antunes, Bruce Mate, Mary Lou Mate, Alicia Salazar, Erin LaBrecque.
Missing: Bill Green, Paul Clark Eddie Webb.
Upper Center. Captain Dana Dyer, *R/V Gyre*
Upper Right. August-September 2002 D-Tag Cruise on *Gyre*
Front Row: Mike Fredericks, Matt Howard.
Second Row: Eddie Webb, Matt Grund, Valeria Teloni, Allesandro Bocconcelli, Natacha Aquilar de Sota, Dee Allen, Sarah Tsoflias, Amy Beier, Dan Engelhaupt, Simon Childerhouse.
Third Row: Todd Pusser, Mark Johnson.
Back Row: Marilena Quero, Laurie Sindlinger, Irene Briga, Aaron Thode, Mandana Mirhaji, Patrick Miller, Nicoletta Biassoni. Missing. Paul Clark, Bill Green.
Lower Left. Texas A&M Research Foundation Management Team.
Doug Biggs, Matt Howard, Ann Jochens.
Lower Center. September 2002 Seismic Controlled Exposure Cruise, *M/V Rylan T.*
Carol Roden, Bill Lang, Sandy Sawyer, Tim Pinnington, Peter Tyack, Cliff Smith, Neil Estay, Craig Douglas, Tony Edwards.
Lower Right. Captain Steve Bennett and First Mate Mick Mullin, *M/V Rylan T*.

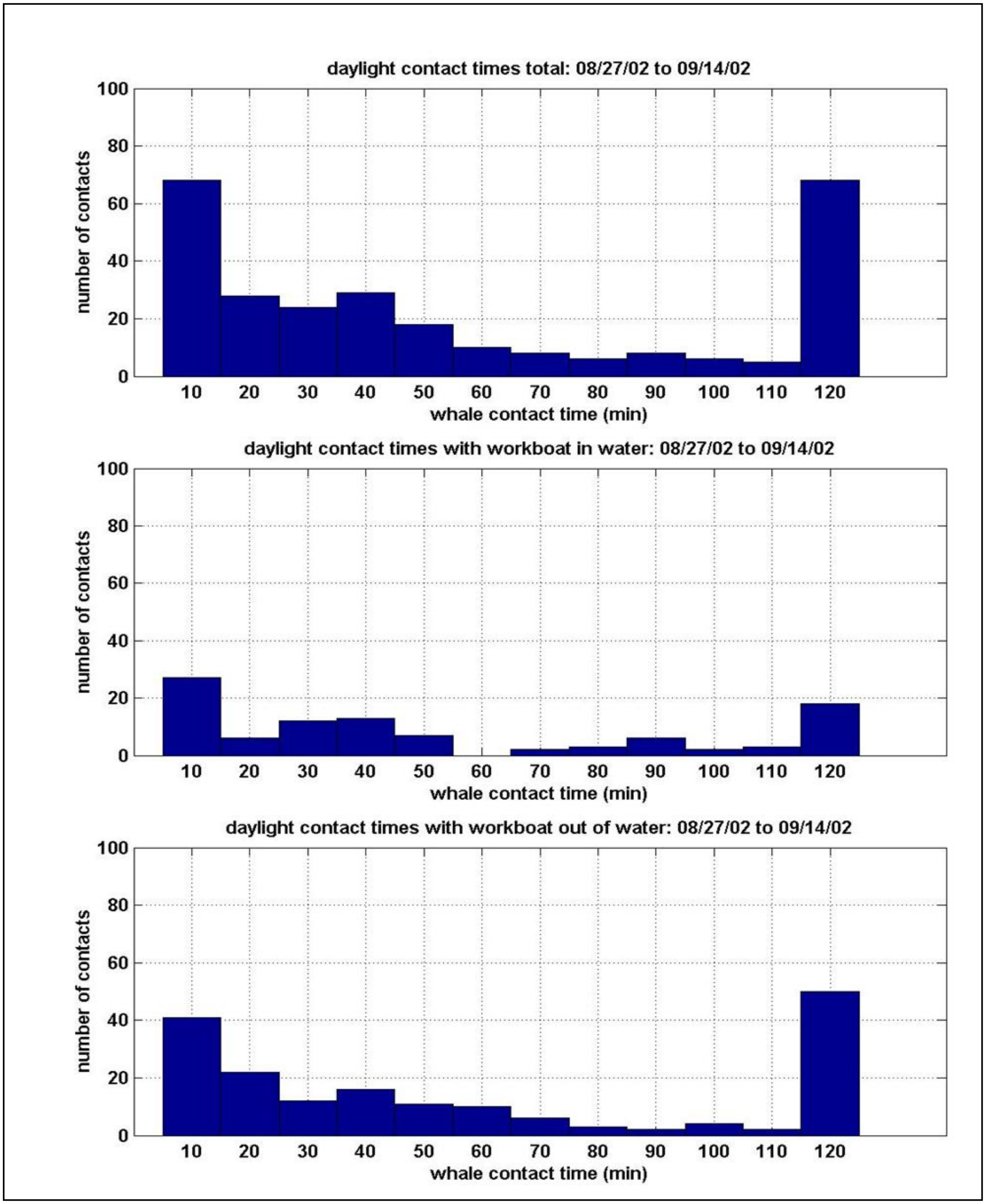


Figure 2C.4. Distribution of acoustic contact times, broken down into times measured with or without a tagging workboat present in the water during daylight hours. The large numbers of extremely short and extremely long dive times are artifacts of the operational and logging protocols.

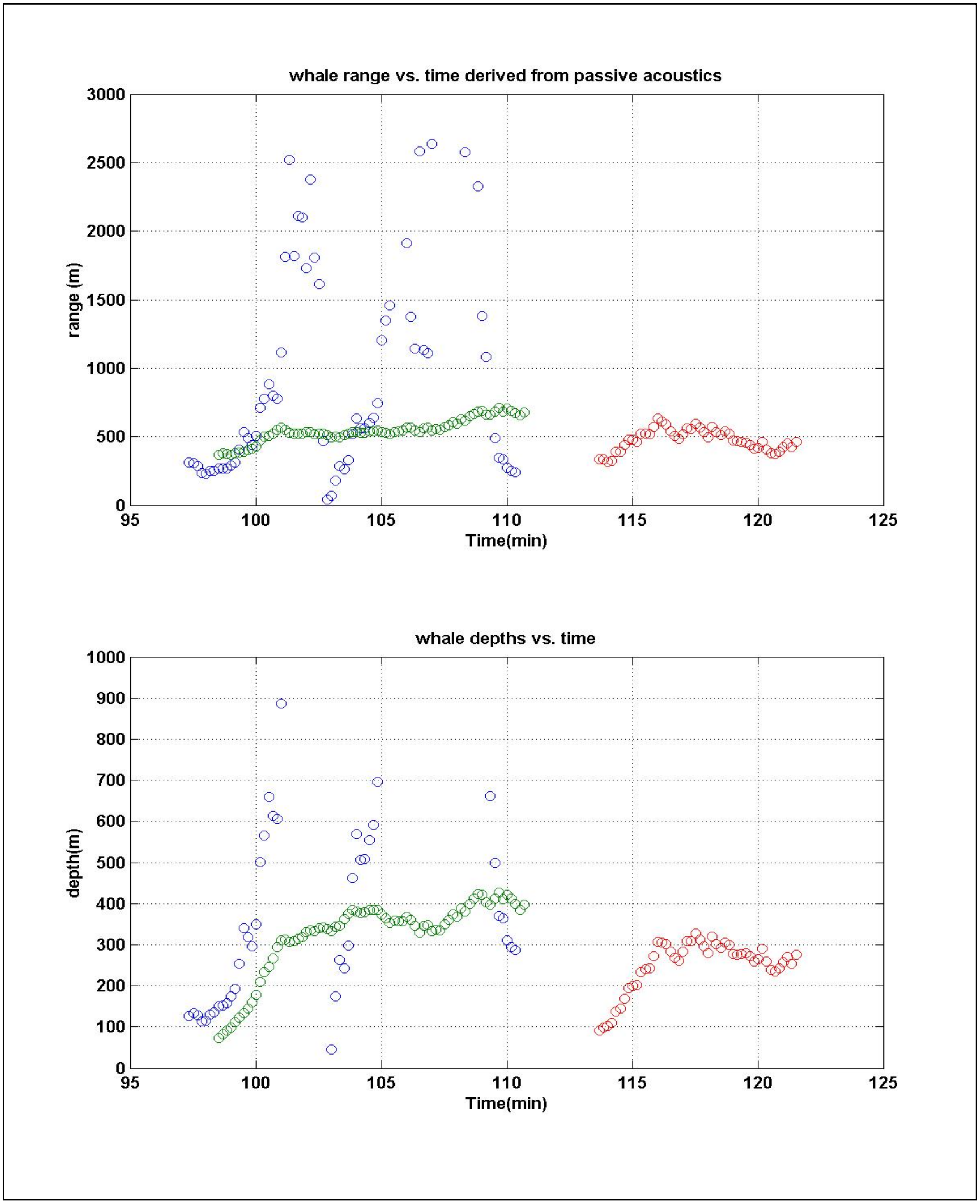


Figure 2C.5. Derived ranges and depths of three whales using two-array passive acoustic localization algorithm. The green and red trajectories are derived from whales forward or behind the ship, while the blue trajectory was from a whale broadside to the two arrays, a situation that makes the inversion unstable.

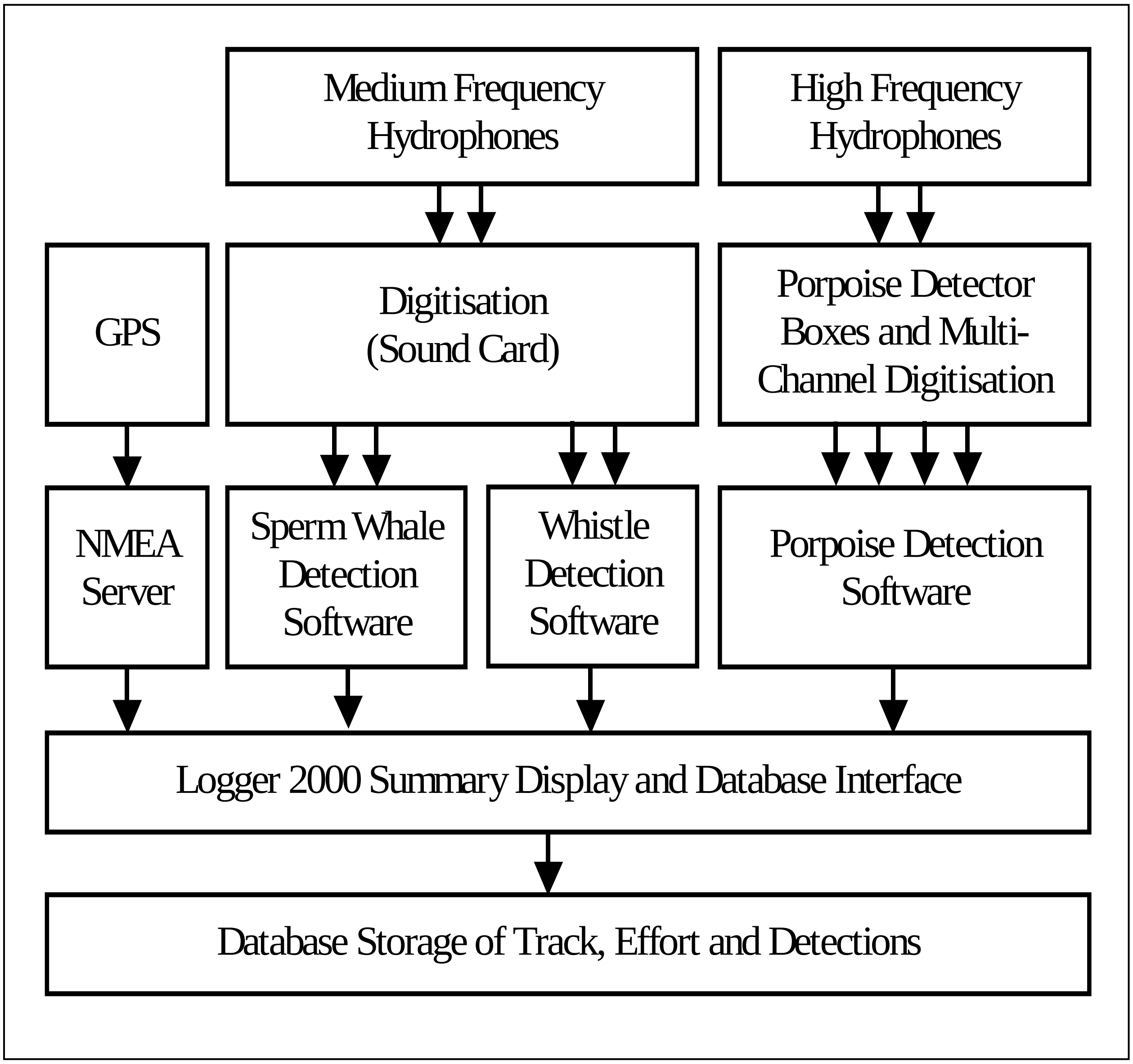


Figure 2C.6. Schematic diagram of the complete detection system.

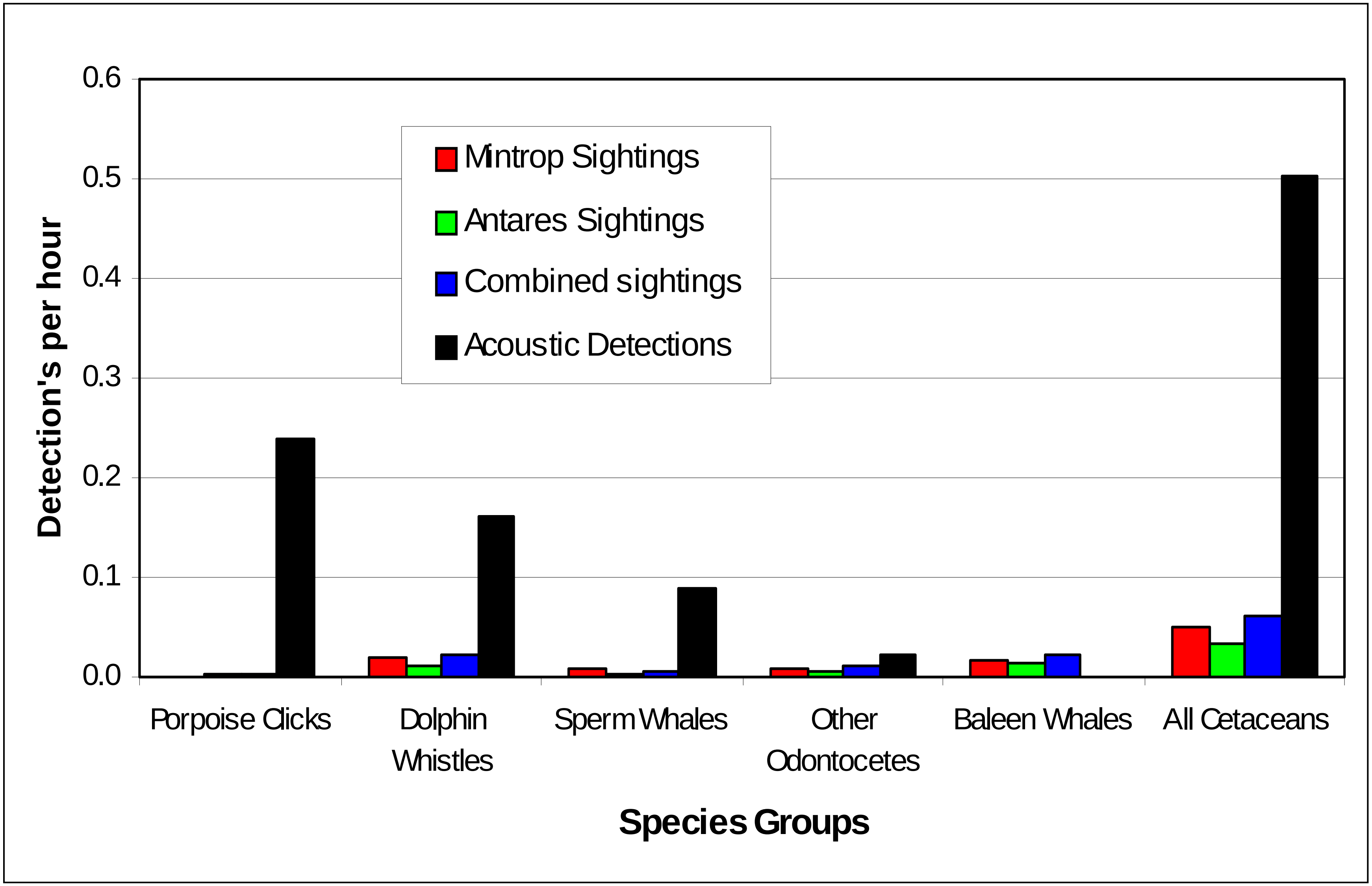


Figure 2C.7. Comparison of visual detection rates from the seismic vessel *Mintrop* with visual and acoustic detection rates from the guard vessel *Antares* in 1997.

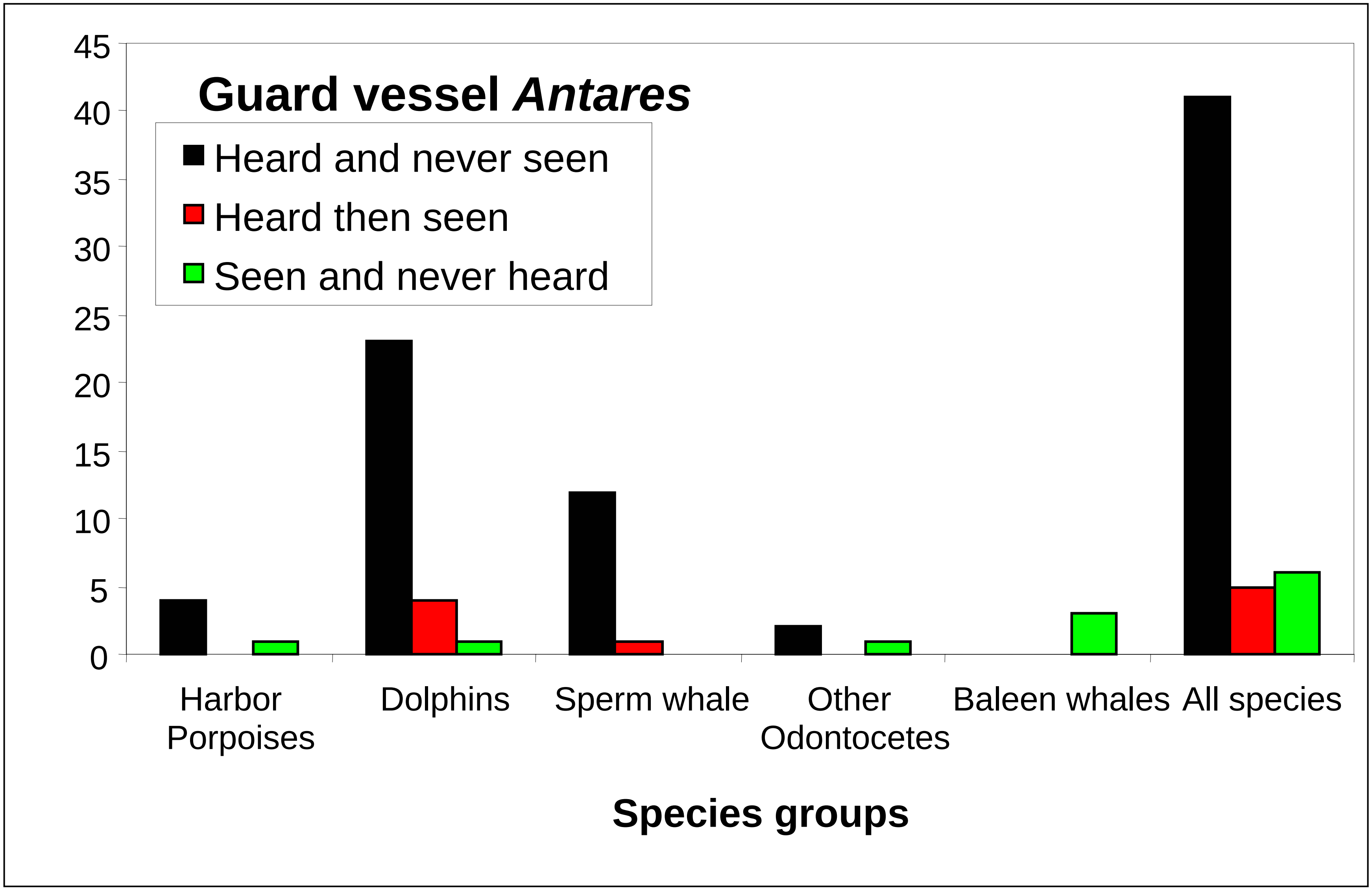


Figure 2C.8. Comparison of visual and acoustic detection rates from the guard vessel *Antares* in 1997 during periods when both methods were being used.

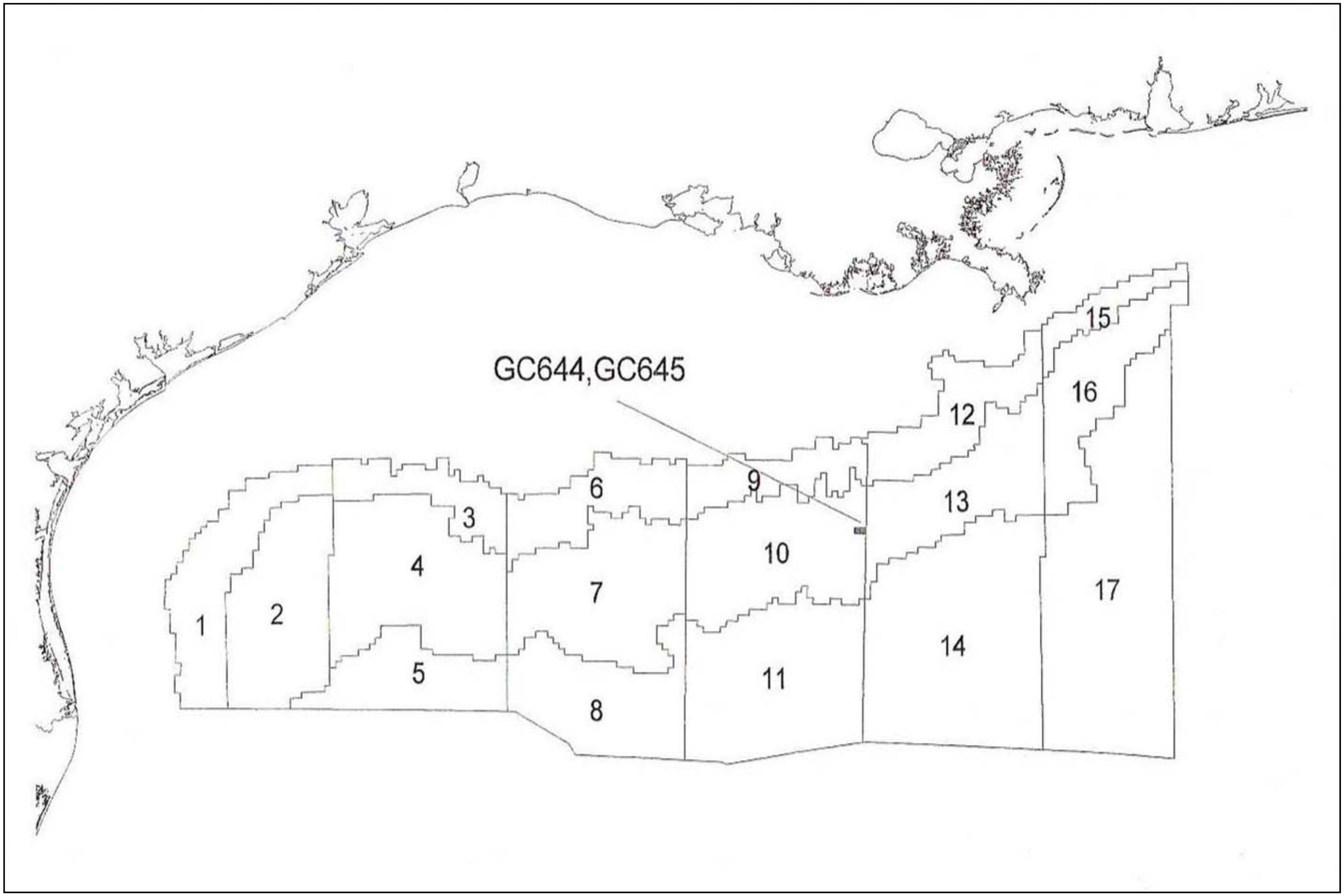


Figure 2D.1. The location of Grid 10 and the Green Canyon 644 and 645 lease blocks where the Holstein Development is sited.

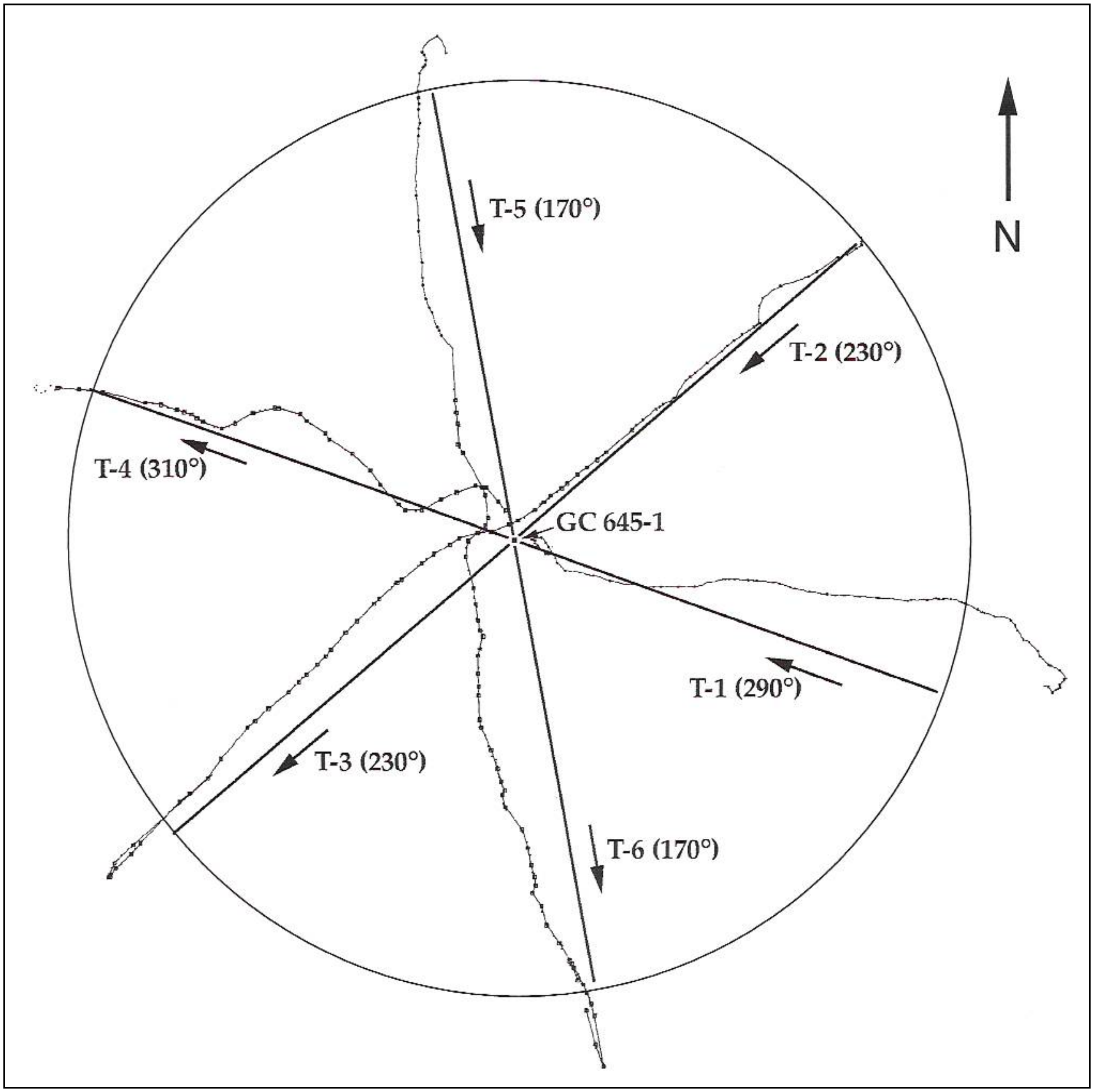


Figure 2D.2. Diagrammatic planned (straight lines) and actual tracks of the ROV pre-development surveys conducted at the BP Holstein Development in the Green Canyon 645 lease block. Arrows (and compass headings) show the direction that the transects were run.

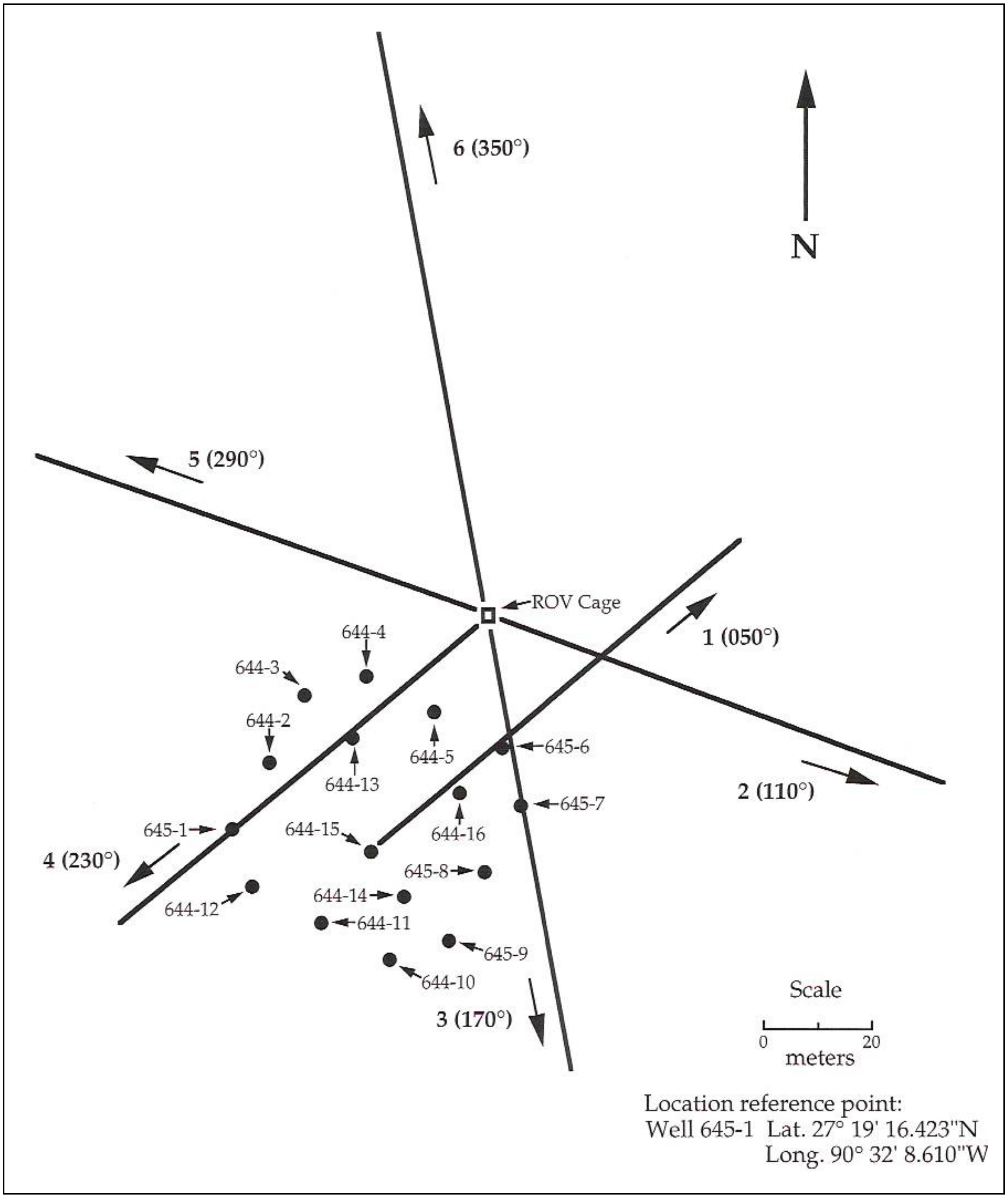


Figure 2D.3. Diagrammatic planned tracks of the ROV post-development survey conducted at the BP Holstein Development in the Green Canyon 645 lease block. Locations of the sixteen wells drilled in the Holstein Development are shown with well numbers preceded by the lease block position at the bottom of the hole.

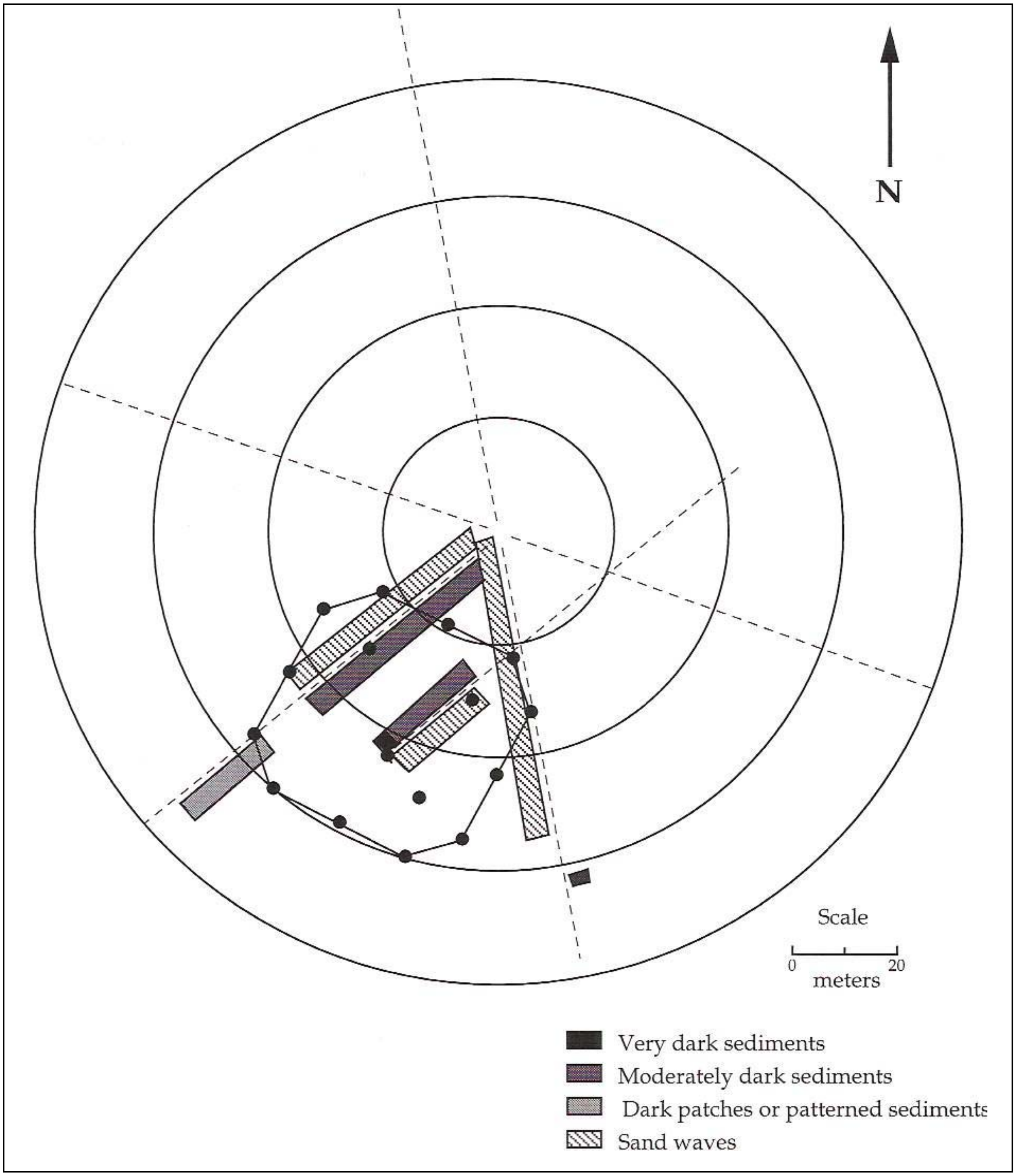


Figure 2D.4. Sediment color and sand wave features observed during the post-drilling survey. We interpret the dark sediments to reflect the presence of synthetic drilling fluids.

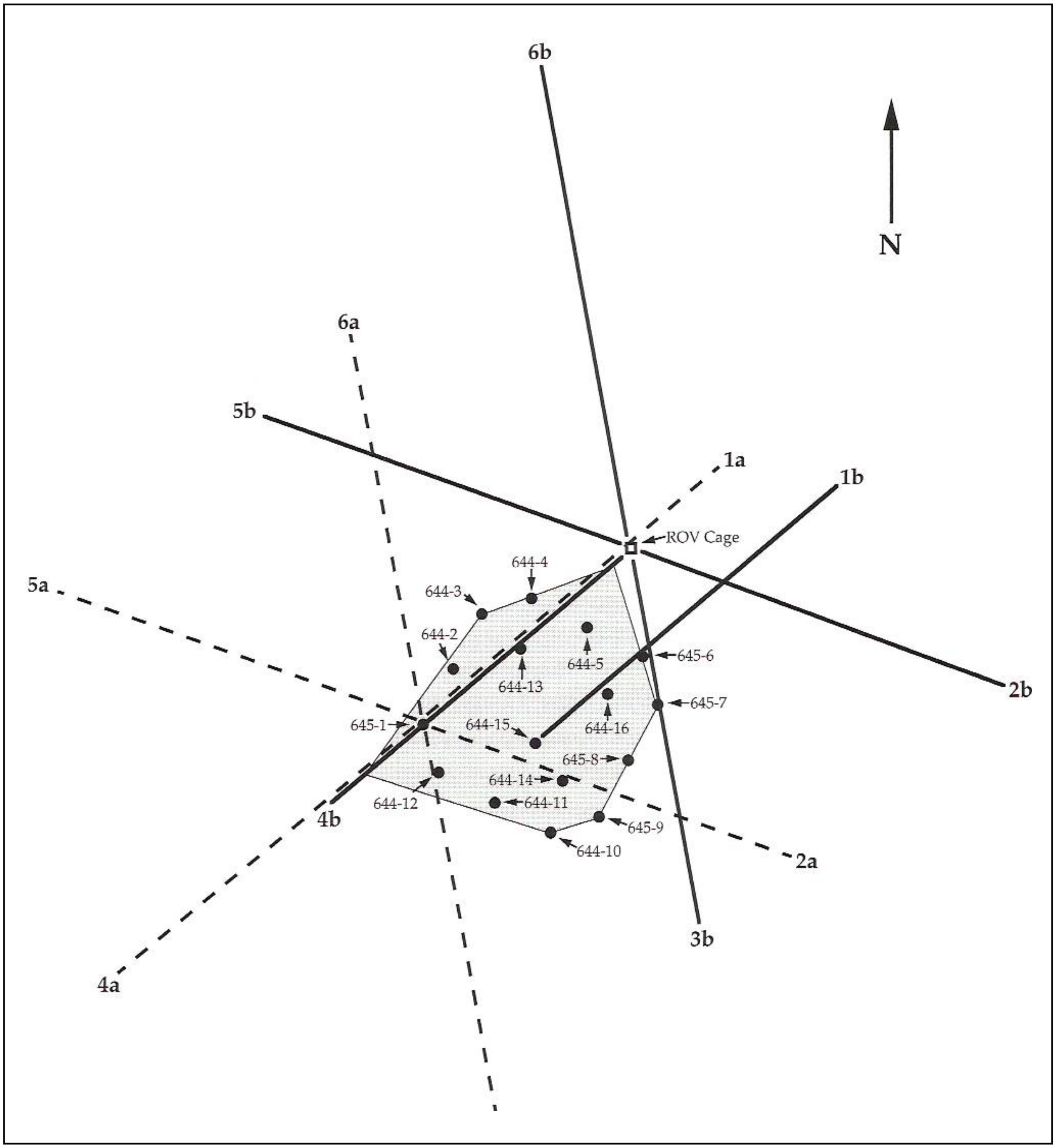


Figure 2D.5. Diagrammatic planned tracks of the ROV pre-development survey (dashed lines) and the post-development survey (solid lines) conducted at the BP Holstein Development in the Green Canyon 645 lease block. Locations of the sixteen wells drilled in the Holstein Development are shown with well numbers preceded by their block numbers (bottom of the hole).

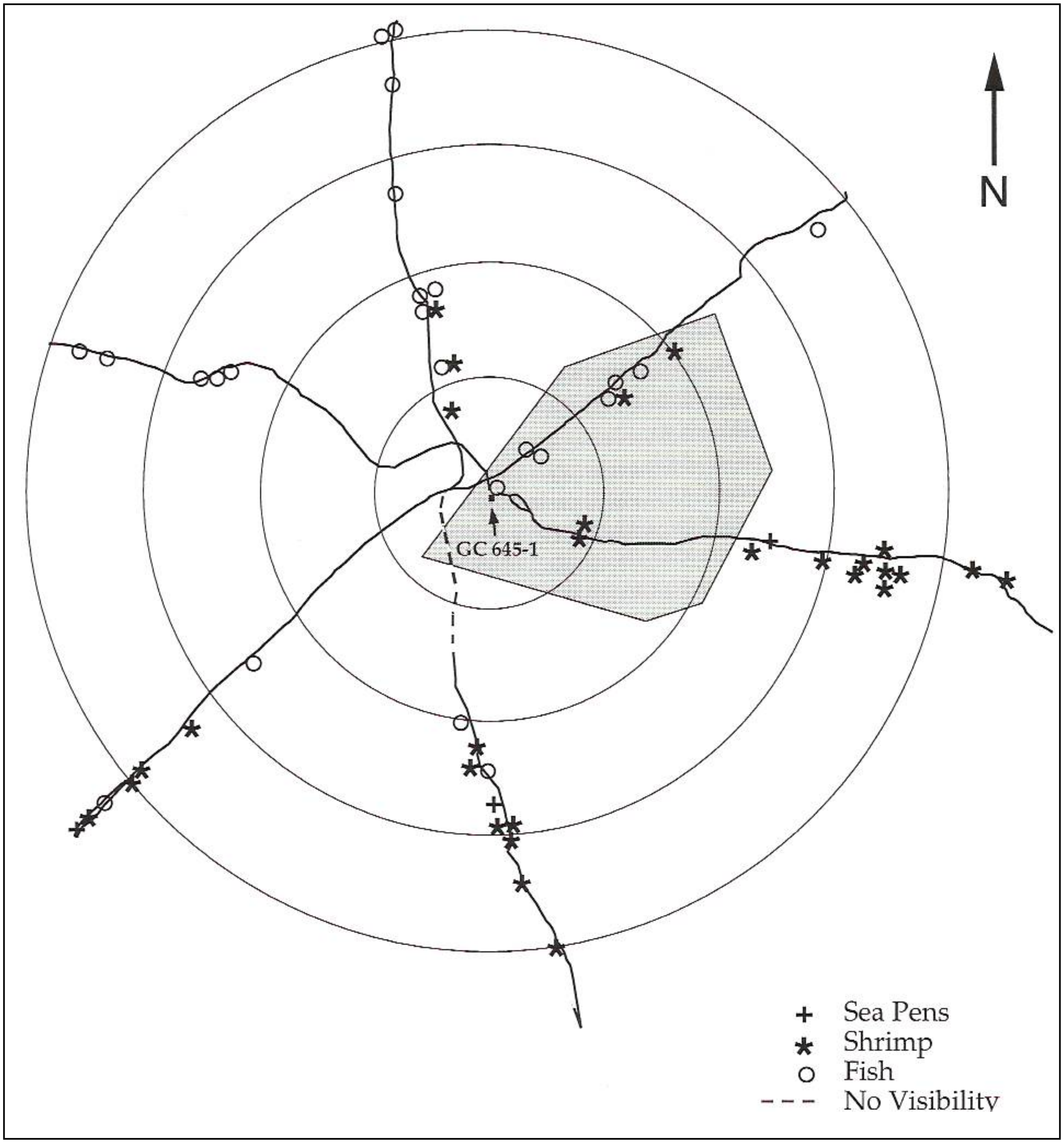


Figure 2D.6. The distribution of megafauna observed on the Holstein Development pre-drilling ROV survey transects, December 2001.

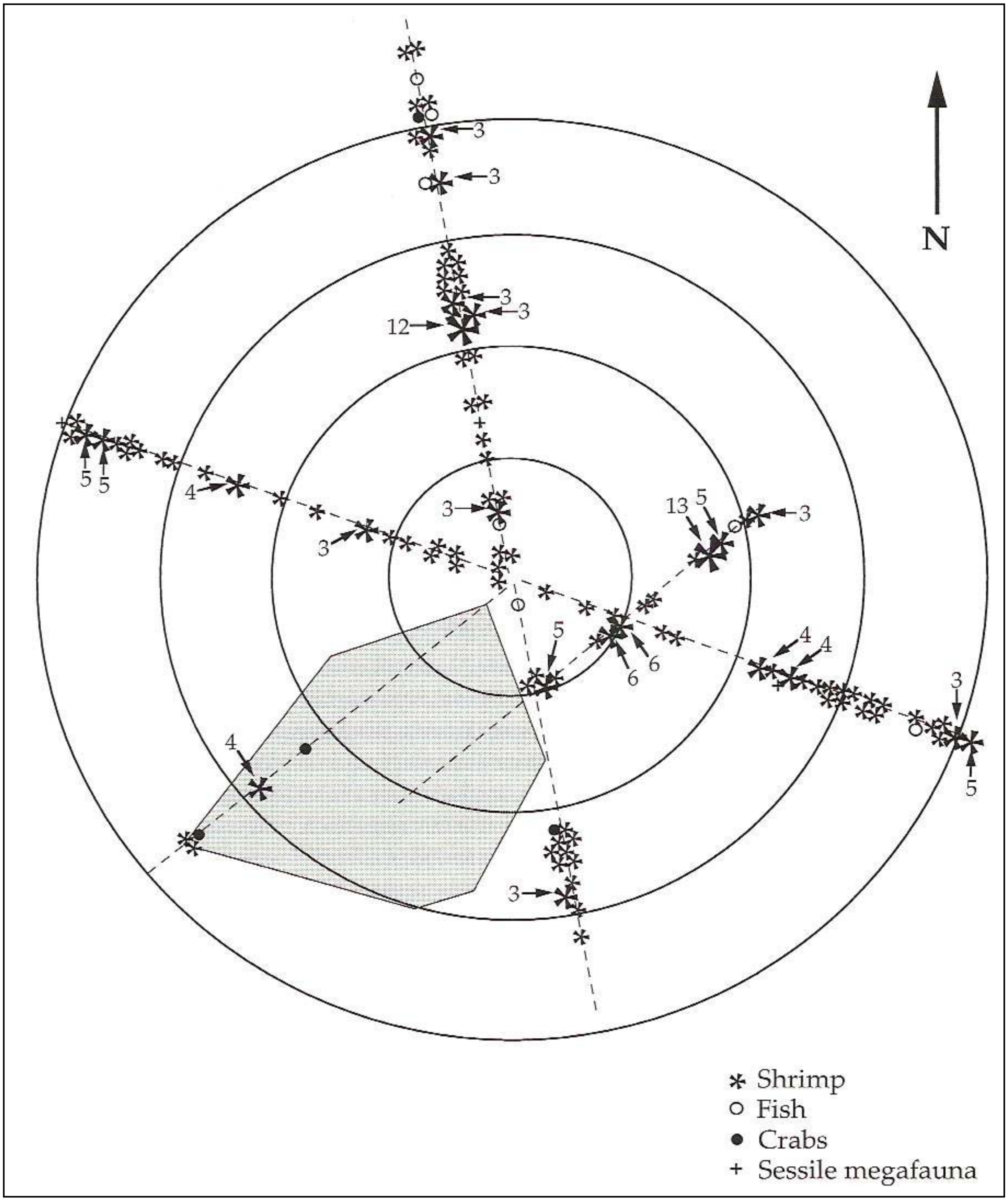


Figure 2D.7. The distribution of megafauna observed on the Holstein Development post-drilling ROV transects, August 2002.

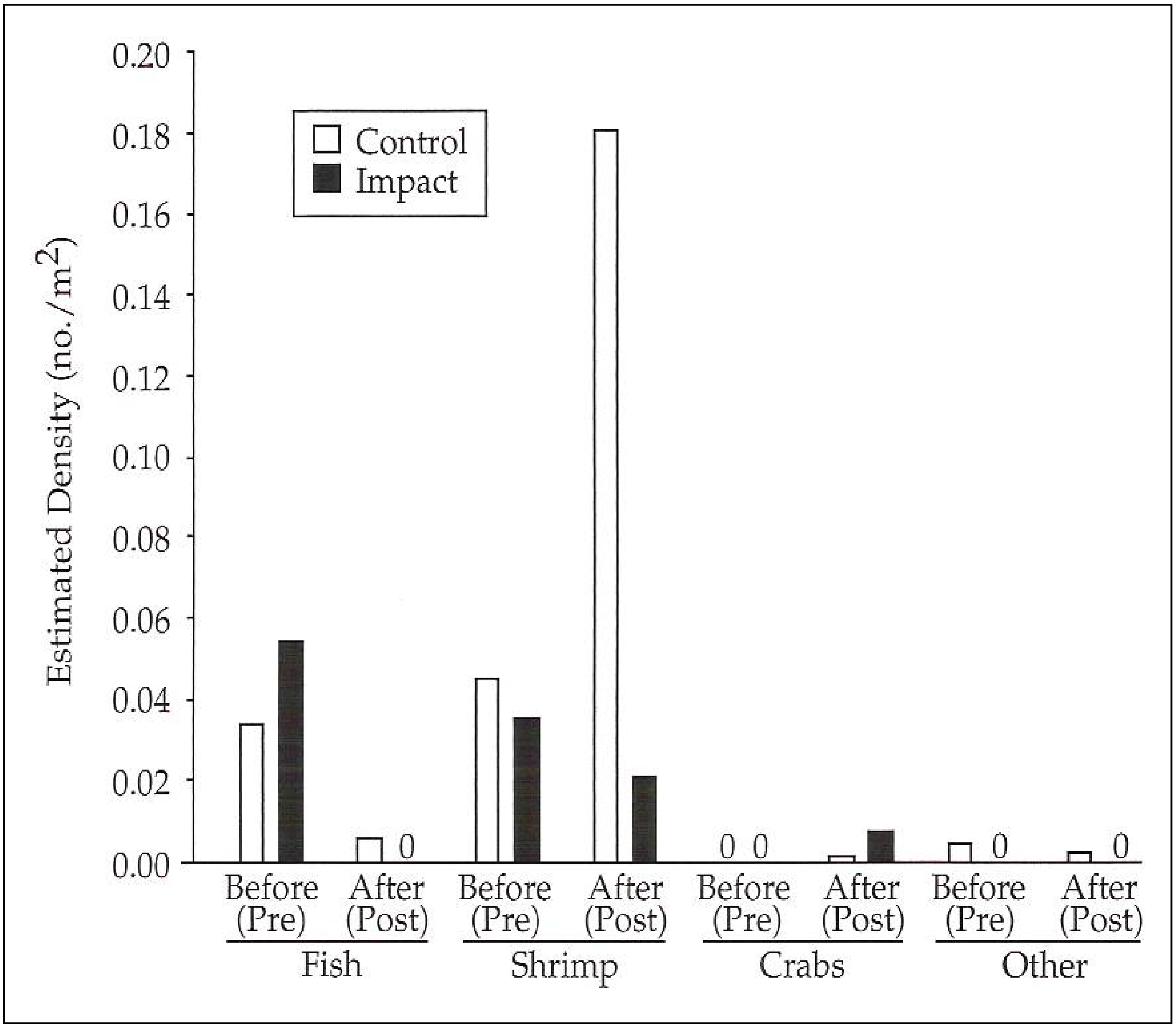


Figure 2D.8. Relative abundance of megafauna in the control and impact areas, before (December 2001) and after (August 2002) drilling.

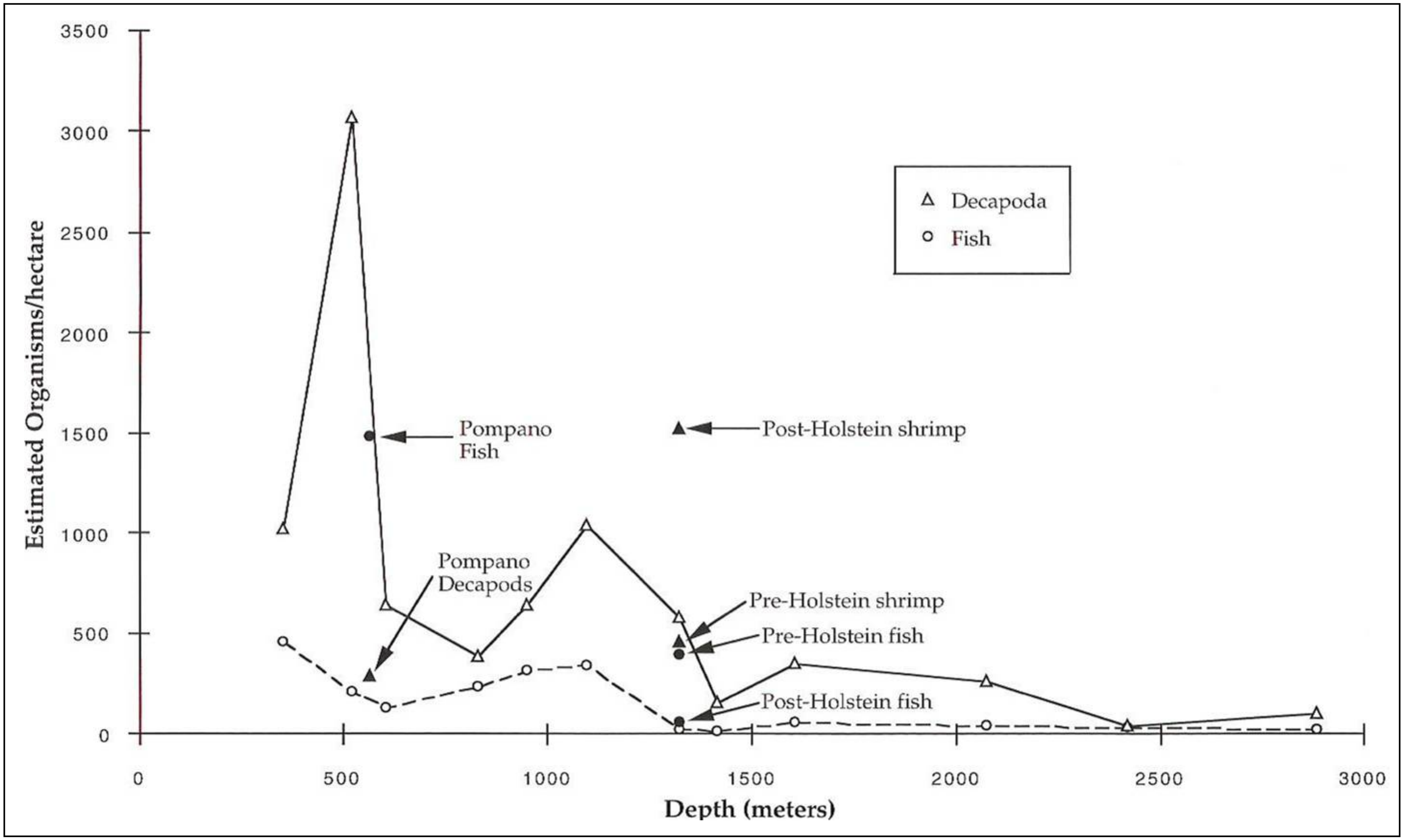


Figure 2D.9. Comparison by depth of mean densities of decapods and fish from Cruises II and III benthic photography on the central Gulf of Mexico continental slope (Gallaway *et al.* 1988) with densities of decapods and fish for Pompano Phase II (Gallaway *et al.* 1997, Gallaway *et al.* 1998, Fechhelm *et al.* 2001) and shrimp and fish for the Holstein Development site (this survey).

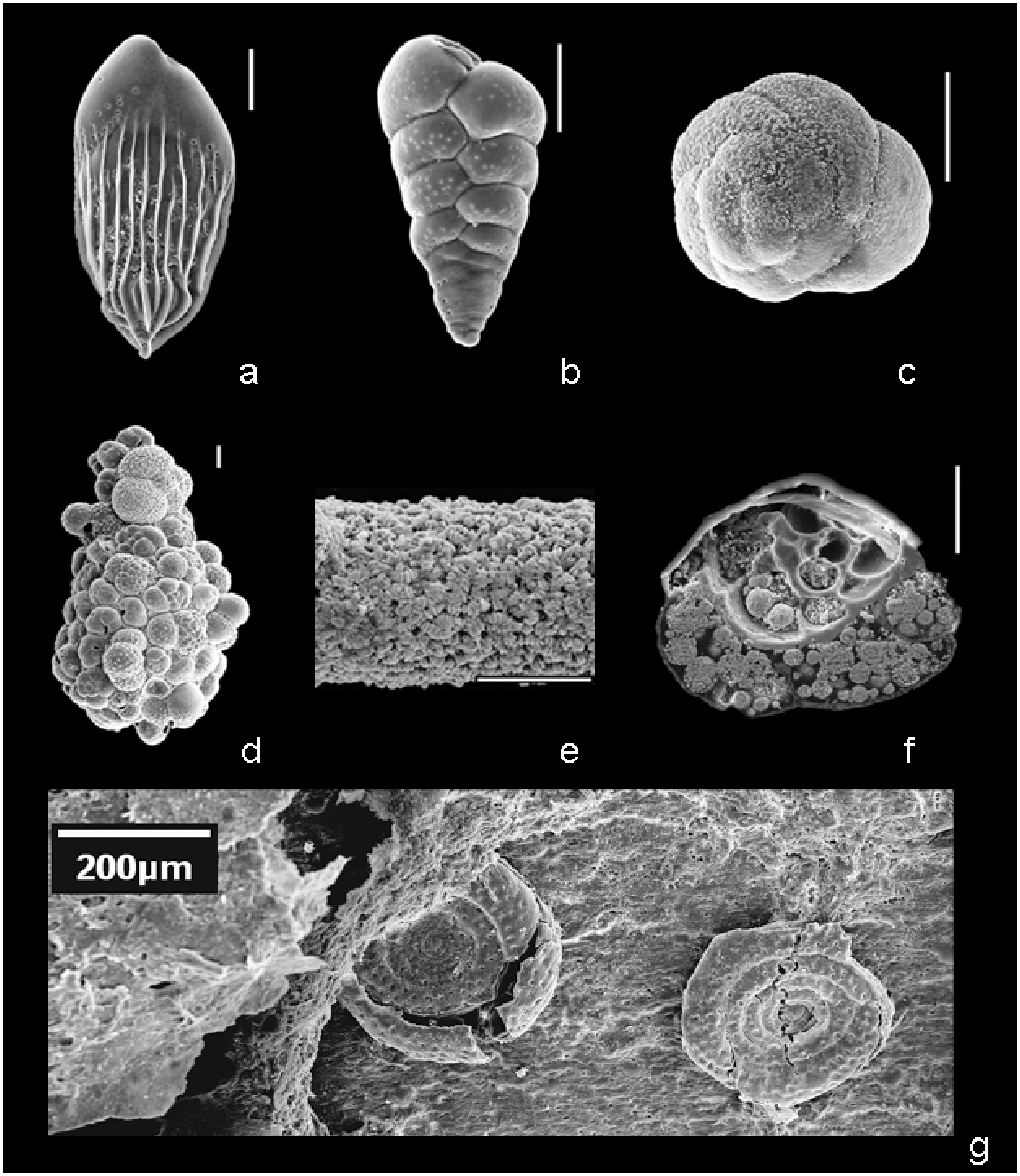


Figure 2D.10. Examples of Gulf of Mexico deep-water Foraminifera from hydrocarbon seepage areas: a, *Bolivina* sp. cf. *B. pusilla*; b, *Bolivina lowmani*; c, *Nuttallides decorata*; d, *Saccammina helenae* (shell composed of planktonic foraminifers); e, *Hyperammina* sp. (shell composed of barite crystals); f, *Nuttallides decorata* (with infilling pyrite framboids); g, *Spirillina* sp. (attached to tubeworm). Scale bars for a-f = 50 µm.

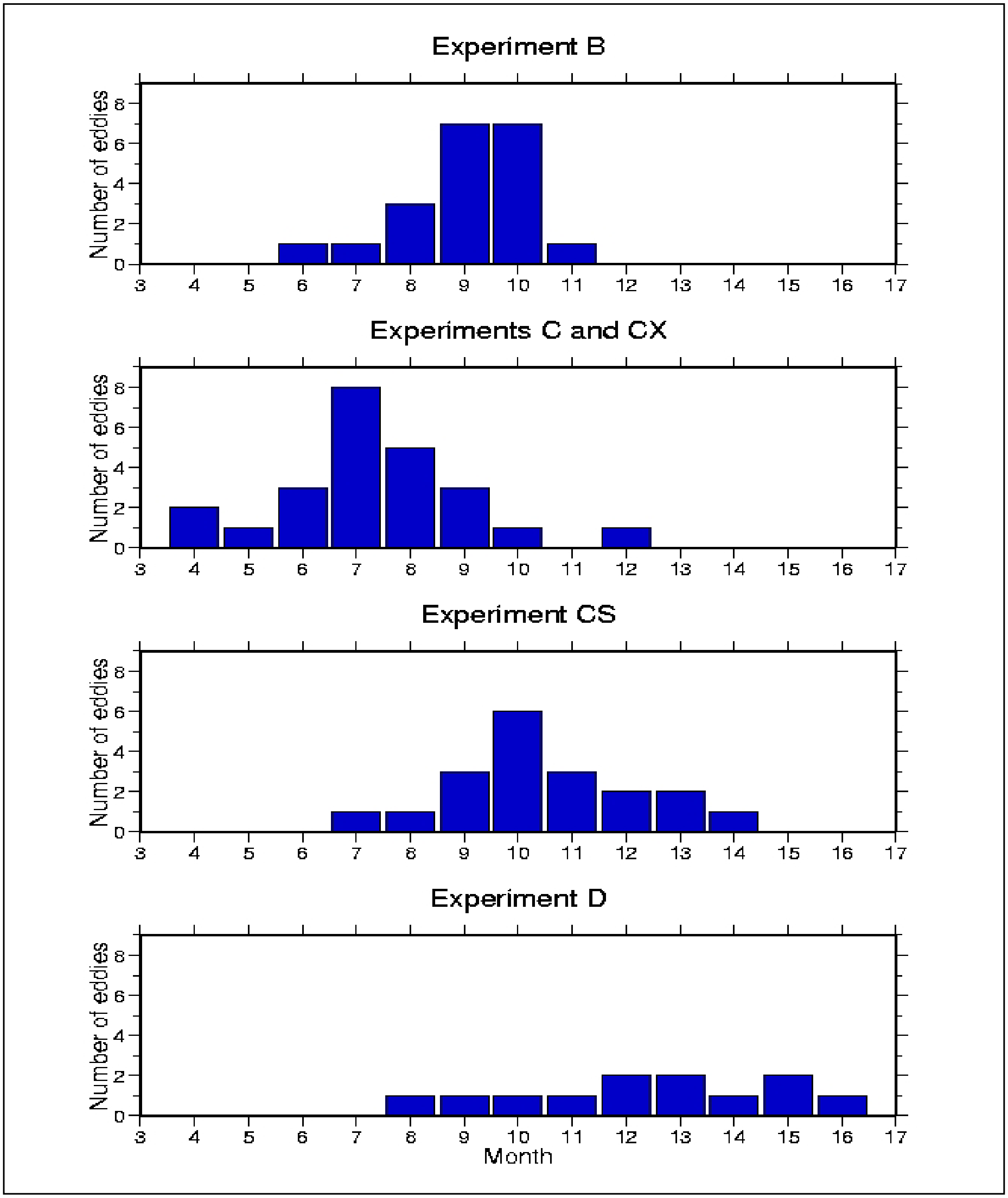


Figure 2E.1. A histogram of Loop Current eddy shedding periods for Experiments B: steady transport forcing, C/CX: six-hourly ECMWF wind forcing, CS: steady ECMWF wind forcing, and D: Caribbean eddy forcing (from satellite). The abscissa is time interval in months between shedding and the ordinate is the number of shed eddies.

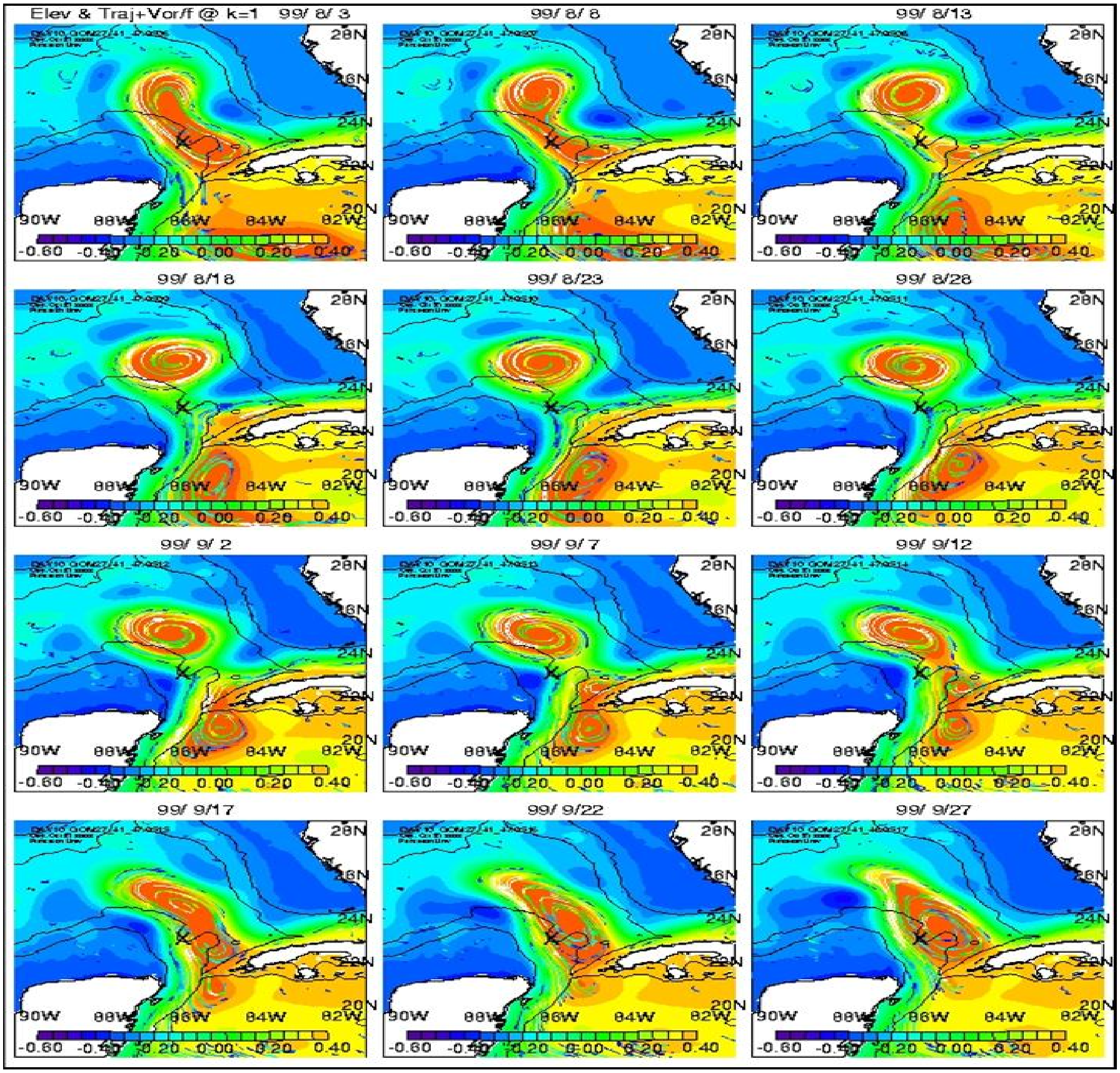


Figure 2E.2. Loop Current eddy detachment and reattachment, experiment CS (steady ECMWF wind forcing case): Eulerian trajectories launched for five days centered around the indicated date in each panel, and from every 10th grid point at the first sigma level (i.e. surface), superimposed on color image of surface elevation (red for values ≥ 0.4 m, blue < -0.6 m). Colors on trajectories indicate ζ/f such that black/dark-blue through yellow indicate ζ/f from 0 through –0.4, and white for ζ/f < –0.4. Cyclonic trajectories are omitted for clarity. Dark contours are the 200 m and 2000 m isobaths. Time interval between panels is five days. The first three panels show a LC on the verge of shedding. The LCE is shed or detaches on 18 August 1999. A CARE can be seen to arrive at the channel from 18–28 August 1999, carrying with it the white-colored trajectories that indicate strong anticyclonic vorticity (ς/f < –0.4), and the LC makes a tight right-hand turn into the straits of Florida. As the CARE completes its passage through the channel, part of its mass 'leaks' along the Cuban northern coast (2–7 September 1999). The remaining (main) portion, however, interacts with the shed eddy (7–12 September 1999) and the two eddies eventually merge (12–27 September 1999).

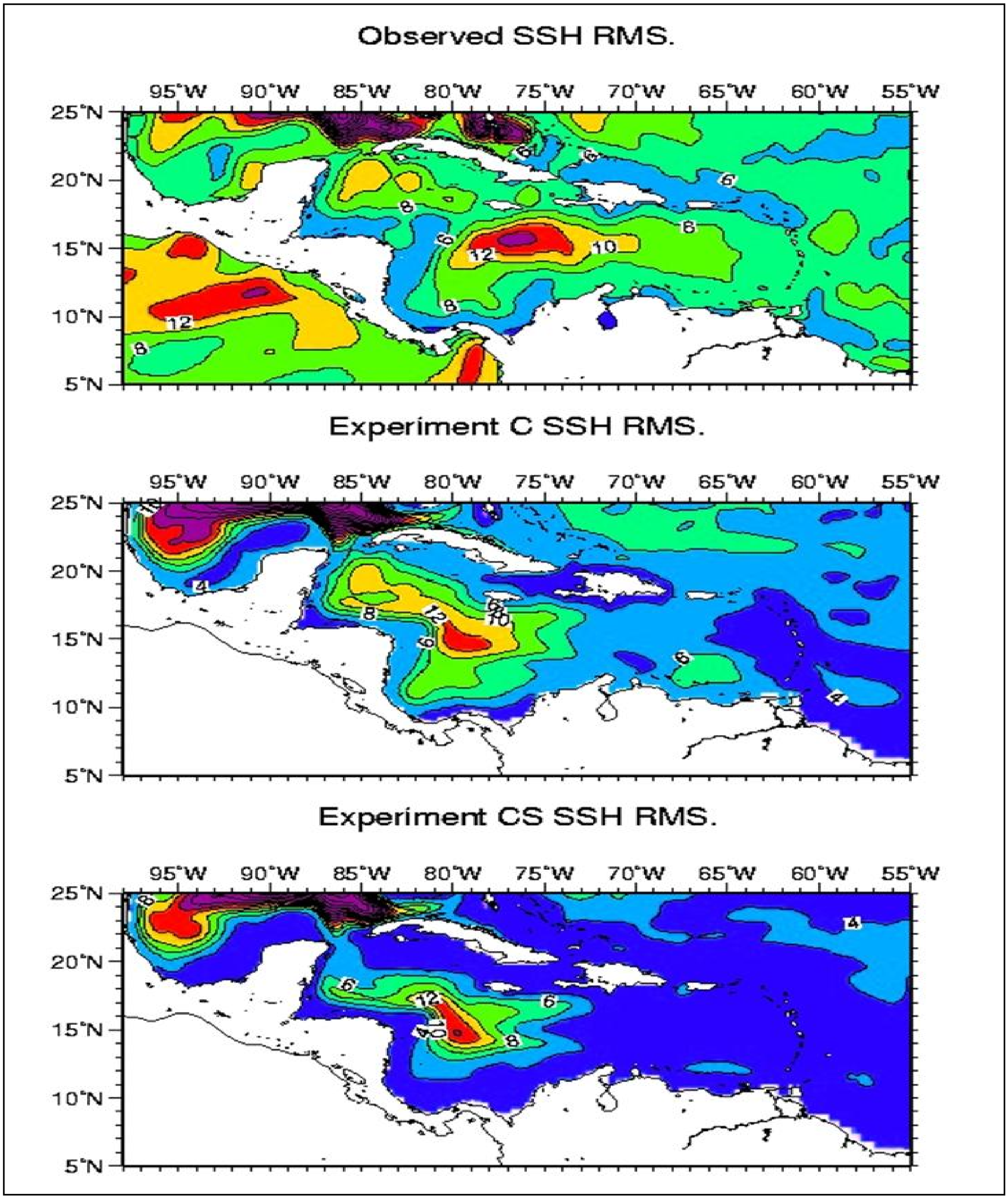


Figure 2E.3. The sea-surface height (SSH) rms from satellite SSH anomaly (1992-1999; top panel), experiment C (the six-hourly ECMWF wind forcing case; middle panel) and experiment CS (the steady ECMWF wind forcing case; lower panel). Note in all three panels the occurrence of high SSH rms south and southwest of Jamaica.

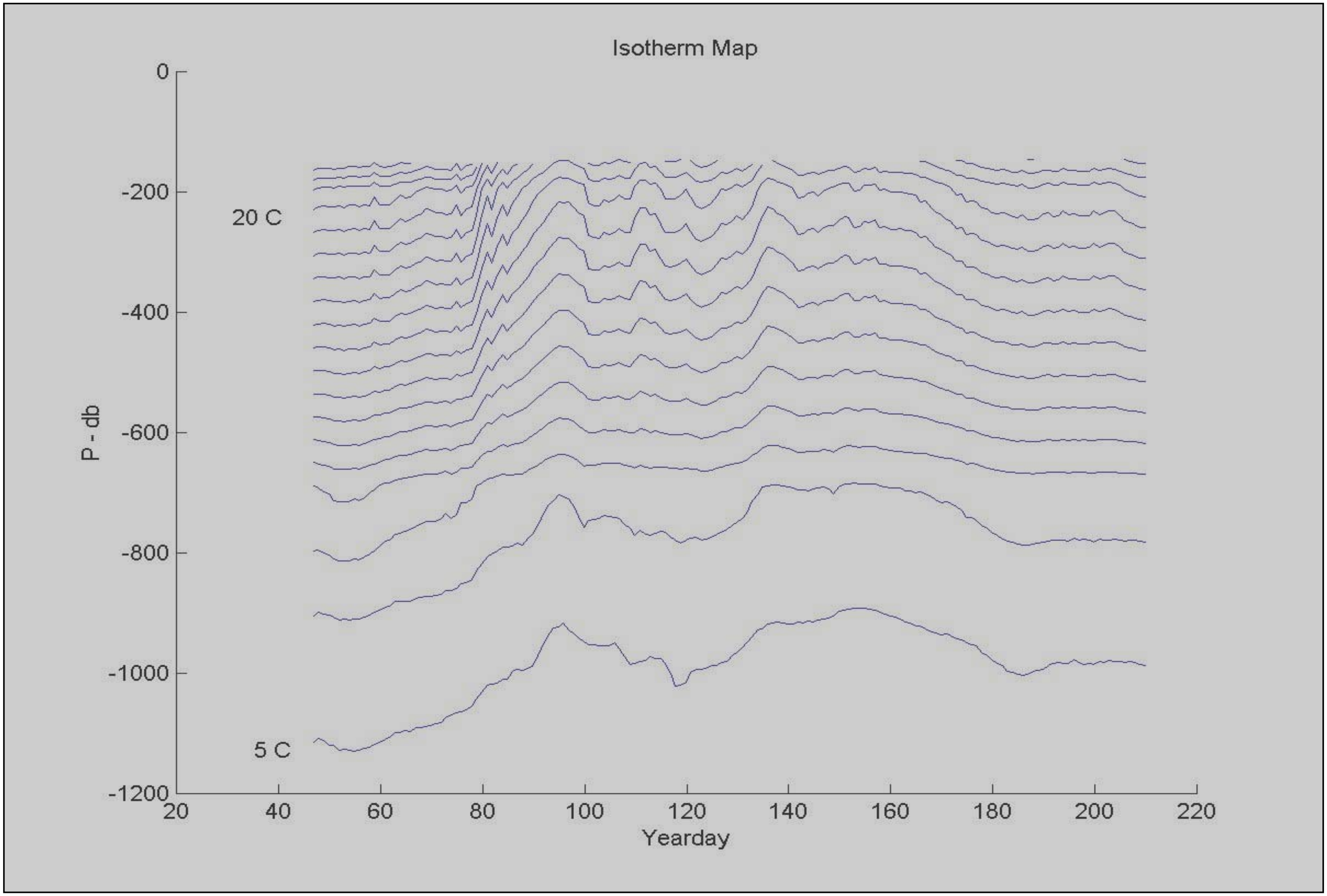


Figure 2E.4. Interpolated positions of isotherms from low-pass filtered Aanderaa data and one SeaCat near 150 db.

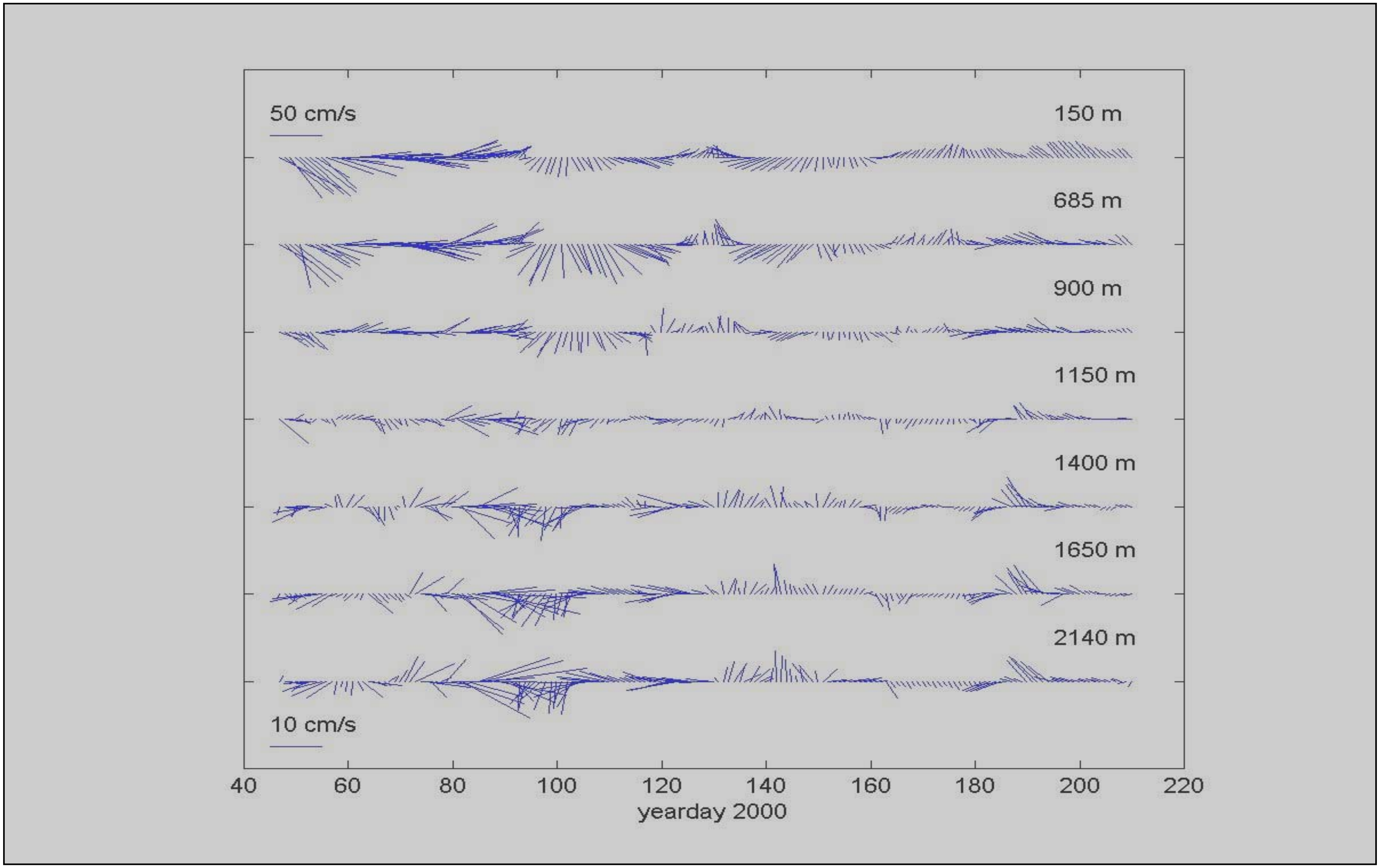


Figure 2E.5. Stick-plots of the low-passed currents at the Aanderaa meters. Note that the currents measured at the meter that is nominally at 150 m depth have been scaled five times smaller than the currents measured at the other meters (Hamilton and Lugo-Fernandez 2001).

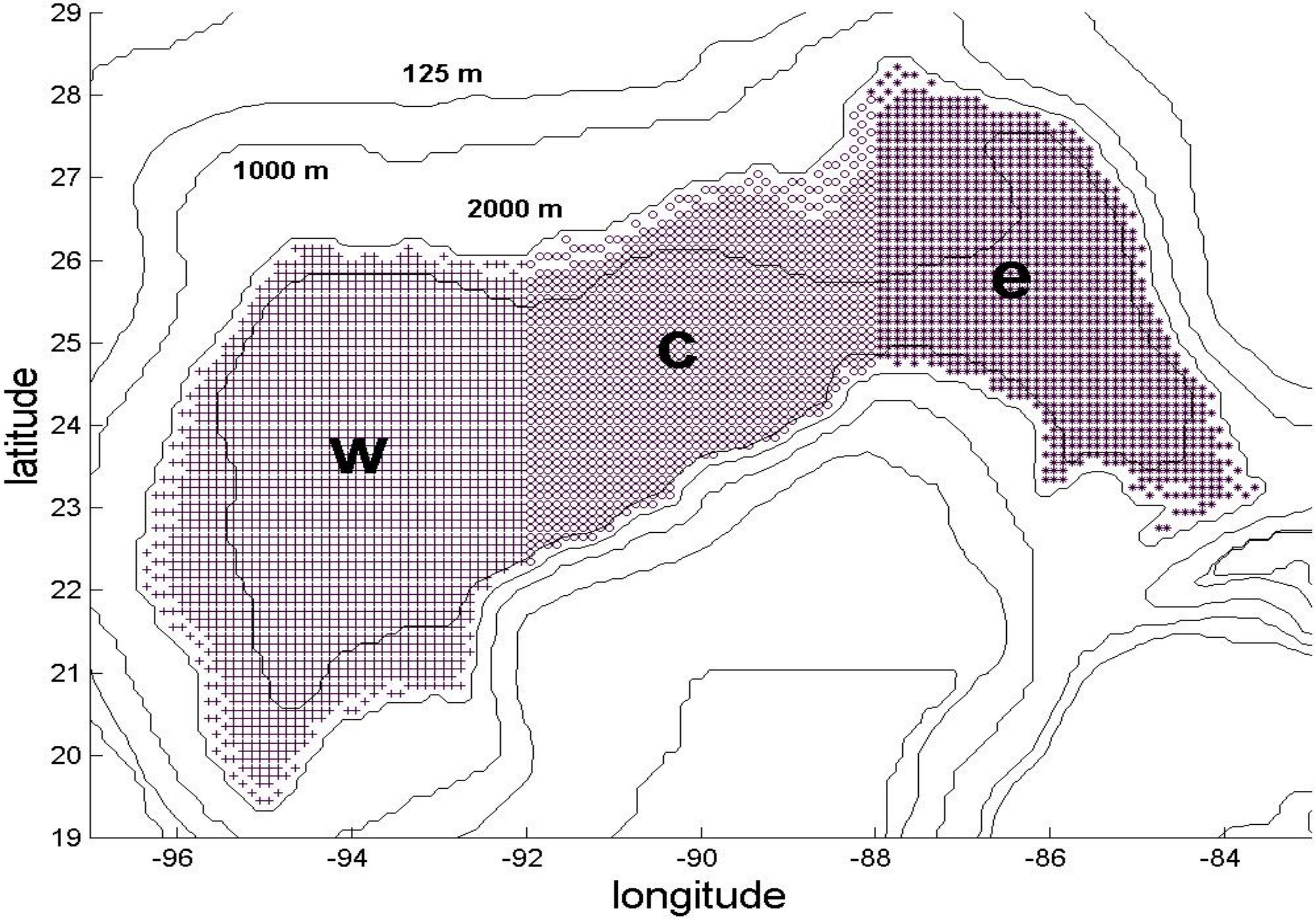


Figure 2E.6. Plan view of initial starting locations at 2200 m for tracer particles in the deepwater release experiment. The bold letters identify the starting regions as west (w), central, (c), and east (e).

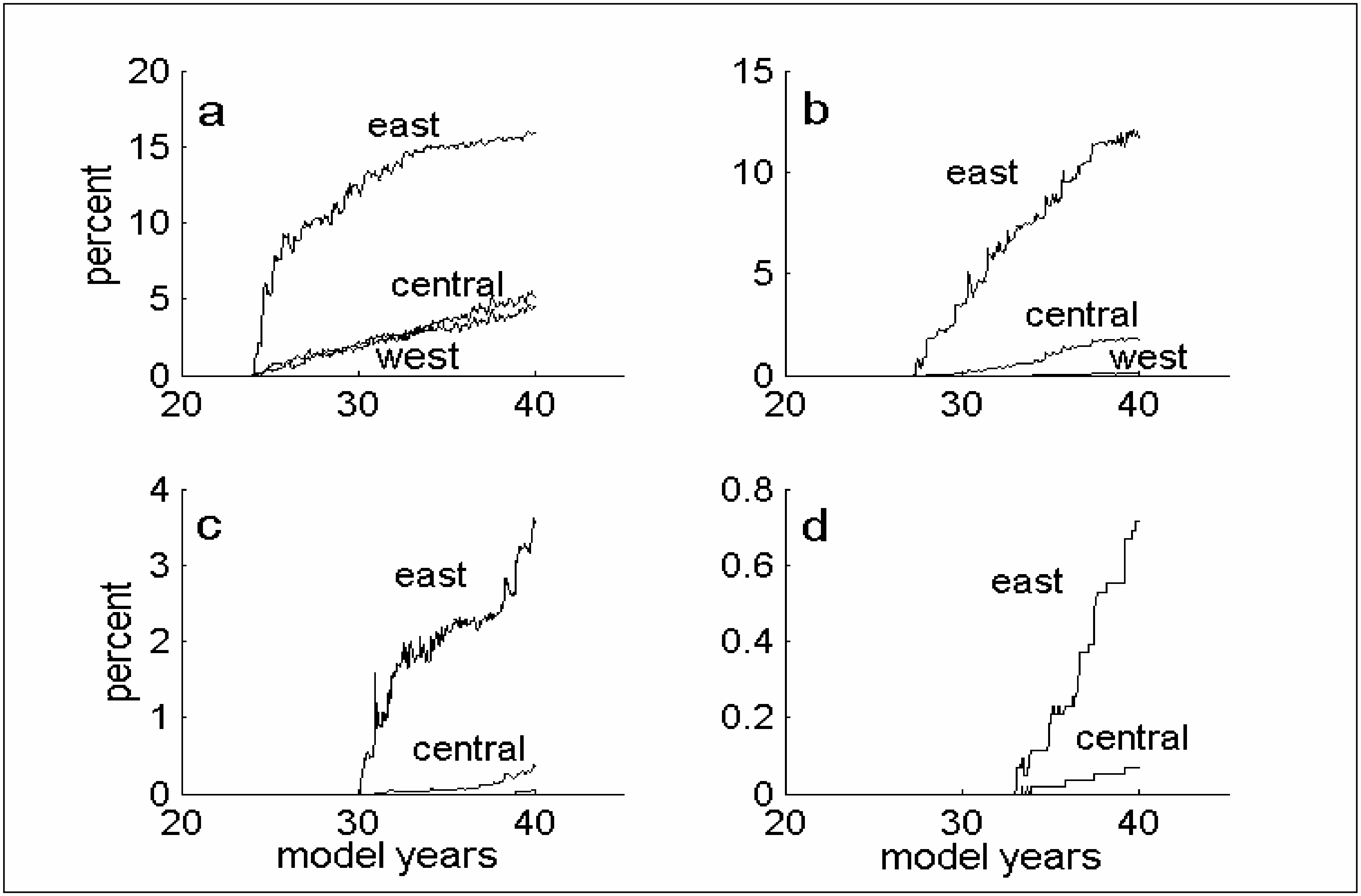


Figure 2E.7. Percentages of all particles to ascend to (a) 2000 m, (b) 1000 m, (c) 500 m, and (d) 200 m according to starting location.

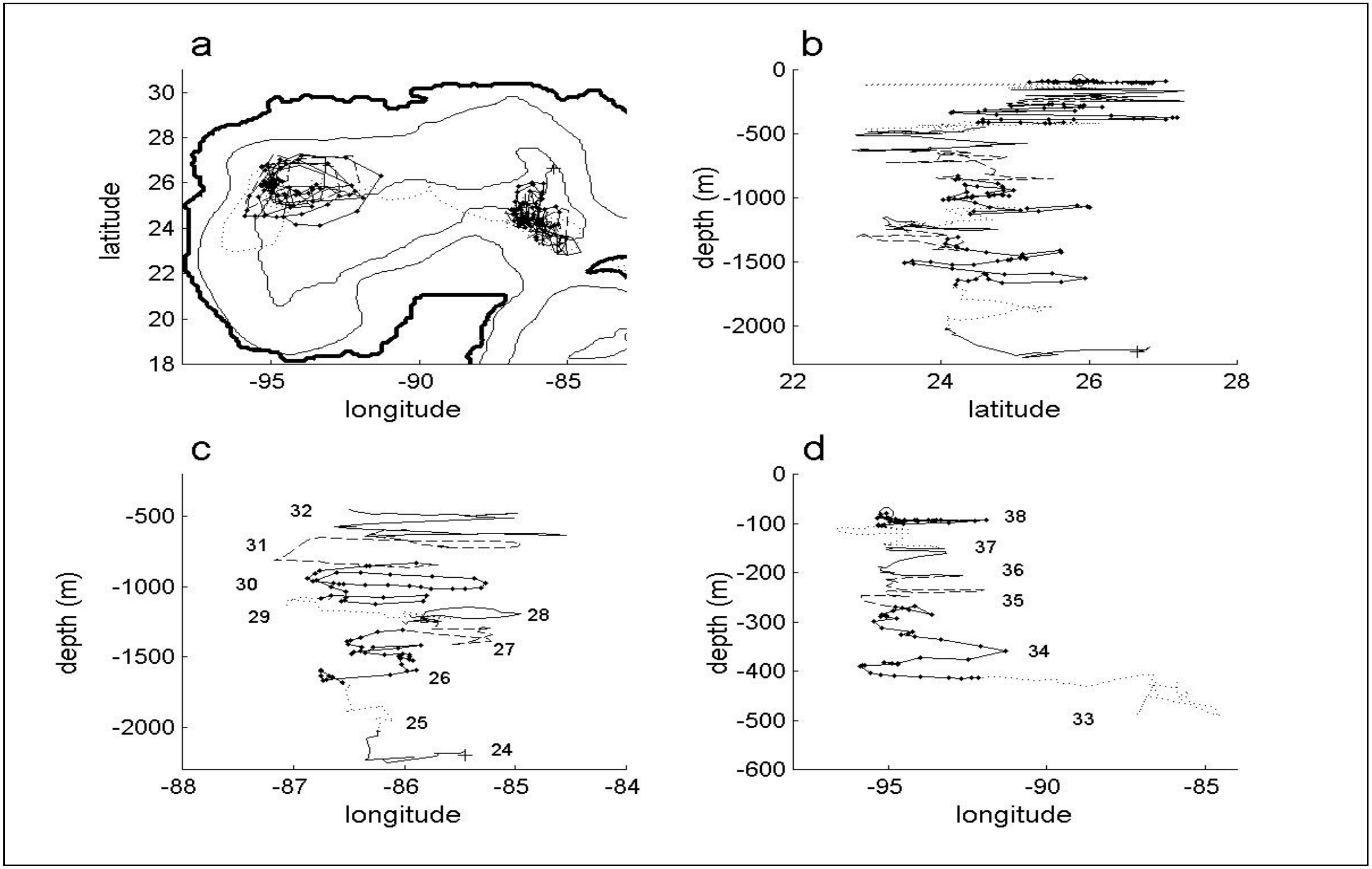


Figure 2E.8. Path of particle 17976: (a) plan view for years 24-38, (b) latitude-depth projection for years 24-38, (c) longitude-depth projection while 17976 was in the eastern basin, (d) longitude-depth projection after 17976 became entrained in Ring S17 in year 33.

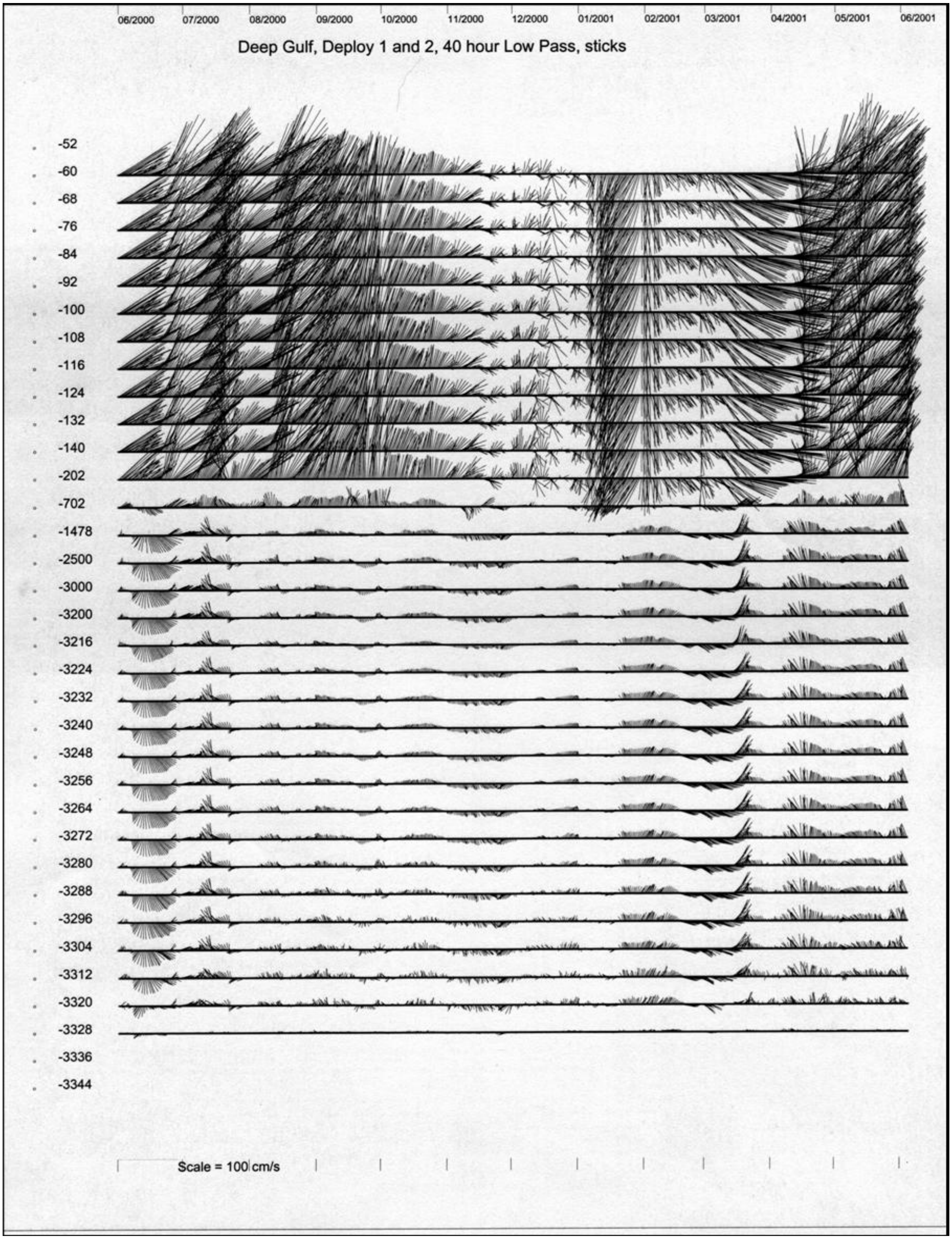


Figure 2E.9. 40-hour low pass filtered ADCP and current meter data at each instrument on the Deep Gulf Mooring for the period June 2000 to June 2001.

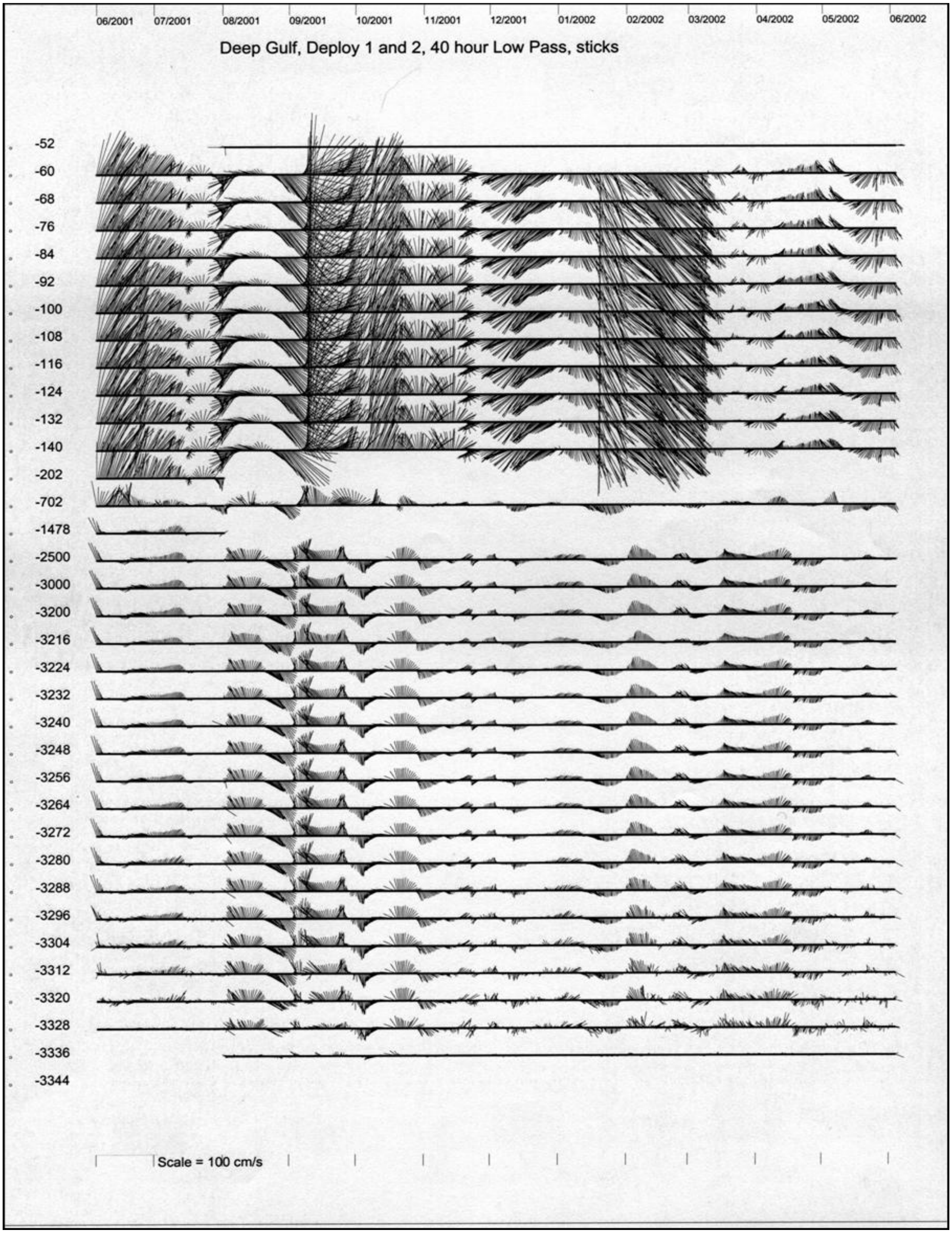


Figure 2E.10. 40-hour low pass filtered ADCP and current meter data at each instrument on the Deep Gulf Mooring for the period June 2001 to June 2002.

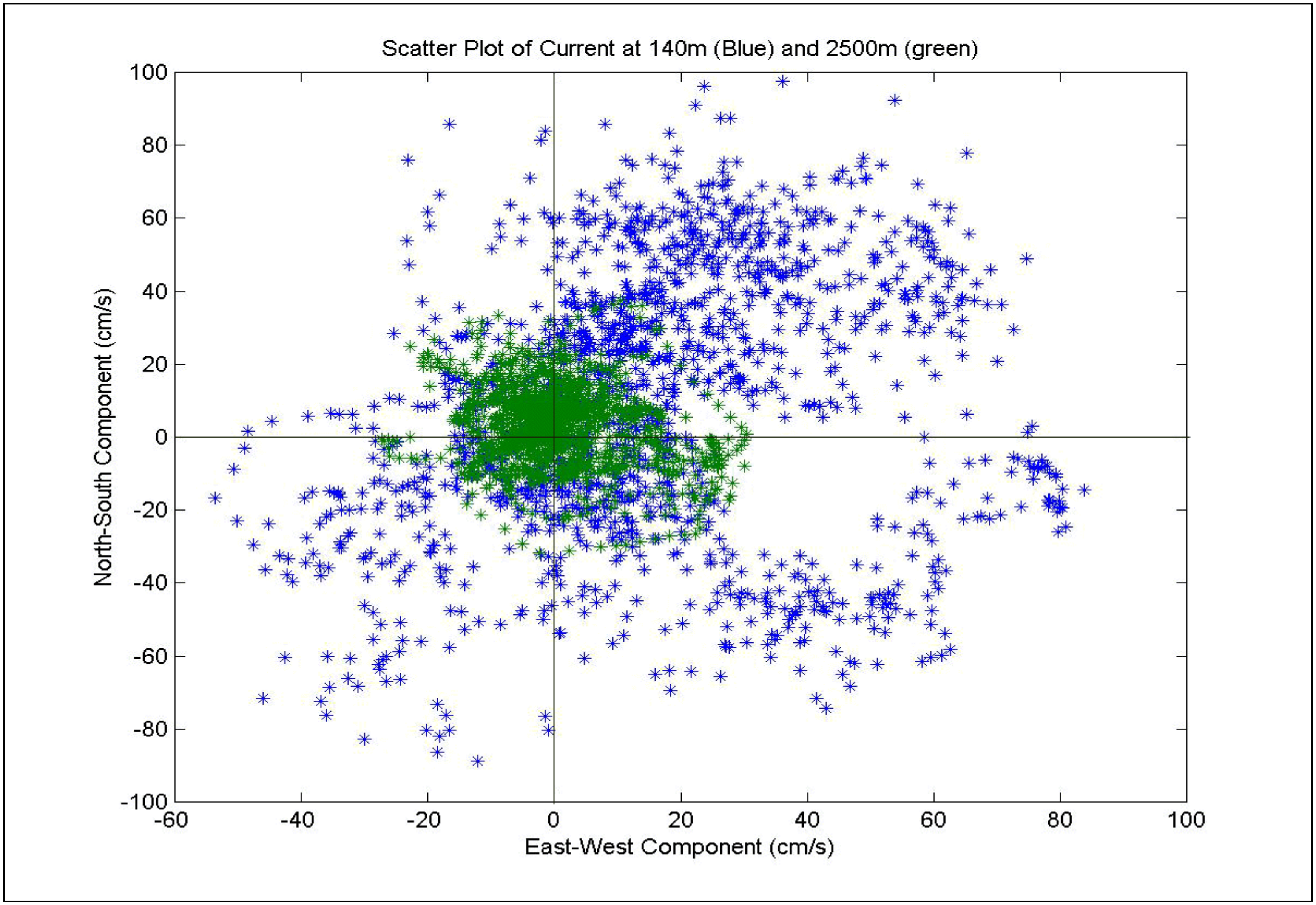


Figure. 2E.11. Scatter plot of 40-hour low passed current at 140 m (blue) and 2500 m (green).

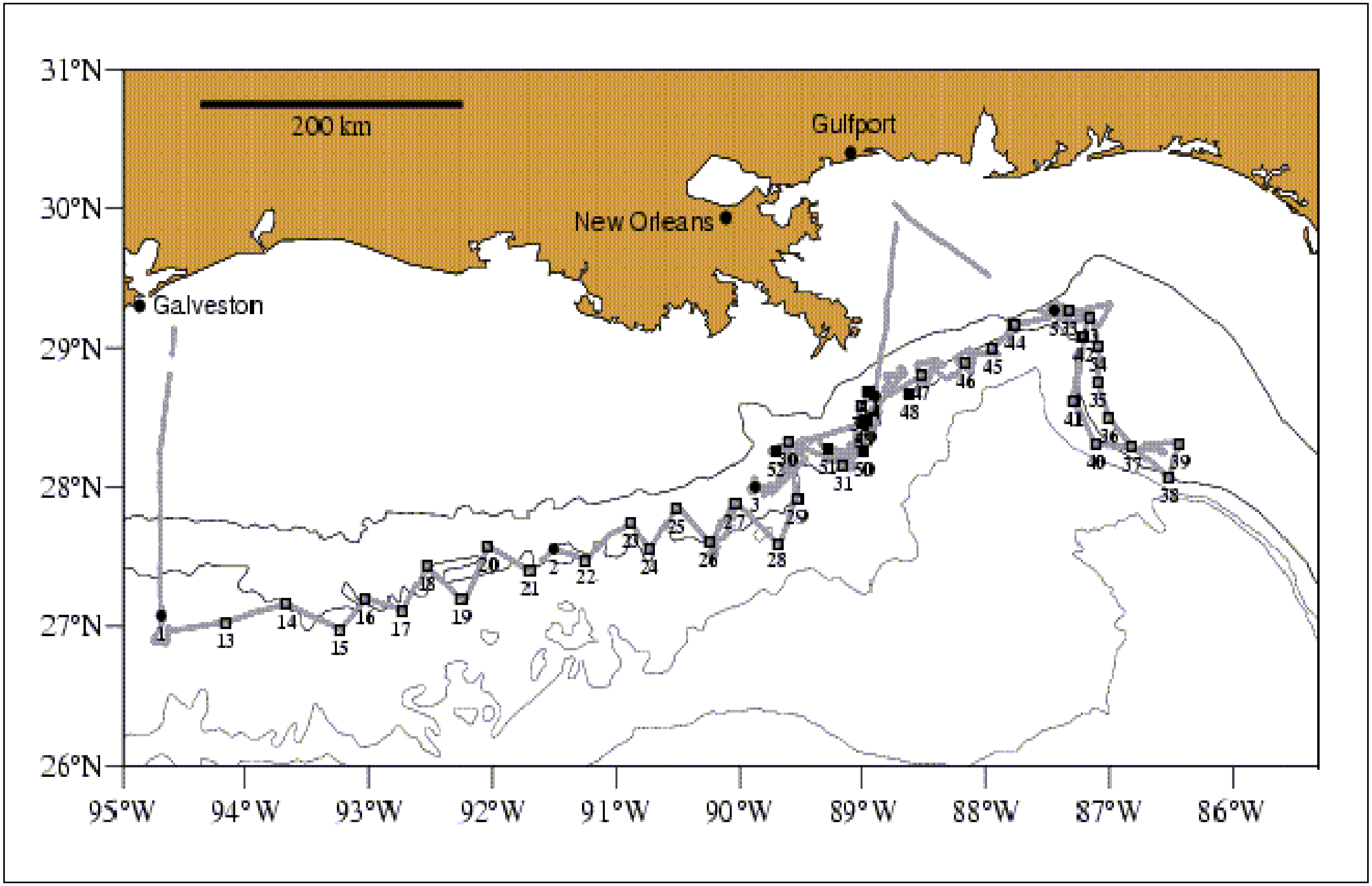


Figure 2F.1. Location of XBT (squares) and CTD (circles) stations during SWSS Leg One. Light gray line is cruise track; other gray lines show 200 m, 1000 m, 2000 m, and 3000 m isobaths.

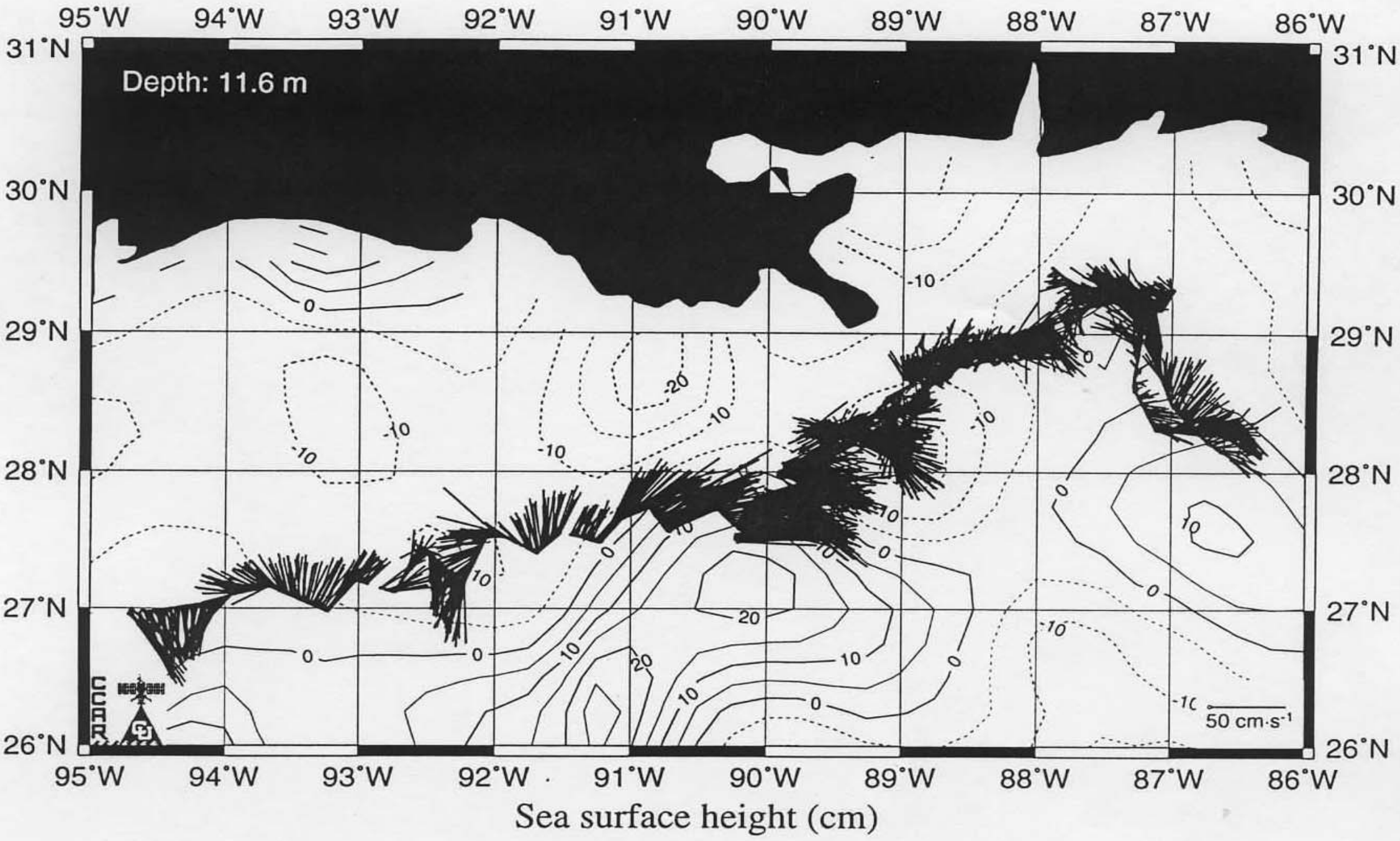


Figure 2F.2. Caterpillar plot of currents measured during SWSS Leg One by the ship's 153 kHz ADCP, superimposed on composite map of Sea Surface Height anomaly sensed remotely by altimeters in earth orbit for the ten day period 24 June–3 July 2002.

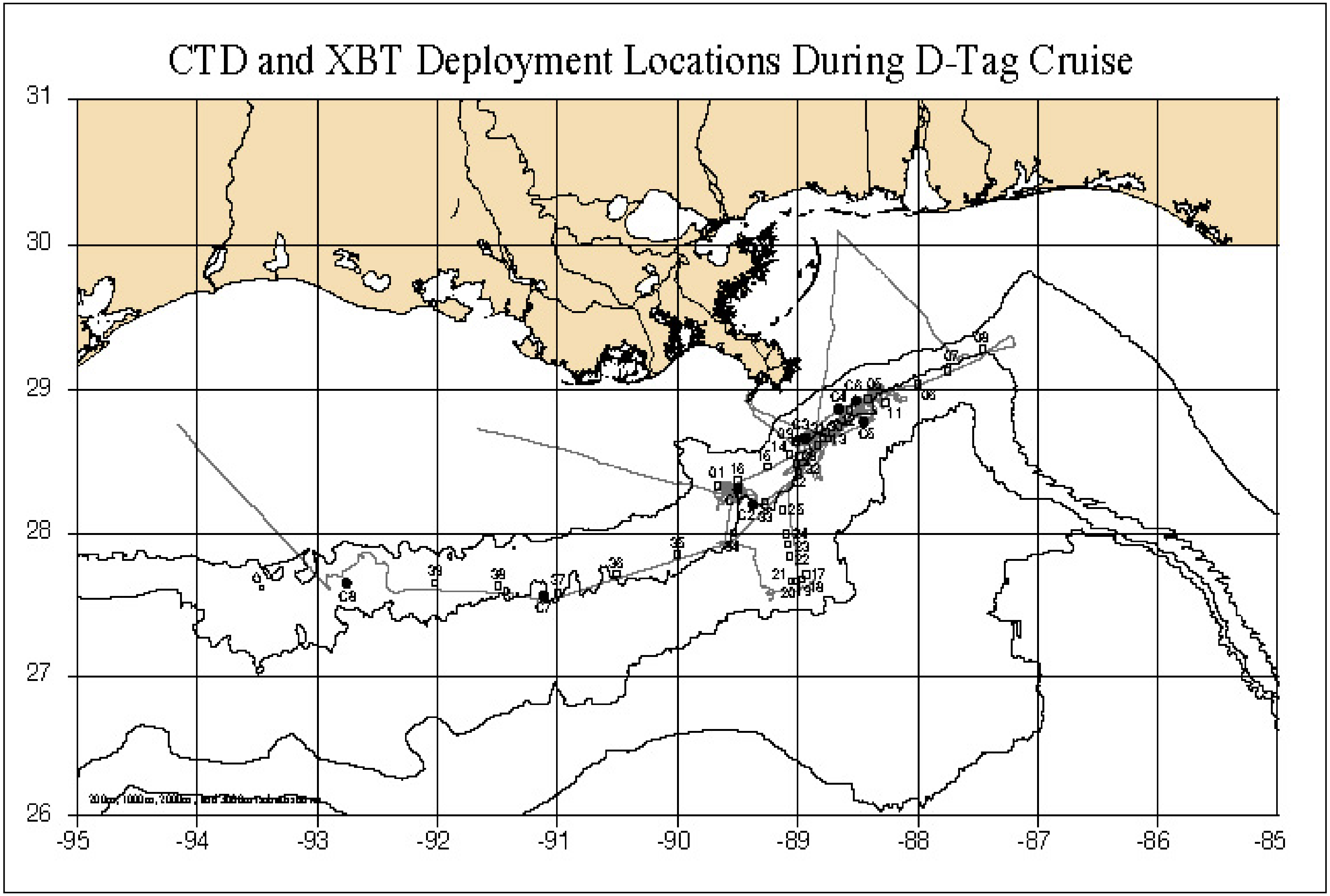


Figure 2F.3. Location of XBT and CTD stations during SWSS Leg Two.

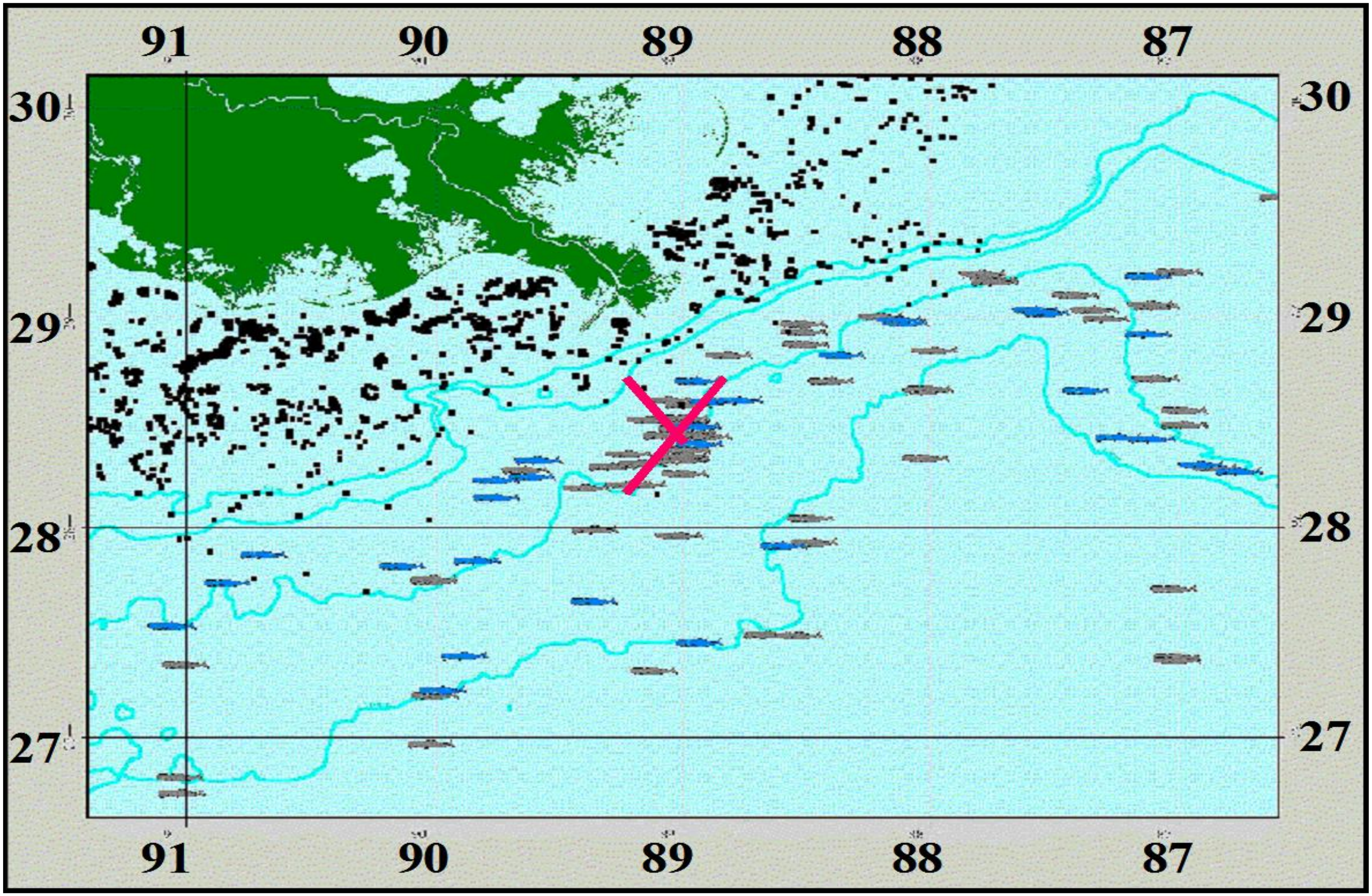


Figure 2F.4. Ship track locations for oceanographic sensing in red. Oil platforms are black dots and whale sightings are blue and gray whale symbols. Louisiana coast is green at upper left.

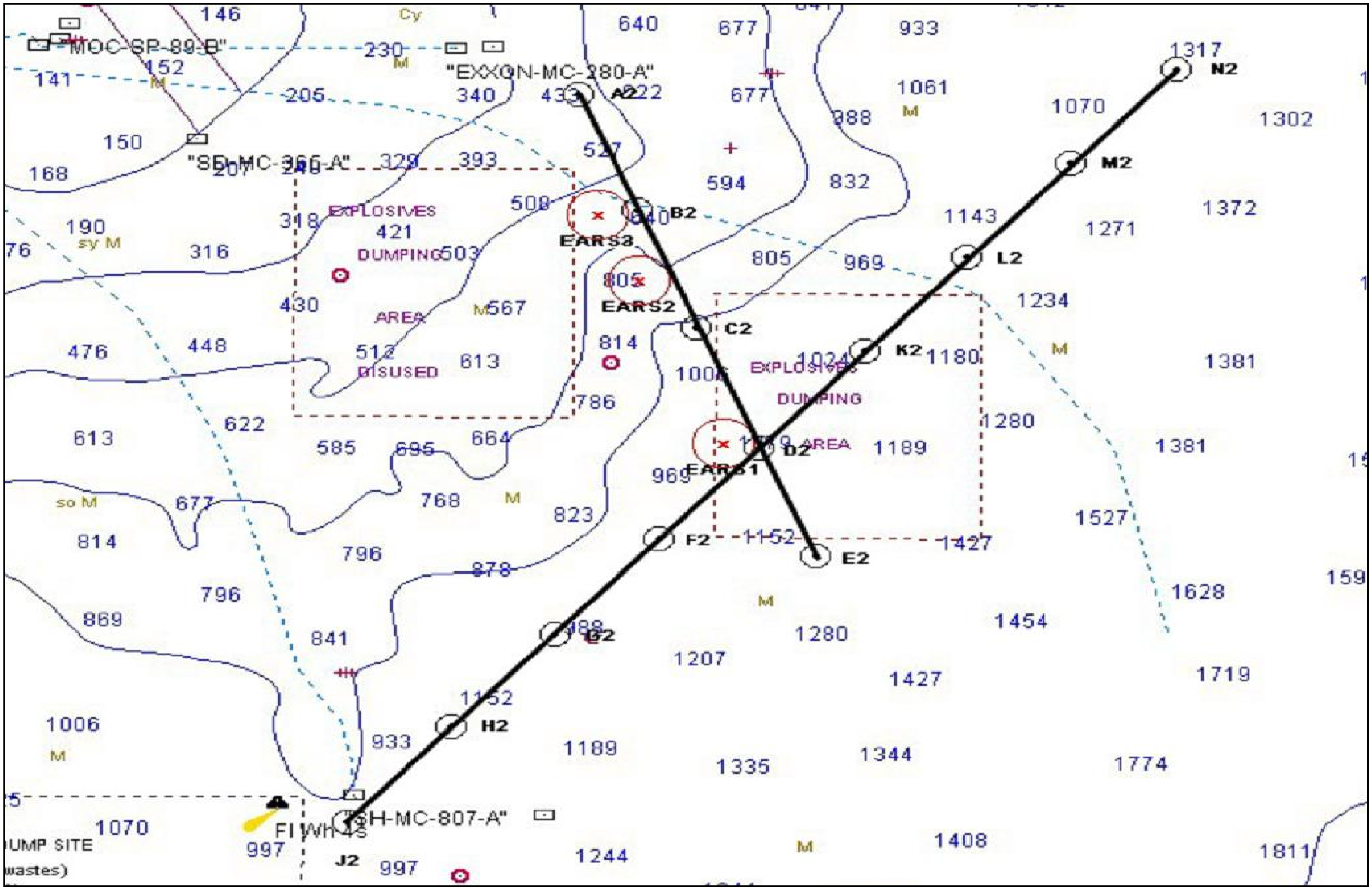
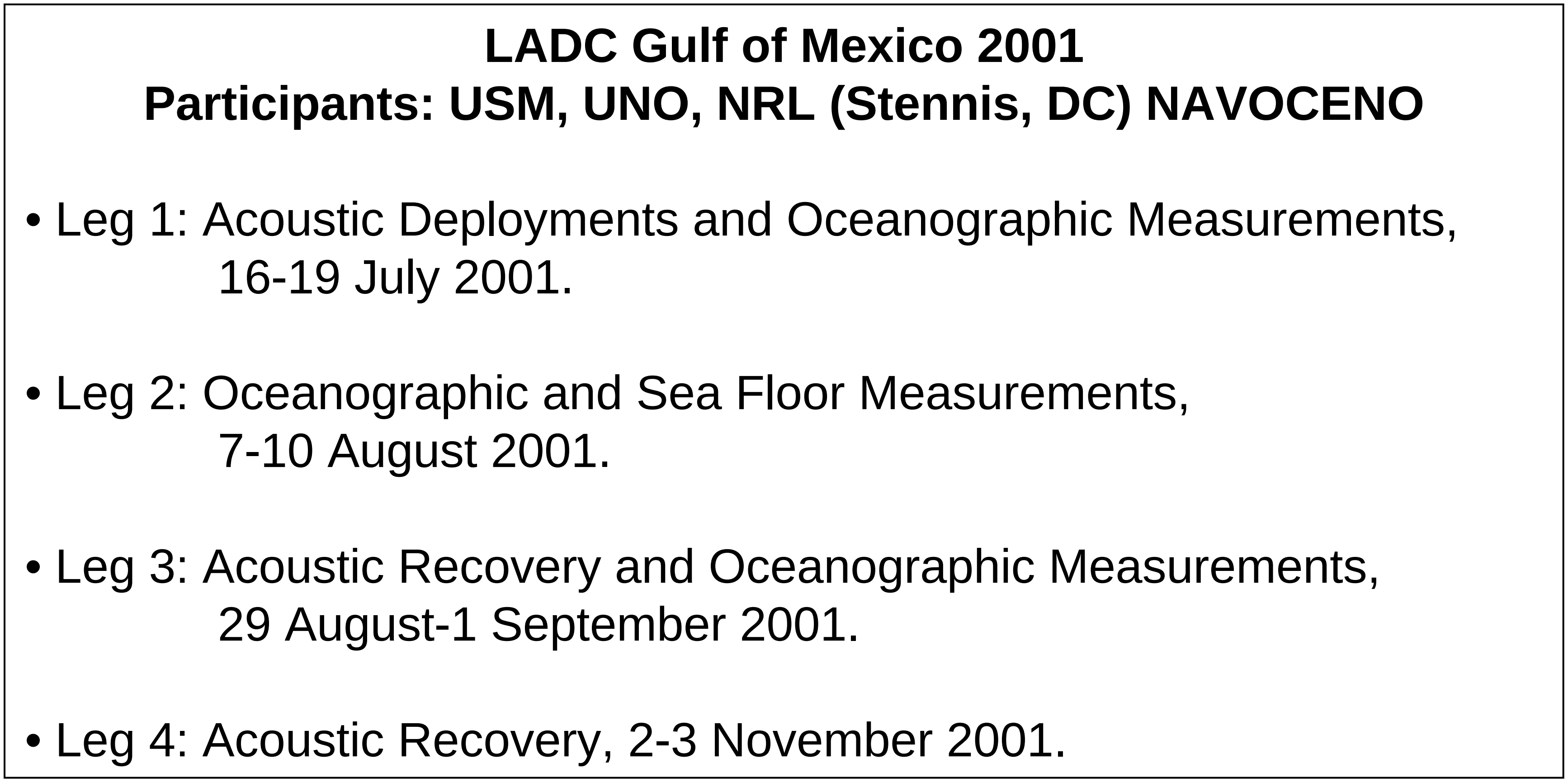


Figure 2F.5. Ship tracks for oceanographic surveys in black, mooring placement at magenta circles, and CTD casts at black circles.



LADC Gulf of Mexico 2001
Participants: USM, UNO, NRL (Stennis, DC) NAVOCENO

- Leg 1: Acoustic Deployments and Oceanographic Measurements, 16-19 July 2001.
- Leg 2: Oceanographic and Sea Floor Measurements, 7-10 August 2001.
- Leg 3: Acoustic Recovery and Oceanographic Measurements, 29 August-1 September 2001.
- Leg 4: Acoustic Recovery, 2-3 November 2001.

Figure 2F.6. Summer 2001 cruise summary.

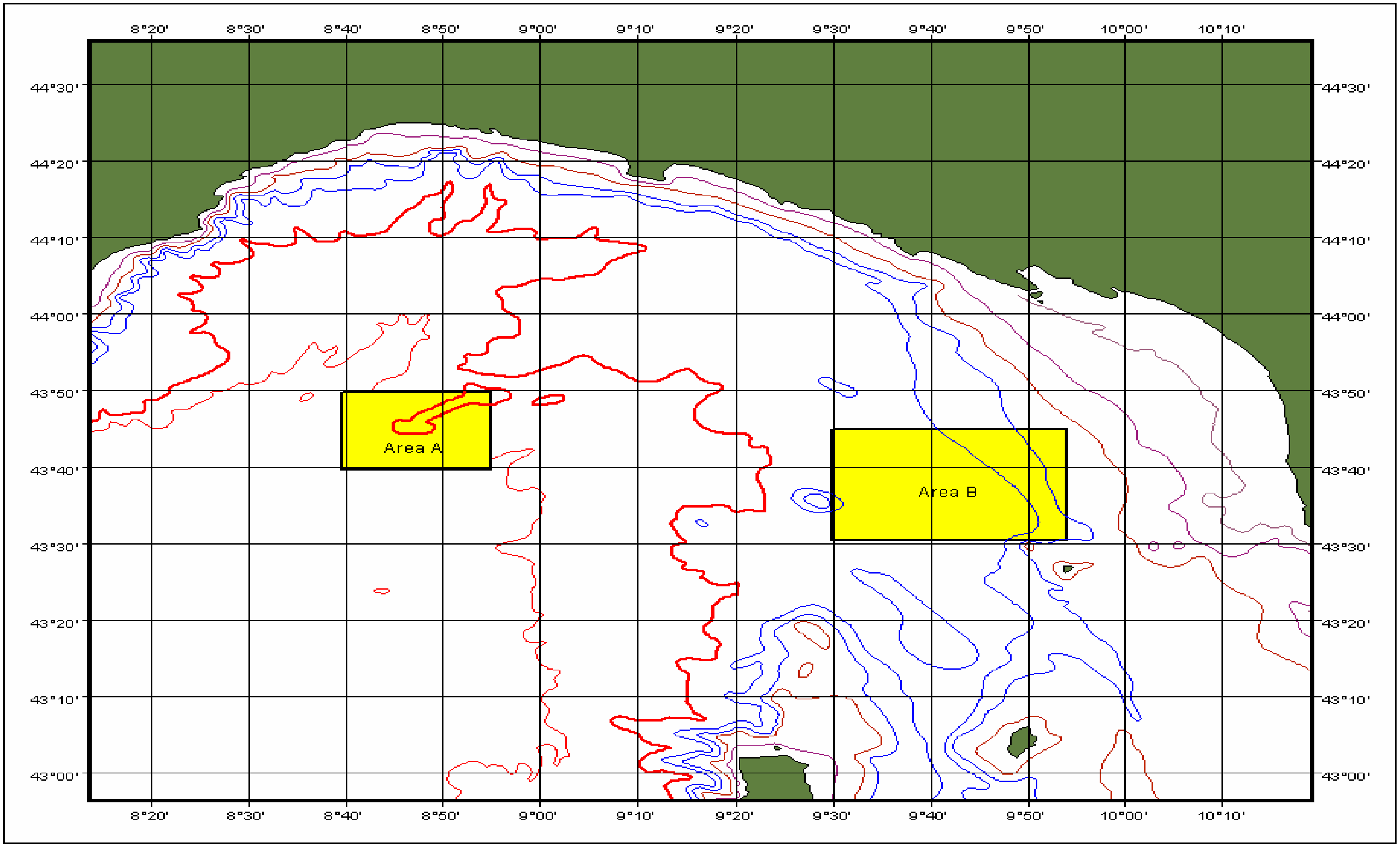
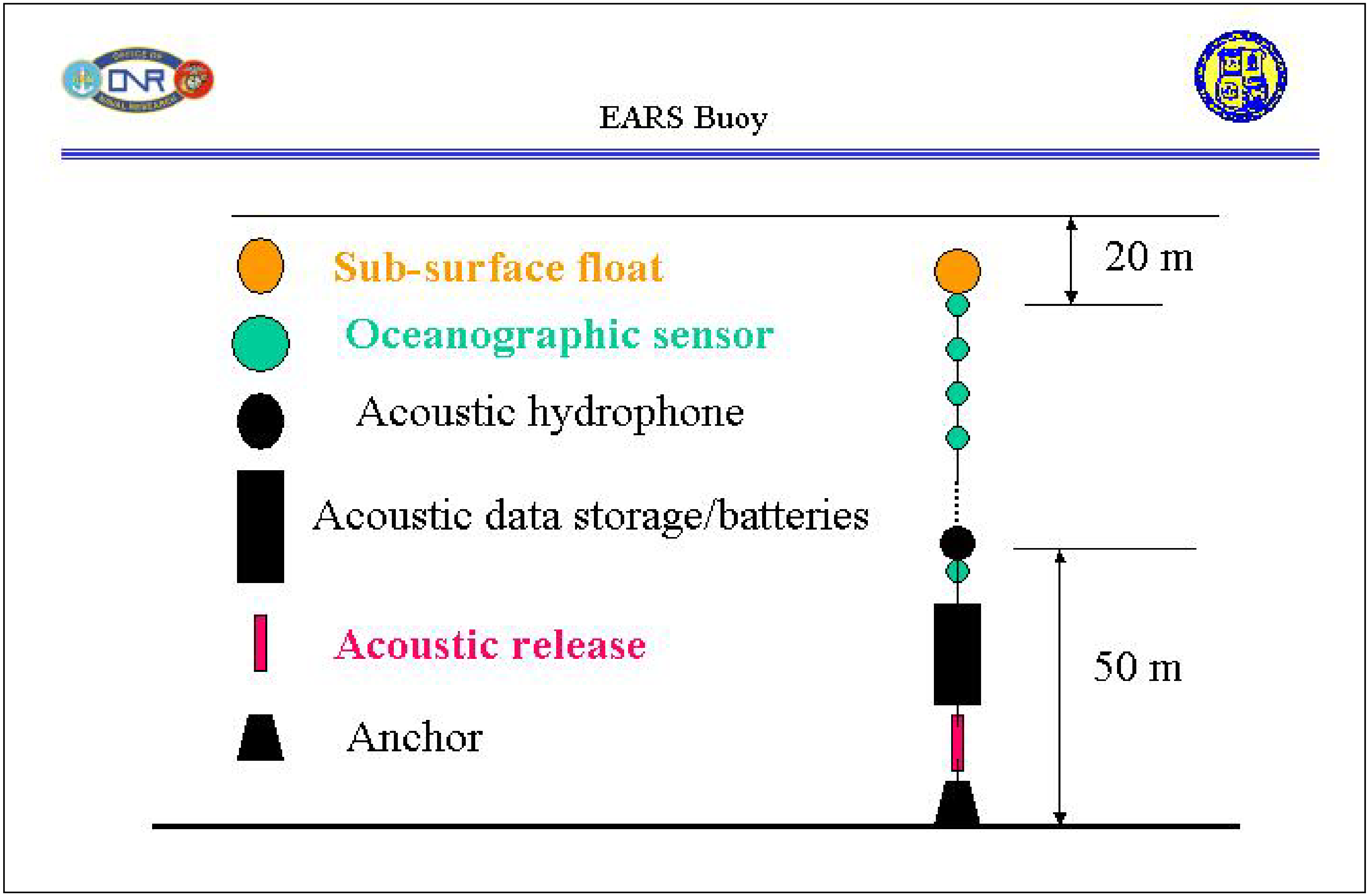


Figure 2F.7. Alliance operation regions during Engineering Test 3-4 July 2002. The NAVOCEANO EARS Buoy will be deployed in Area A near the 900 m contour on 3 July. Area B will be used to source, array, and visual calibration 3–4 July 2002. Area A: 8°54'E 43°39.6'N 8°42'E 43°39.6'N 8°42'E 43°51'N 8°54'E 43°51'N; Area B: 9°30'E 43°30'N 9°30'E 43°45'N 9°54'E 43°45'N 9°54'E 43°30'N; Location of EARS buoy: 8°47.050'E 43°46.107'N



EARS Buoy

● Sub-surface float

● Oceanographic sensor

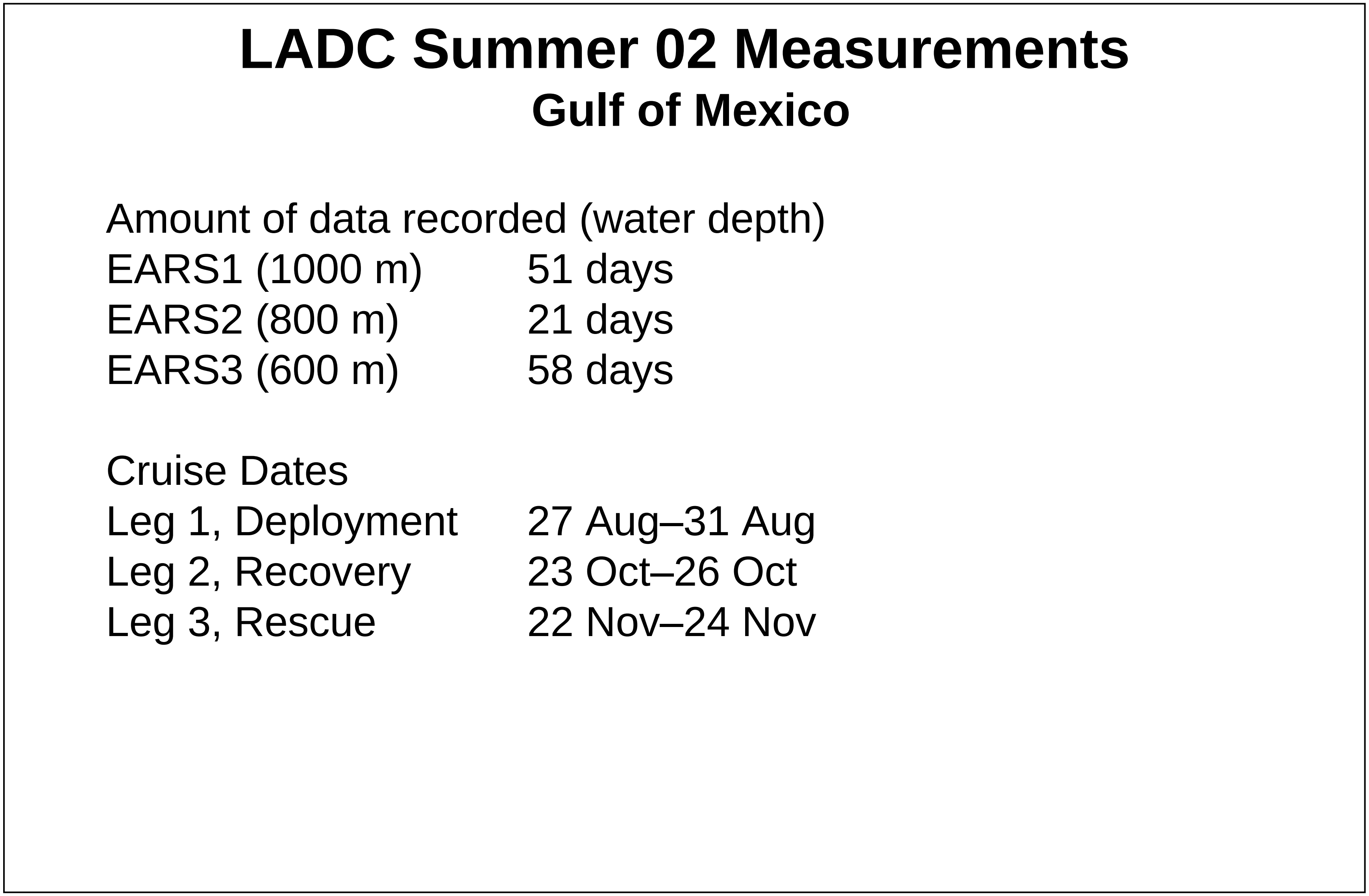
● Acoustic hydrophone

■ Acoustic data storage/batteries

▮ Acoustic release

▲ Anchor

Figure 2F.8. Bottom moored instrumented cable deployment Acoustic portion is EARS buoy.



LADC Summer 02 Measurements

Gulf of Mexico

Amount of data recorded (water depth)	
EARS1 (1000 m)	51 days
EARS2 (800 m)	21 days
EARS3 (600 m)	58 days

Cruise Dates	
Leg 1, Deployment	27 Aug–31 Aug
Leg 2, Recovery	23 Oct–26 Oct
Leg 3, Rescue	22 Nov–24 Nov

Figure 2F.9. Summer 2002 cruise summary.

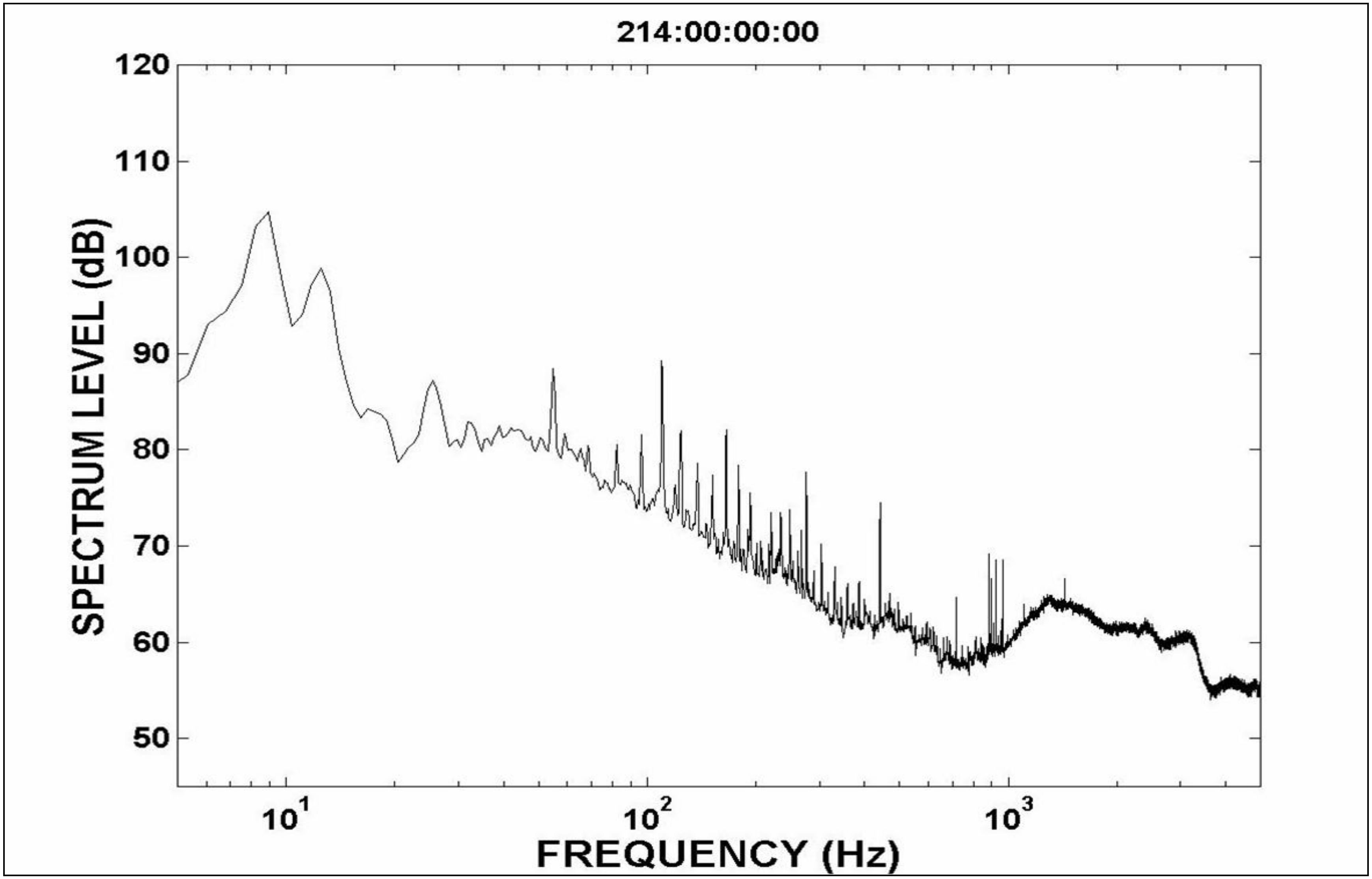


Figure 2F.10. Ambient noise spectrum in dB re 1µPa/Hz versus the log of the frequency from 5 to 5000 Hz. 10-minute average of data taken at 800 m mooring with hydrophone depth of 750 m. Average begun at year 2001, Julian Day 214, Zulu 0hr 0min 0sec. Day 214 is before the passage of Tropical Storm Barry.

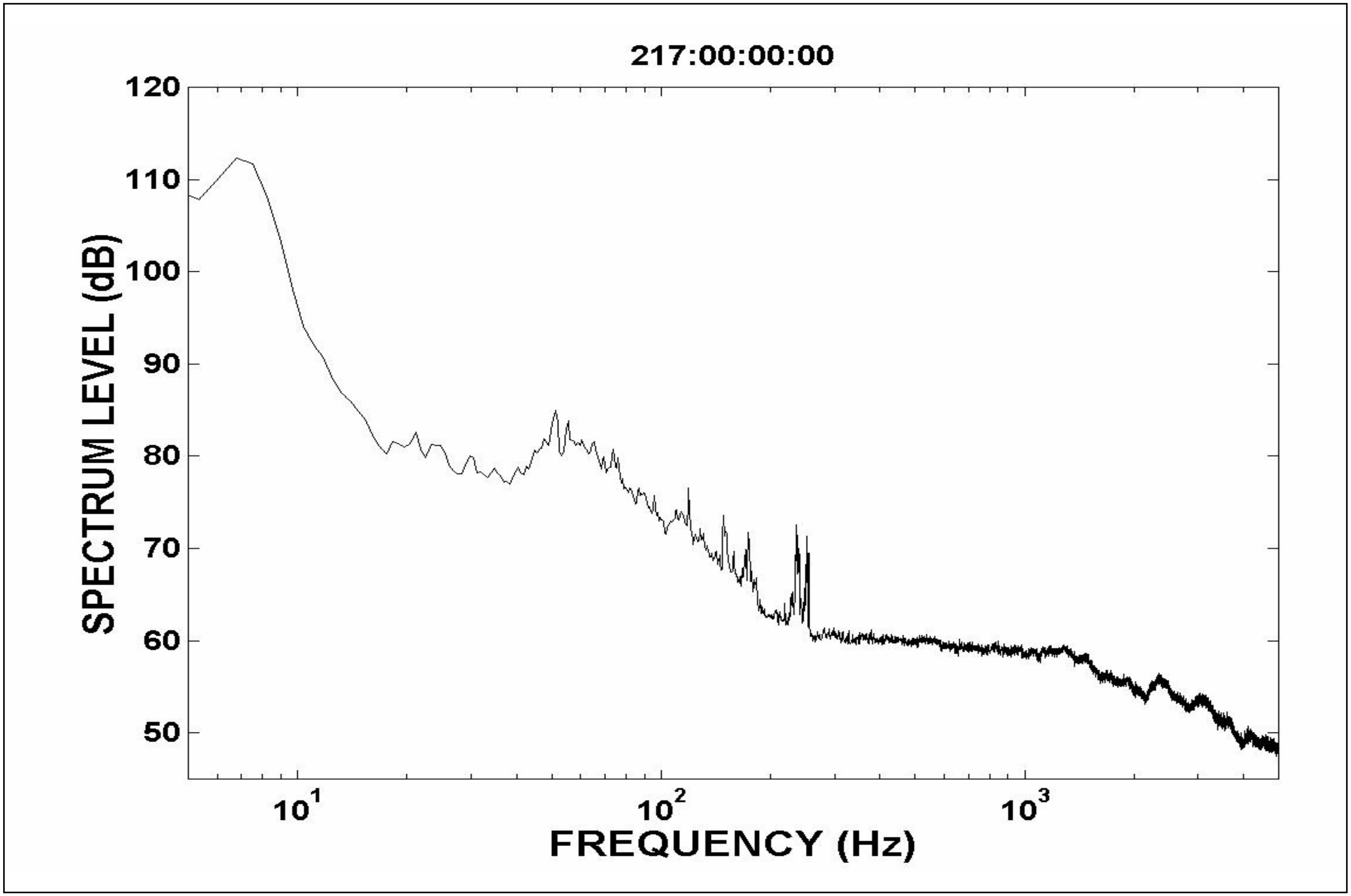


Figure 2F.11. Ambient noise as in Figure 2F.10 except on Julian Day 217 during the passage of Tropical Storm Barry.

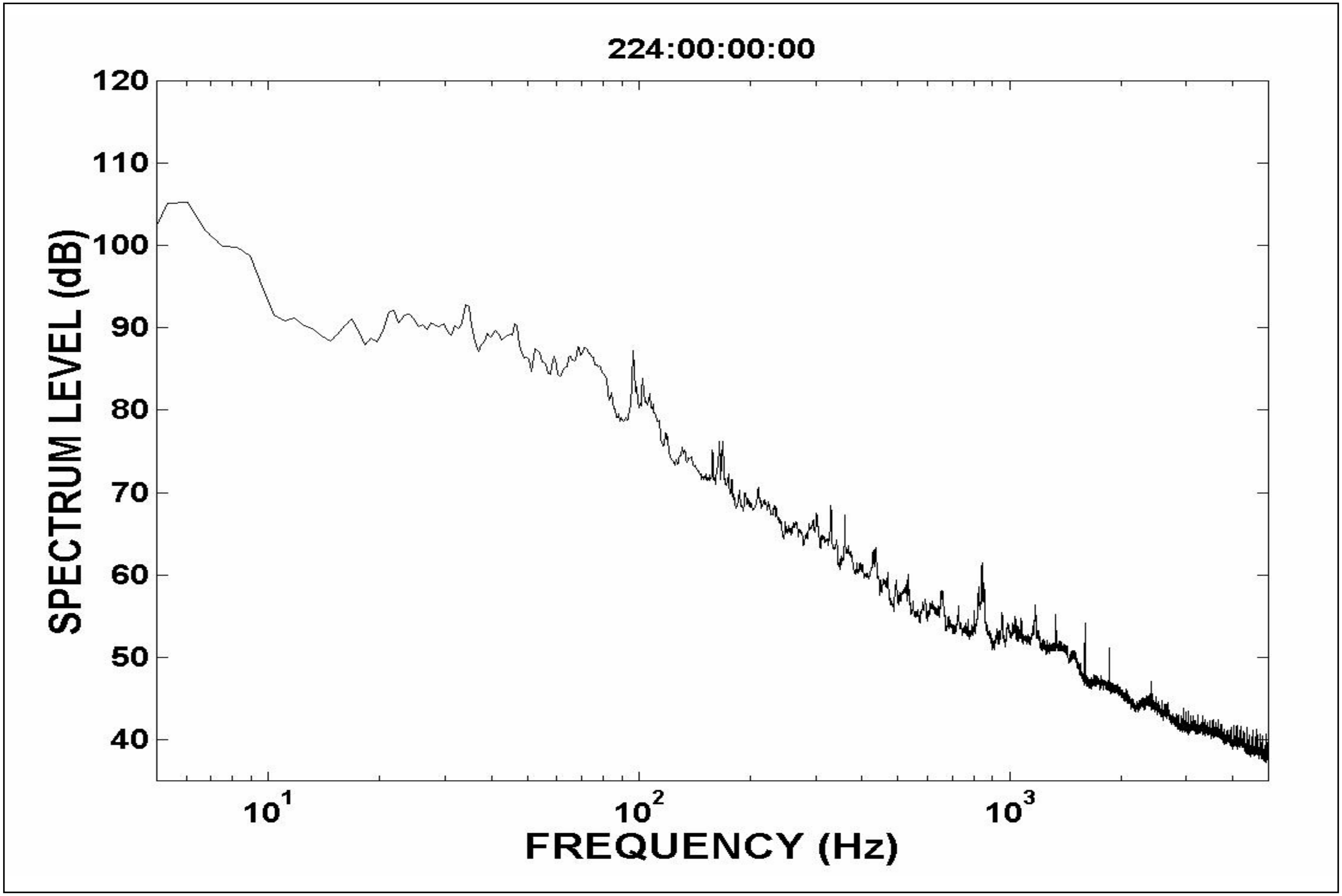


Figure 2F.12. Ambient noise as in Figure 2F.10 except on Julian Day 224, after the passage of Tropical Storm Barry.

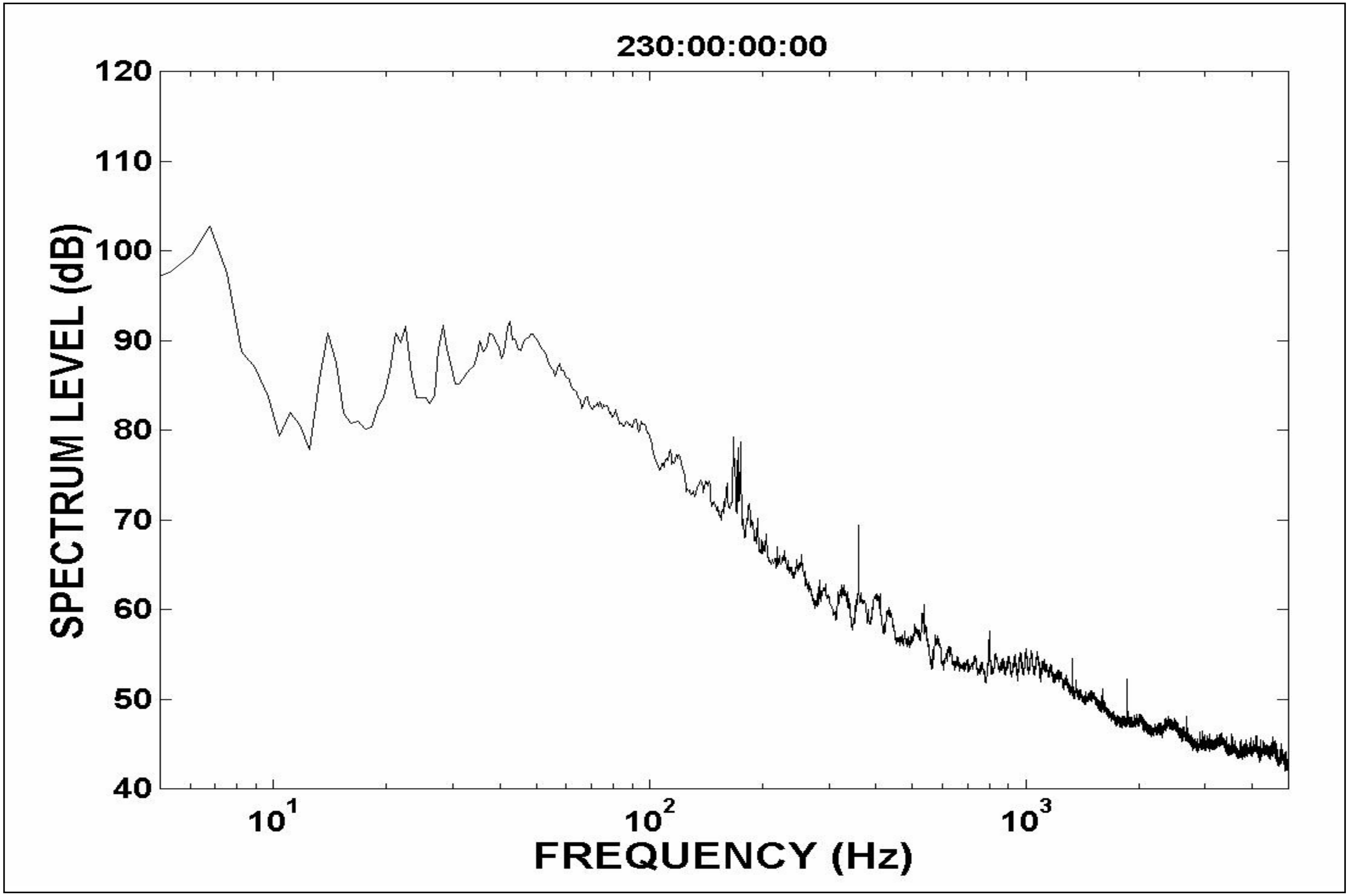


Figure 2F.13. Ambient noise as in Figure 2F.10 except on Julian Day 230, after the passage of Tropical Storm Barry.

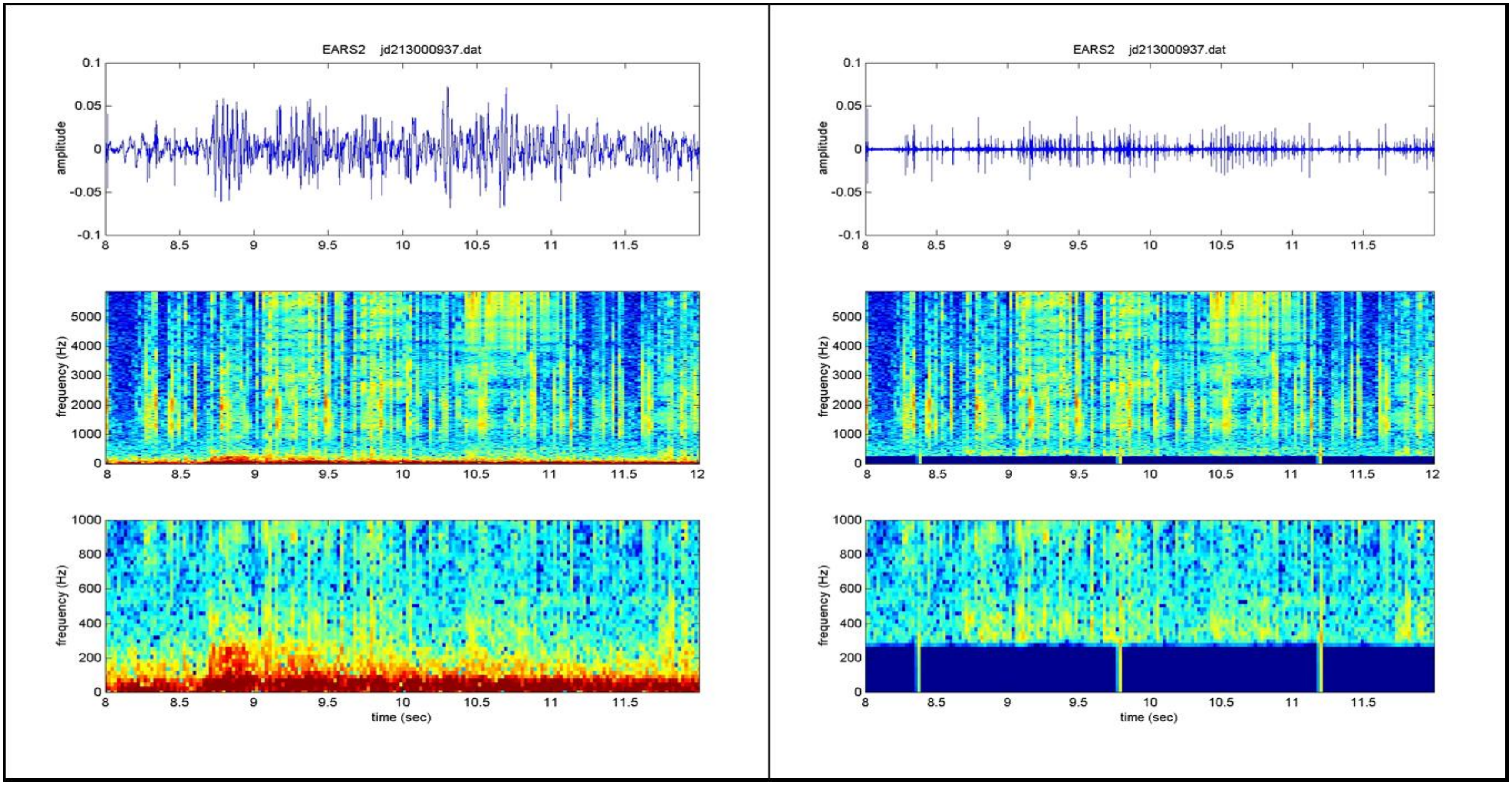


Figure 2F.14. 800-m mooring data extracted from a 60-sec segment beginning at Julian Day 213, Zulu 0 hr, 9 min, 37 sec. The top two figures are graphs of the eighth through eleventh seconds. On the left is the original data; on the right is the data after application of a highpass filter at 300 Hz. Removing the low frequencies including the seismic airgun causes the sperm whale click trains to show up very clearly. The two middle and bottom figures are spectrograms. All frequencies up to 5859 Hz are shown in the middle figures and frequencies up to 1000 Hz are shown in the bottom figures. Broadband transform lines in the middle figures are sperm whale clicks and closely spaced clicks are creaks. The red peak in the left bottom figure is the seismic airgun. Since it is 107 km away from the EARS buoy, significant reverberation is present.

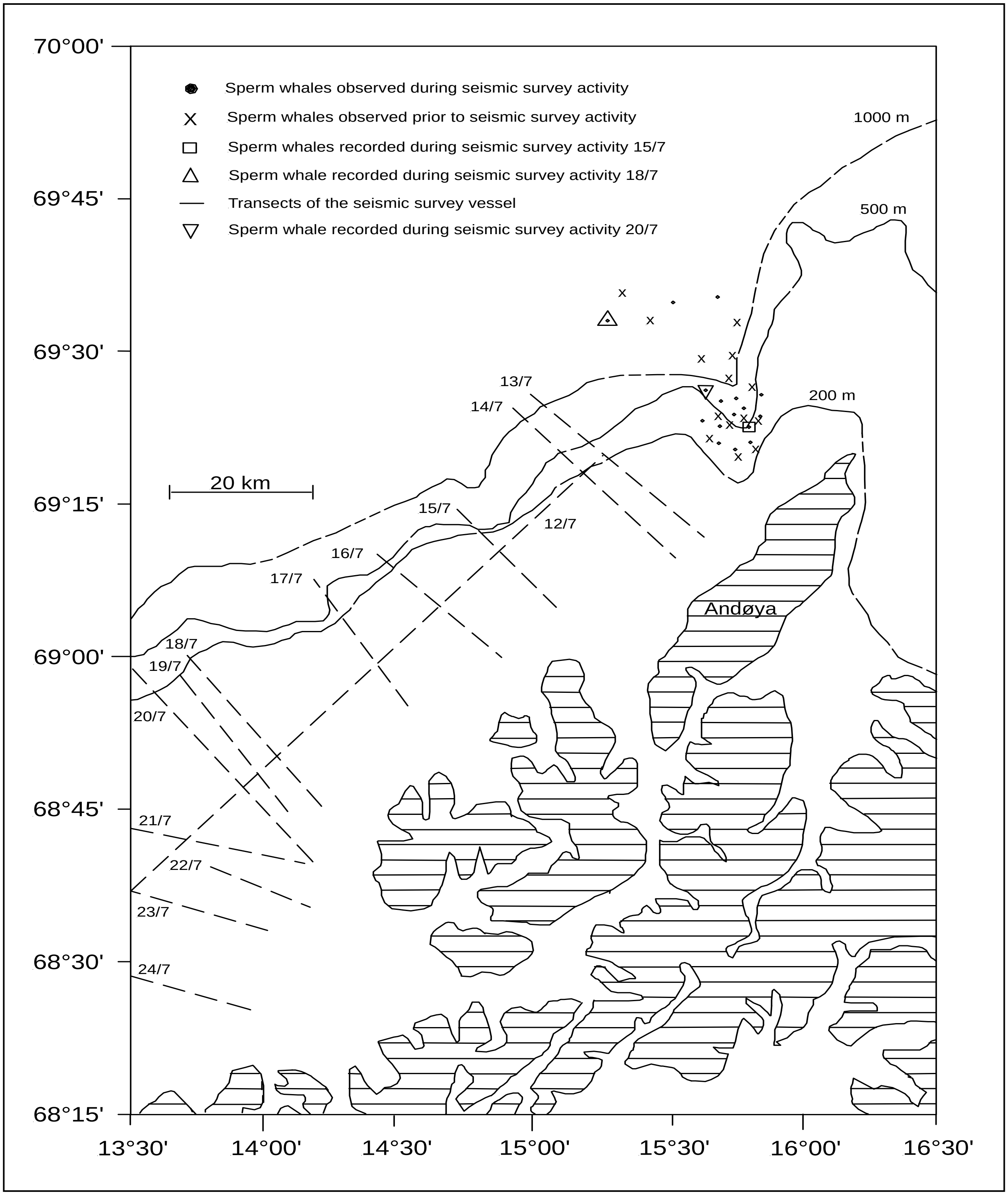


Figure 2F.15. Map of sperm whale observations and transect lines of the seismic survey vessel. Abscissa-numbers denote eastern longitude and ordinate-numbers denote northern latitude. Numbers associated with transect lines denote date. Whale Safari boats and/or research vessels were looking for whales during the entire period (6 to 25 July) and whales were observed on all dates except on the 17 July (Madsen *et al.* 2002).

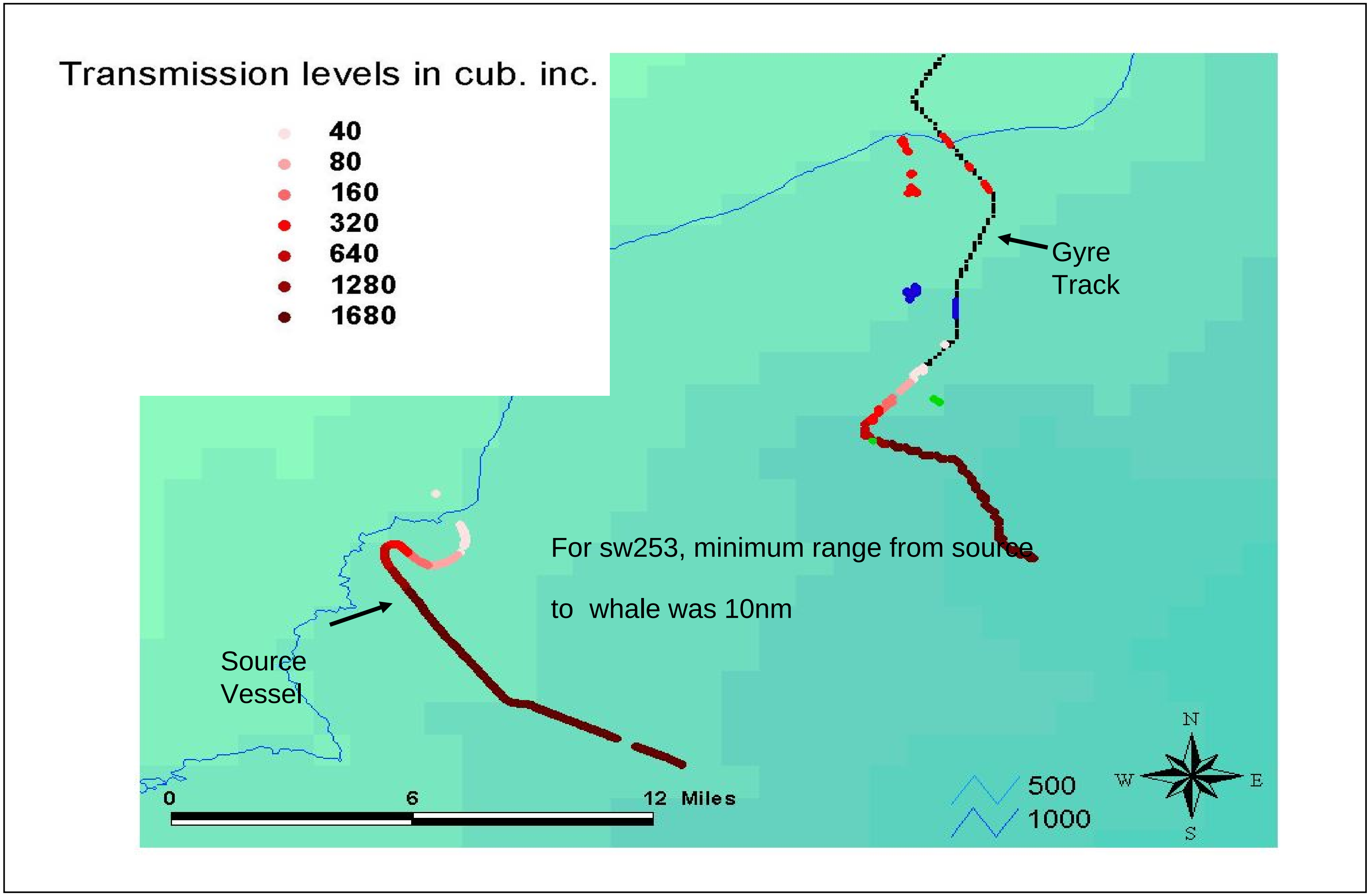


Figure 2F.16. Map of the first experiment on 10 September 2002.

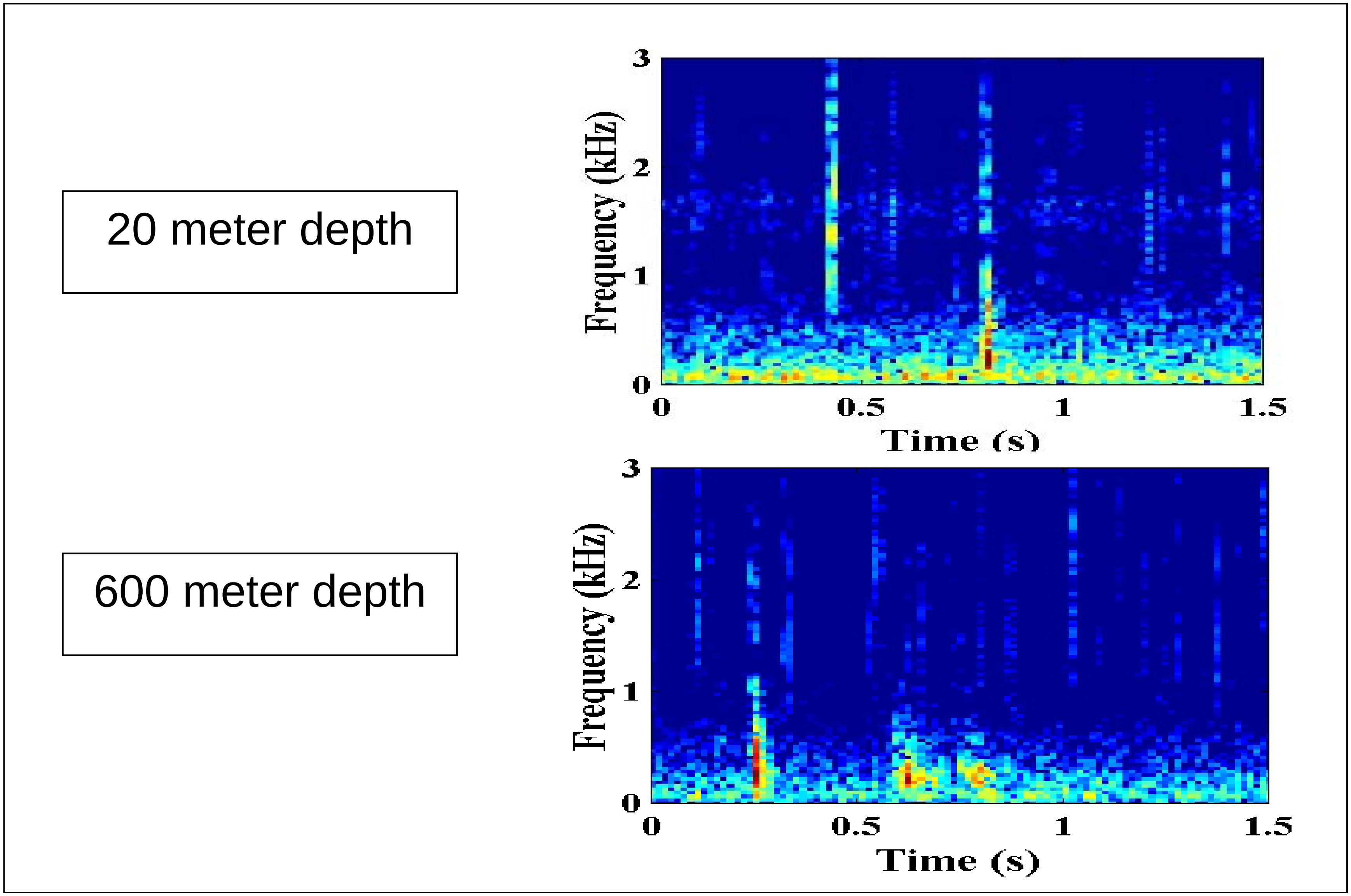


Figure 2F.17. Spectra for airgun pulses recorded at different depths.

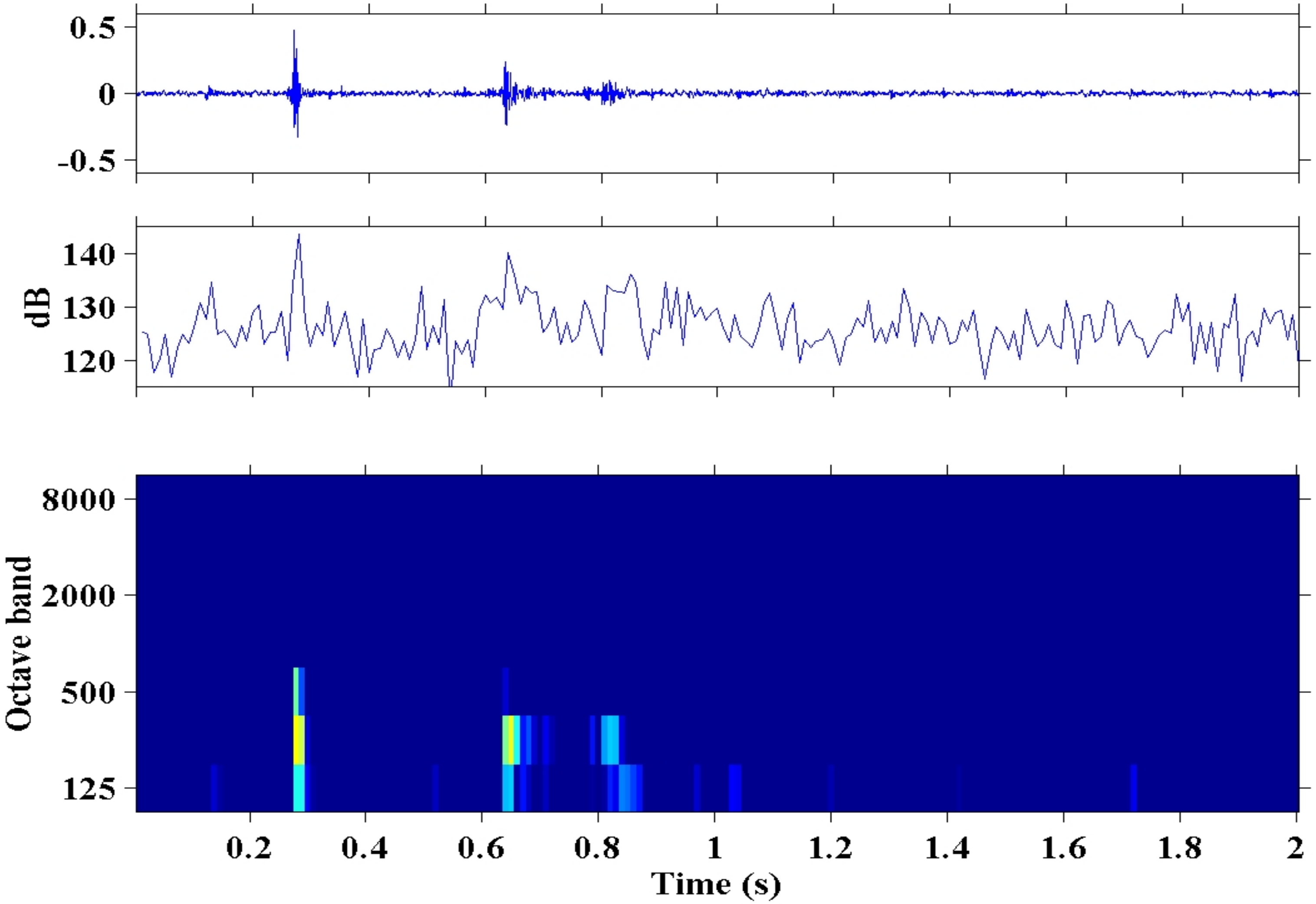


Figure 2F.18. Received level analysis for an airgun impulse recorded at 600 m depth and 10 nautical miles away from the array.

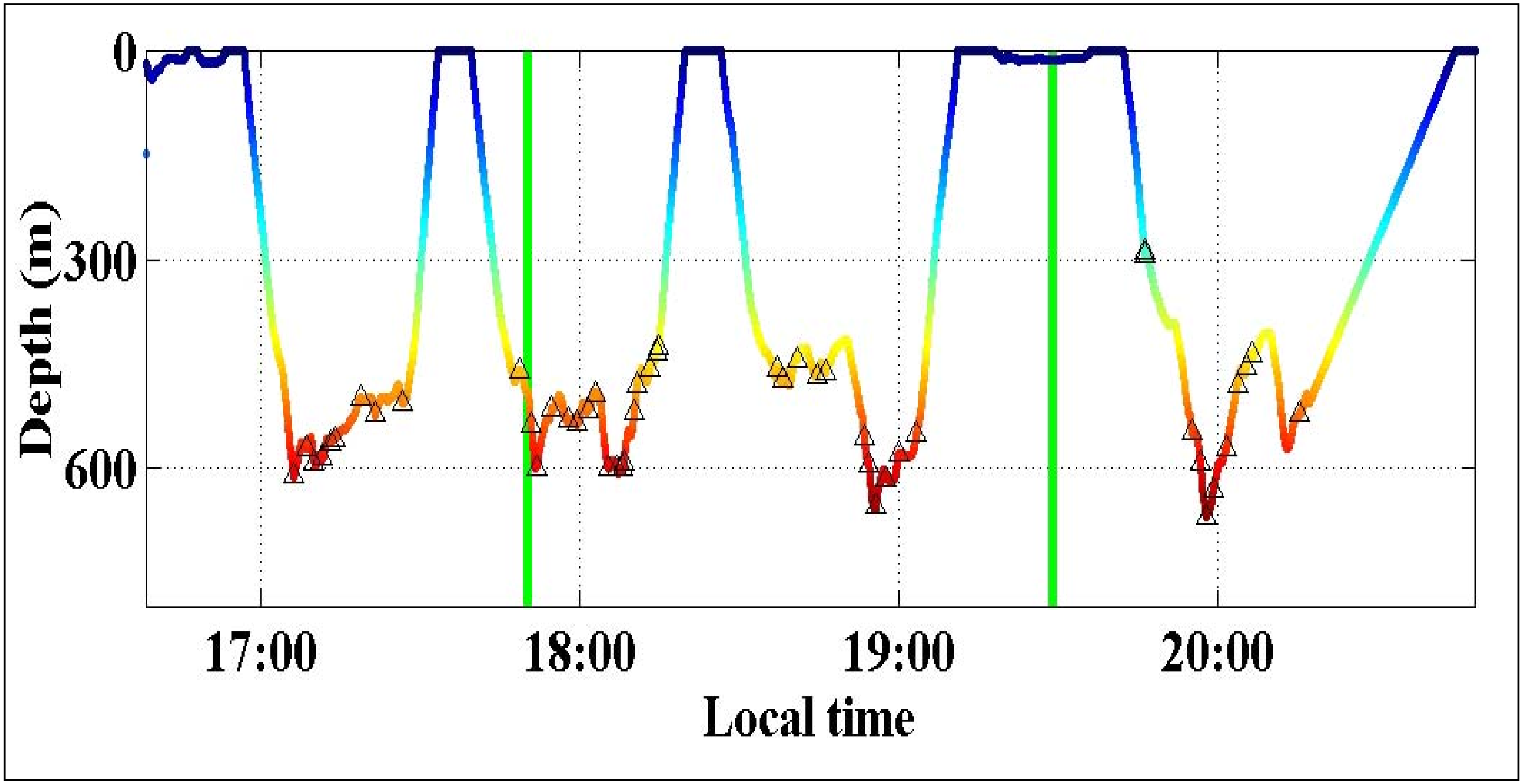


Figure 2F.19. Dive pattern and creak rates before, during, and after sperm whale's exposure to airgun impulses.

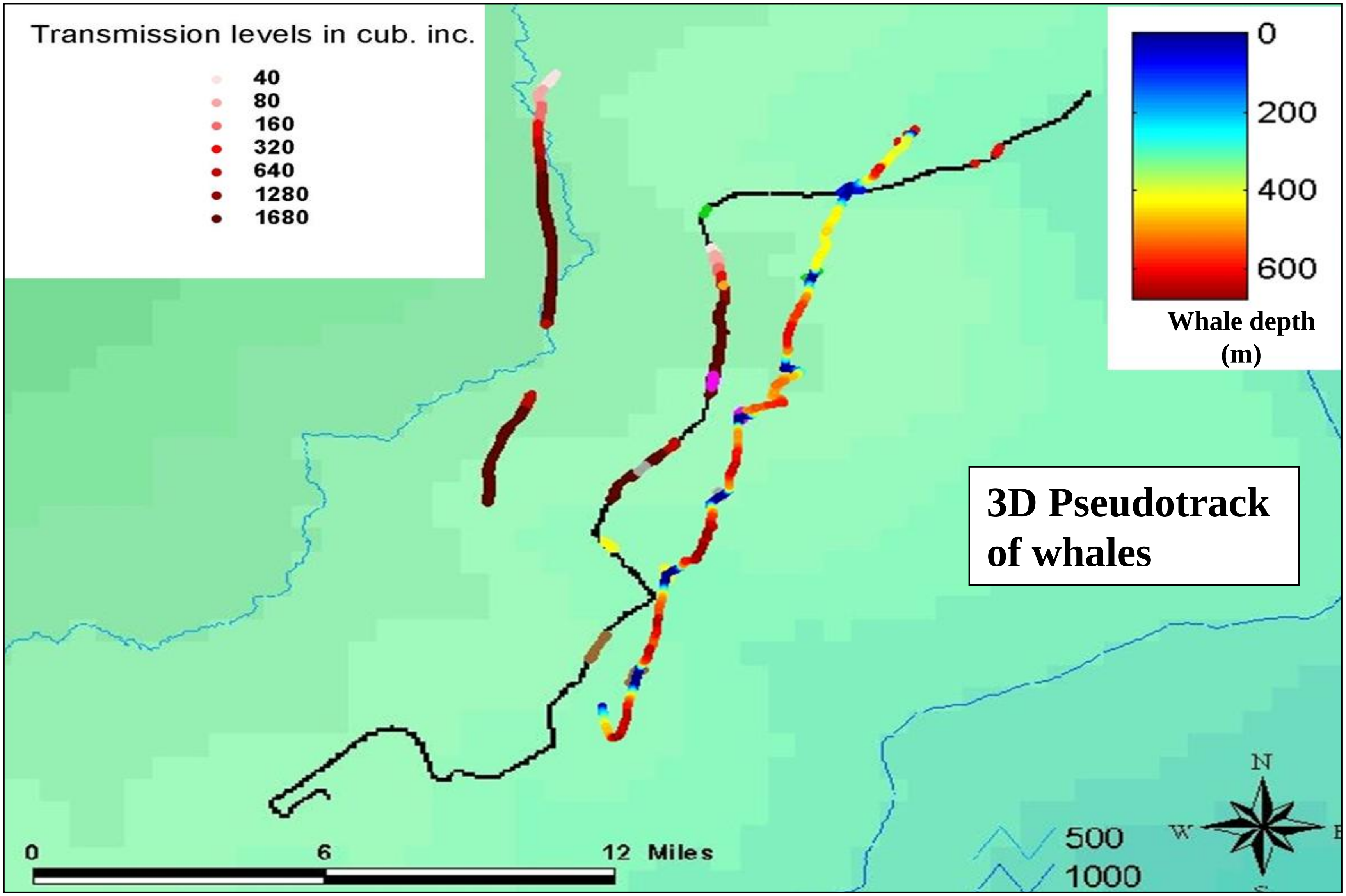


Figure 2F.20. Map of the second experiment conducted on 11 September 2002.

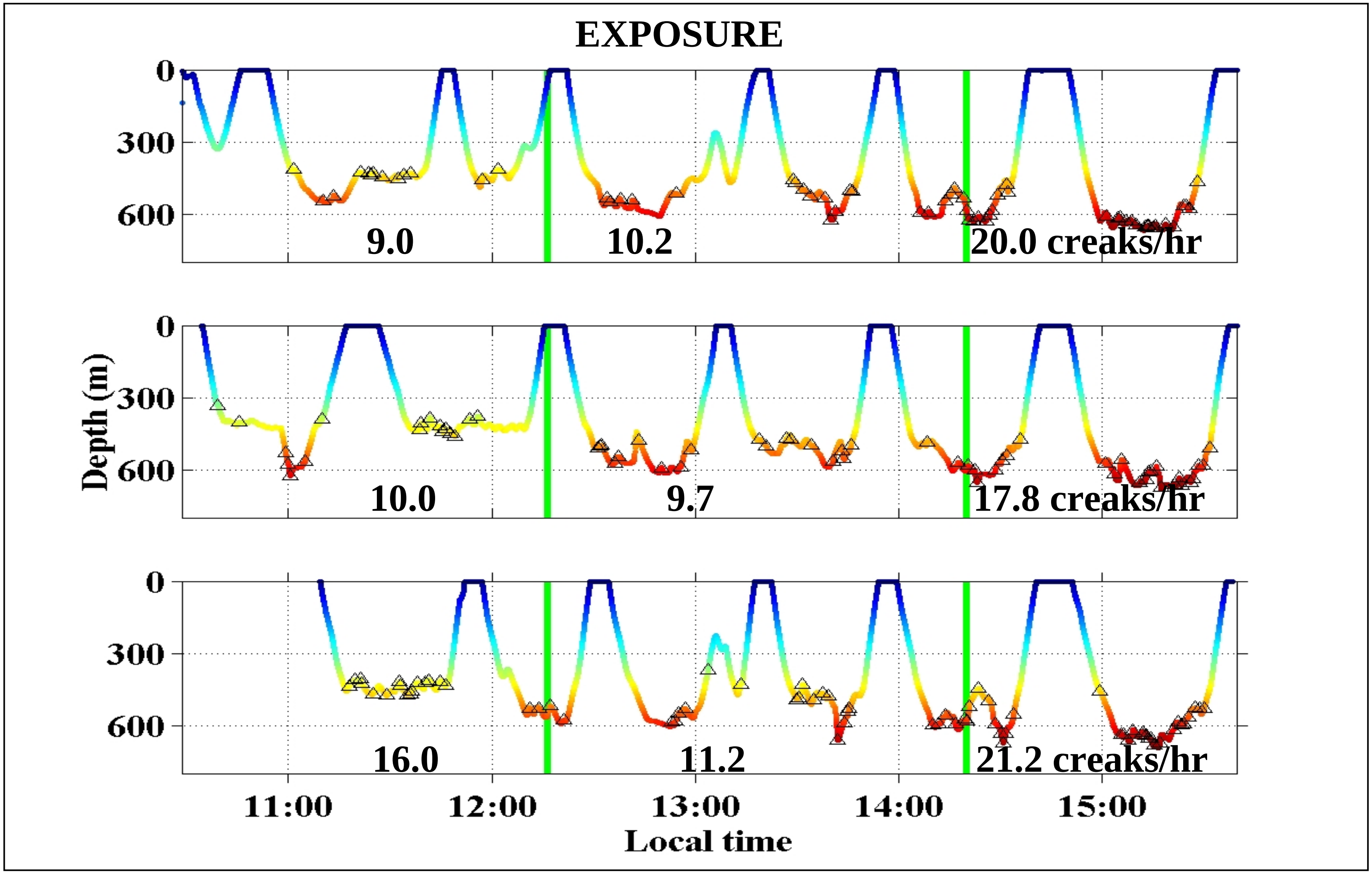


Figure 2F.21. Dive profiles and creak rates of all three tagged whales.

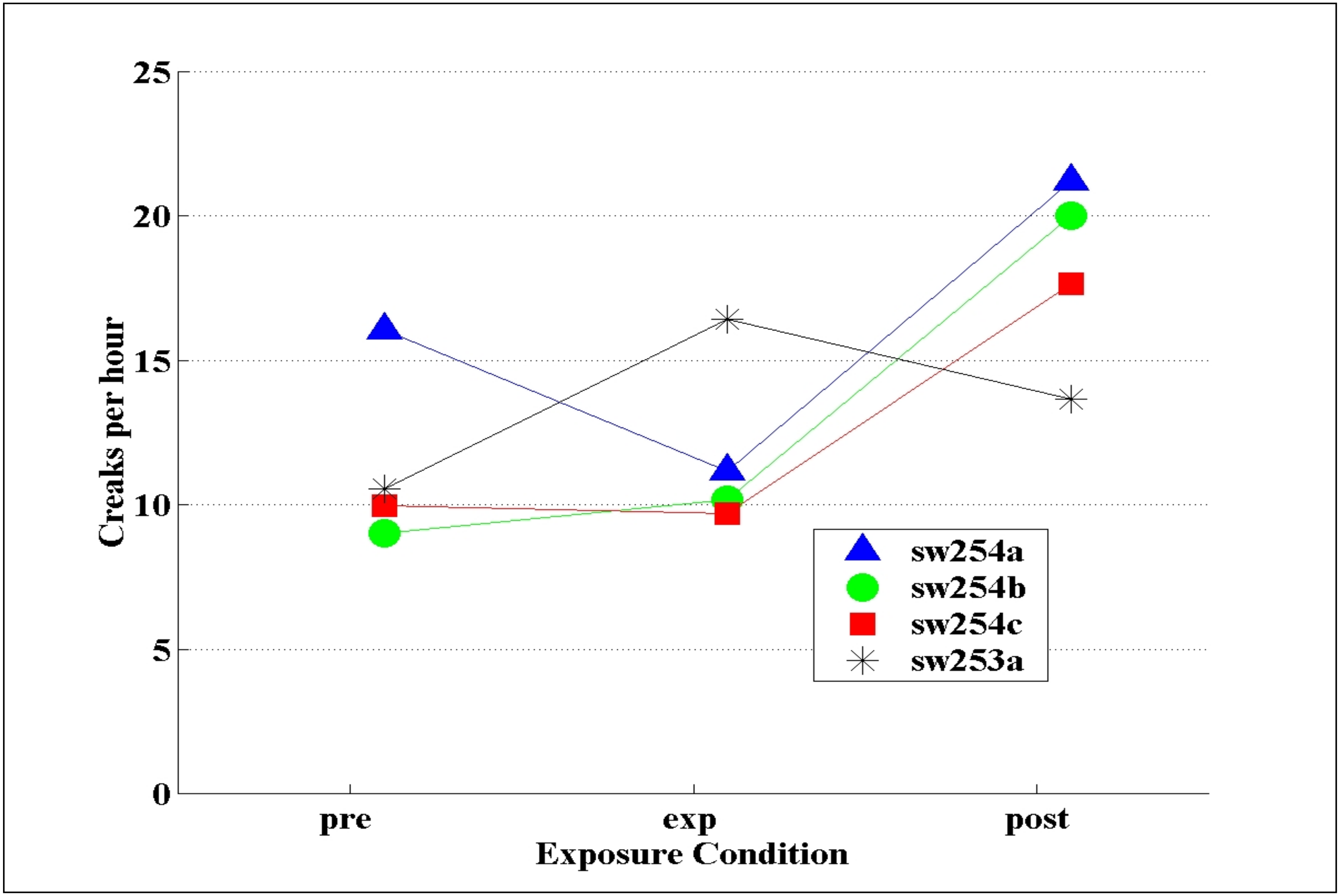


Figure 2F.22. Variation in creak rates before, during, and after exposure.

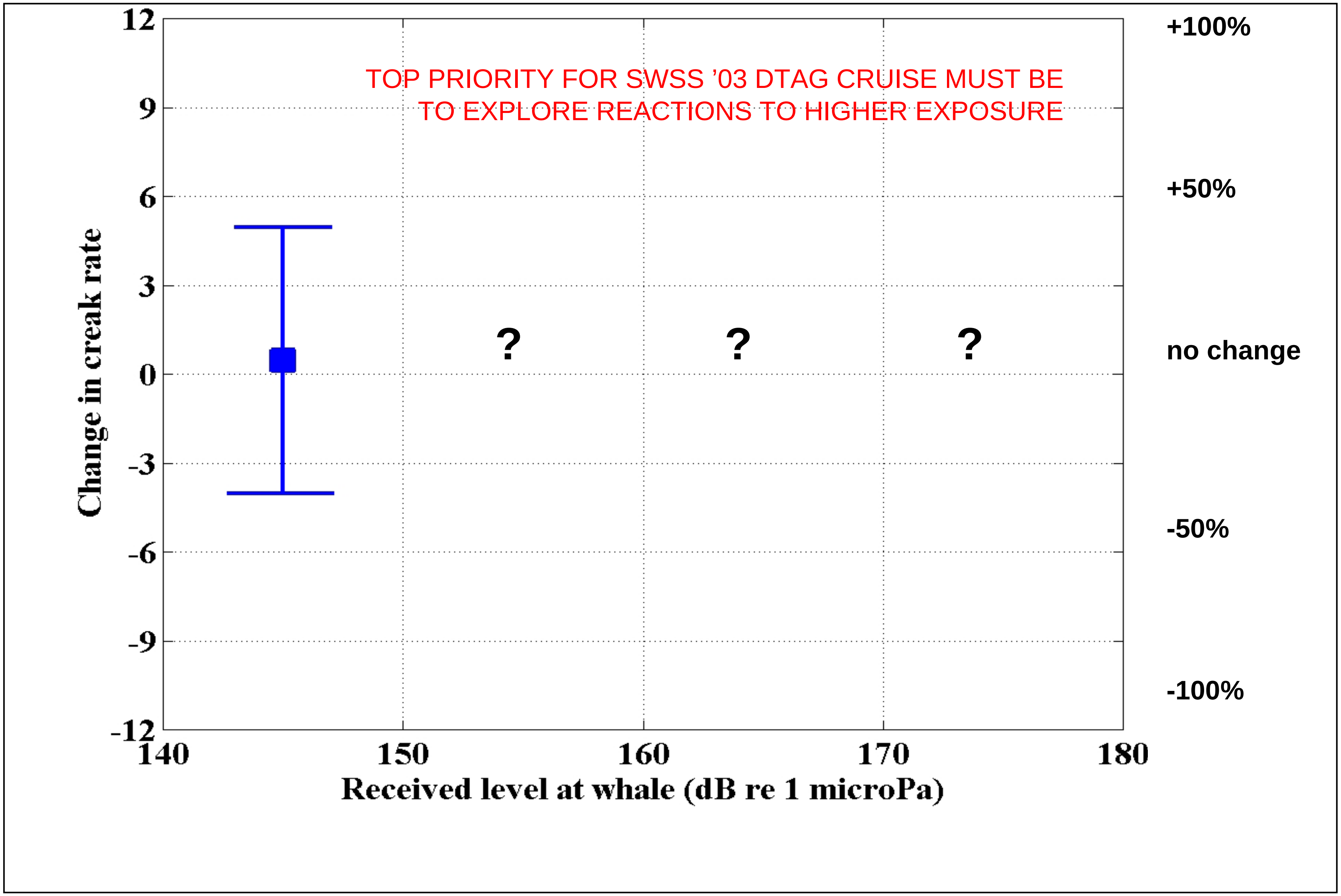
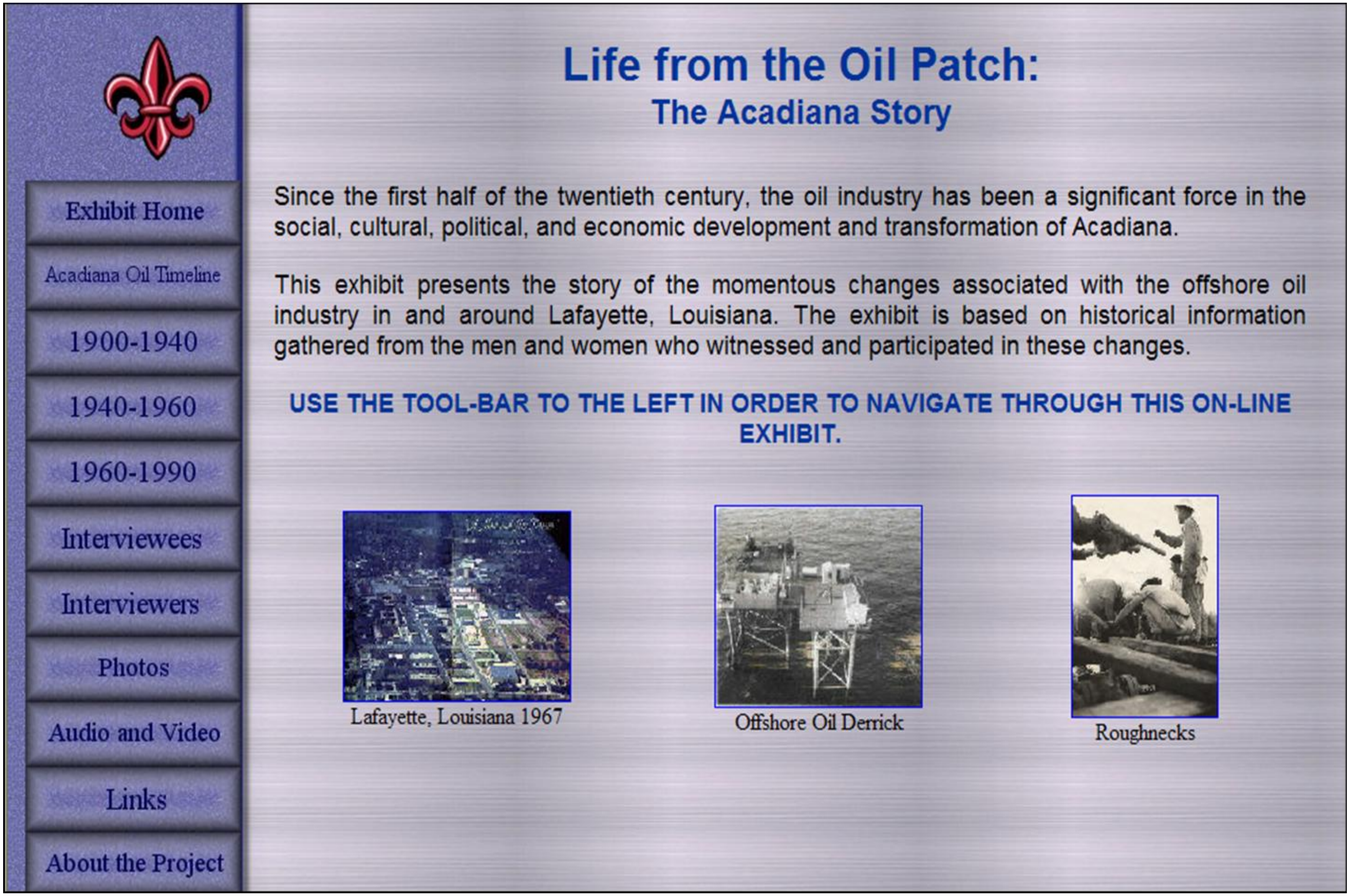


Figure 2F.23. Comparison of creak rates before versus during exposure to 143-148 dB indicating no change.



Life from the Oil Patch:

The Acadiana Story

Since the first half of the twentieth century, the oil industry has been a significant force in the social, cultural, political, and economic development and transformation of Acadiana.

This exhibit presents the story of the momentous changes associated with the offshore oil industry in and around Lafayette, Louisiana. The exhibit is based on historical information gathered from the men and women who witnessed and participated in these changes.

USE THE TOOL-BAR TO THE LEFT IN ORDER TO NAVIGATE THROUGH THIS ON-LINE EXHIBIT.

Figure 3A.1. The home page of the web exhibit, *Life from the Oil Patch: The Acadiana Story*. http://www.louisiana.edu/Academic/LiberalArts/HiGe/OCS/exhibit.htm

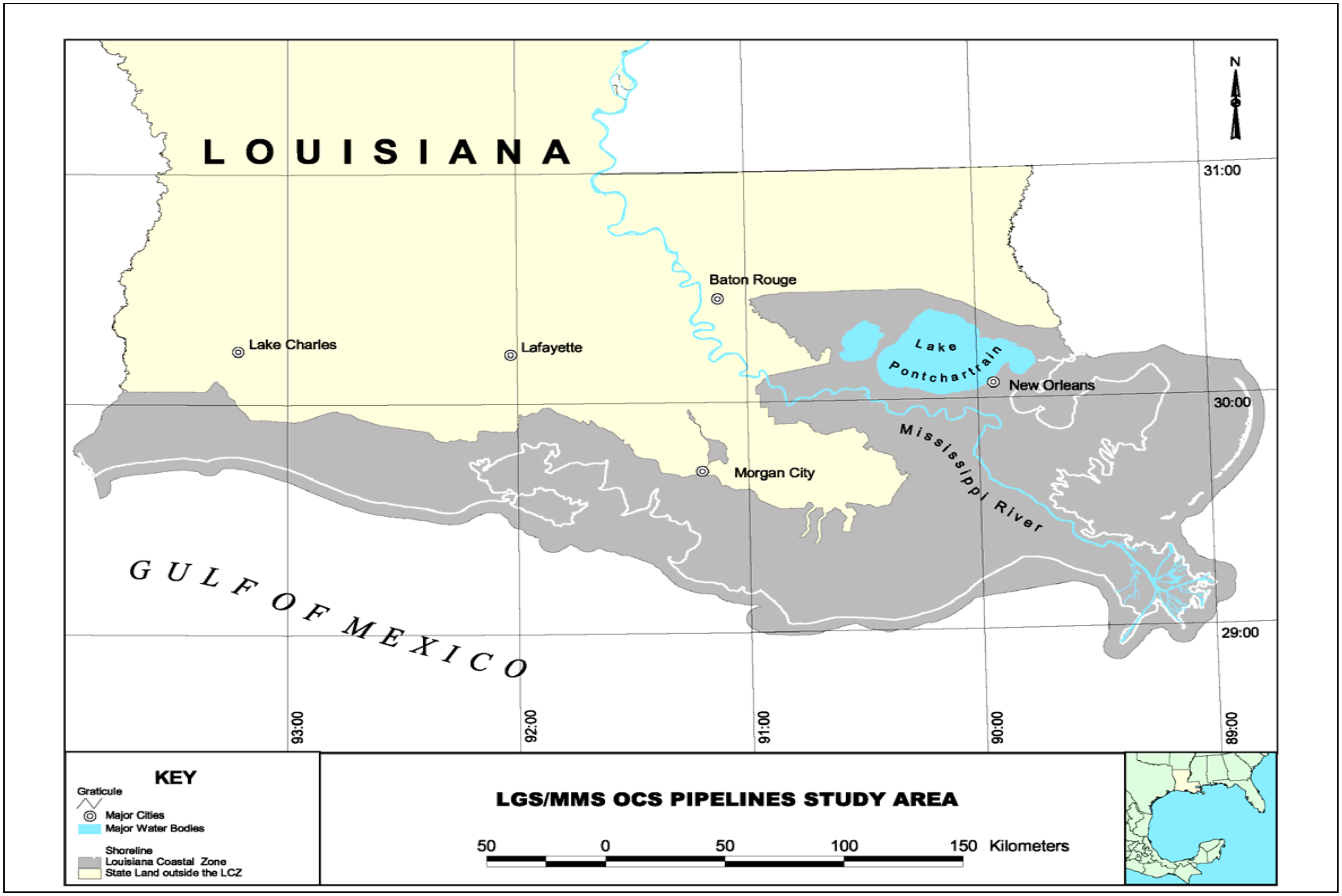


Figure 3B.1. Project study area.

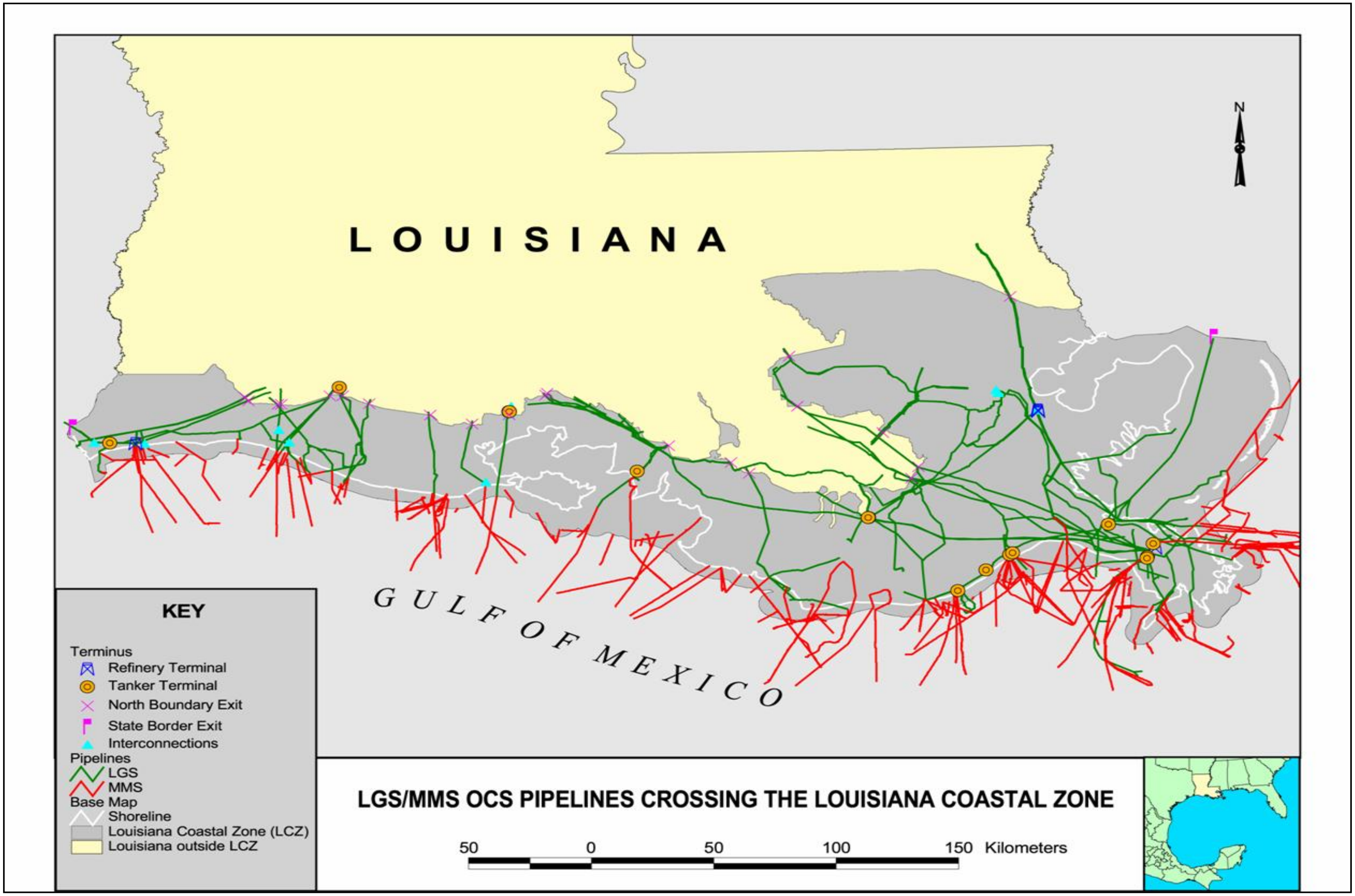


Figure 3B.2. OCS pipelines crossing the Louisiana coastal zone.

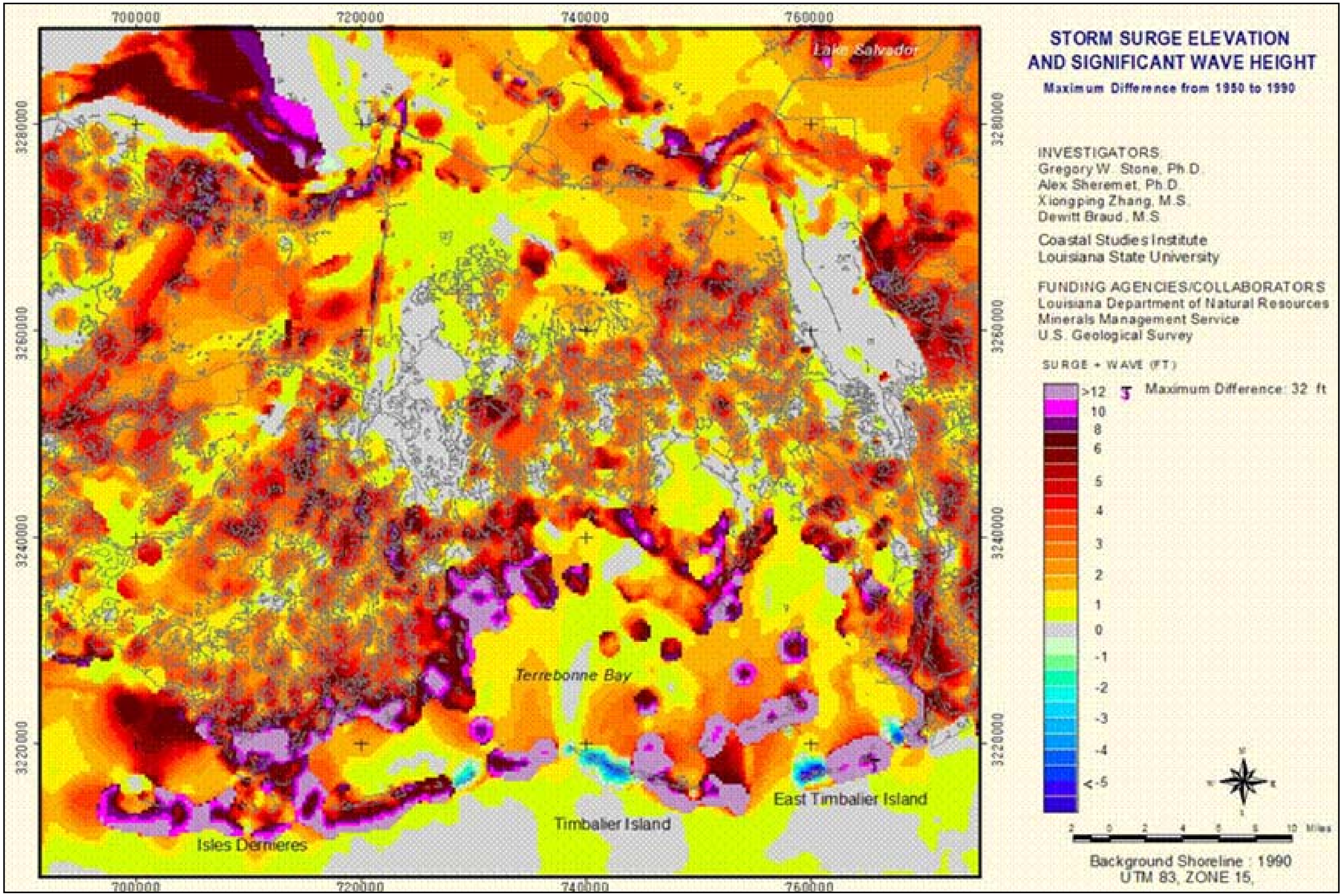


Figure 3B.3. Difference in maximum storm surge and significant wave height between 1950 and 1990s scenarios.

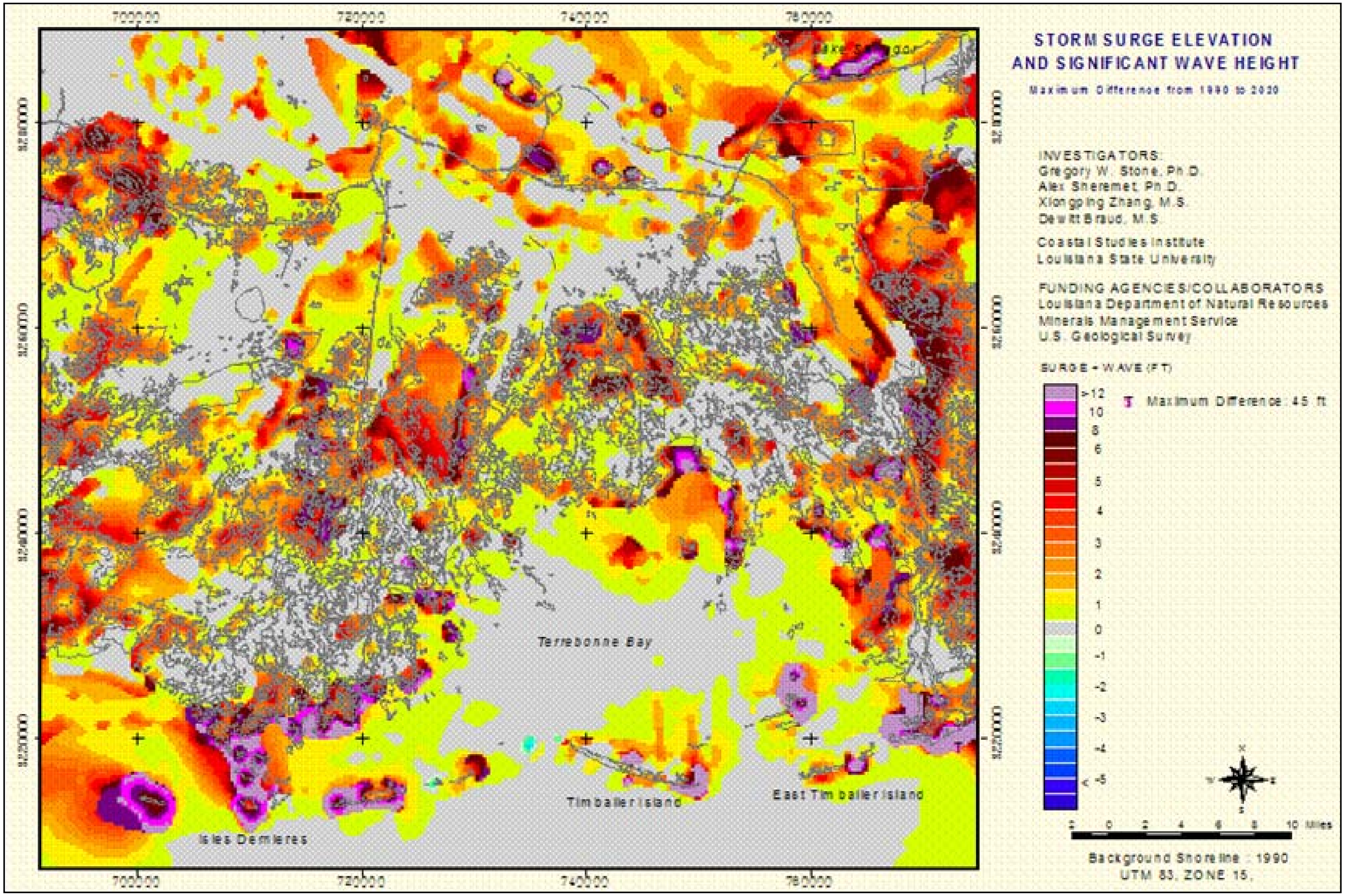


Figure 3B.4. Difference in maximum storm surge and maximum wave height between 1990s and 2020 scenarios.

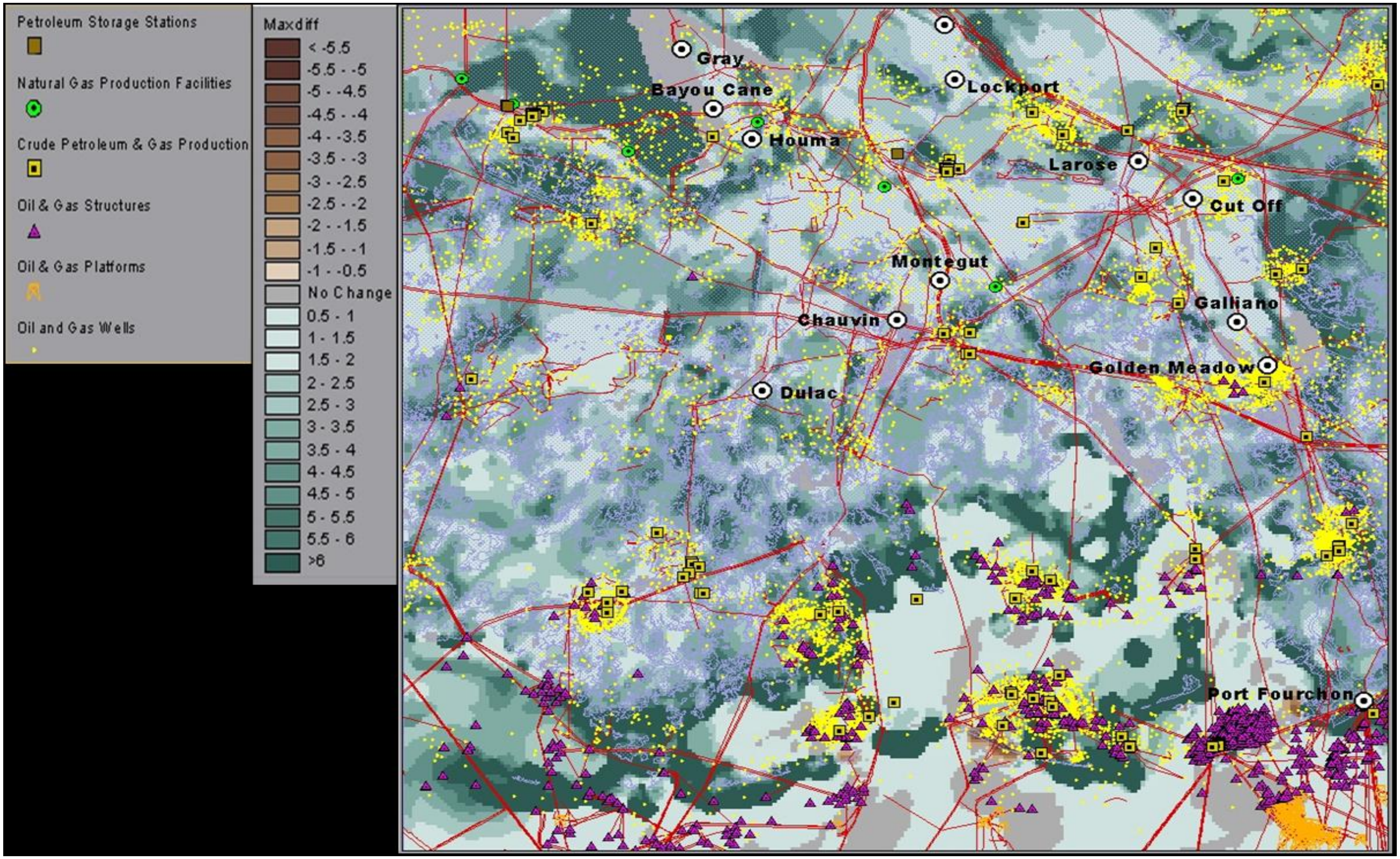


Figure 3B.5. Distribution of wells, pipelines, structures, platforms and facilities superimposed on the change in combined storm surge levels and wave heights for the period 1950–1990s. The green shades indicate an increase in surge and wave height combined. Note that for clarity those increases above 6 feet are not provided.

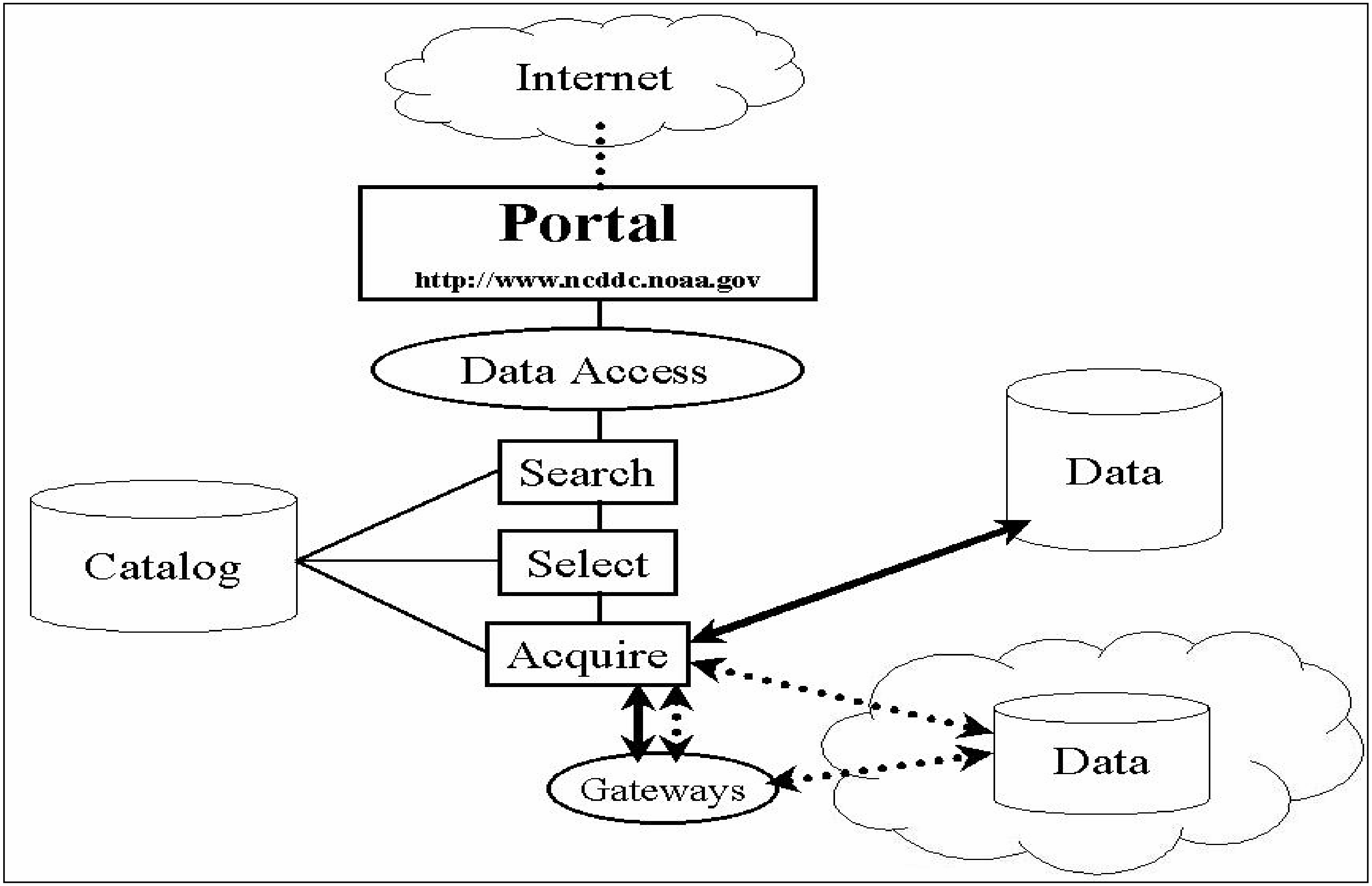


Figure 3B.6. The data portal uses "gateways" to geographically-distributed web sites and databases to bring data from multiple sources to a single user interface.

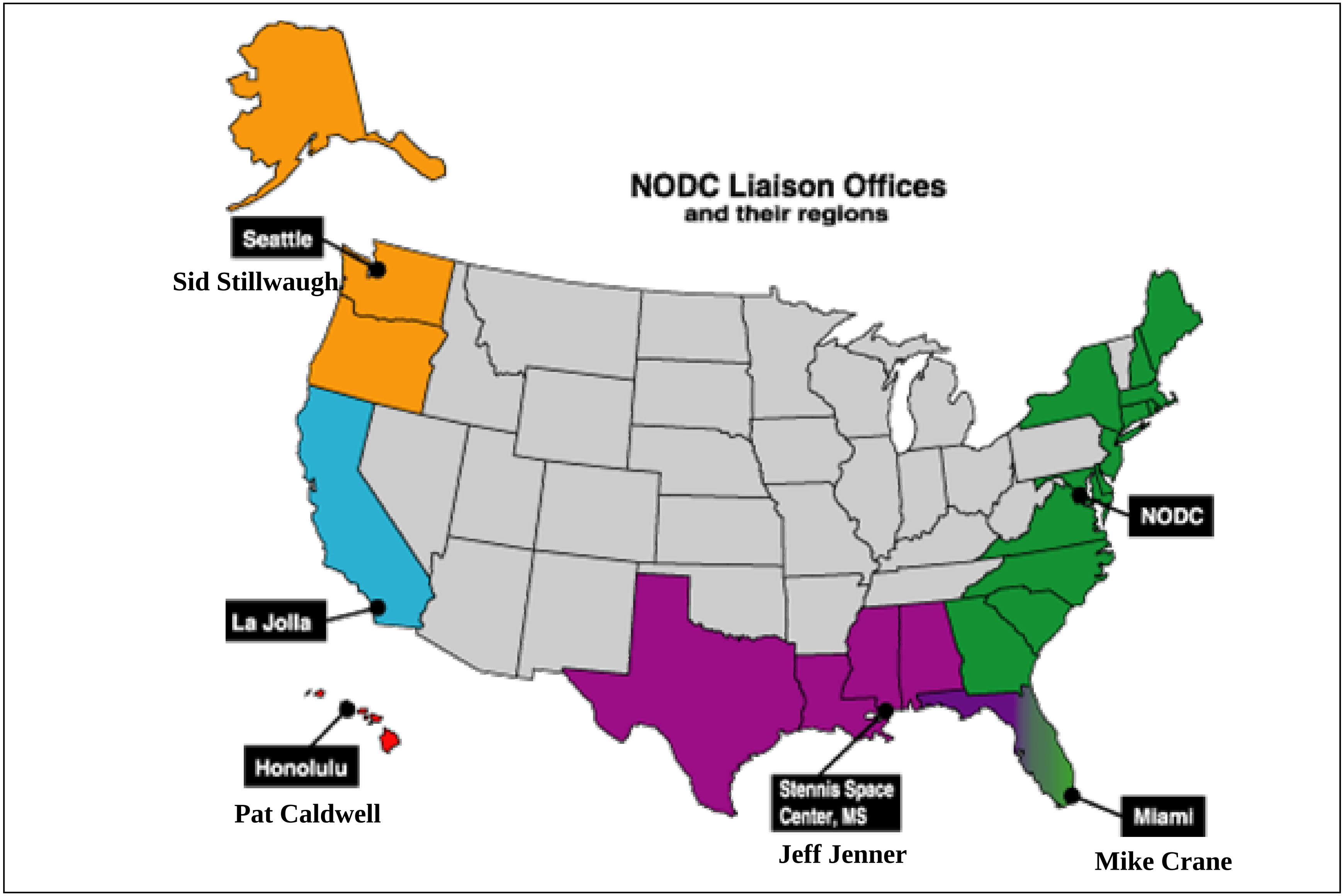


Figure 3B.7. The six NODC liaison offices and their regions.

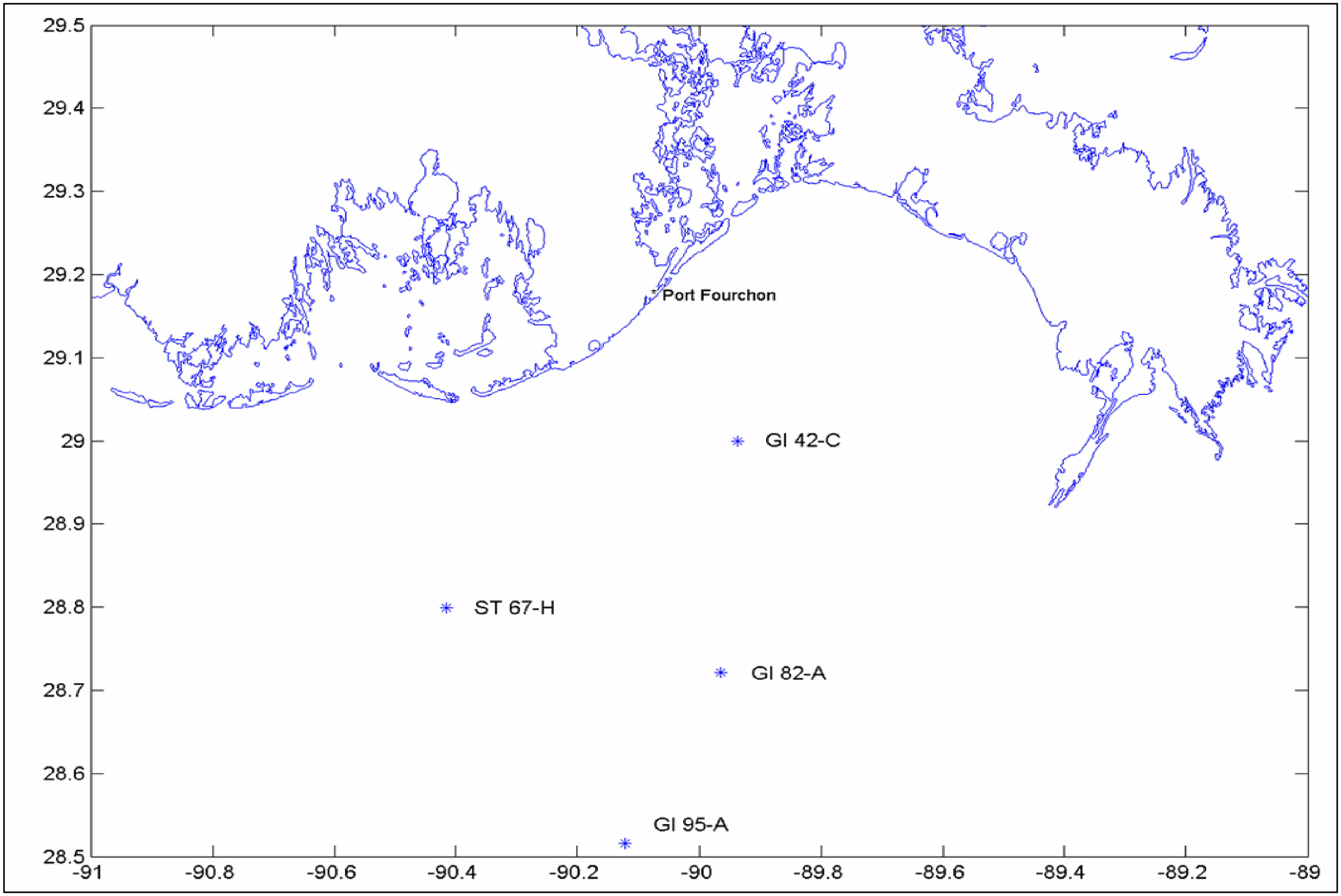
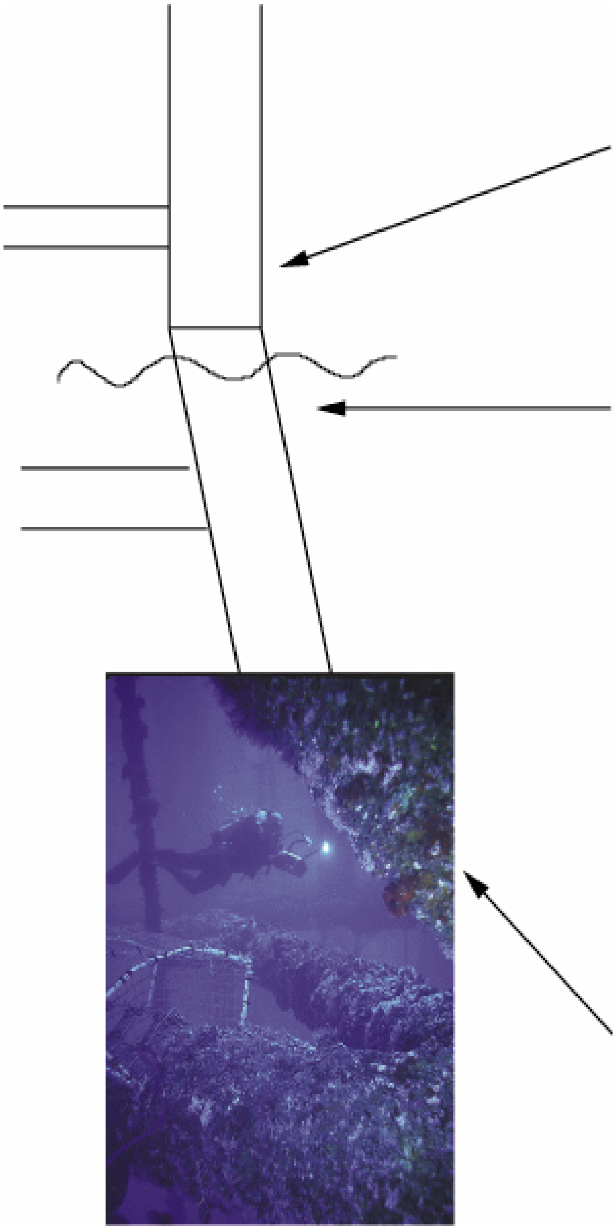


Figure 3D.1. The four platforms where algae were collected during the May 2002 cruise.

Vertical Distribution of Algae



Representative Species:

Above Intertidal

Enteromorpha spp.
Ulva fasciata

Low Intertidal to Shallow Intertidal

Chaetomorpha aerea
Cladophora sp.
Kuetzingiella elachistaeformis
***Gelidium pusillum* and epiphytes**
Antithamnionella breviramosa
Herposiphonia secunda f. ***tenella***
Centroceras clavulatum

10m Below Mean Low Water

Oscillatoria acuminata
Jania capillacea
Bryopsis pennata

Figure 3D.2. Vertical distribution of the algae commonly collected at the platforms.

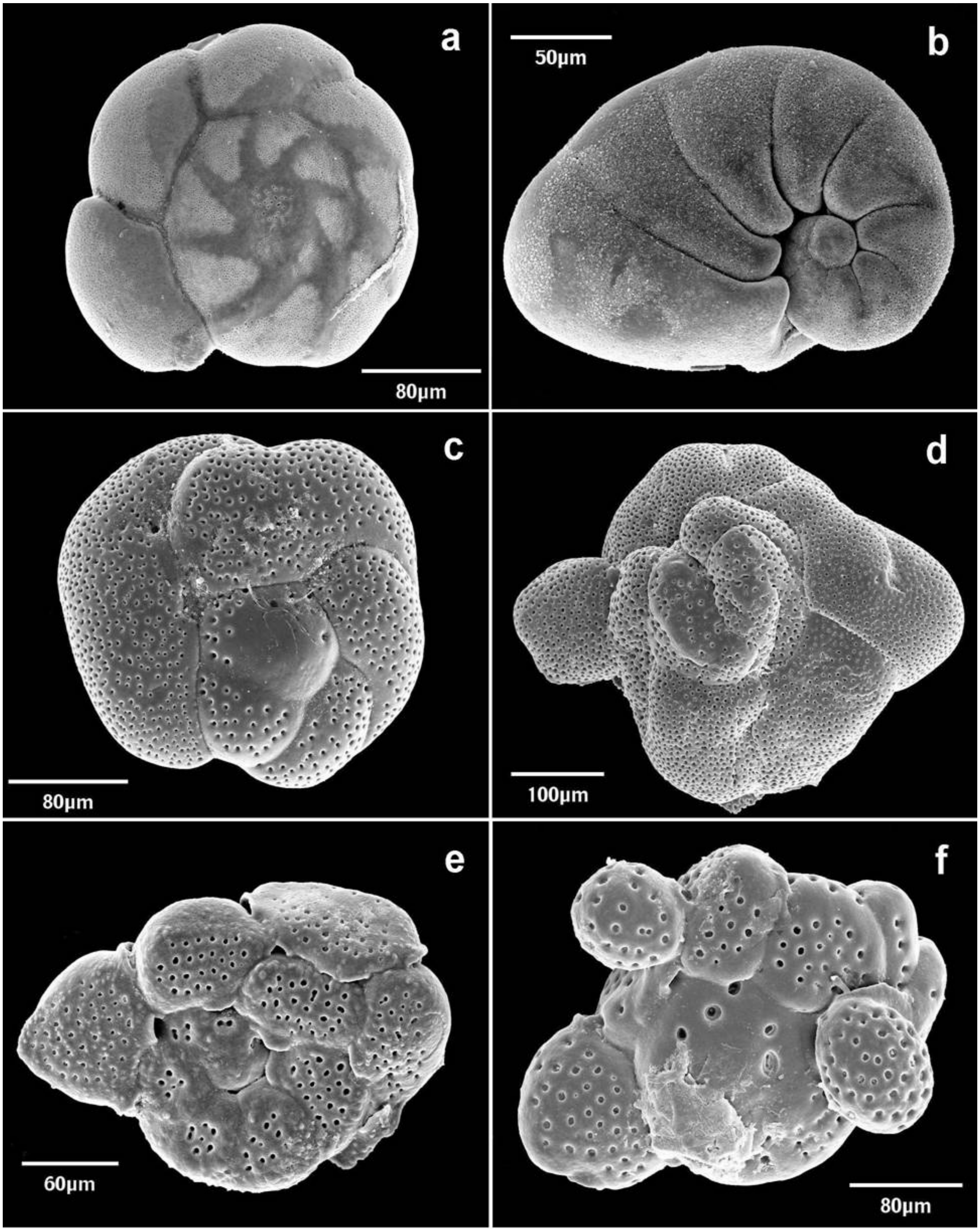


Figure 3D.3. Examples of Foraminifera of Gulf of Mexico petroleum platforms: a and b are motile species (a, *Ammonia parkinsoniana*; b, *Nonionella basiloba*); c–f are sessile species (c, d, *Rosalina globularis*, morphological variants; e, f, *Planorbulina mediterranensis*, morphological variants).

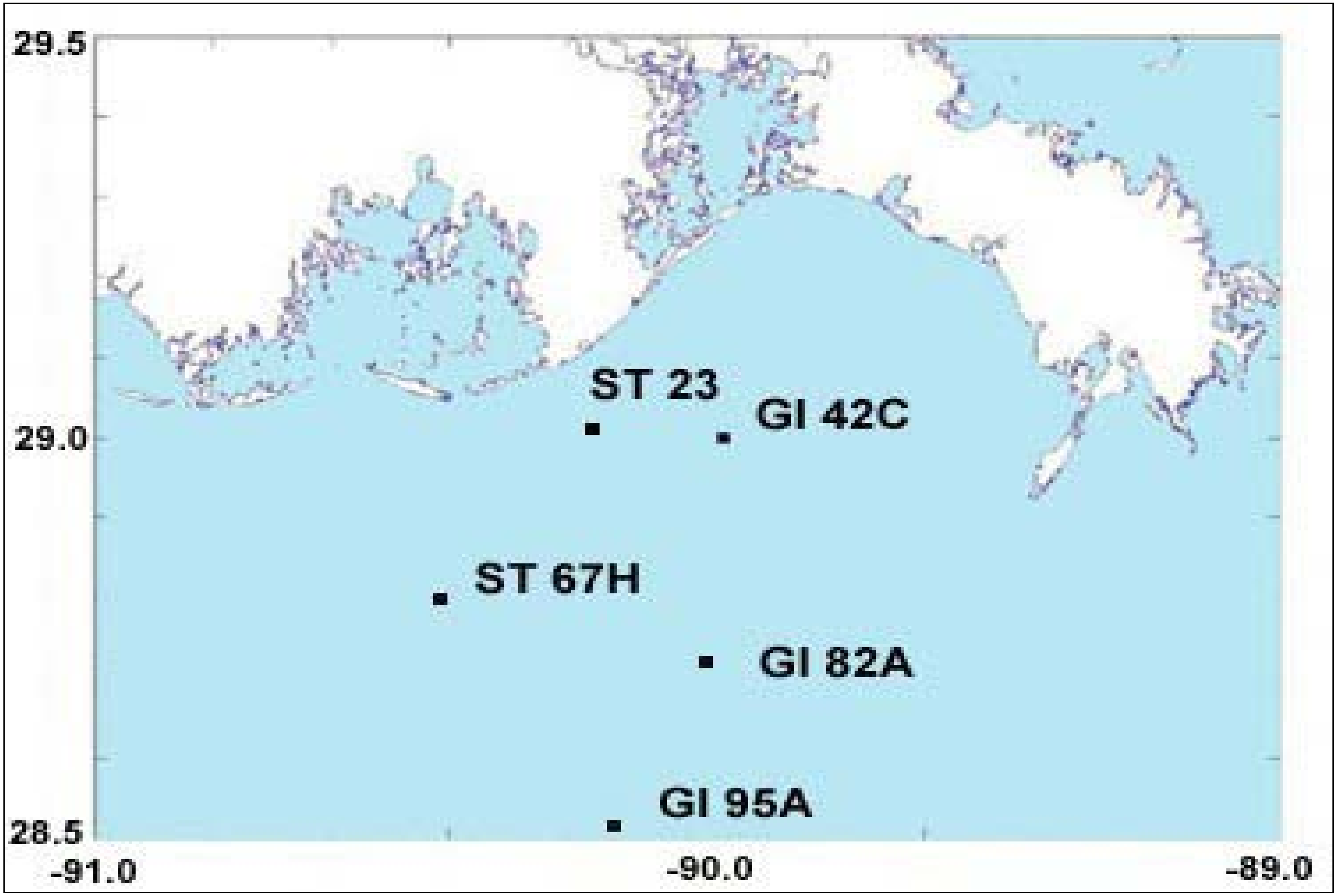


Figure 3D.4. Locality map.

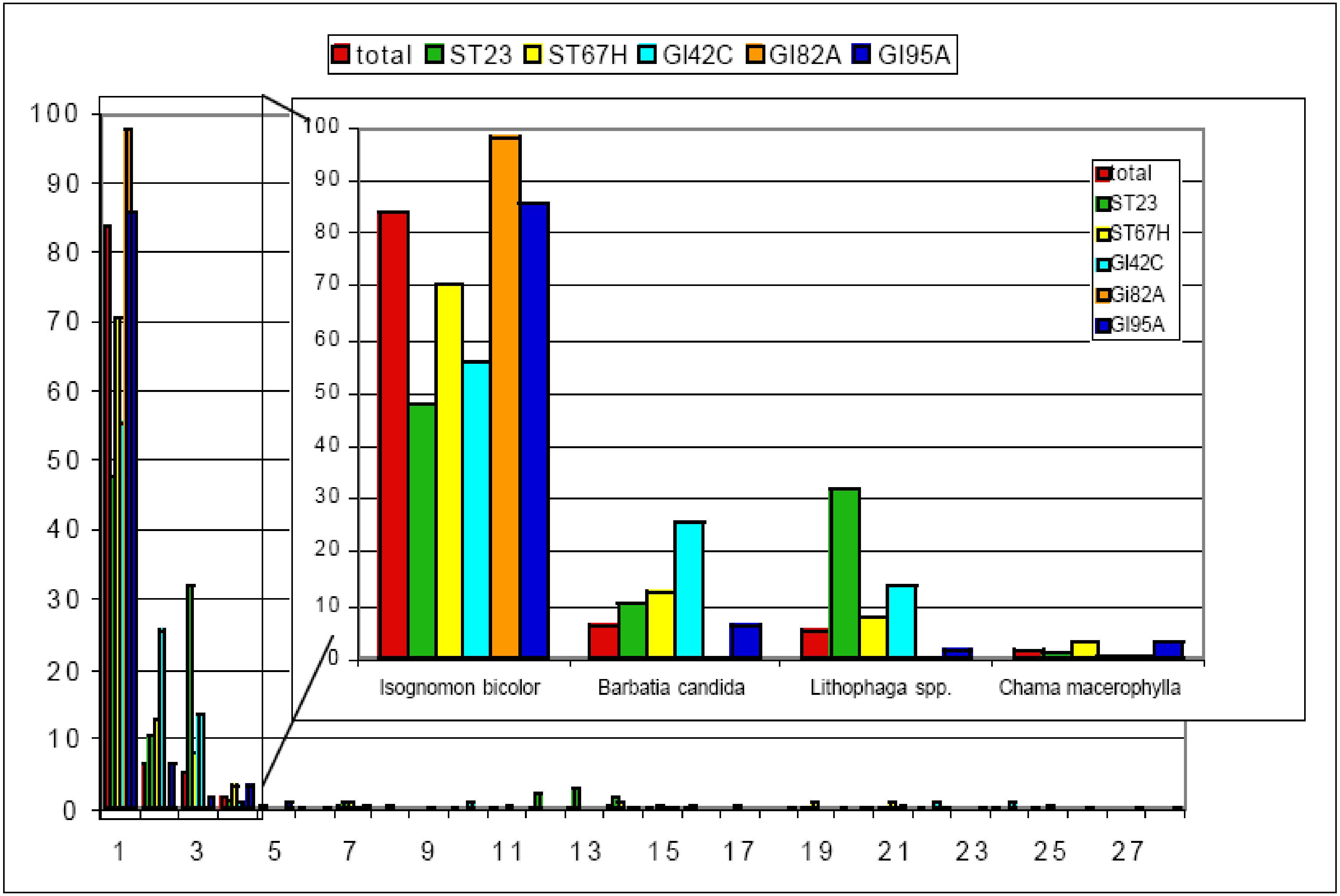


Figure 3D.5. Relative abundance of molluscan species for each platform and for all platforms combined (total).

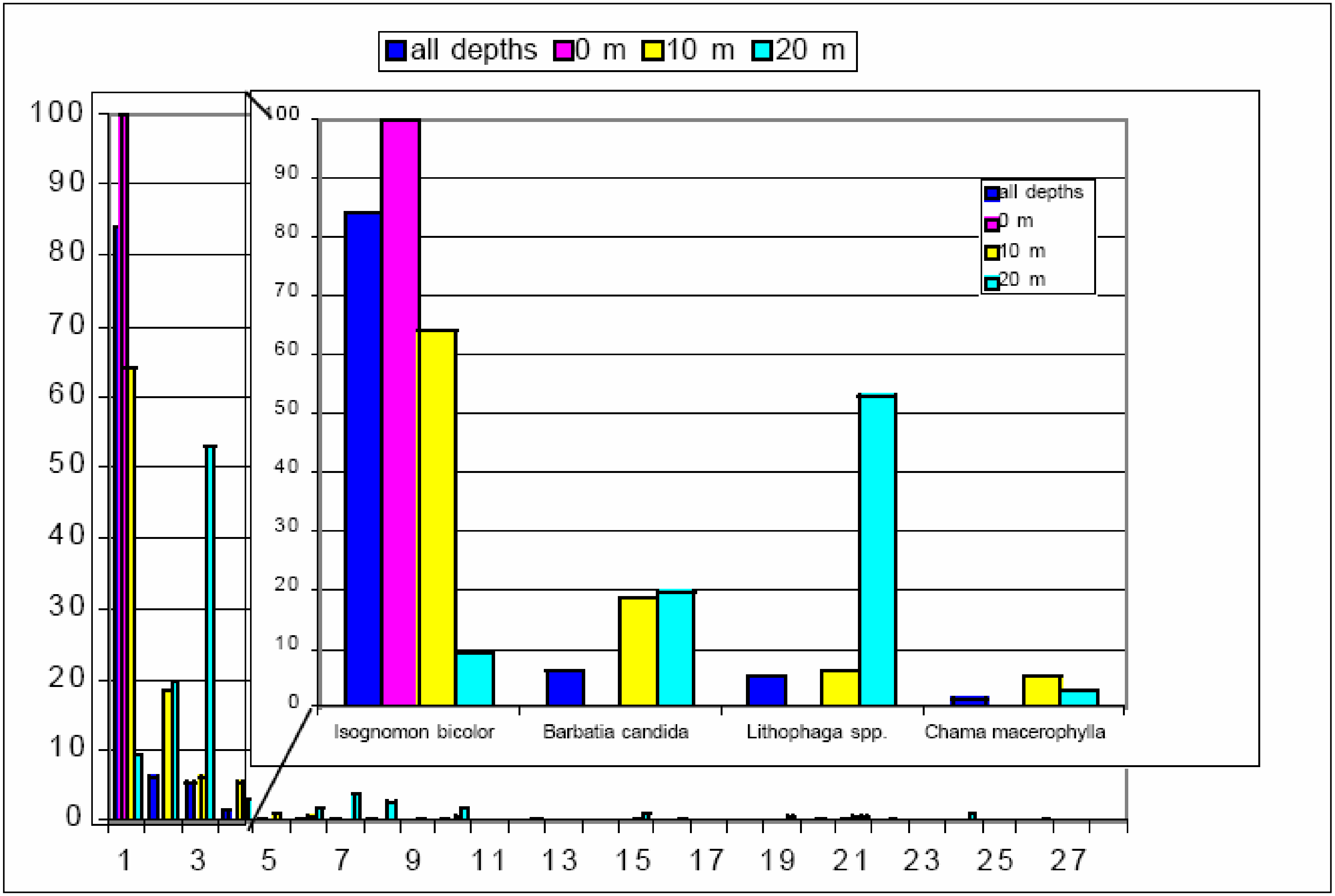


Figure 3D.6. Relative abundance of molluscan species at each sampling level and for all sampling levels combined (all depths).

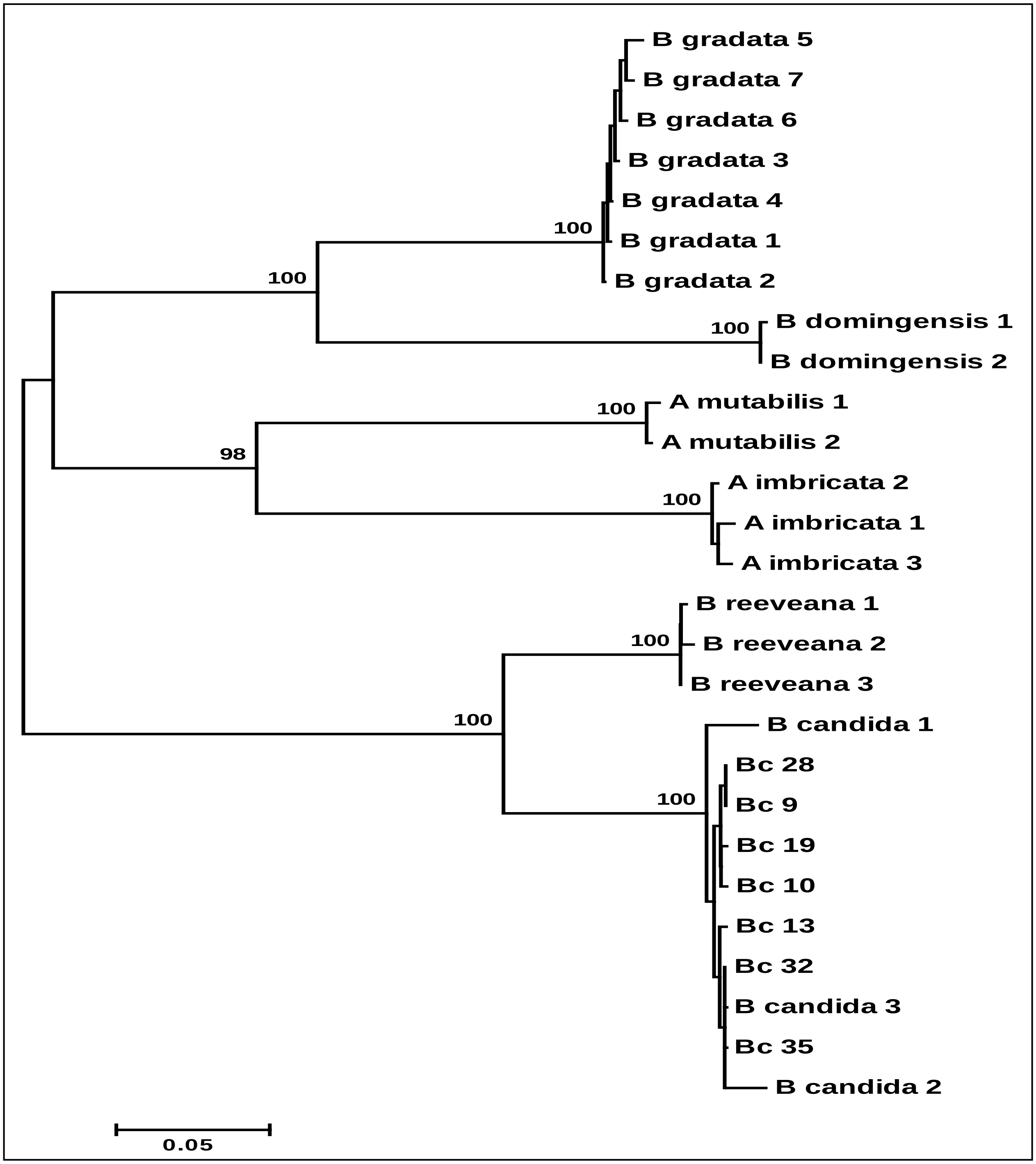


Figure 3D.7. Neighbor-joining phylogenetic reconstruction based on genetic distances (K-2-P) of the mitochondrial cytochrome c oxidase subunit I gene from bivalves in the family Arcidae. Operational taxonomic units (OTUs) with a letter followed by a species name (e.g., B reeveana 1) are previously published DNA sequences (Marko 2002; Marko and Moran 2002) and OTUs labeled Bc # are from the present study. Branch lengths are proportional to genetic distances according to the scales shown. Numbers above branches are nonparametric bootstrap support values based on 500 replicates.

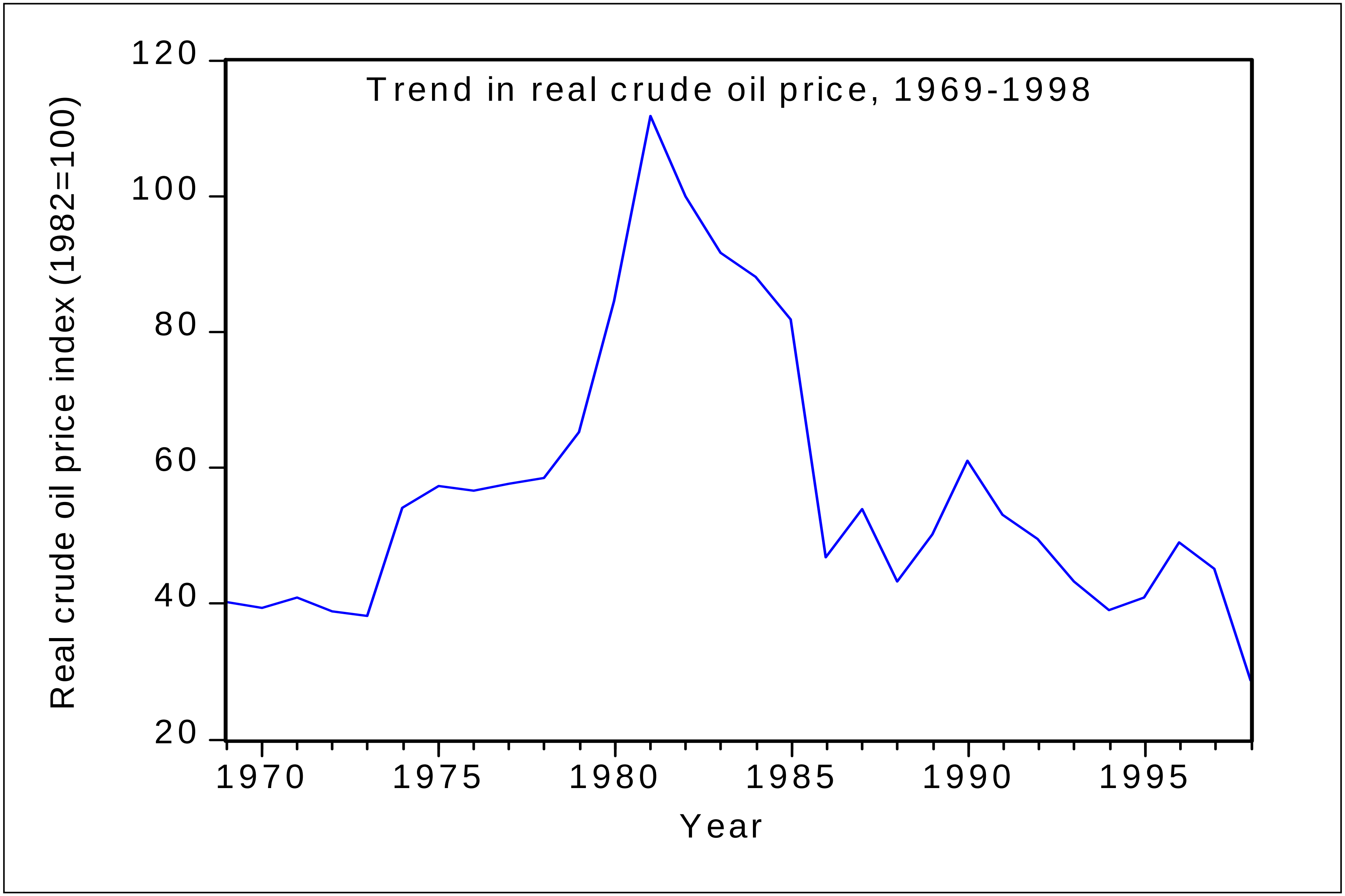


Figure 3E.1. Trend in real crude oil price, 1969–1998.

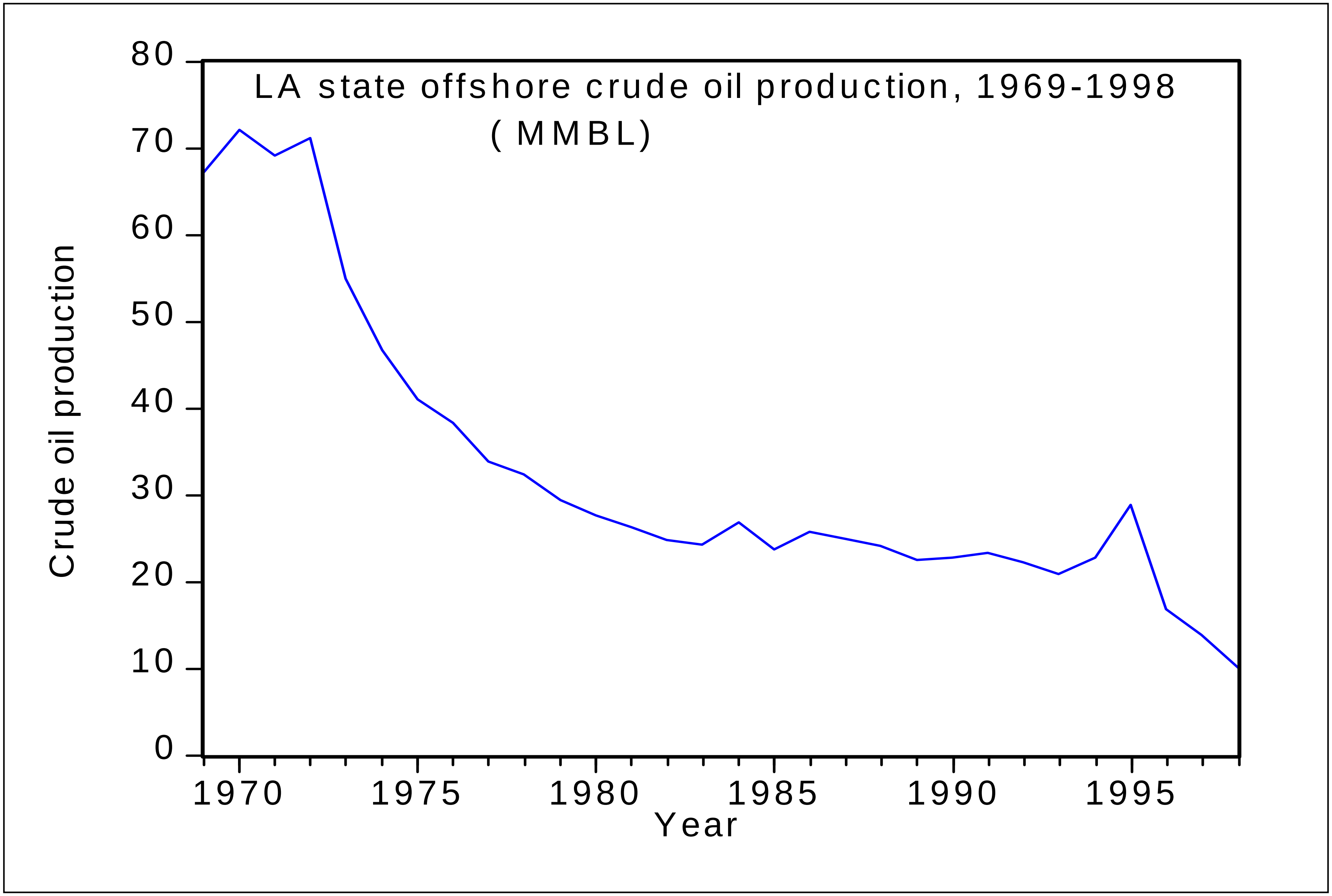


Figure 3E.2. Louisiana state offshore crude oil production, 1969–1998.

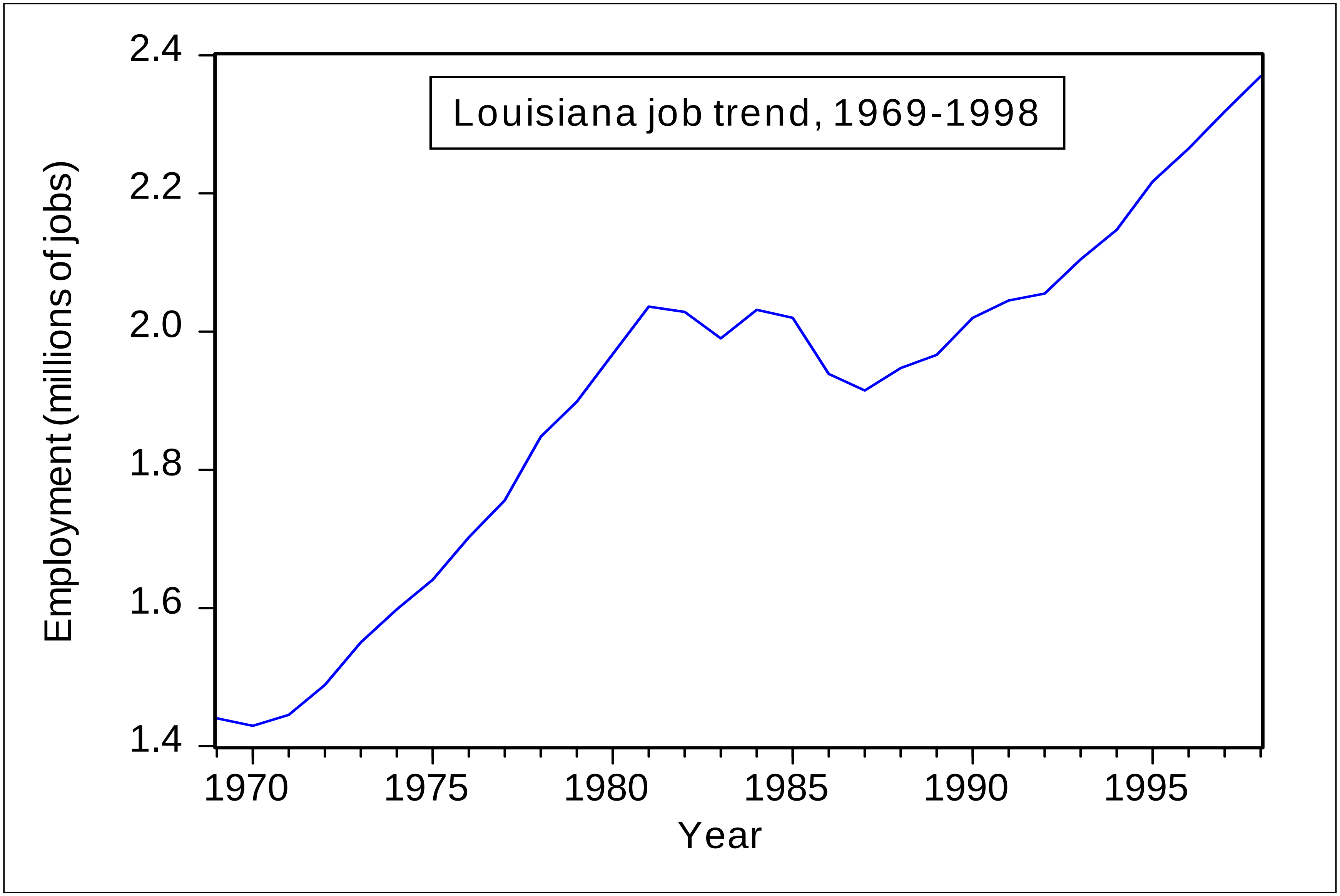


Figure 3E.3. Louisiana job trend, 1969–1998.

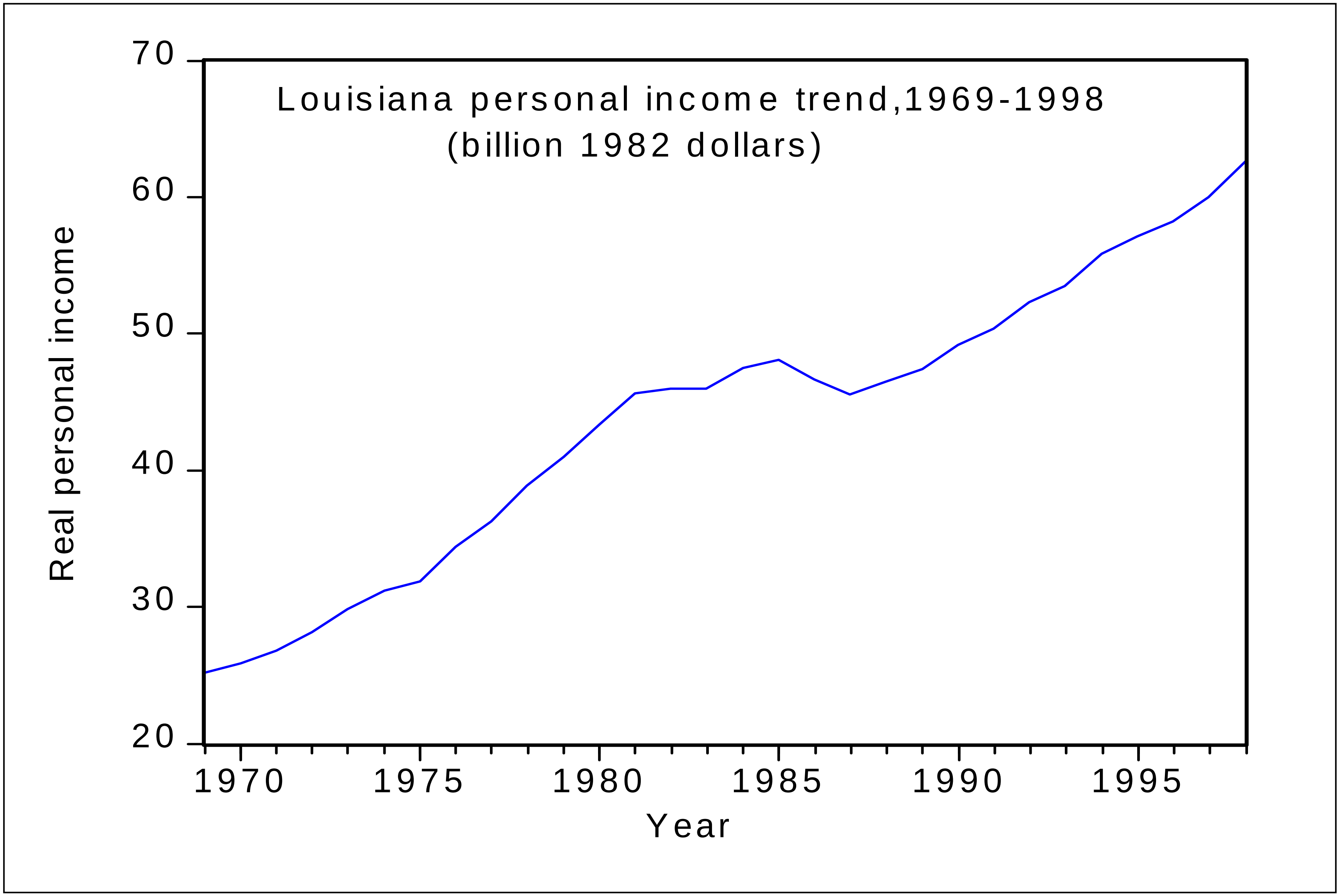


Figure 3E.4. Louisiana personal income trend, 1969–1998 (billion 1982 dollars).

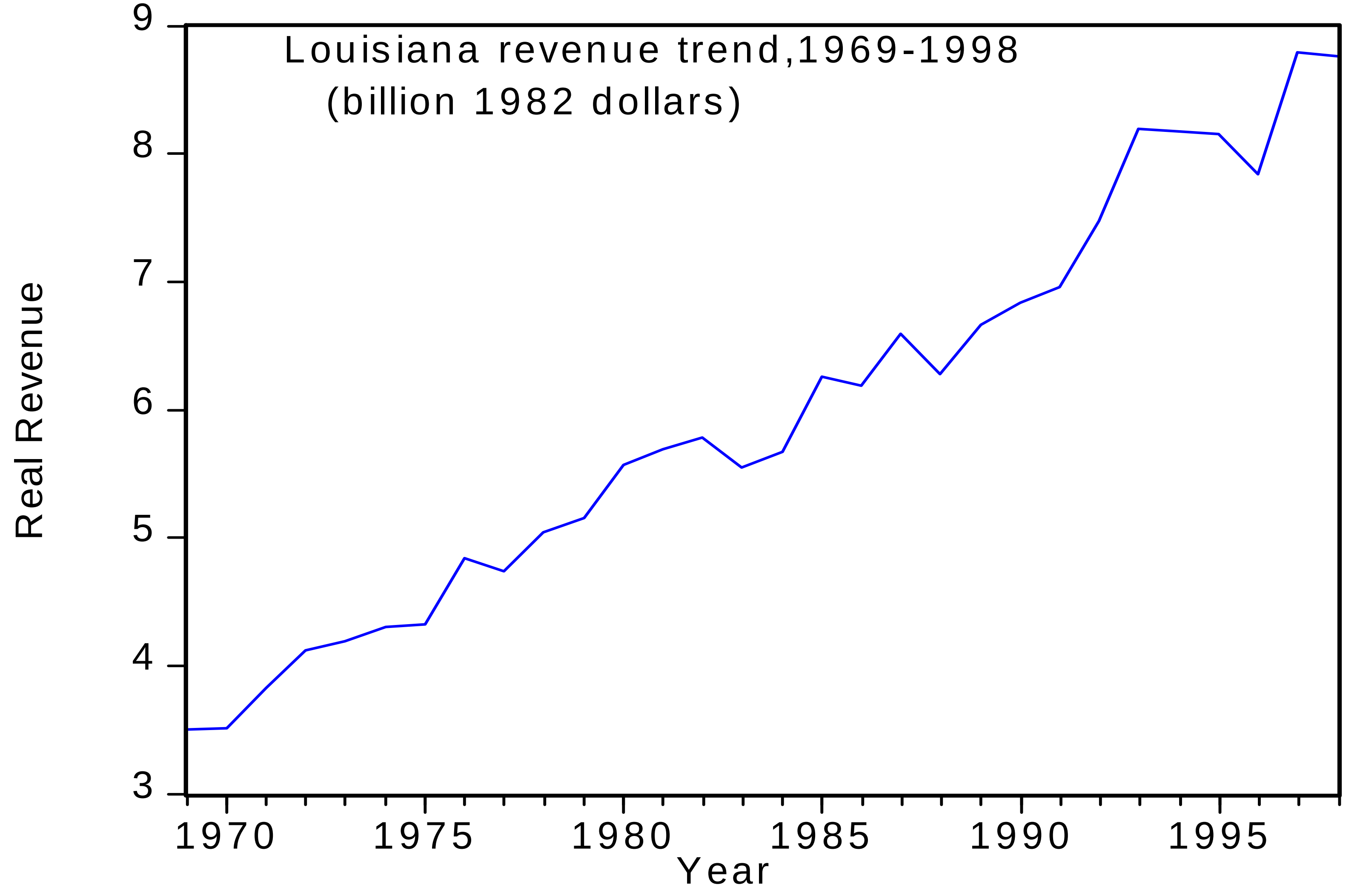


Figure 3E.5. Louisiana revenue trend, 1969–1998 (billion 1982 dollars).

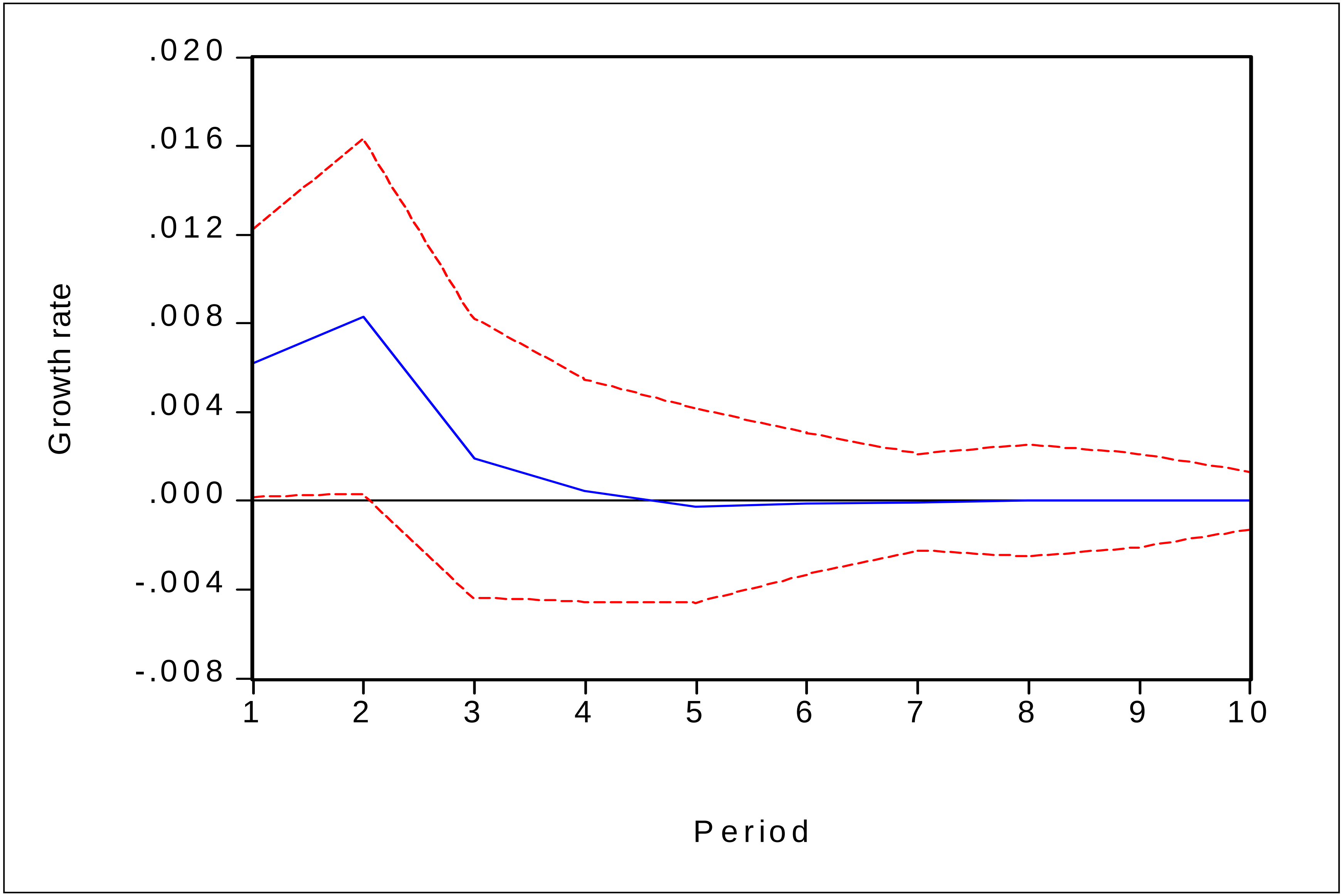


Figure 3E.6. Response of employment to a price shock.

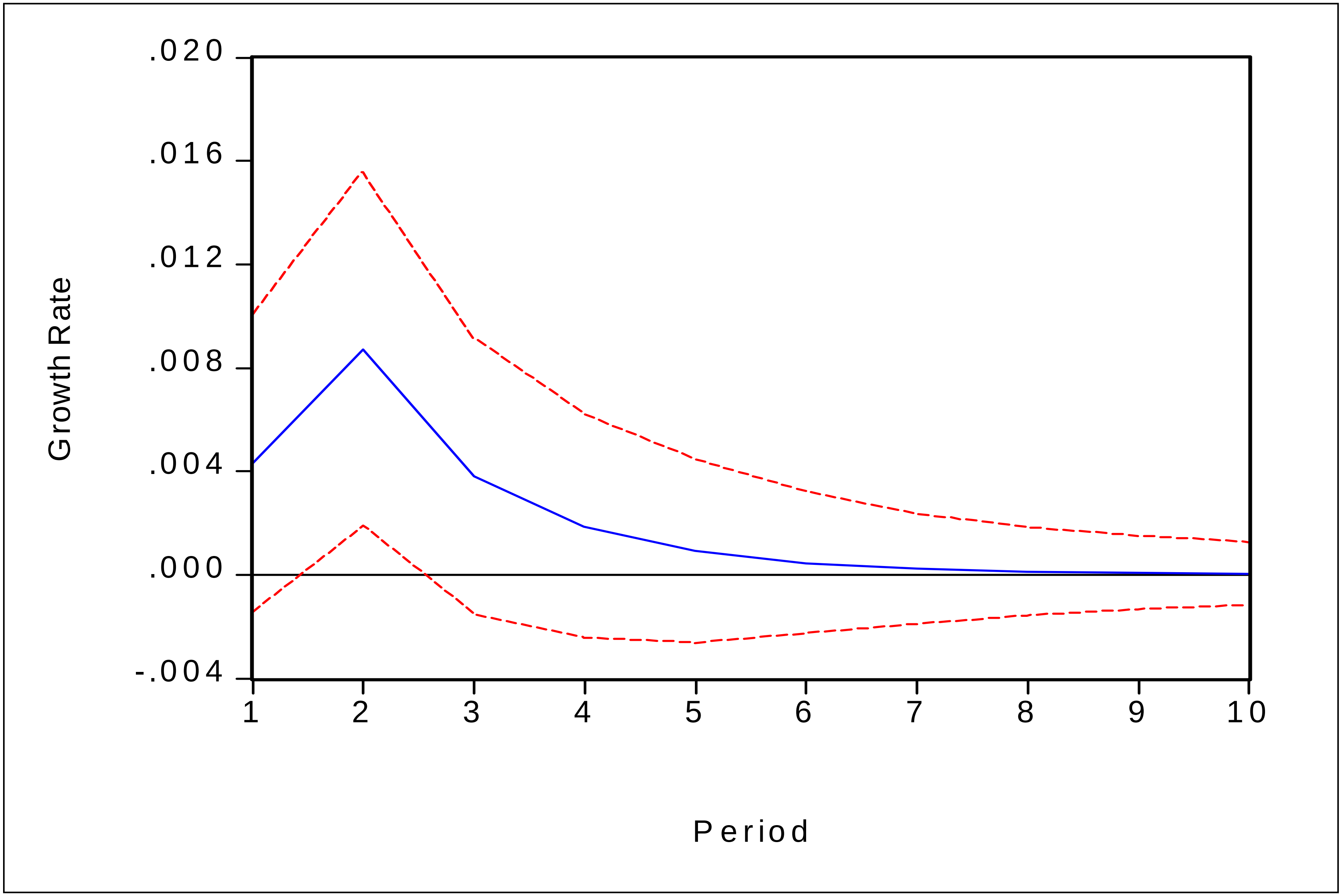


Figure 3E.7. Response of personal income to a price shock.

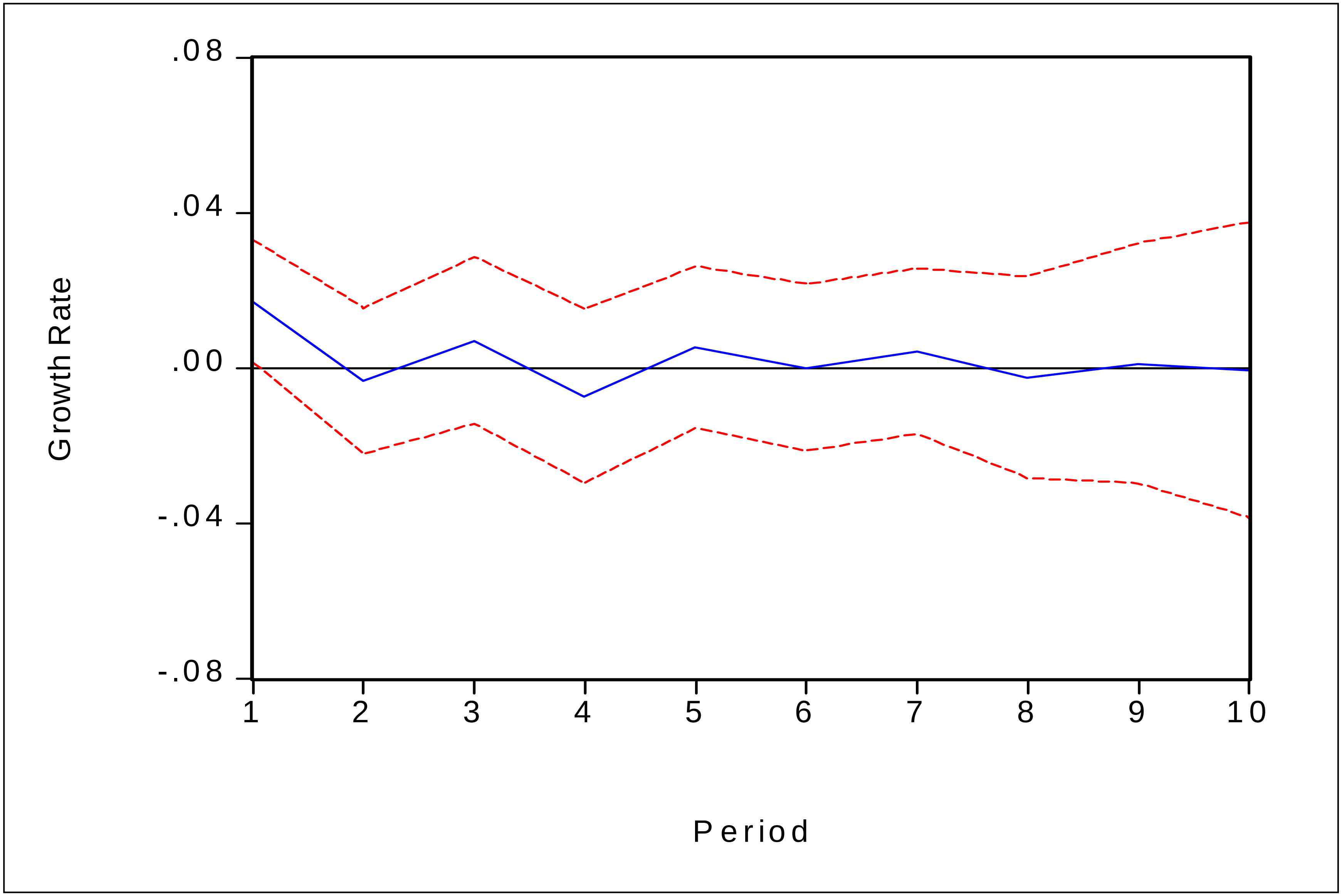


Figure 3E.8. Response of revenue to a price shock.

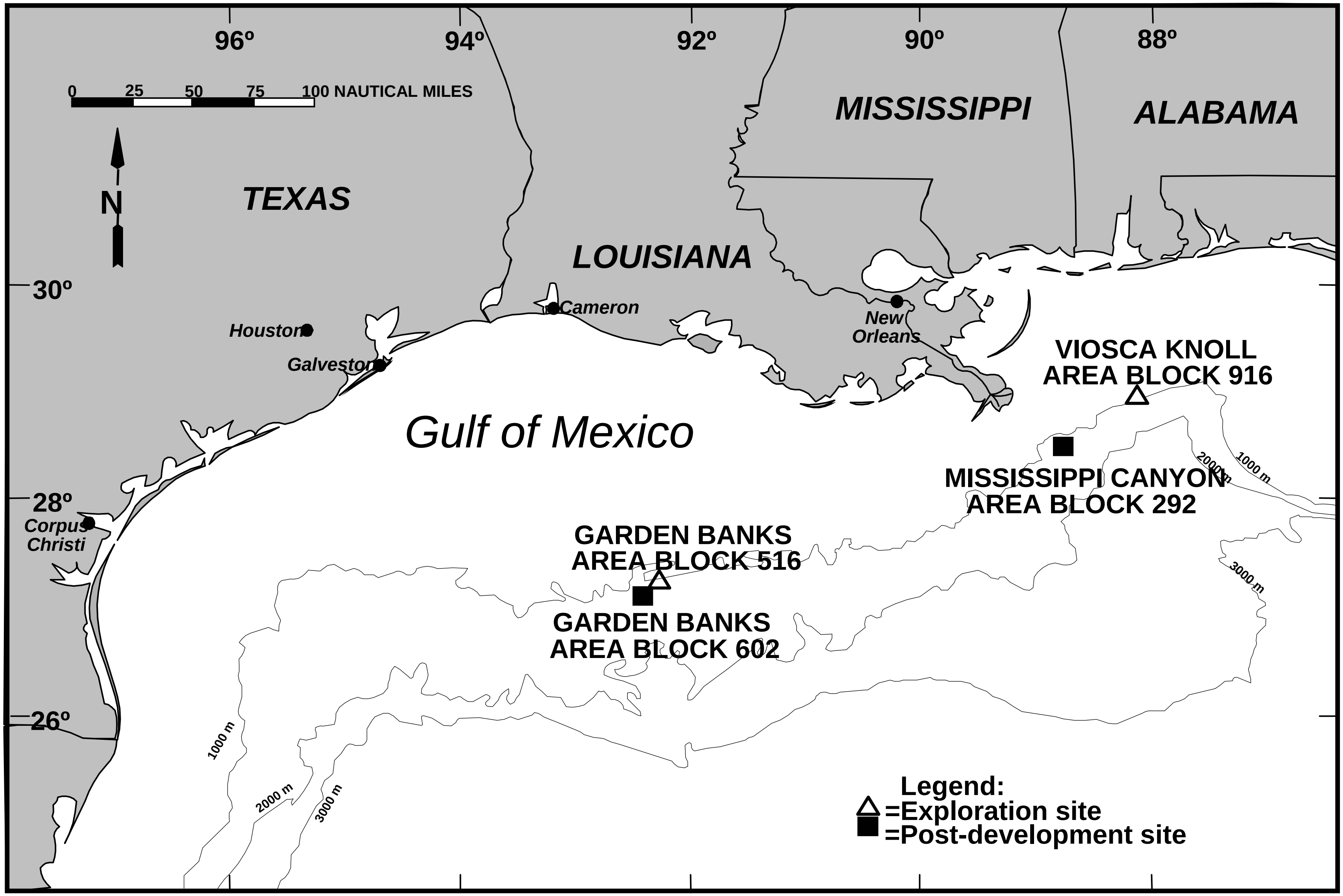


Figure 3F.1. Locations of study sites.

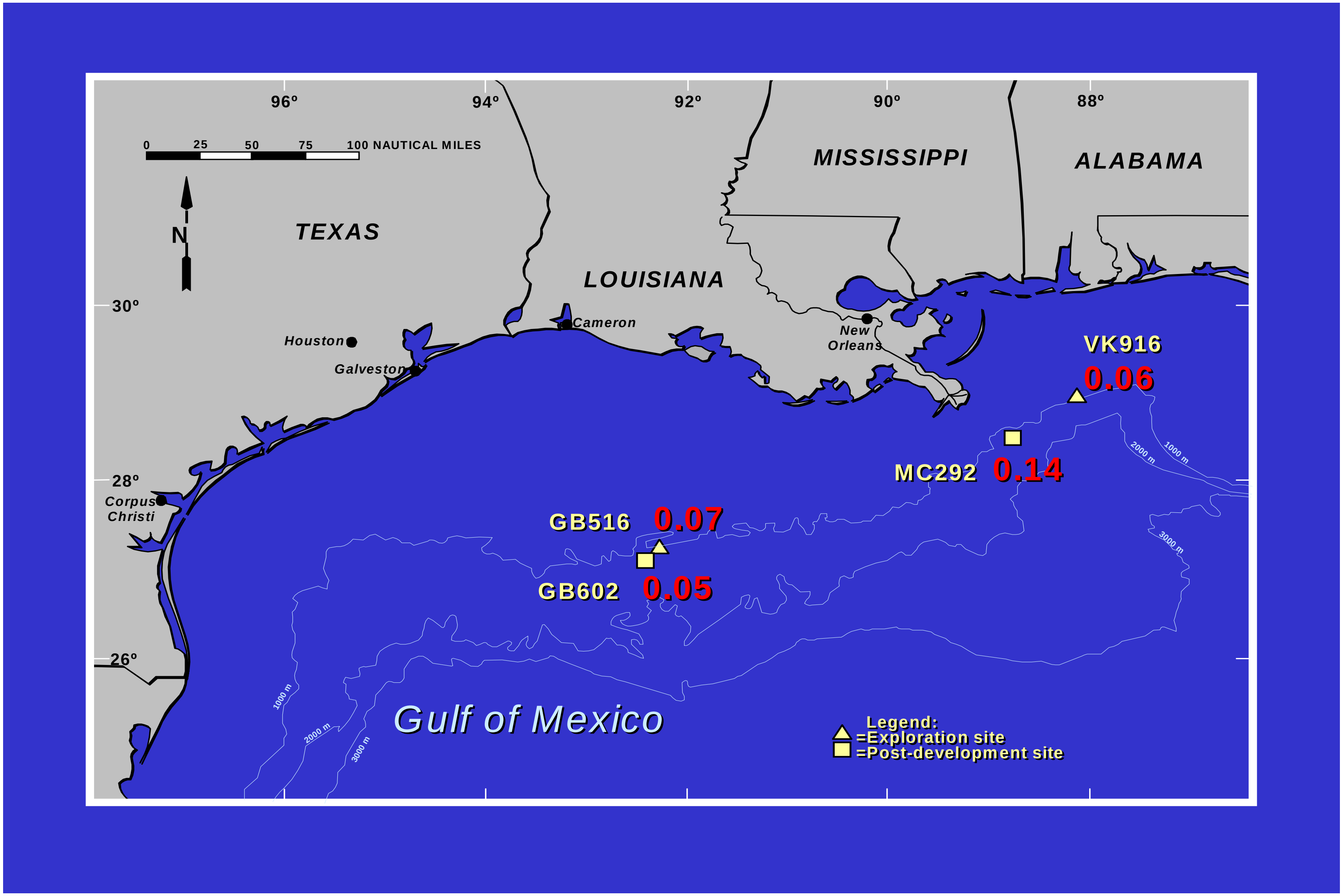


Figure 3F.2. Map showing sampling sites in the Gulf of Mexico with sedimentation rates in cm yr-1.

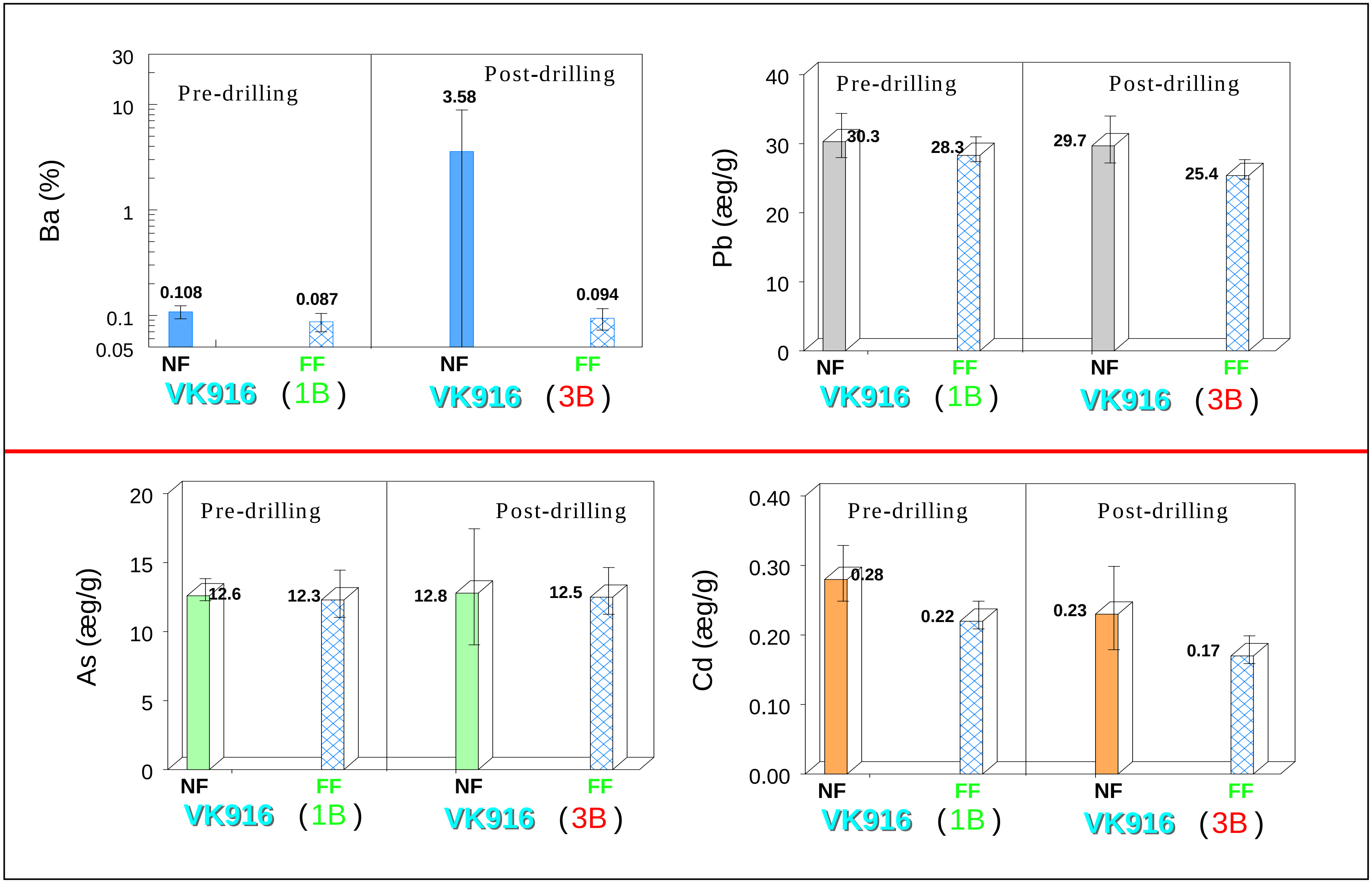


Figure 3F.3. Concentrations of Ba, Pb, As and Cd at nearfield (NF) and farfield (FF) stations for pre-drilling (1B) and post-drilling (3B) sampling periods.

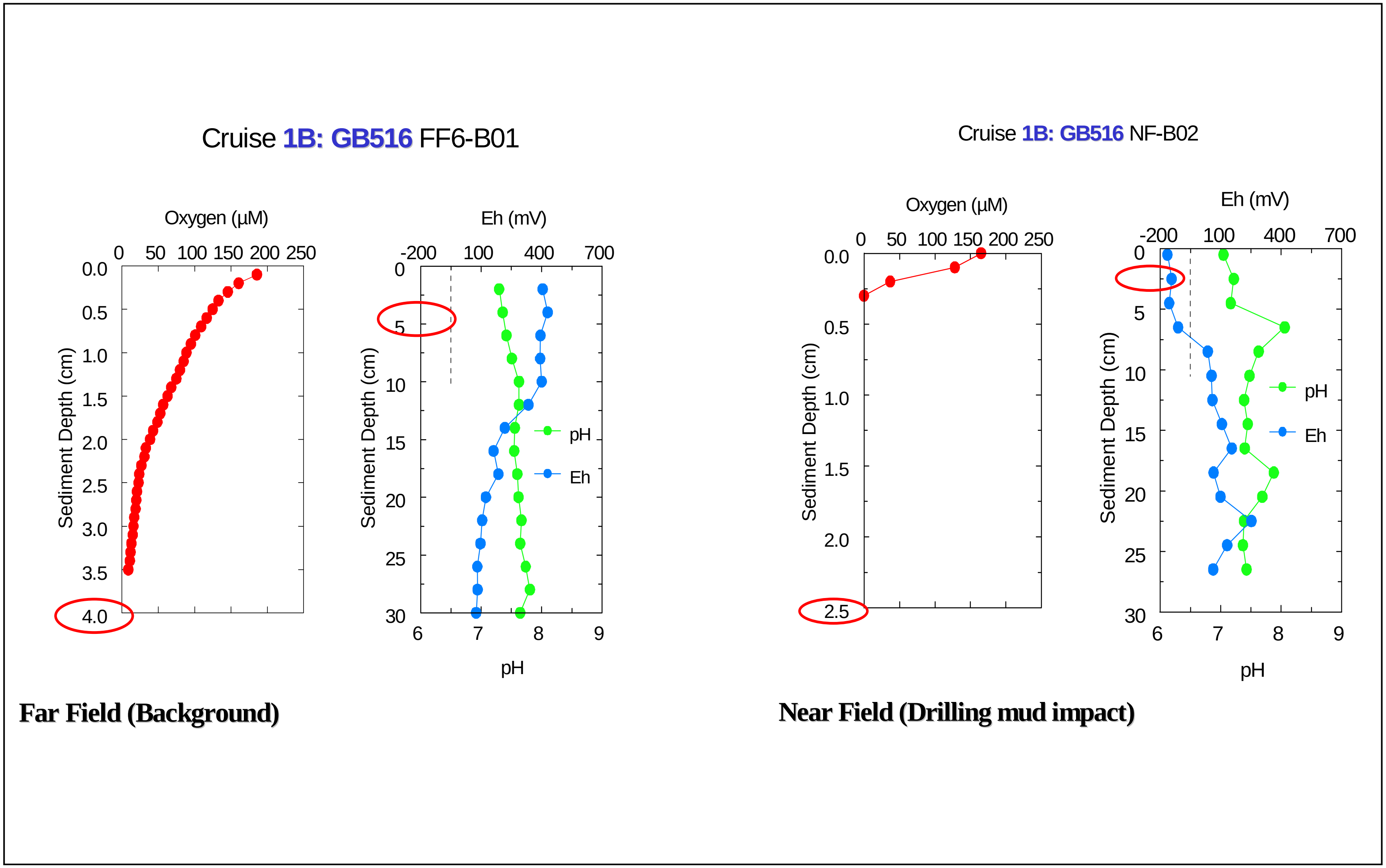


Figure 3F.4. Vertical profiles for dissolved oxygen and redox potential (Eh) for (a) farfield (FF) and (b) nearfield (NF) sediments at site GB516 where drilling discharges had occurred. Scales on oxygen profiles (4 and 2.5 cm) are much smaller than on the Eh profiles (30 cm).

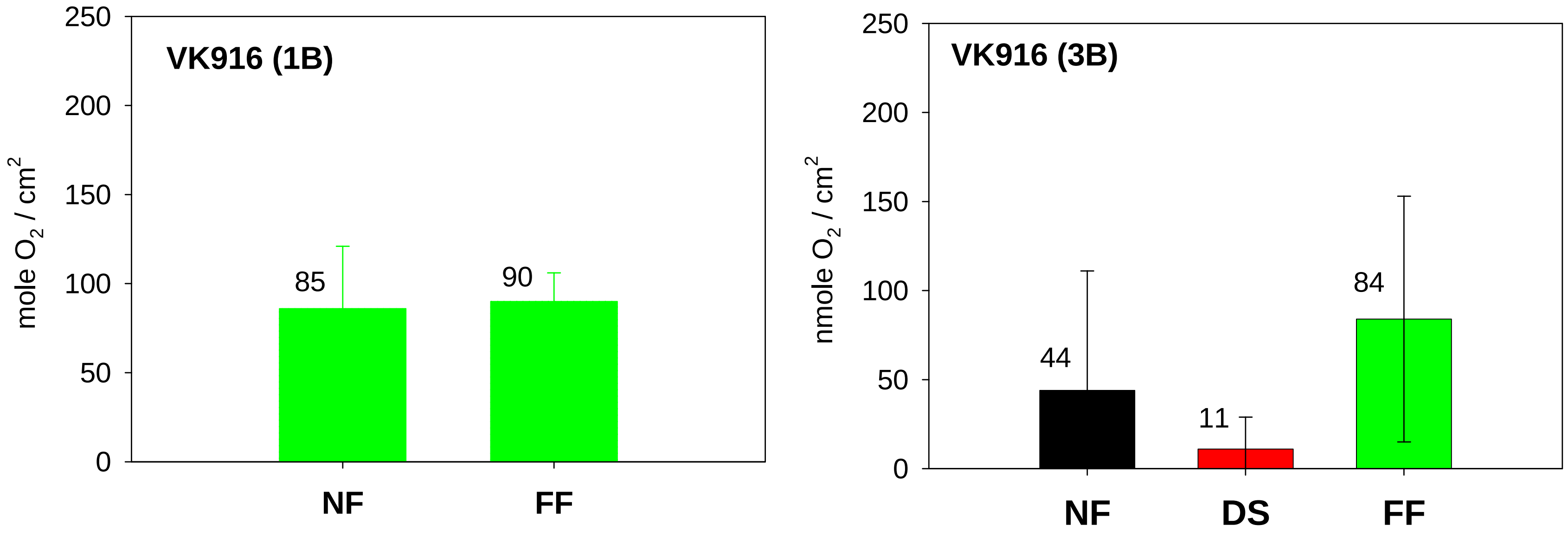


Figure 3F.5. Means and standard deviations for integrated amounts of dissolved oxygen in sediments from site VK916 for nearfield (NF), NF discretionary (DS) and farfield (FF) stations during pre-(1B) and post-development (3B) sampling.

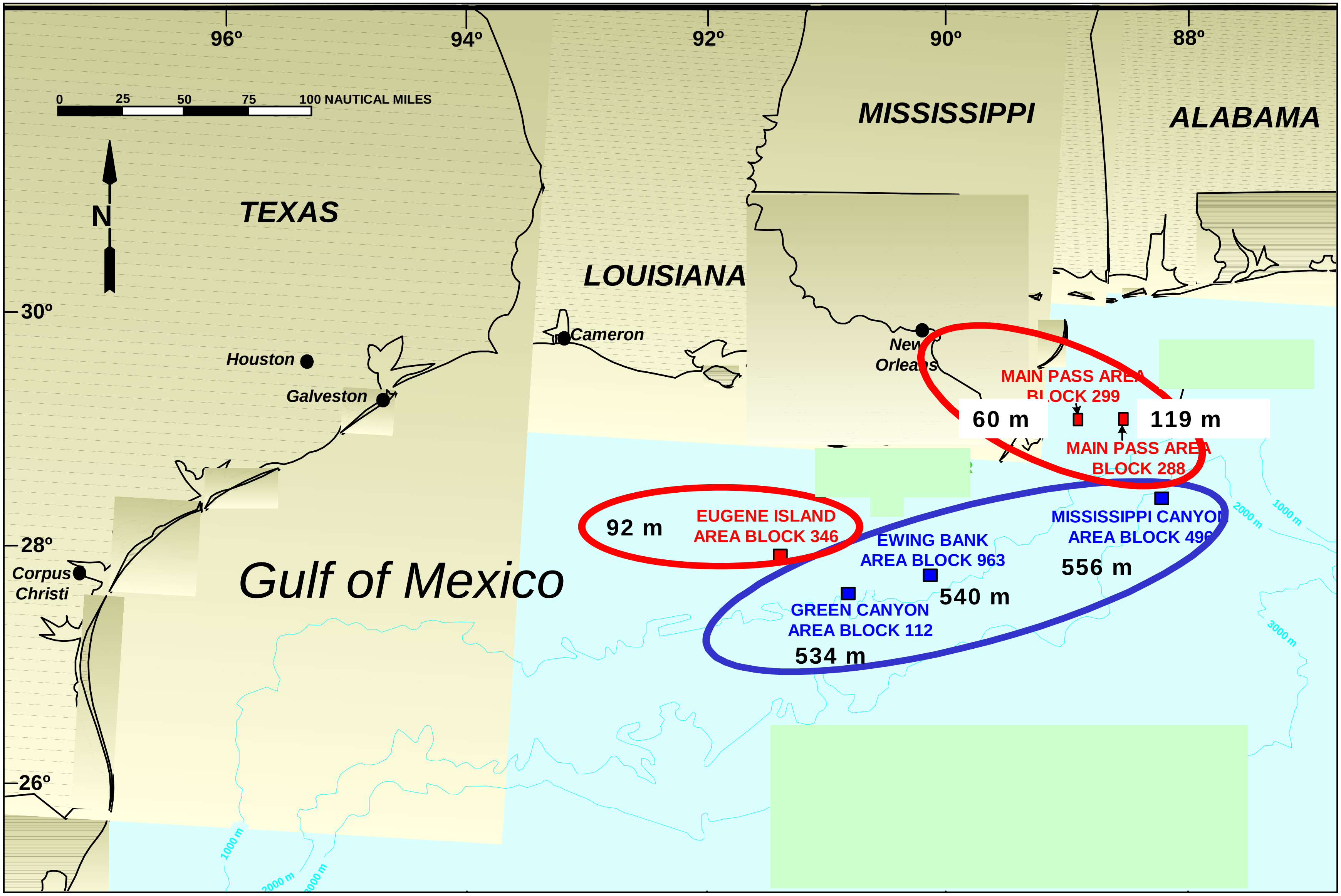


Figure 3F.6. Map showing sampling sites in Gulf of Mexico for sediment mercury study.

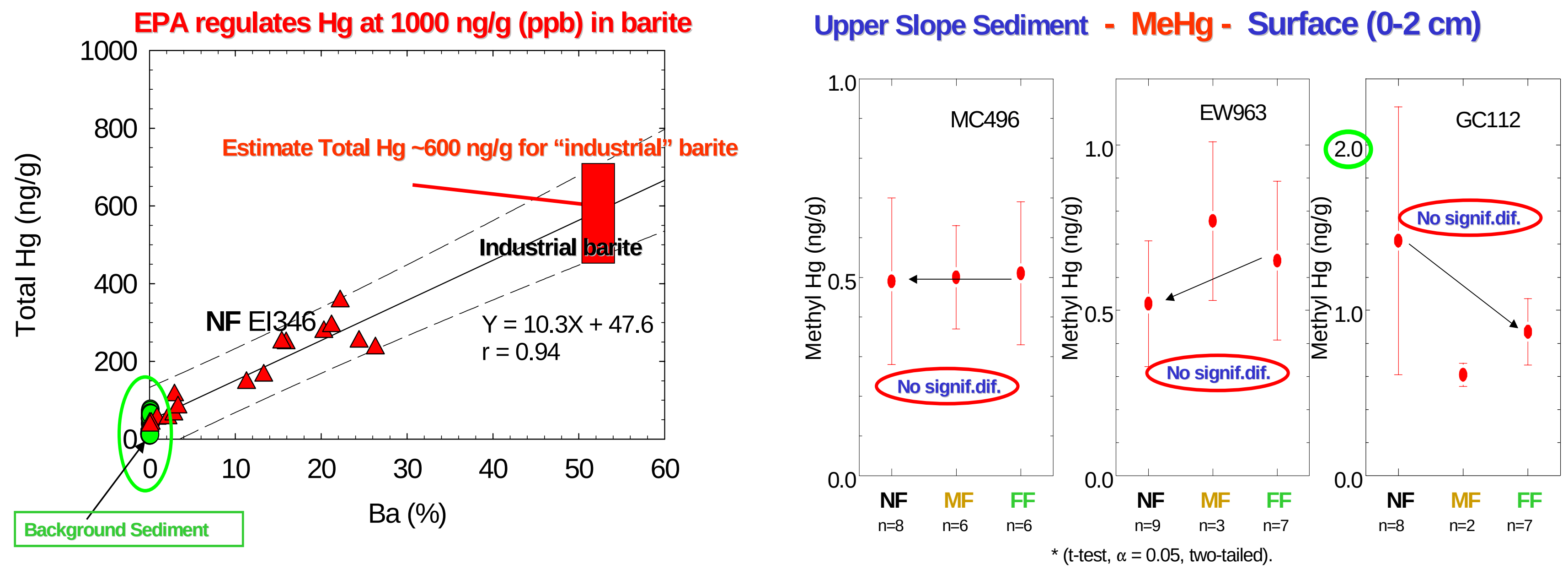


Figure 3F.7. (a) Concentrations of Ba versus total Hg in nearfield (NF) sediment from site EI346 with linear regression line, correlation coefficient (r), and 95% prediction interval. Straight line represents a mixing line between background sediment and industrial barite, and (b) Mean concentrations of methylmercury in sediment from NF, midfield (MF) and farfield (FF) stations at upper slope sites MC496, EW963 and GC112. Vertical lines show standard deviations.

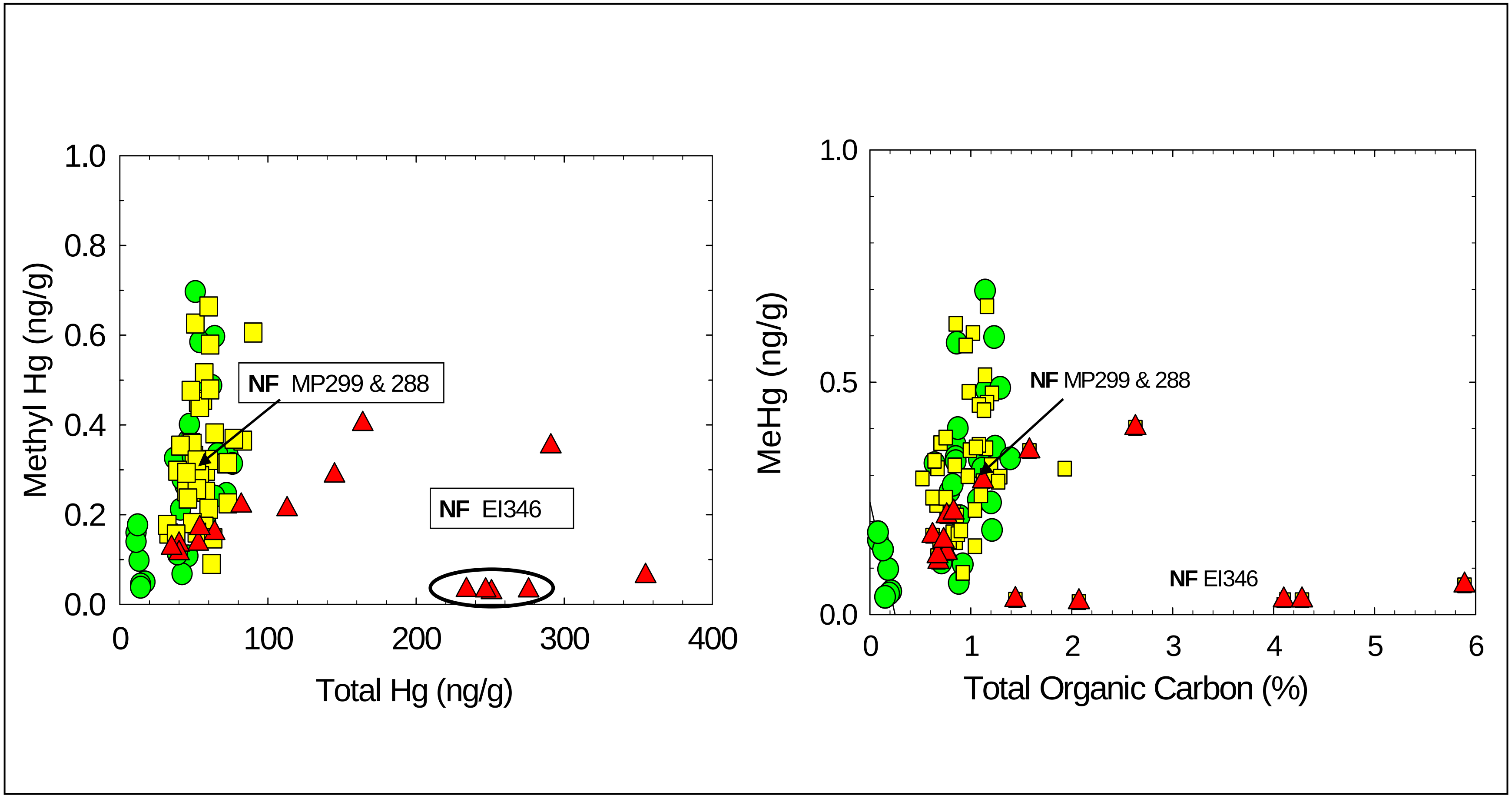


Figure 3F.8. (a) Concentrations of total Hg versus methylmercury for farfield stations on the shelf (circles) and nearfield (NF) stations at sites MP299 and MP288 (squares) and EI346 (triangles) and (b) Concentrations of total organic carbon versus methylmercury for farfield stations on the shelf (circles) and NF stations at sites MP299 and MP288 (squares) and EI346 (triangles).

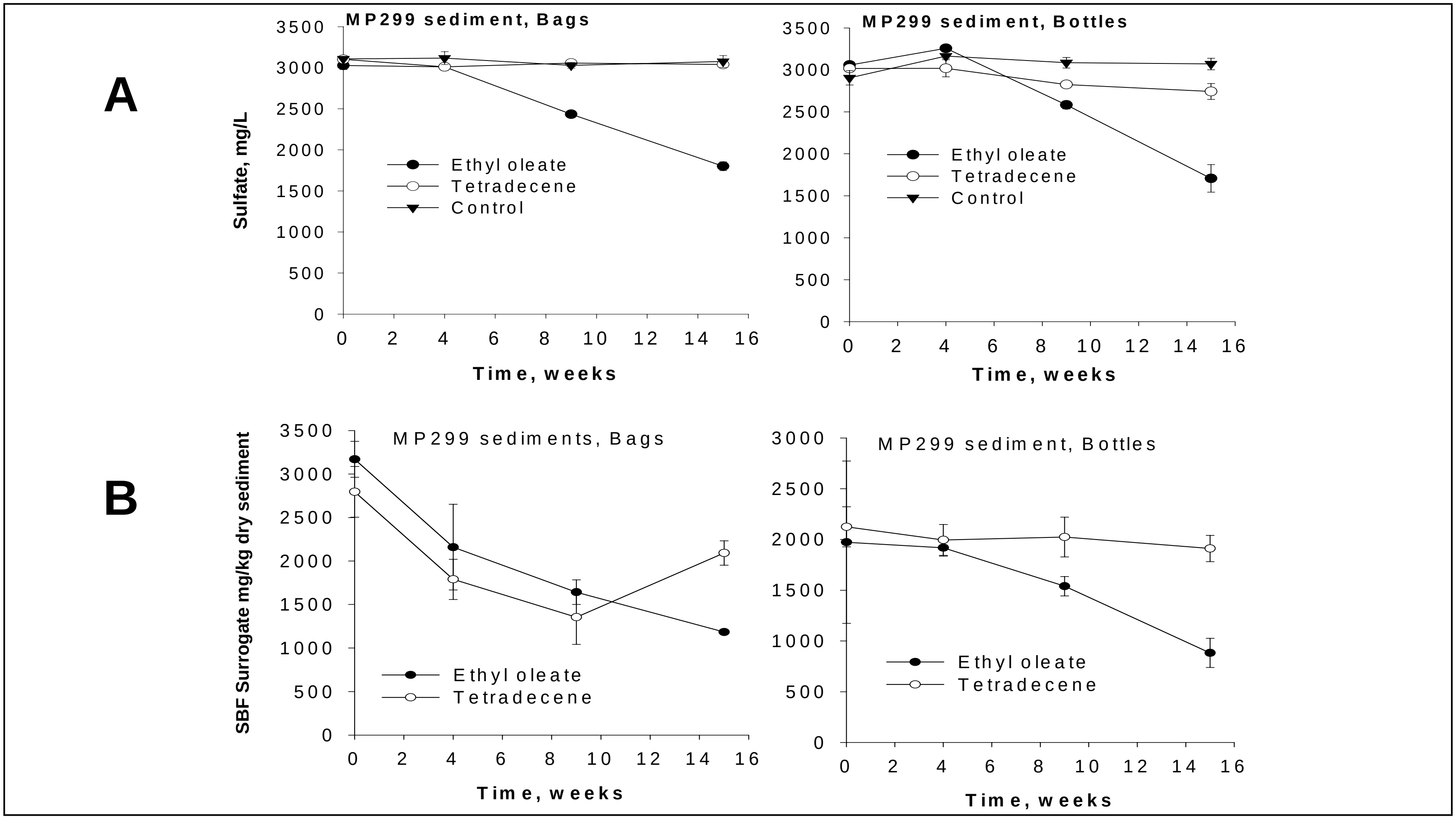


Figure 3F.9. Biodegradation of surrogate ester-based SBF, ethyl oleate, and of the surrogate olefin-based SBF, tetradecene, in sediment collected from 66 m depth in the Gulf of Mexico incubated at 4ºC. The sediment-filled bags were incubated inside the pressure vessels at 97-psi hydrostatic pressure, while the bottles containing sediment were incubated at atmospheric pressure. Part A compares sulfate concentrations in sediment pore water between the control (free of SBF) and SBF-spiked sediments. Part B compares the removal of ethyl oleate and tetradecene from the sediment. Each point represents the mean (± standard deviation) of triplicate samples.

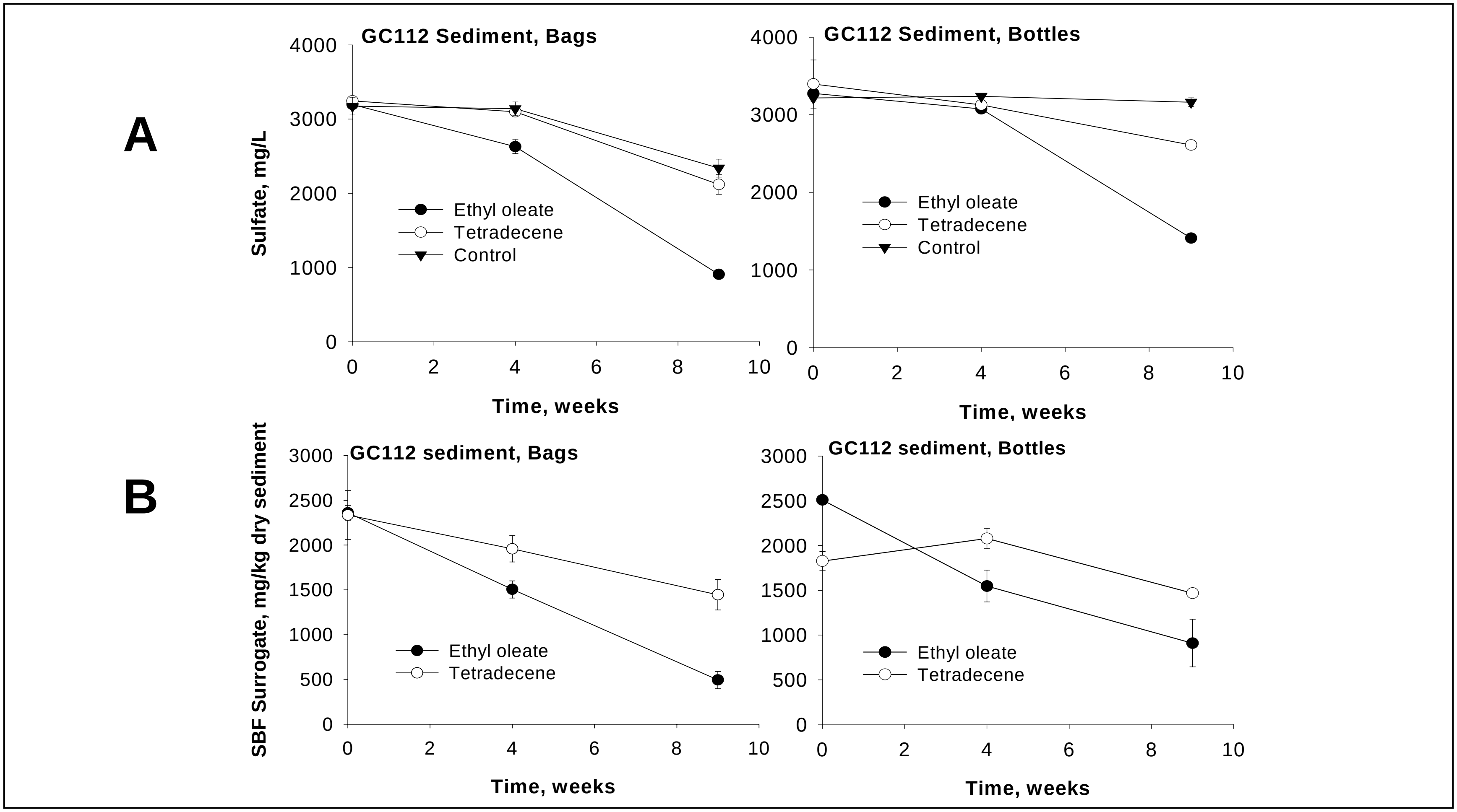
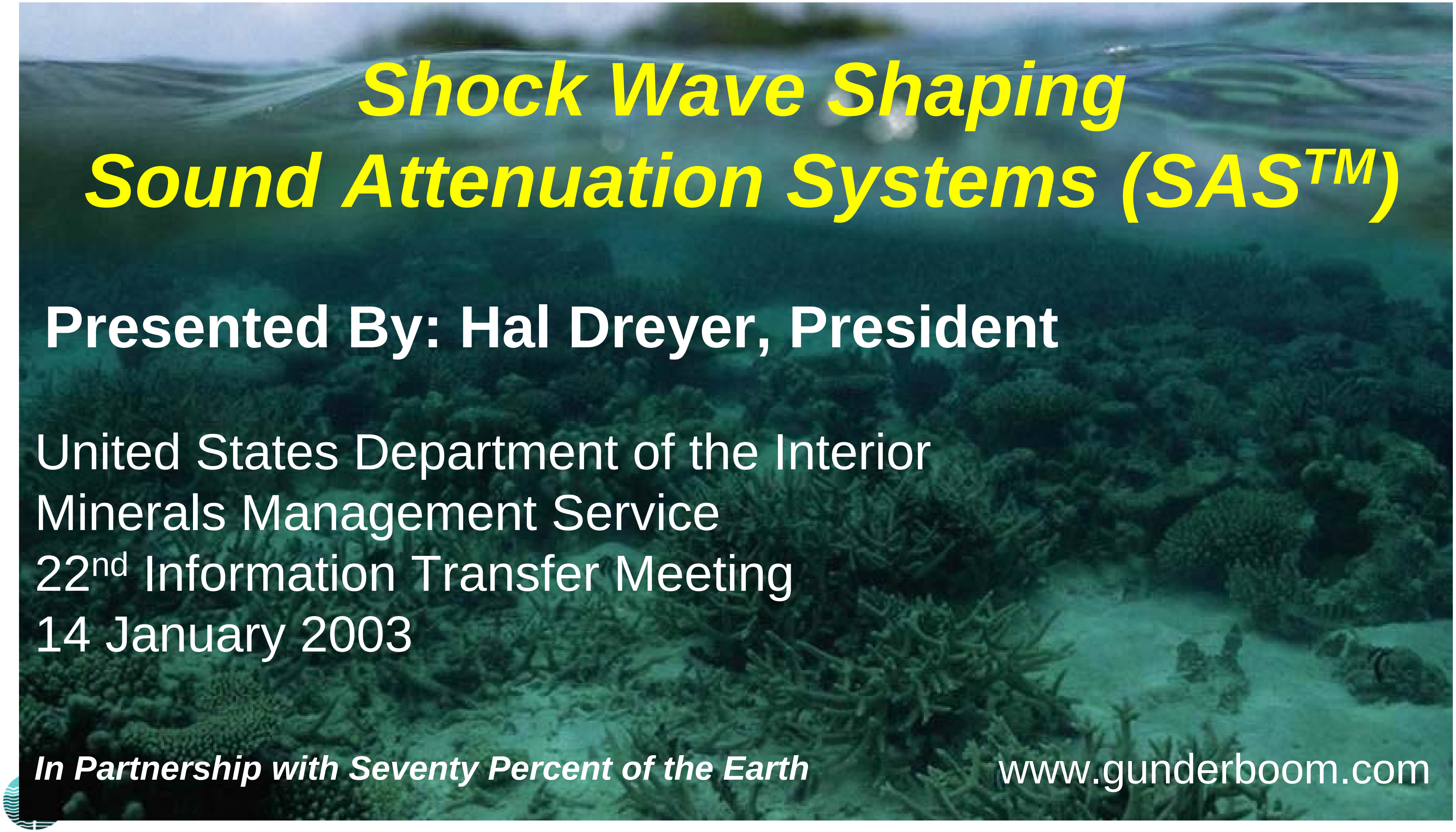


Figure 3F.10. Biodegradation of surrogate ester-based SBF, ethyl oleate, and of the surrogate olefin-based SBF, tetradecene, in sediment (GC112) collected from 535 m depth in the Gulf of Mexico incubated at 4ºC. The sediment-filled bags were incubated inside the pressure vessels at 786-psi hydrostatic pressure, while the bottles containing sediment were incubated at atmospheric pressure. Part A compares sulfate concentrations in sediment pore water between the control (free of SBF) and SBF-spiked sediments. Part B compares the removal of ethyl oleate and tetradecene from the sediment. Each point represents the mean (± standard deviation) of triplicate samples.

GUNDERBOOM

Engineered Aquatic Filter Barrier Systems



Shock Wave Shaping
Sound Attenuation Systems (SAS™)

Presented By: Hal Dreyer, President

United States Department of the Interior
Minerals Management Service
22nd Information Transfer Meeting
14 January 2003

In Partnership with Seventy Percent of the Earth

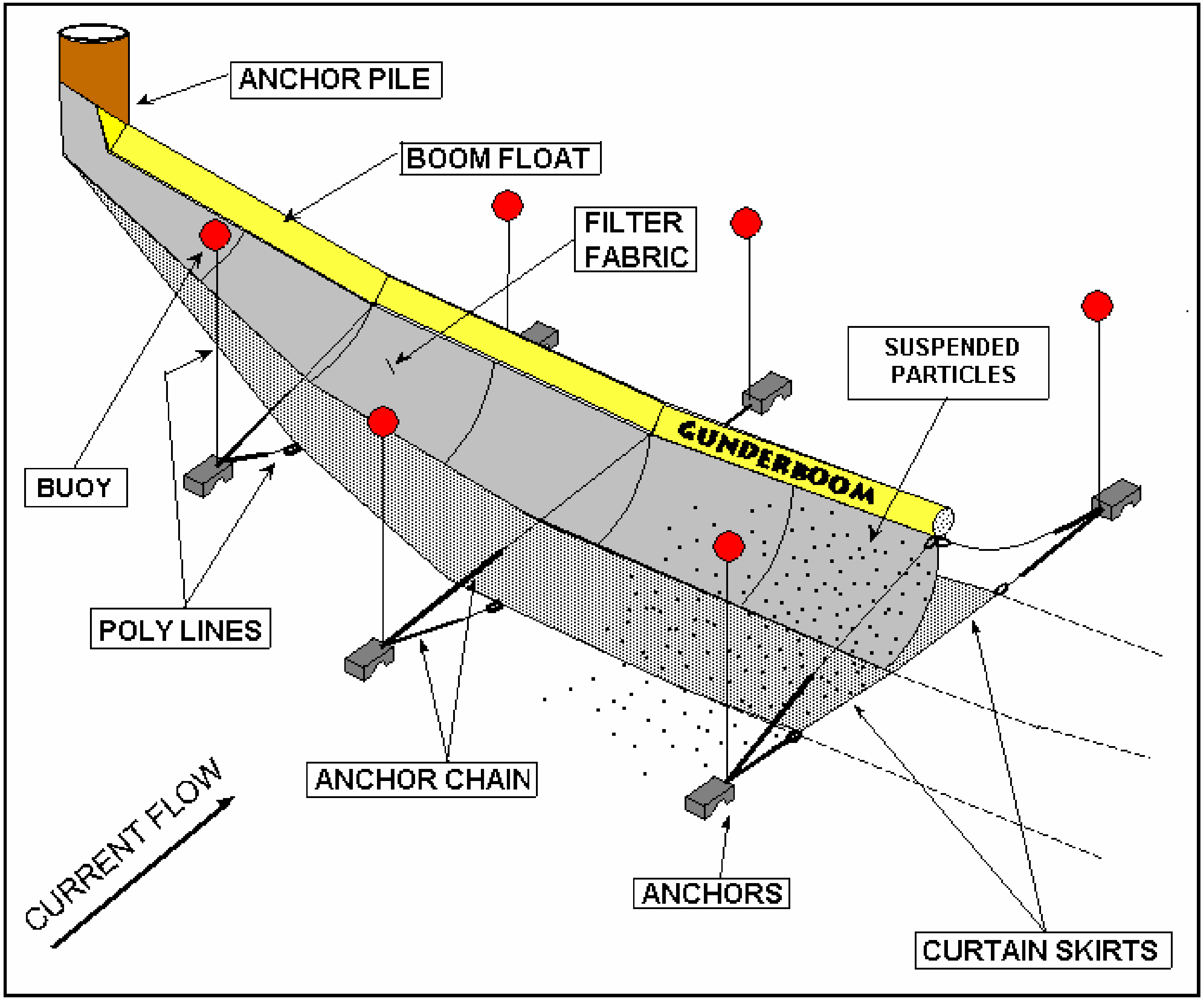
www.gunderboom.com

Background

- GUNDERBOOM was formed in 1995 by marine and oilfield specialists to further expand technology originally developed in 1986.
- To develop aquatic filter barrier technologies using poly fiber materials.
- GUNDERBOOM Principals
  - H. Dreyer, formerly president and CEO of Underwater Construction
  - Peratrovich, Nottingham & Drage, Inc., a marine and heavy civil engineering firm
  - Mirant Corporation, a merchant energy provider based in Atlanta, Georgia

Our Aquatic Filter Barrier Systems

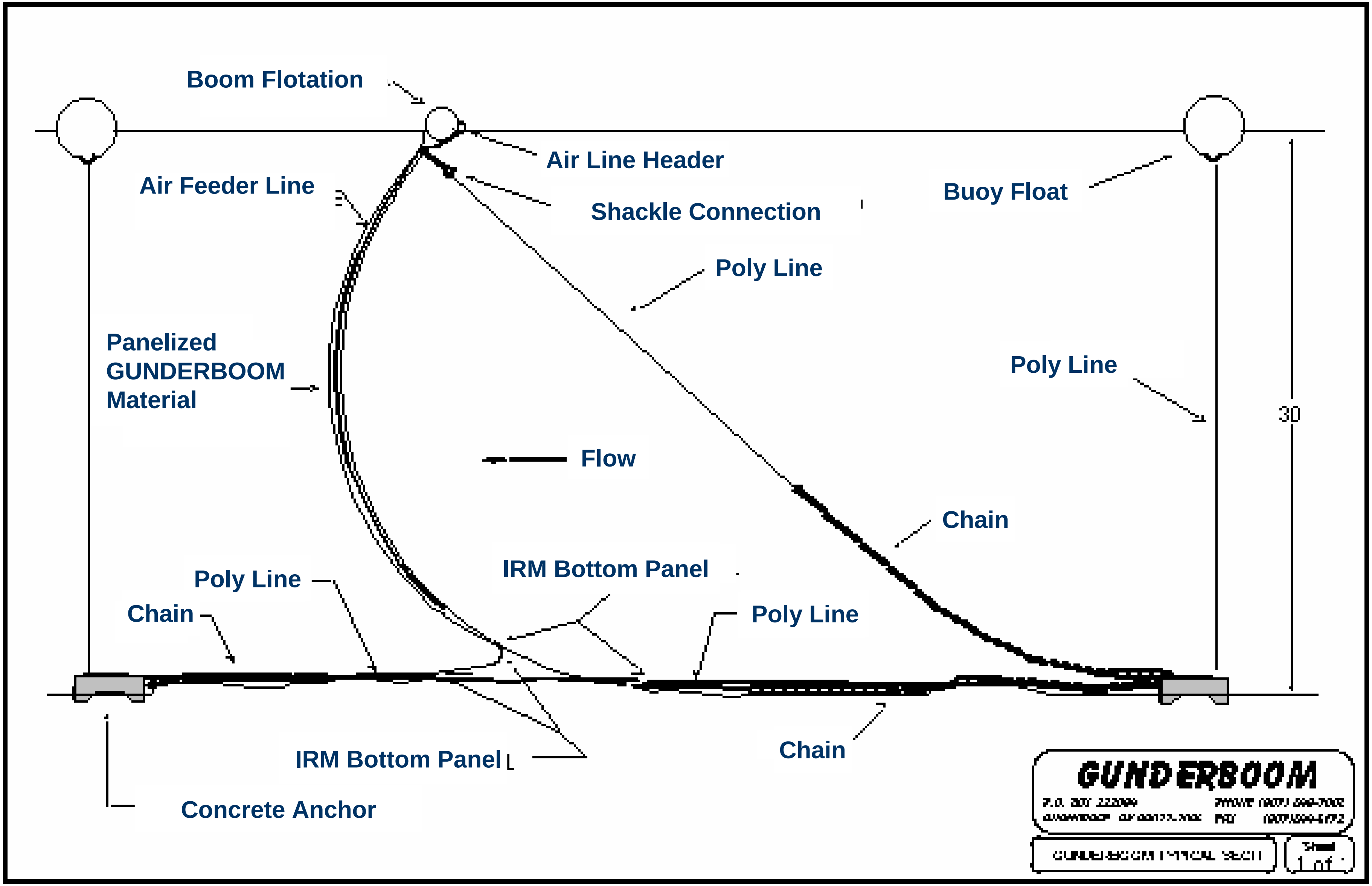
- Control water quality during dredging
- Protect and improve bathing beaches
- Control stormwater–derived contaminants
- Protect surface water for drinking water supplies
- Contain contaminated sediment during remediation
- Prevent aquatic organism entrainment and impingement
- Control harmful underwater sound and pressure



Patented full-water-depth filter curtain comprised of treated polypropylene/ polyester fabric, suspended by floatation billets on the water's surface and secured in place with an anchoring system.

GUNDERBOOM

The Basic GUNDERBOOM Includes…



Boom Flotation

Air Line Header

Air Feeder Line

Shackle Connection

Buoy Float

Poly Line

Panelized GUNDERBOOM Material

Poly Line

Flow

Chain

IRM Bottom Panel

Poly Line

Chain

Poly Line

IRM Bottom Panel

Chain

Concrete Anchor

GUNDERBOOM Systems

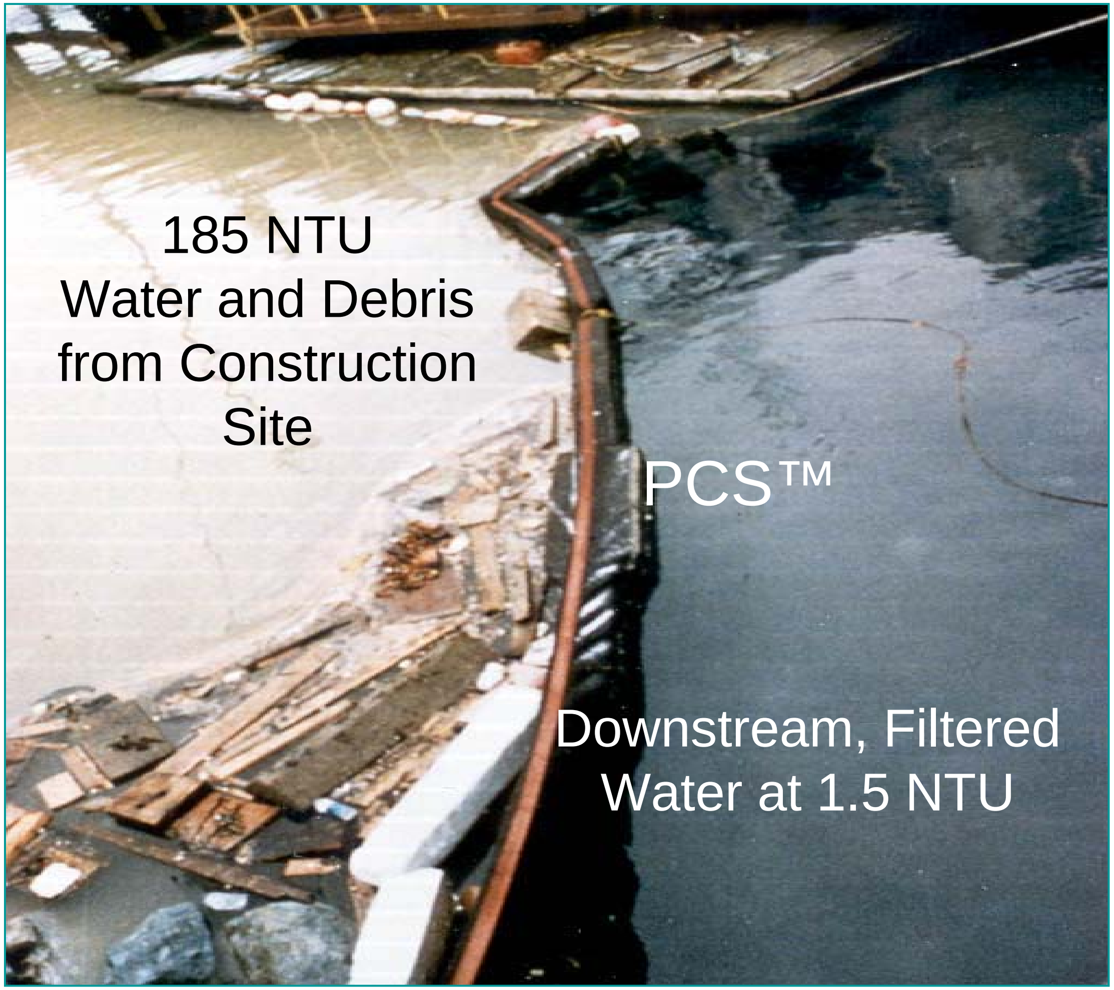
- **Particulate Control System (PCS™)**
- **Beach Protection System (BPS™)**
- **Reservoir Protection System (RPS™)**
- **Marine Life Exclusion System (MLES™)**
- **Sound Attenuation System (SAS™)**

Particulate Control System™

- **The PCS™ encloses an underwater work site or other contaminant source.**
- **Acting as a filter, the system prevents contaminants from migrating away from the operation.**
- **By slowing water passage, the PCS™ promotes suspended solid settlement.**
- **The PCS™ can be deployed to protect resources, such as clam beds and salmon spawning areas. It can also be used to control settling pond and mining discharge.**

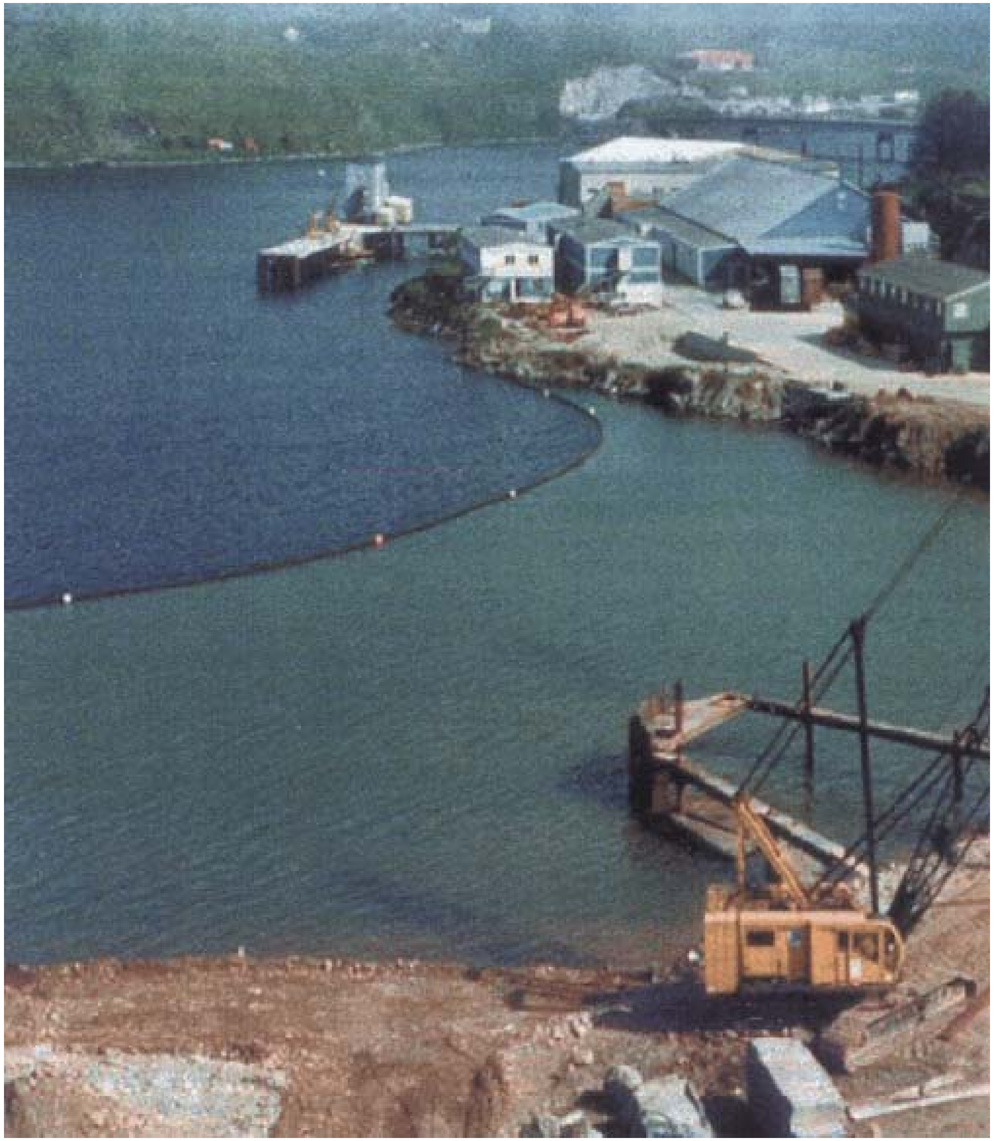
The Birth of the Boom

- **1986**
- **Alaska**
- **Harbor development**
- **Dredge spoil disposal**
- **Sediments and construction debris**



Particulate Control System (PCS™)

Waterfront construction site



GUNDERBOOM

Particulate Control System (PCS™)

Creosote contaminated dredge site

GUNDERBOOM

Beach Protection System (BPS™)

GUNDERBOOM

Reservoir Protection System (RPS^{TM})

Results

Turbidity:	20 NTUs	1 NTU
Coliforms:	> 2400 MPN	22 MPN
TSS:	9.9 mg/l	0.7 mg/l

GUNDERBOOM

Marine Life Exclusion System (MLES^{TM})

Created to exclude all life stages of target aquatic organisms from industrial cooling water intakes preventing entrainment and impingement.

Clean Water Act, Section 316(b) Compliance

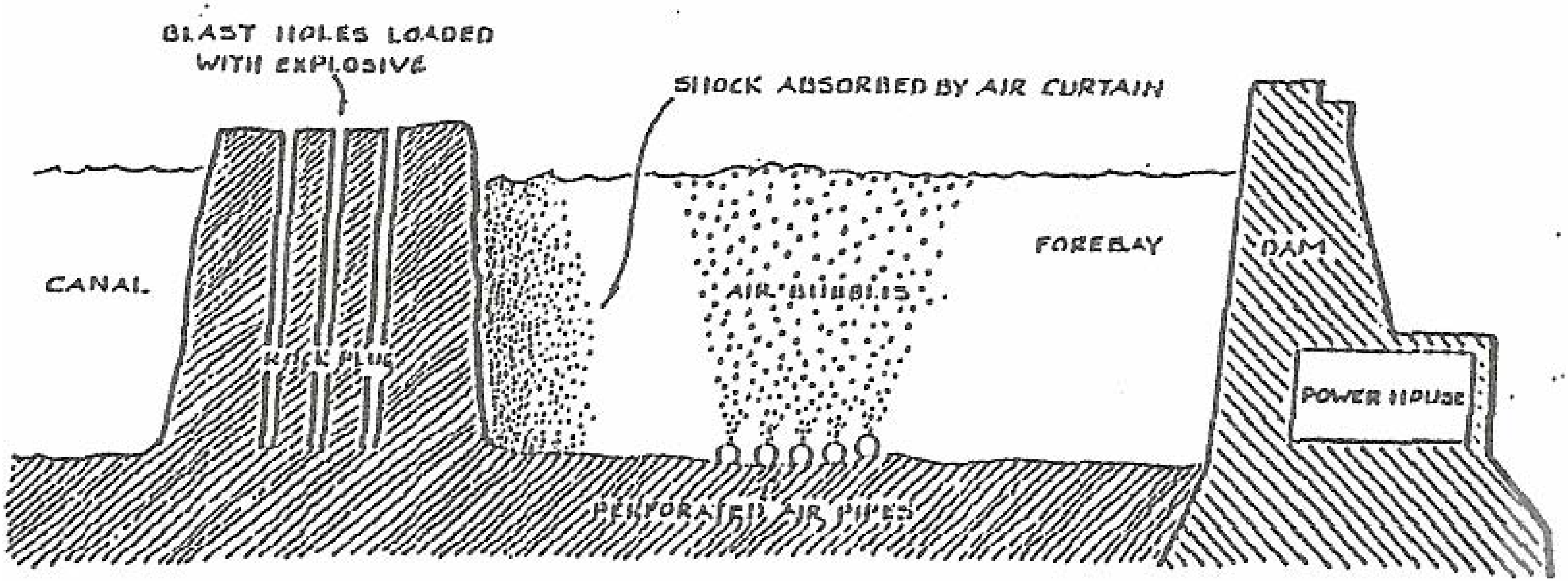
Sound Attenuation System (SAS^{TM})

Designed to mitigate damaging effects of sound and pressure waves produced by underwater construction and demolition activities.

Air Bubble Curtain Technology

- Developed and patented in Canada in 1955.
- Consists of multiple rings of single bubbles rising through the water column.
- Overpressures reduced by 90%

Air Bubble Curtain Patent Drawing



Air Bubble Curtain Research and Development

Size of bubbles is important.
Frequency and bubble size are inversely related.

Flux and integrity of curtain are critical.
Tidal currents can disperse bubbles.

Porous mediums absorb energy and attenuate sounds.

Environmental Impact of Seismic Exploration and Blasting in the Aquatic Environment

Lance Trasky, Conastal Habitat Protection Alaska Dept. of Fish and Game

“Underwater explosions produce shock waves and bubble pulse waves.”

“Overpressure from shock waves are harmful to marine mammals and fish.”

“The shock wave is propagated through water as a pulse of compression.”

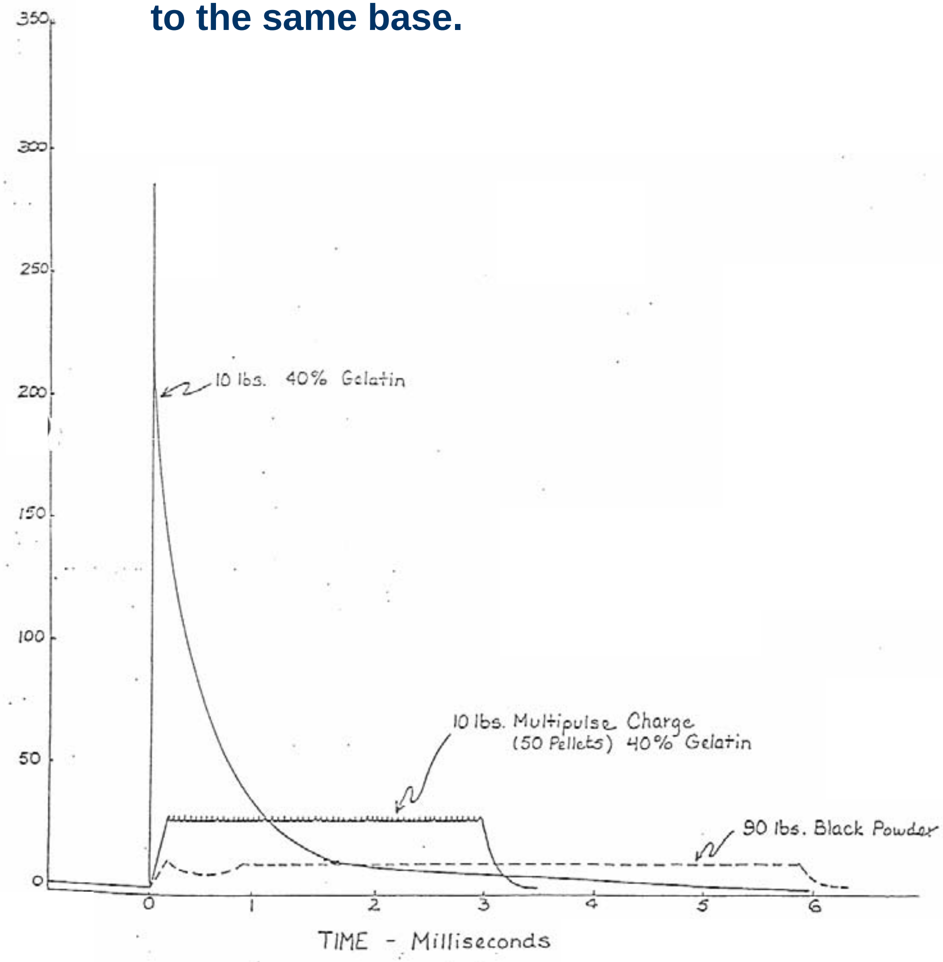
“The leading front of compression wave is steep or gentle, depending on the source.”

“The lethal threshold pressures for high velocity explosives vary from 40 - 50 psi.”

“The lethal threshold pressures for low velocity explosives, such as black powder, are as high as 124 - 160 psi.”

Comparative Pressure/Time Curves for Explosives

Pressure time curves for ten pounds of 40% gelatin, 40 pounds of multipulse and 90 pounds of black powder, computed to the same base.

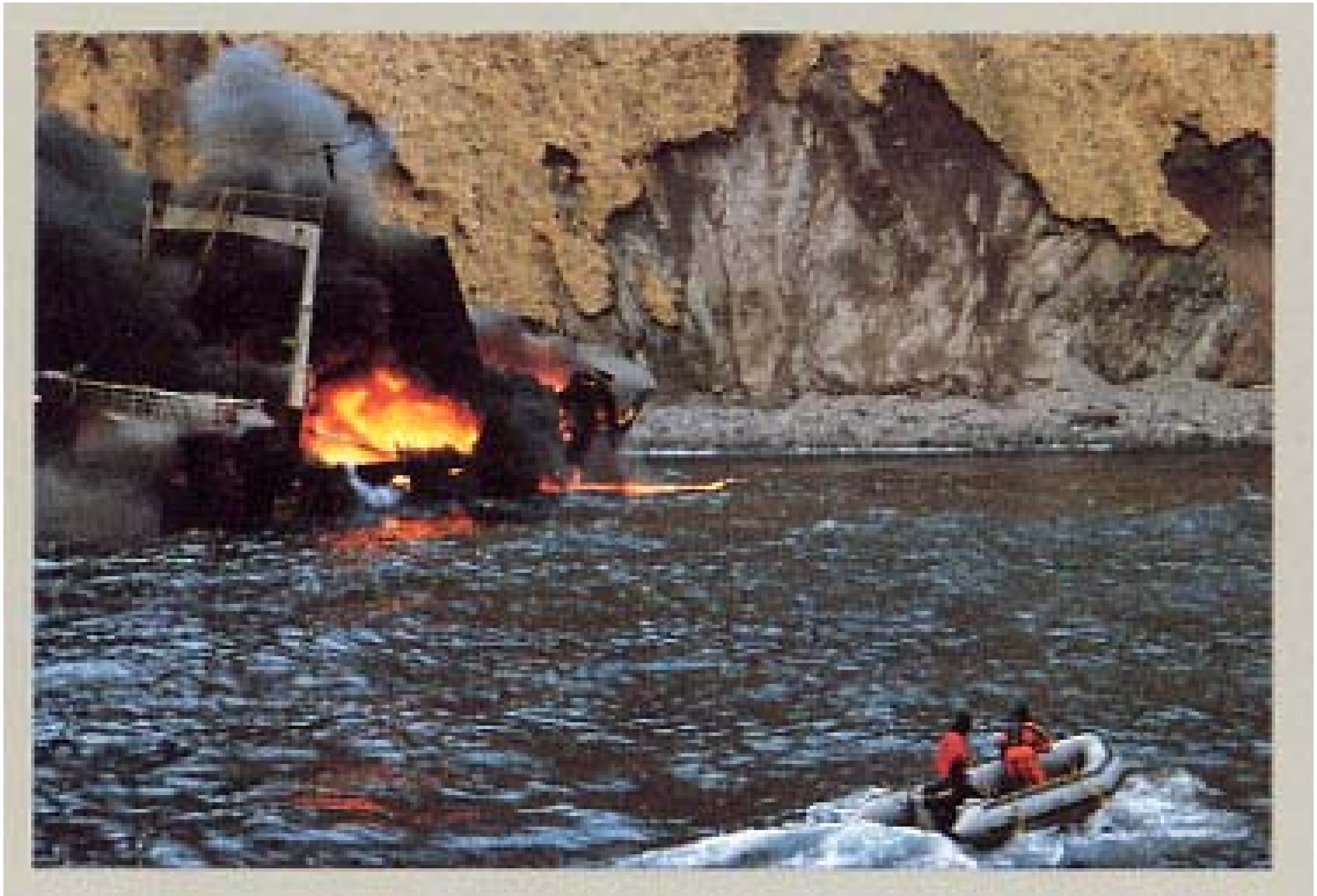


Related SAS^{TM} Experience

- Alaskan Marine Construction/Demolition
  - Vessel Removal, Pipeline Trenching, Harbor Deepening

- Underwater activities were surrounded by an SAS^{TM} to contain the associated sound and pressure waves.

Alaskan Marine Construction/Demolition



GUNDERBOOM

Vessel Demolition and Fuel Removal

GUNDERBOOM

Pipeline Trenching

GUNDERBOOM

Location: Oakland Bay, Calif.

Problems:

- **Concussive force of driving 8 ft diameter piles deleterious to fish populations.**
- **Damaging affects occur at 190 dB for marine mammals, fish, as low as 170 dB for fish with swim bladders.**

GUNDERBOOM

GUNDERBOOM^{TM} Sound Attenuation Framed-Support Assembly

MENCK MHU 1700 ~1.2 Million Ft Pounds Hammer for Driving 8’ Piles

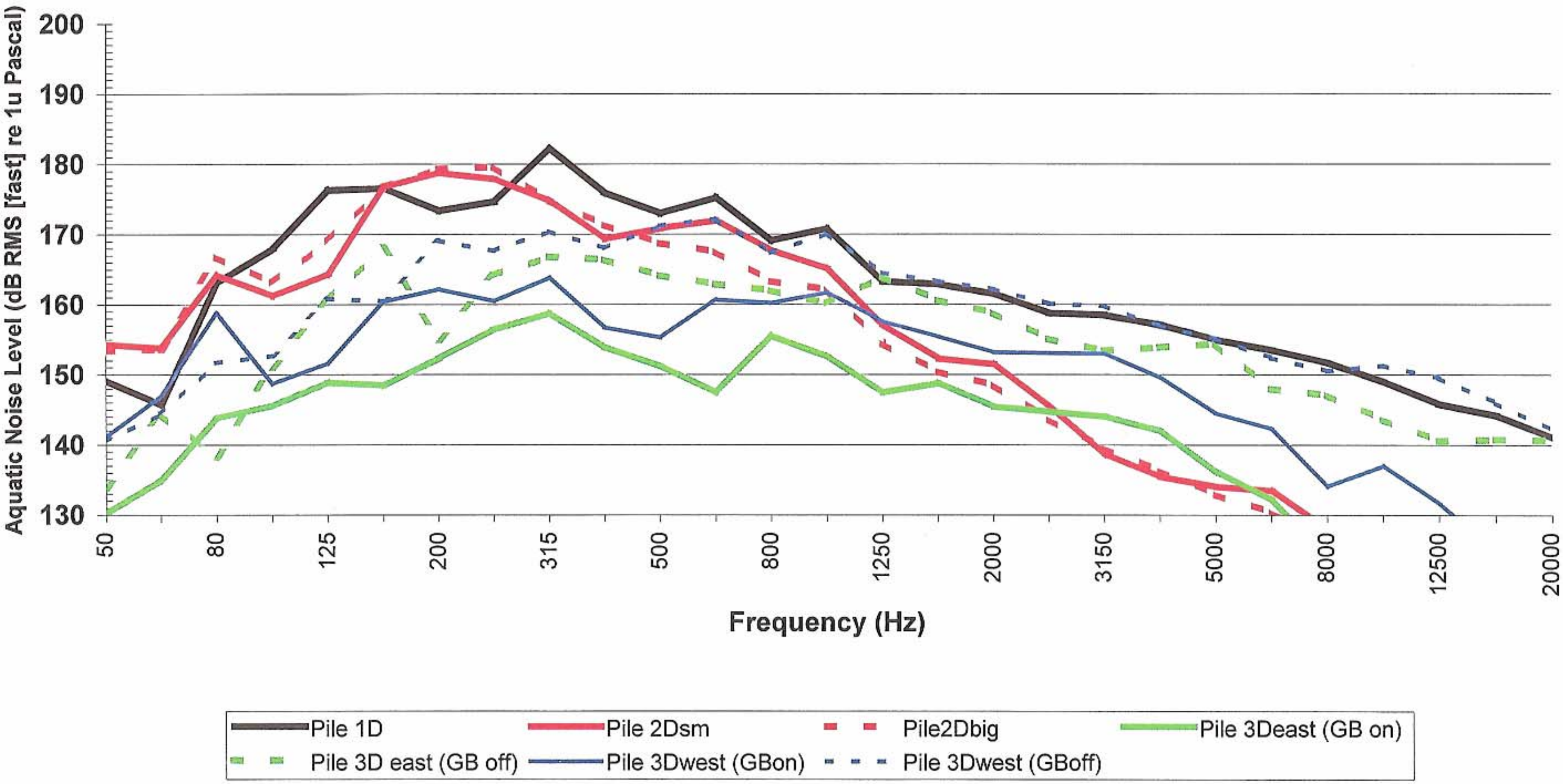
GUNDERBOOM

Top view of installed system

GUNDERBOOM

Operational View

Figure 8. Summary of Representative Underwater Noise Spectra

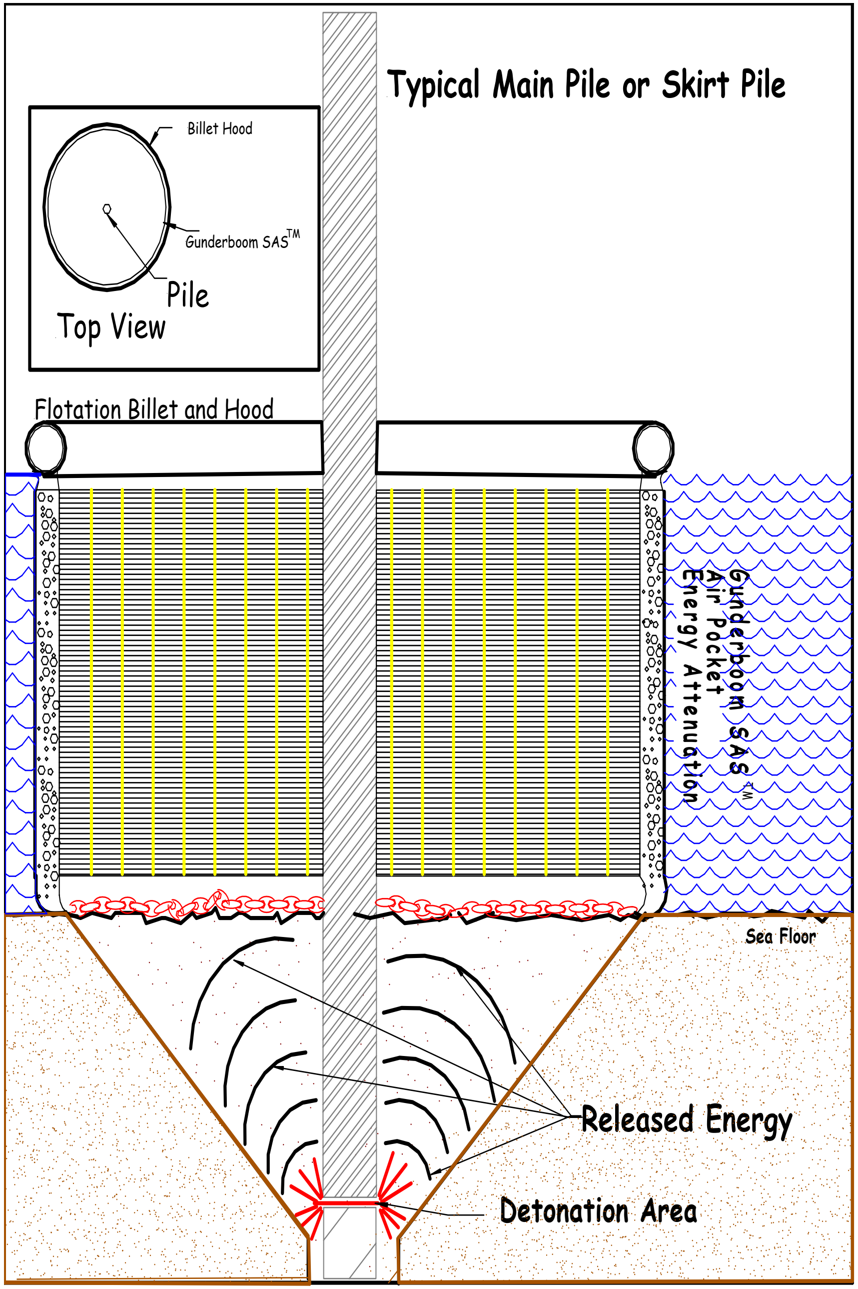


Performance of Caltrans GUNDERBOOM System

Distance from Hammer (M)	Observed Sound, No Attenuation (dB)	Observed Sound, No Attenuation (Pa)	Observed Sound, Gunderboom Installed (dB)	Observed Sound, Gunderboom Installed (Pa)	Sound Reduction with Gunderboom (dB)	% Reduction Linear Scale
95	197	7079	Air On: 175	562	22	92%
			Air Off: 184	1585	13	78%
110	195	5623	Air On:172-175	398	20	93%
			Air Off: 179	891	16	84%
500	173.5	473	Air On: 160	100	13.5	79%

GUNDERBOOM

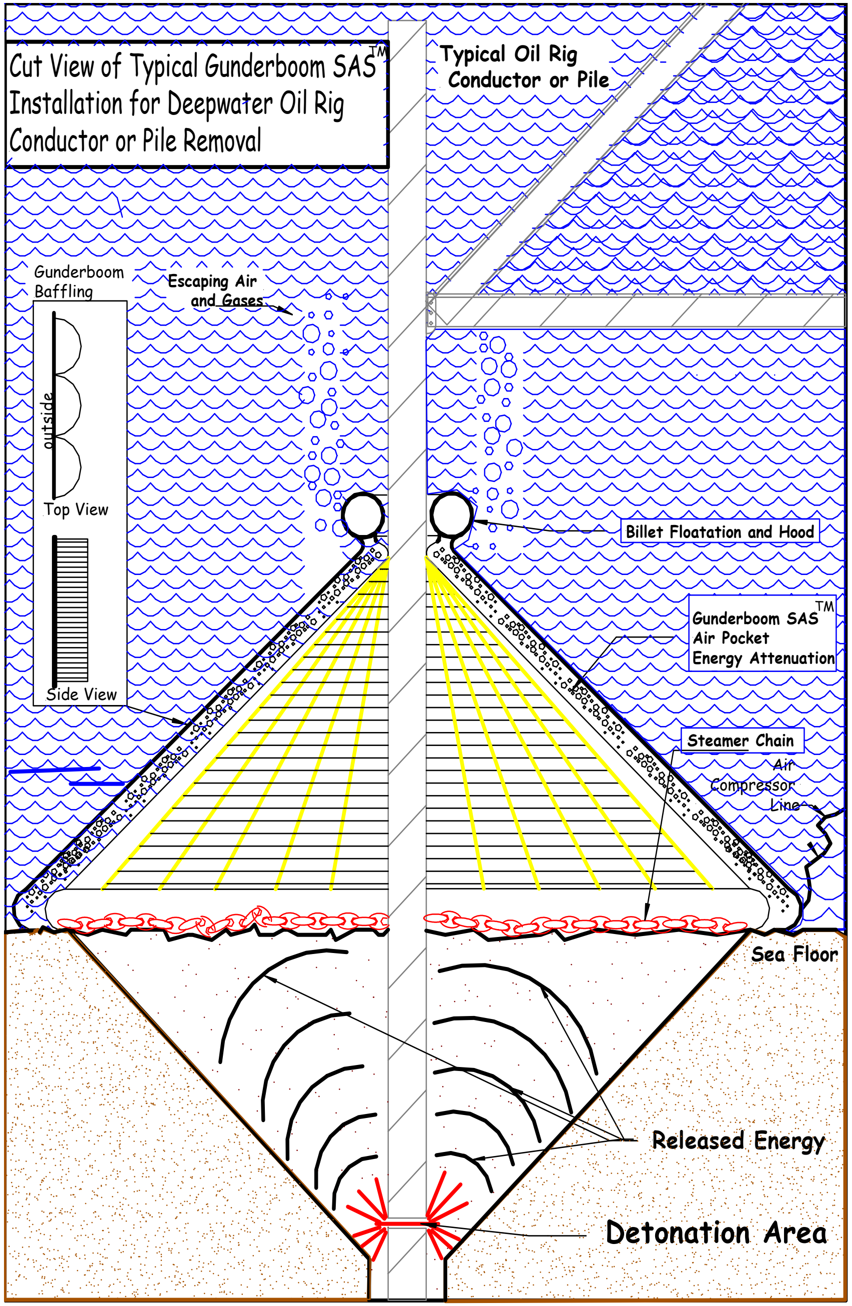
Platform Removal Application Concept



Full-water depth floating barrier system

GUNDERBOOM

Platform Removal Application Concept



Submerged, fixed-barrier system

Technology Application Summary

- **Effective suppression of explosive shock waves.**
- **Demonstrated attenuation of sound energy.**
- **Adaptable for various applications, frequencies and pressure ranges.**
- **Low cost in relationship to suppression and attenuation levels achieved.**
- **NEXT STEP: Testing and pilot demonstrations**

GUNDERBOOM

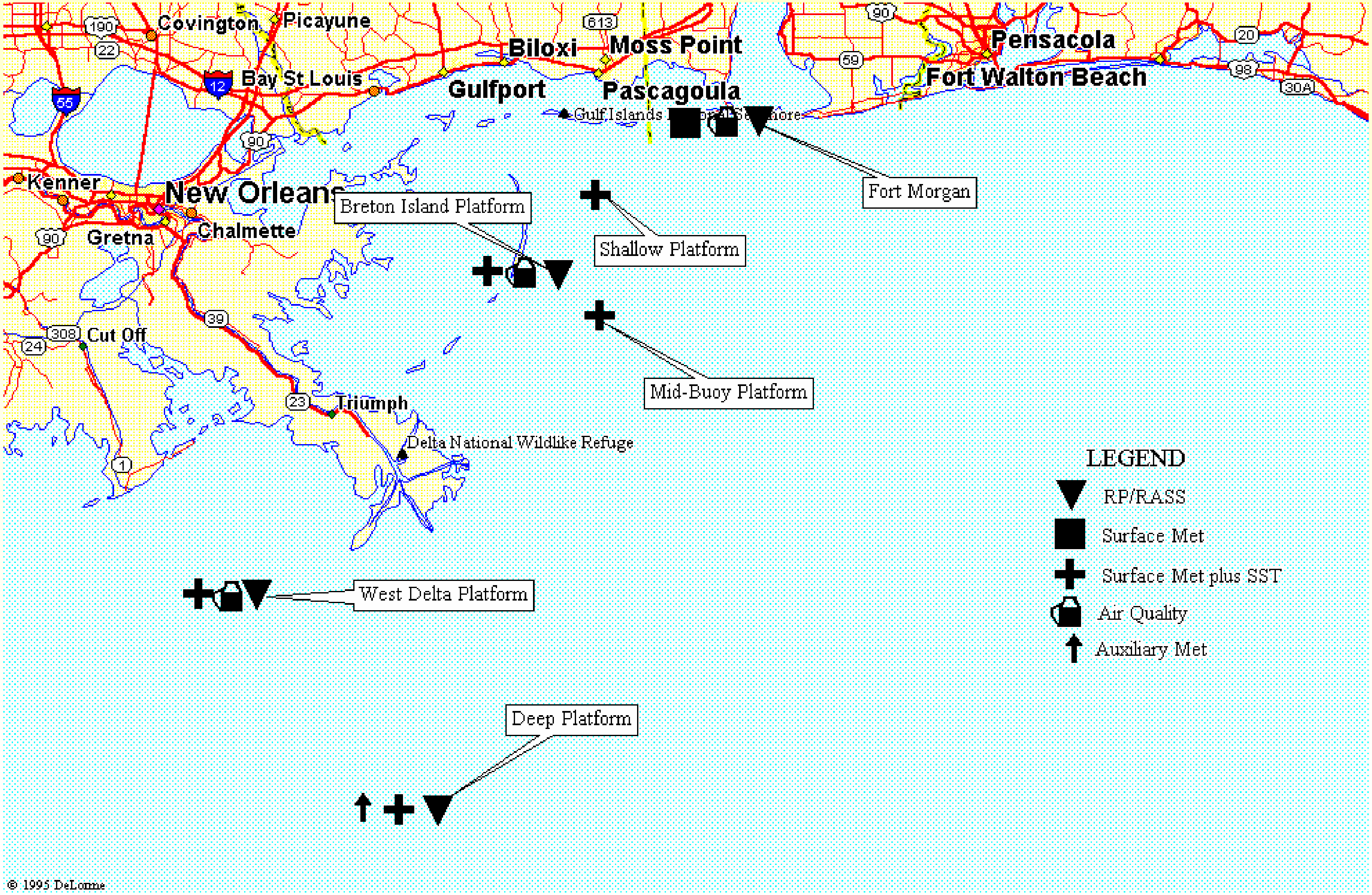
BAMP Phase II Data Analysis

Mr. Brian E. Shannon

b.e.shannon/ENVIRONMENT.Consultant

Dianne S. Miller
Clinton P. MacDonald
Paul T. Roberts
Sonoma Technology, Inc.
Petaluma, CA

Data – Site Map



© 1995 DeLorme

Sonoma Technology, Inc.

Data – Web Site

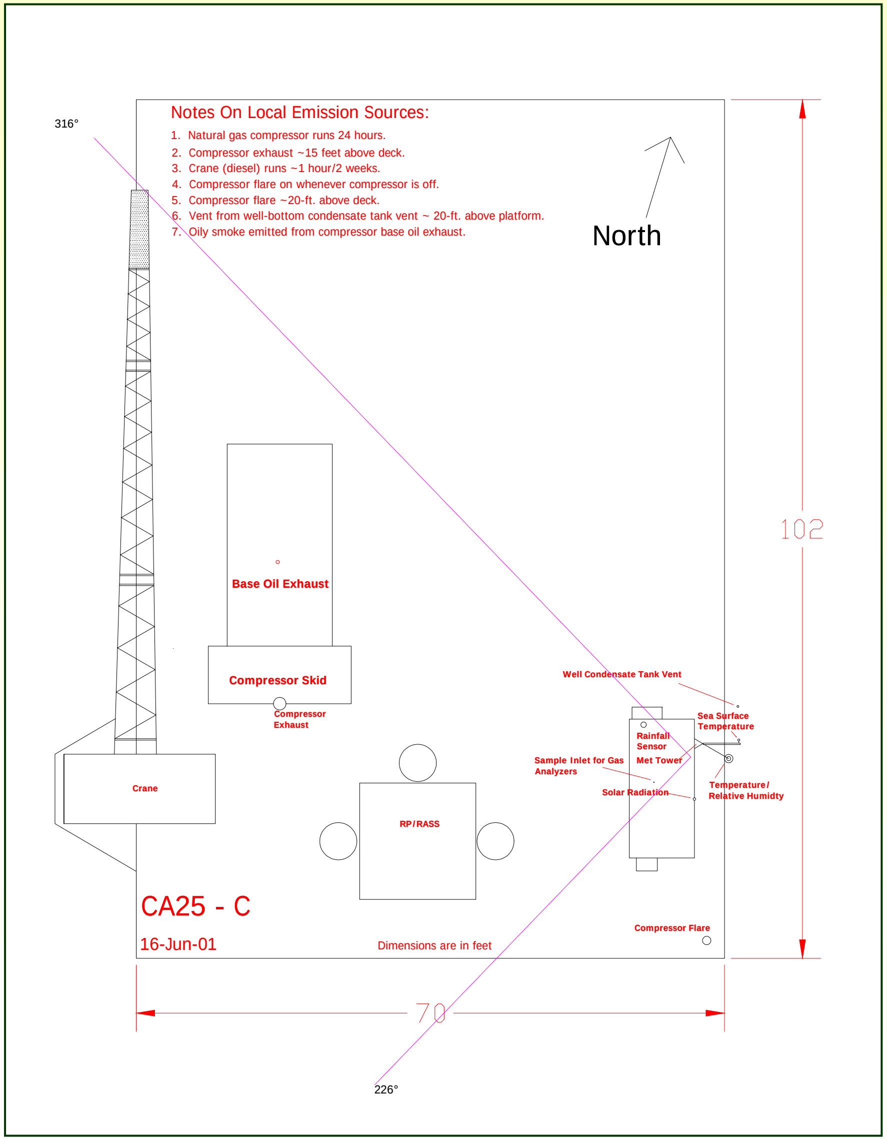
http://www.sonomatech.com/BAMP

- Username: BampTeam
- Password: GoBamp

Available items:

- Request for Proposal
- Draft Collection Plan
- Monthly Level 1 QC databases
- Monthly and Interim reports
- Image Viewer to View Data
- Field and Data Report (July 2002)
- Interim Data Analysis Presentation
- Final Data Analysis Presentation and Executive Summary

Data – Air Quality, Quality Control



Notes On Local Emission Sources:

1. Natural gas compressor runs 24 hours.
2. Compressor exhaust ~15 feet above deck.
3. Crane (diesel) runs ~1 hour/2 weeks.
4. Compressor flare on whenever compressor is off.
5. Compressor flare ~20-ft. above deck.
6. Vent from well-bottom condensate tank vent ~ 20-ft. above platform.
7. Oily smoke emitted from compressor base oil exhaust.

BIP layout

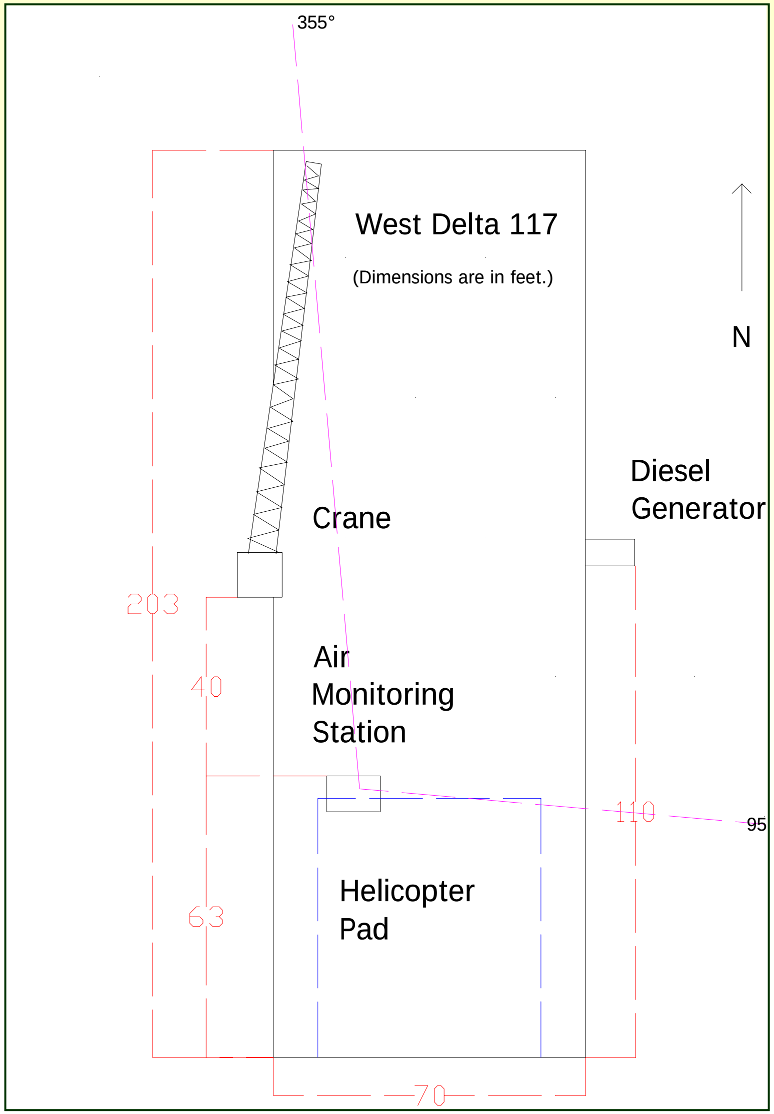
Data – Air Quality, Quality Control

NO_y pollution rose analysis showed platform influence during the following conditions:

Site	Wind Dir.
BIP	226°-316°
WDP	355°-95°

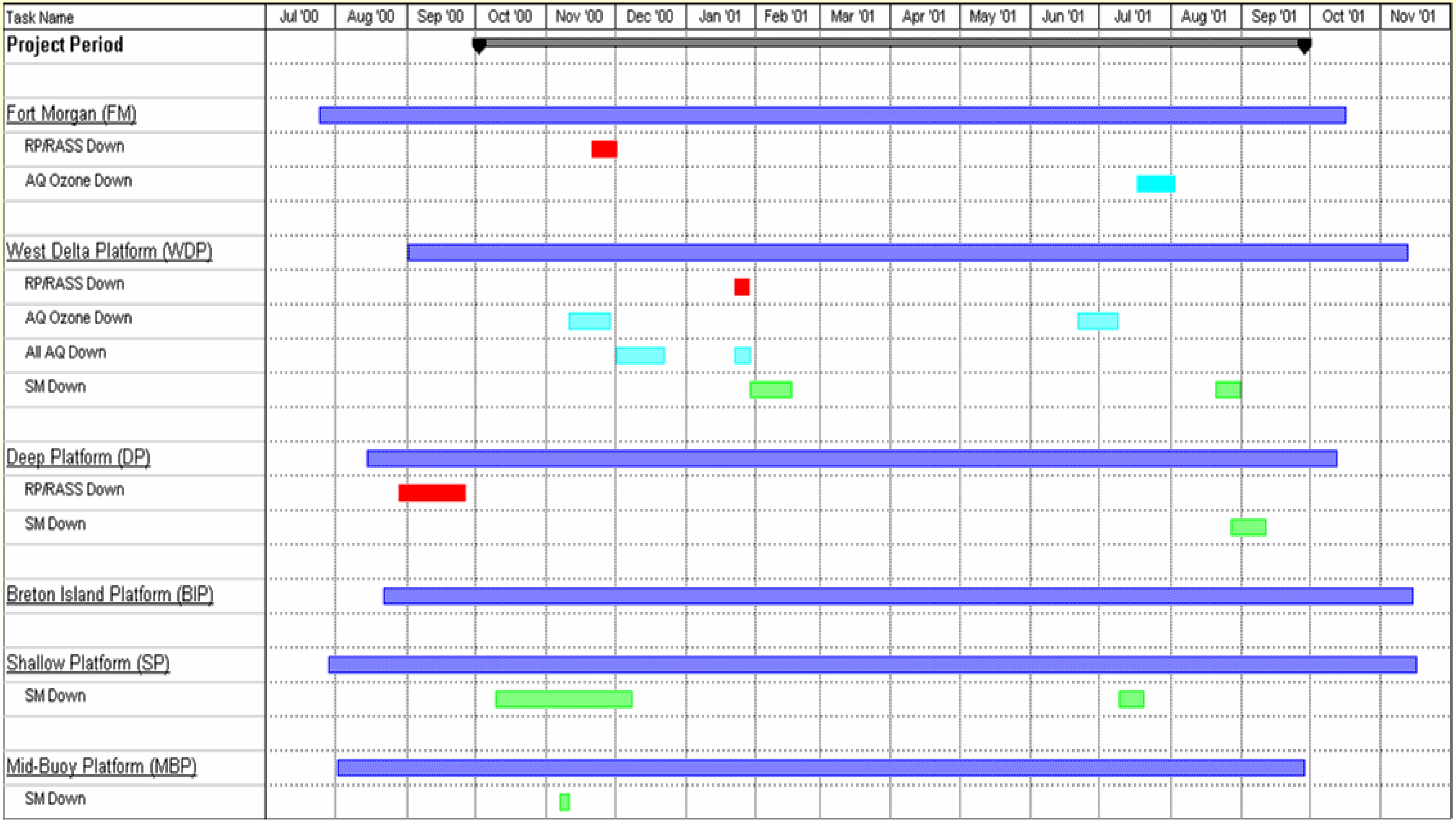
Initially, all AQ data was flagged suspect within this wind direction range.

Data – Air Quality, Quality Control



WDP layout

Data – Site Up/Down Times



Data – Surface Meteorology

Sites

- BIP, DWP, FTM, MBP, SWP, and WDP

Variables

- T, T_d, WS, WD, RH, P, SST, WS_v, rain, and solar radiation
- Hourly data

Duration

- Data collected from August 2000 through November 2001
- Official study period was October 2000 through September 2001

Data – Surface Meteorology

% Data Capture	
Site	**Surface Met (%)**
FTM	97.6
BIP	98.1
WDP	88.0
DWP	93.6
SWP	75.1 (90.9)*
MBP	84.5

* SWP monitor was dismantled for 64 days from October 2000 through December 2000. The data capture rate excluding these days was 90.9%.

% Data Recovery

Site	WS	WD	T	RH	SST	P	WS_v	SDWS_v	Rain	SolRad
BIP	85.9	85.9	100.0	100.0	99.9	100.0	4.9	4.9	100.0	100.0
DWP	78.3	78.3	91.9	76.3	79.7	91.9	5.4	6.8	100.0	91.9
FTM	94.2	94.2	100.0	100.0	N/A	100.0	99.9	99.9	95.7	94.2
MBP	90.4	90.4	99.7	99.6	99.4	100.0	0.0	0.0	99.9	100.0
SWP	100.0	89.4	99.6	99.8	32.3	100.0	0.0	0.0	99.8	99.5
WDP	57.1	57.1	99.7	100.0	72.3	100.0	24.3	24.3	99.2	99.5

WS_v and SDWS_v recovery rates were low at all sites except FTM. Data values were consistently higher than normal, which is believed to be caused by exhaust vents on the platforms.

Data – Upper-Air Meteorology

Sites

- BIP, DWP, FTM, WDP

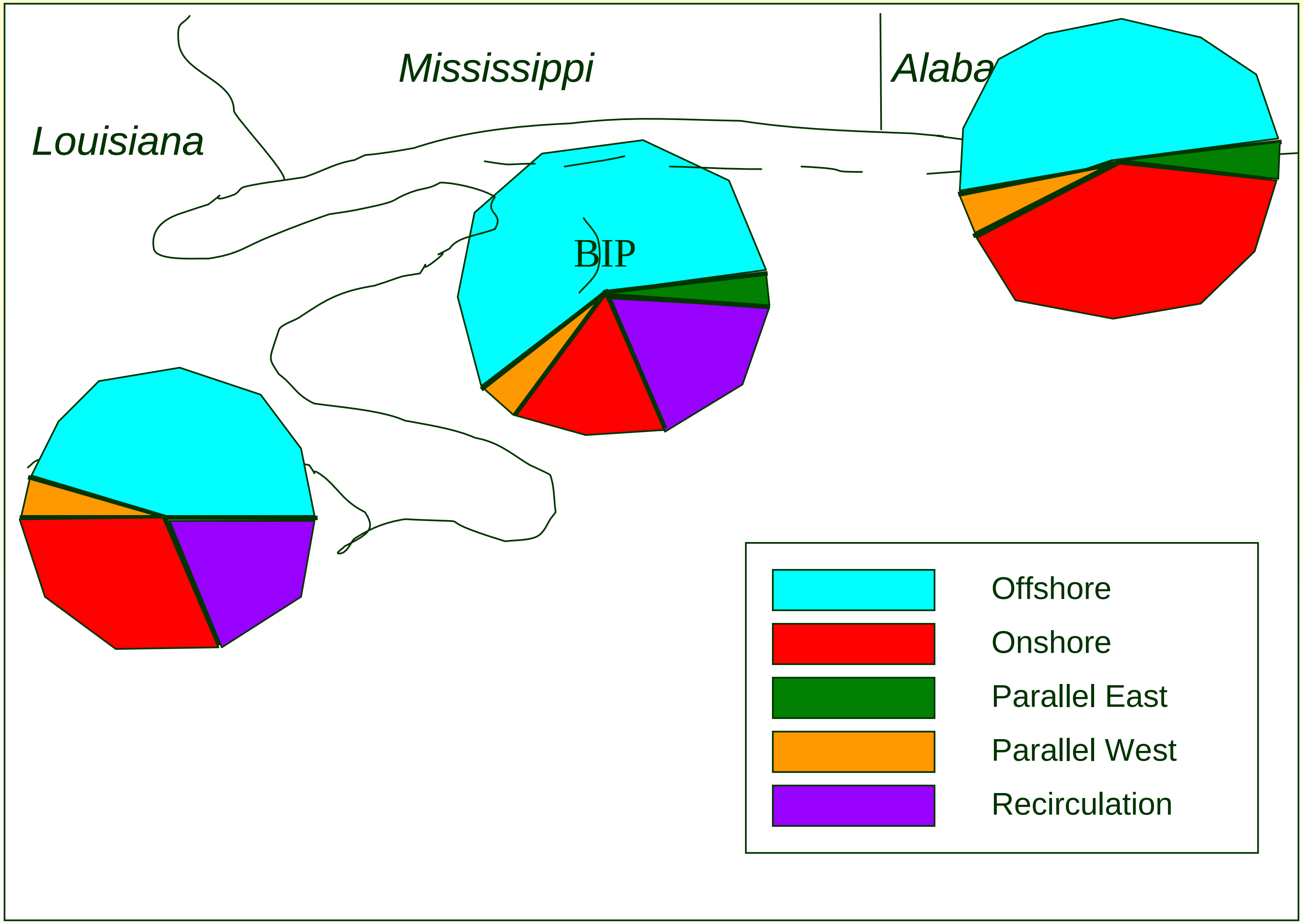
Variables

- Radar Wind Profiler (RWP)
  - RWS, RWD, C_n^2, and w;
- Radio Acoustic Sounding System (RASS)
  - T_v and w
- Hourly data

Duration

- Data collected from August 2000 through November 2001
- Official study period was October 2000 through September 2001

Analysis – Statistical, Meteorology



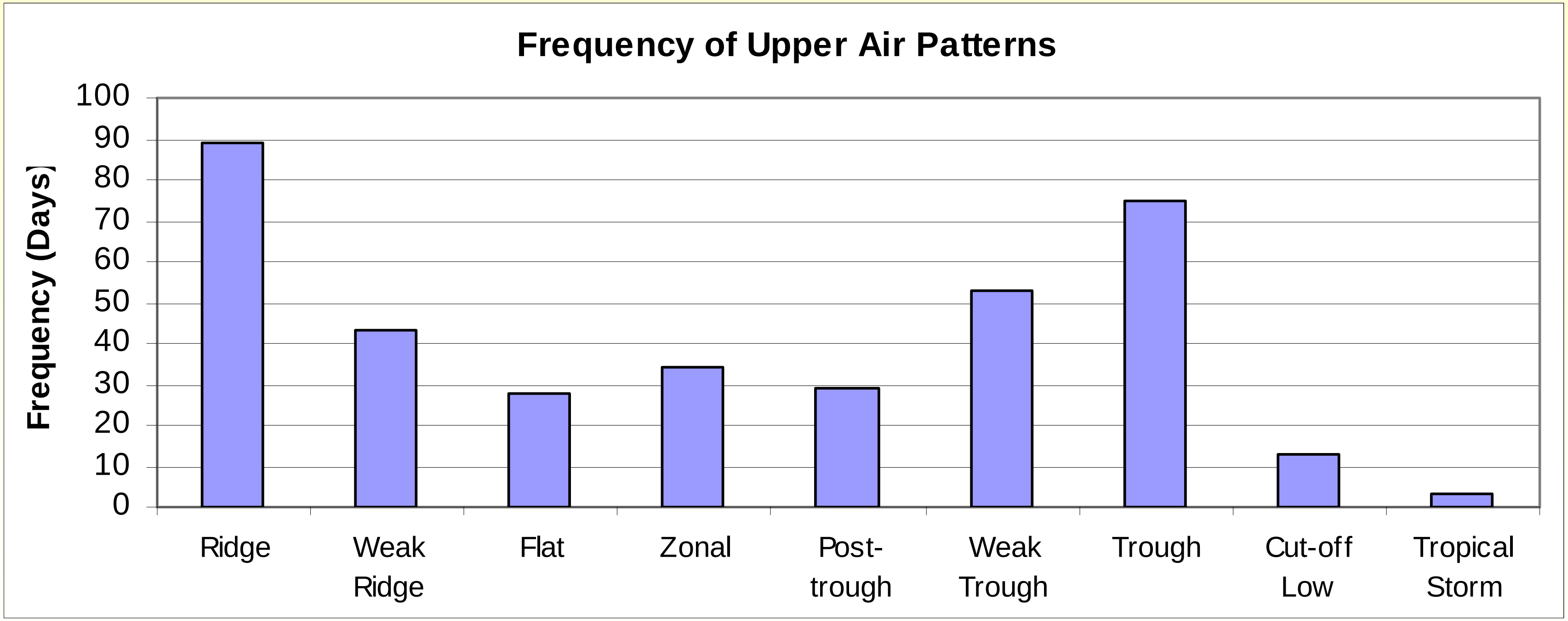
Data – Upper-Air Meteorology

RWP and RASS Data Capture Rates

% Data Capture		
Site	**Upper-air Winds (%)**	**Upper-air T_v (%)**
FTM	**92.3**	**93.3**
BIP	**97.1**	**97.4**
WDP	**94.0**	**94.2**
DWP	**96.9**	**97.5**

Analysis – Statistical, Meteorology

Results – upper-air pattern



Sonoma Technology, Inc.

Data – Air Quality

Sites

- FTM, BIP, WDP

Variables

- O_3, NO, NO_y, and SO_2
- Hourly data

Duration

- Data collected from August 2000 through November 2001
- Official study period was October 2000 through September 2001

Data – Air Quality

Data Statistics from October 2000 through September 2001

Data Capture = (Number of records received) / (Number of records possible) * 100

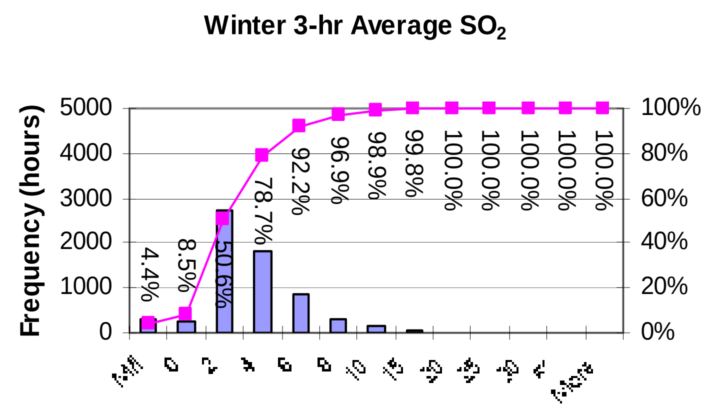
Data Recovery = (Number of valid records) / (Number of records received) * 100

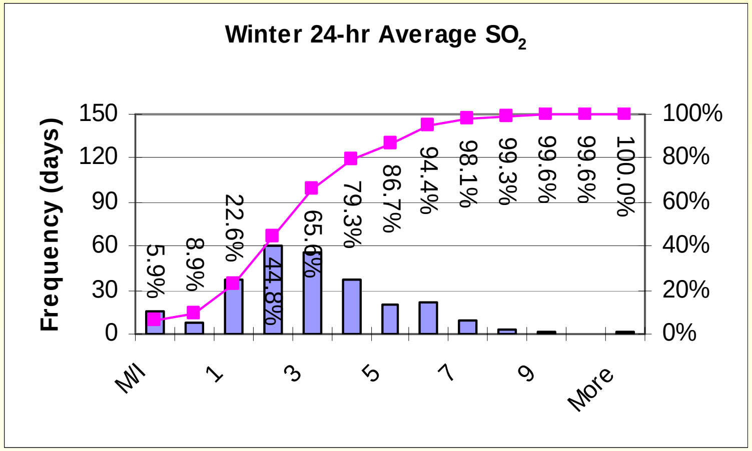
% Data Capture				
	NO	**NO_y**	**O_3**	**SO_2**
BIP	**98.0**	**97.6**	**99.5**	**97.6**
FTM	**100.0**	**100.0**	**100.0**	**100.0**
WDP	**99.2**	**98.9**	**99.7**	**99.7**

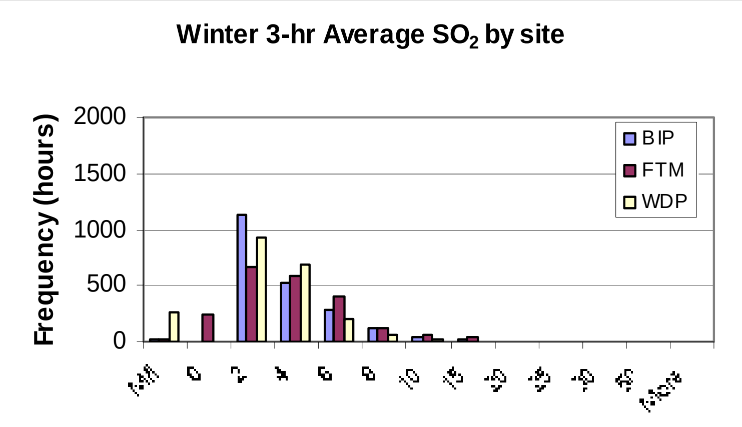
% Data Recovery				
	NO	**NO_y**	**O_3**	**SO_2**
BIP	**92.5**	**92.5**	**99.2**	**99.6**
FTM	**98.3**	**98.3**	**95.8**	**99.6**
WDP	**96.8**	**96.8**	**72.8**	**99.7**

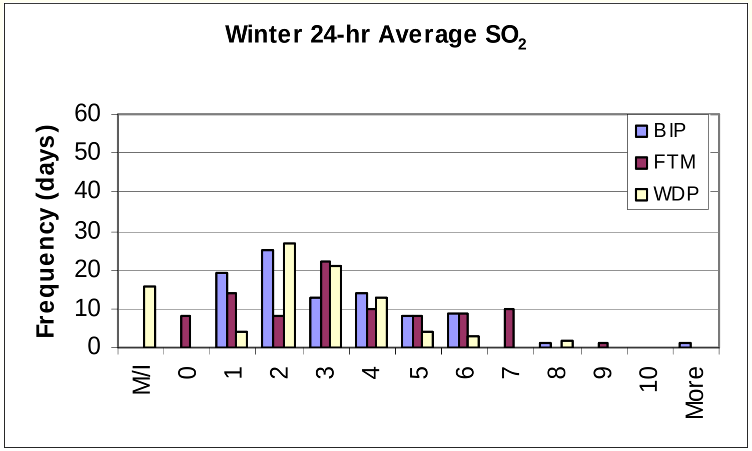
NAAQS 140 ppb (24-hr), 500 ppb (3-hr)

Class I PSD Increment 2 ppb (24-hr), 10 ppb (3-hr)



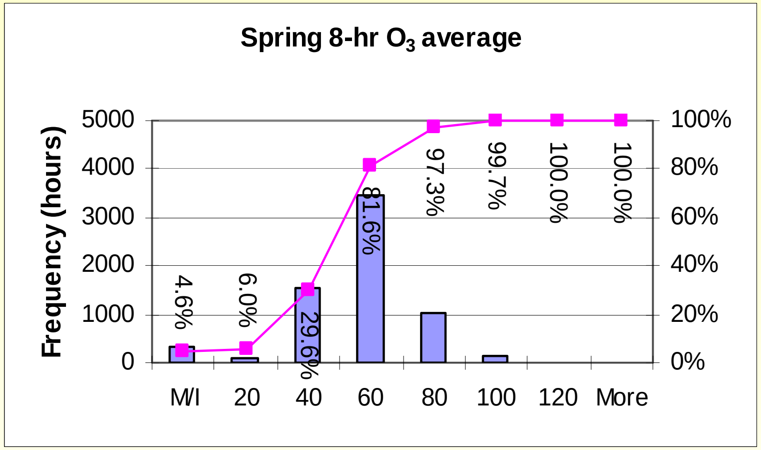




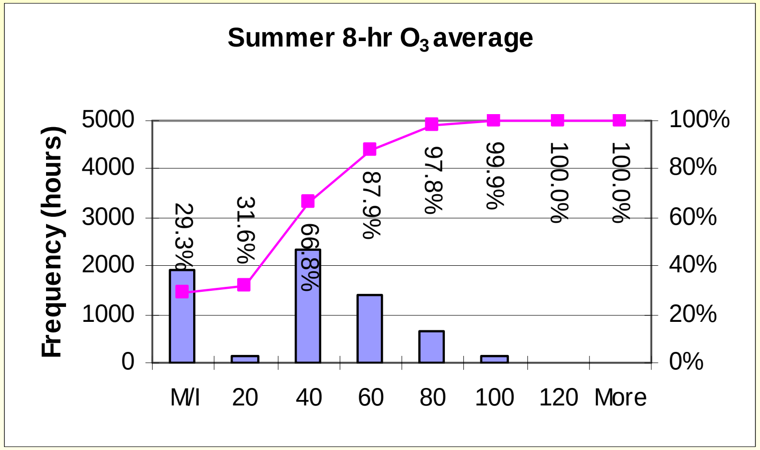


Sonoma Technology, Inc.

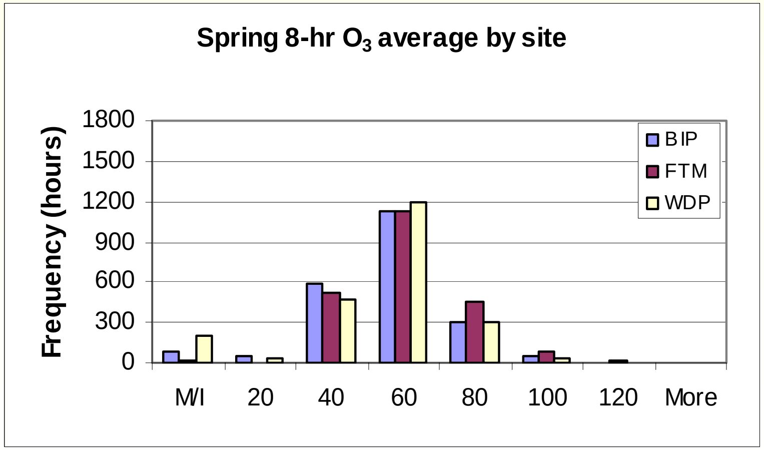
NAAQS 124 ppb (1-hr), 84 ppb (8-hr)



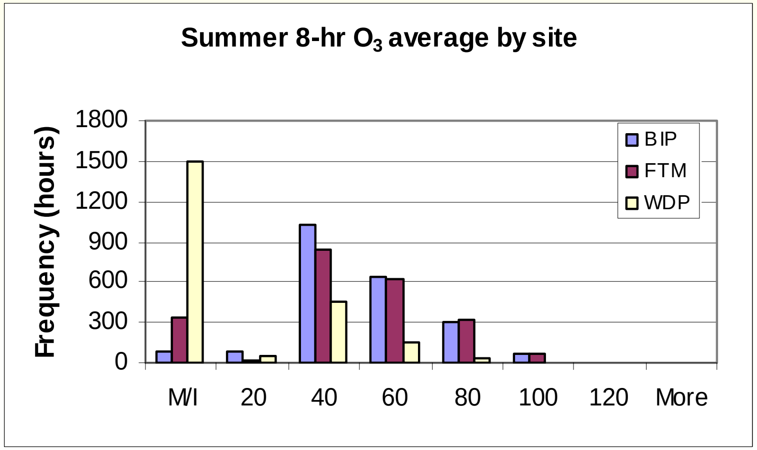
Spring 8-hr O_3 average



Summer 8-hr O_3 average

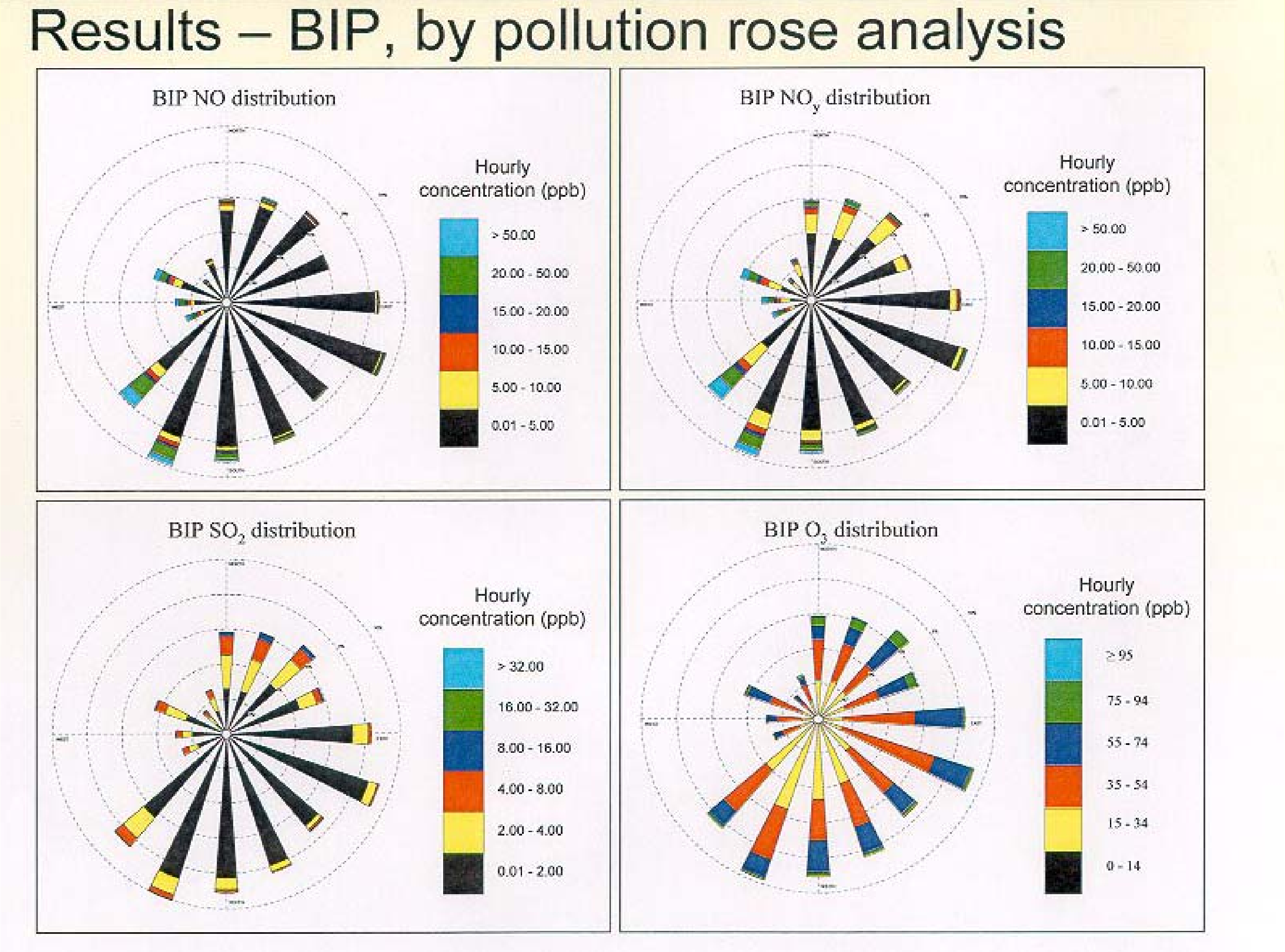


Spring 8-hr O_3 average by site



Summer 8-hr O_3 average by site

Analysis – Statistical, Air Quality and Meteorology



Results – BIP, by pollution rose analysis

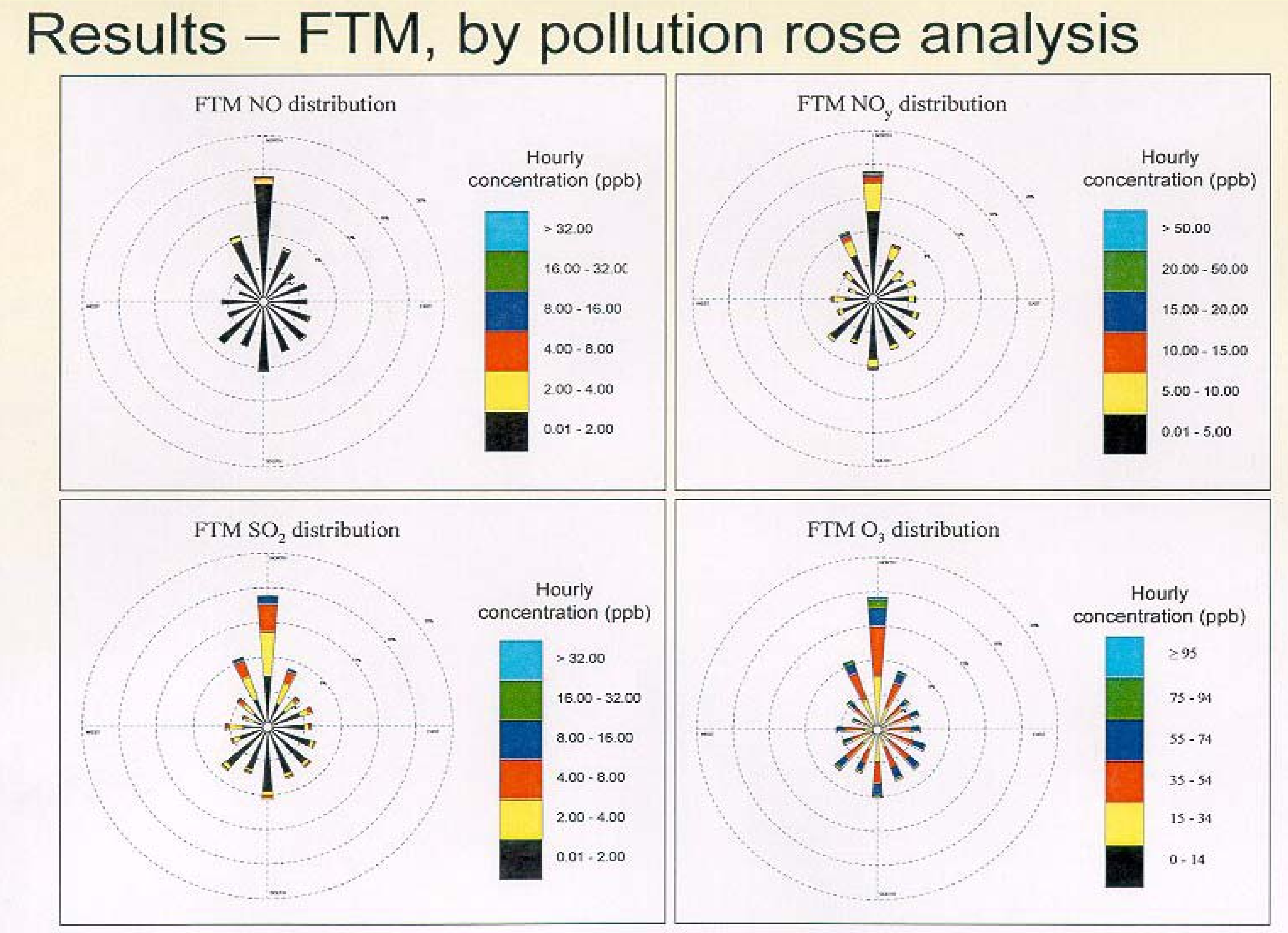
BIP NO distribution

BIP NO_y distribution

BIP SO_2 distribution

BIP O_3 distribution

Analysis – Statistical, Air Quality and Meteorology



Results – FTM, by pollution rose analysis

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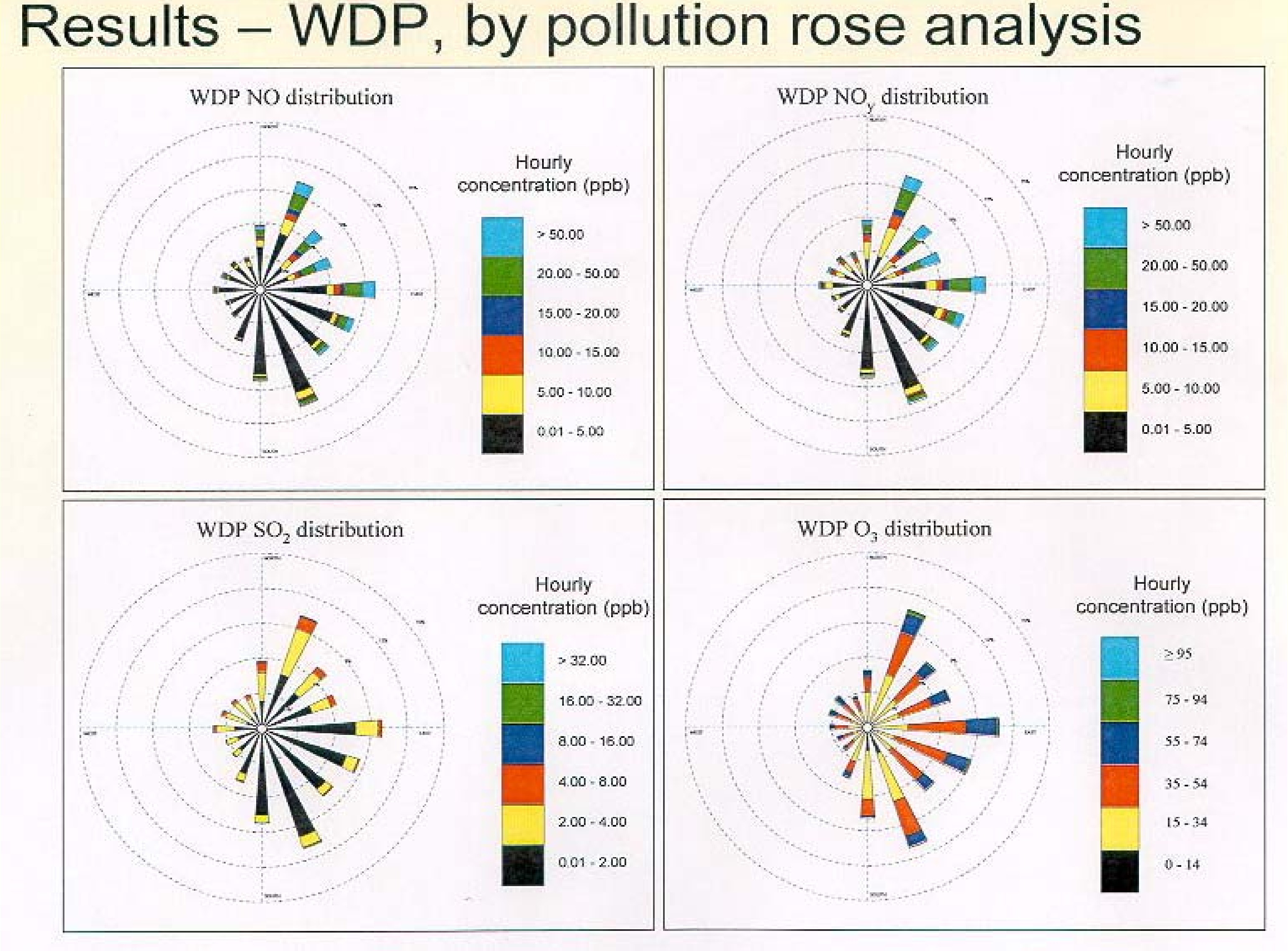
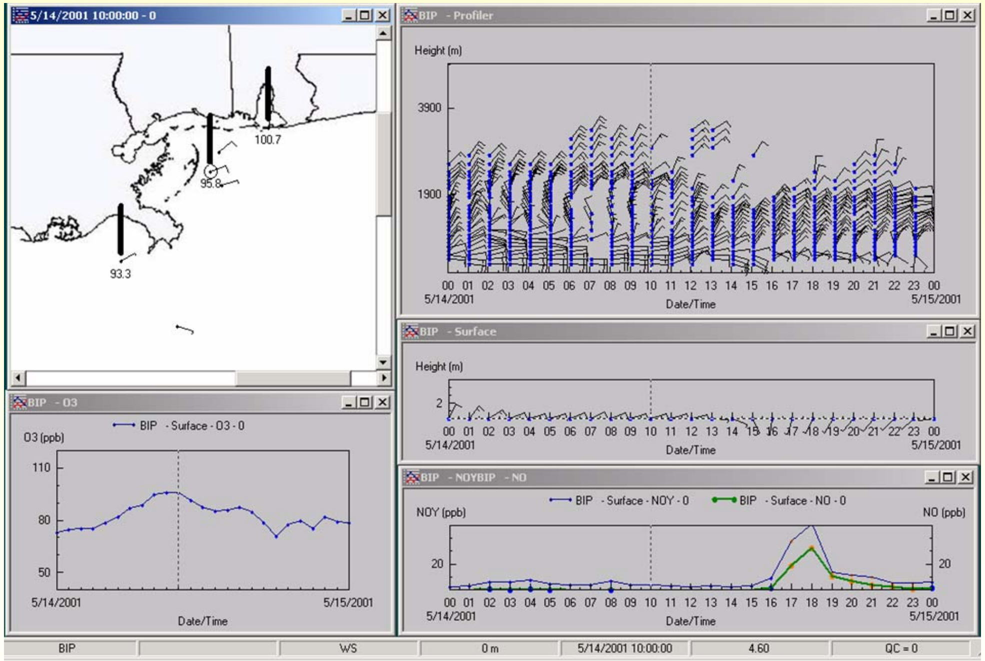
Analysis – Statistical, Air Quality and Meteorology



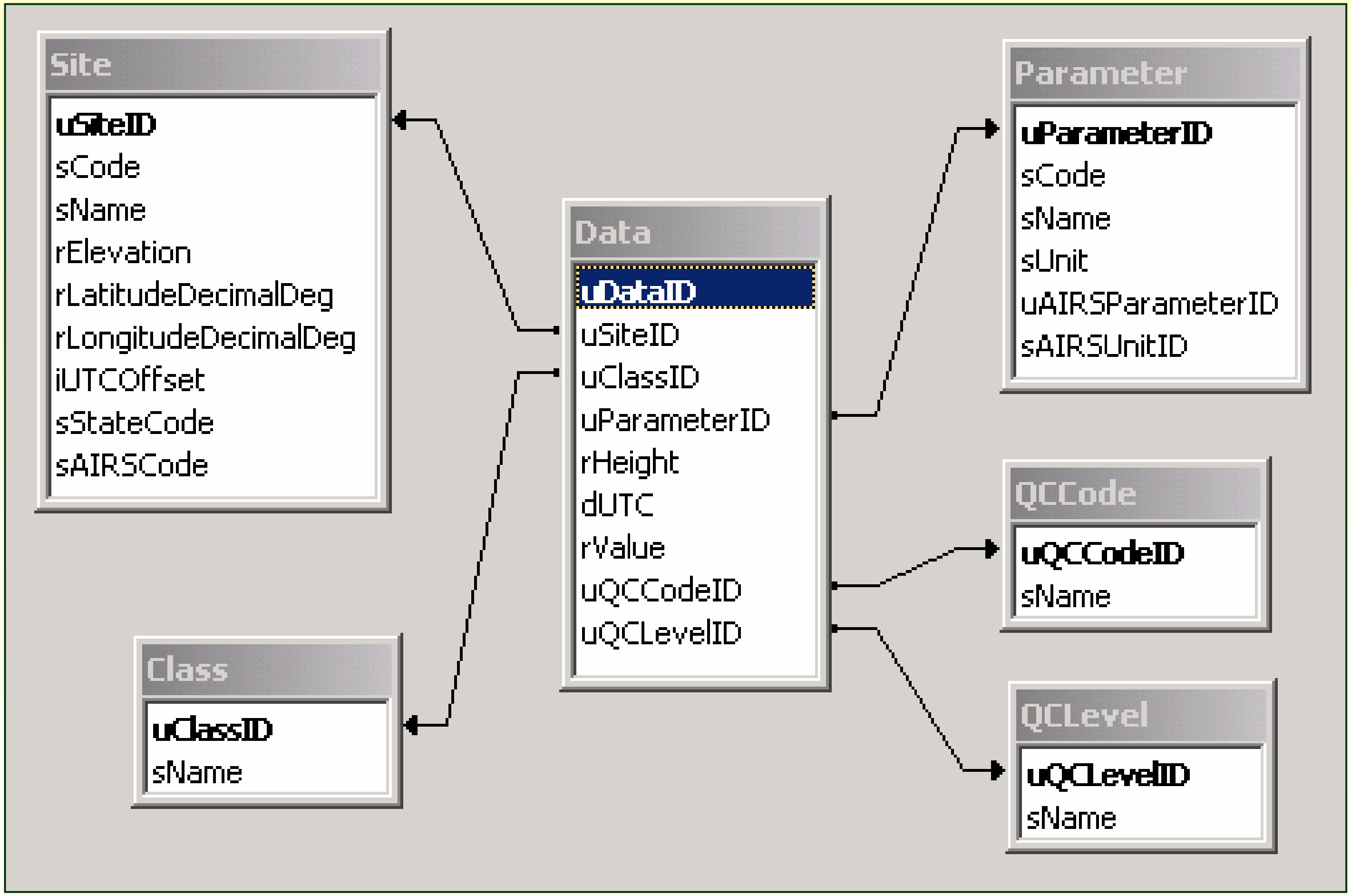
Results – WDP, by pollution rose analysis

Data – EDAT

- **Displays BAMP data including the profiler/RASS, surface meteorological, and air quality data sets.**
    - **time series**
    - **time-height cross-sections**
    - **vertical profiles**
    - **spatial plots**
    - **images**
- **Exports to EPA's WRLPlot wind rose program**
- **Reads from a Microsoft Access or Microsoft SQL Server database**



Database – Structure



Site
uSiteID
sCode
sName
rElevation
rLatitudeDecimalDeg
rLongitudeDecimalDeg
iUTCOffset
sStateCode
sAIRSCode

Data
uDataID
uSiteID
uClassID
uParameterID
rHeight
dUTC
rValue
uQCCodeID
uQCLevelID

Parameter
uParameterID
sCode
sName
sUnit
uAIRSParameterID
sAIRSUnitID

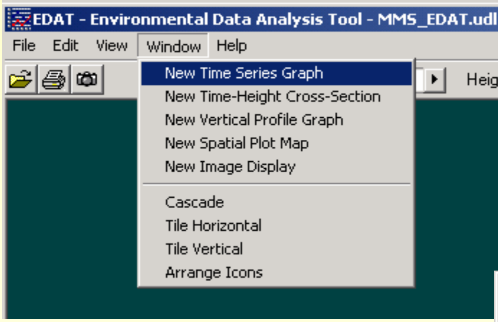
QCCode
uQCCodeID
sName

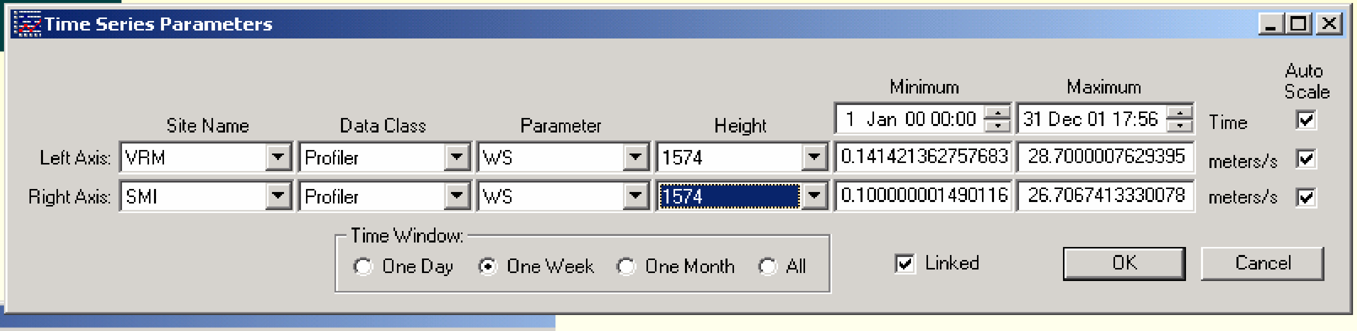
QCLevel
uQCLevelID
sName

Class
uClassID
sName

Data – EDAT

Example process for producing a time series plot

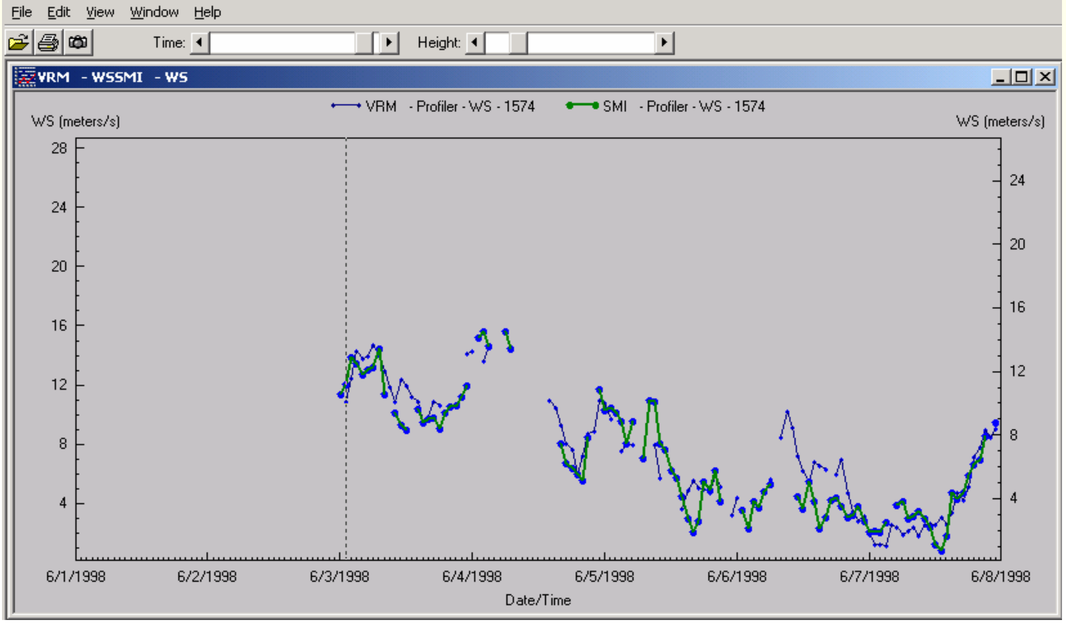



Time Series Parameters

	Site Name	Data Class	Parameter	Height	Minimum	Maximum		Auto Scale
					1 Jan 00 00:00	31 Dec 01 17:56	Time	☑
Left Axis:	VRM	Profiler	WS	1574	0.141421362757683	28.7000007629395	meters/s	☑
Right Axis:	SMI	Profiler	WS	1574	0.100000001490116	26.7067413330078	meters/s	☑

Time Window: ○ One Day ● One Week ○ One Month ○ All

☑ Linked



Data statistics: Summary

- Surface meteorology
  - Recovery rates were low at most sites for WS_v and $sdWS_v$ because the data values were unusually high. It is believed the sensors were located over exhaust vents or something that could cause a constant updraft.
  - Recovery rates were lower than expected for wind speed and direction at WDP because the sensor failed an audit, so several months of data were suspected.
  - Recovery rates were lower than expected for wind speed and direction at DWP because the sensor was missing a component arm for several months.
- RWP recovery rates
  - Ideal rates are 80% at 1500 m and 50% at 3000 m.
  - BIP was close to these rates.
  - At BIP, FTM, and WDP, rates were poor in the lower-range gates due to radio frequency and wave interference.
- RASS recovery rates
  - Ideal rate is 80% at 700 m
  - Rates at BIP were the poorest of the three sites due to radio frequency and wave interference.

Data statistics: Summary

- Air quality recovery rates
  - Recovery rates were very good at all sites for all parameters except for ozone at WDP.
  - Ozone data at WDP were suspect for two months because the analyzer sample flow rate decreased over time to about 100 cm^3/min.
- Auxiliary meteorology recovery rates
  - Ideal rates are 80% at 1500 m and 50% at 3000 m.
  - BIP was close to these rates.
  - At all three sites, rates were poor in the low range gates due to radio frequency and wave interference.

U.S. Coast Guard Update

LCDR John Cushing

Eighth Coast Guard District
New Orleans, LA

January 15, 2003

USCG Update

- Deepwater Ports (DWP) ←
- Dynamic Positioning
- Offshore Security
- Questions/Answers

Deepwater Ports

Deepwater Ports Act of 1974

- Promote transportation efficiency
- Regulate commerce
- Protect environment (full EIS required)
- Only for oil, not natural gas

- 3 deepwater port license applications submitted
- LOOP was only deepwater port built (1981)

Louisiana Offshore Oil Port (LOOP)

- 18 miles offshore
- 110 ft water depth
- 3 mooring buoys
- Accepts VLCC & ULCC tankers
- Up to 1.2M BOPD
- Salt domes for onshore storage
- Restrictive DWP Safety Zone

Louisiana Offshore Oil Port (LOOP)

Offloading via Single-point Mooring Buoy

Deepwater Ports

Deepwater Port Modernization Act of 1996

- Update existing Act
- Reduce regulatory burden
- Recognize effective competitiveness exists
- Promote innovation, flexibility, and efficiency
- Still only for oil, not natural gas

- ANPRM published on 08/97
- NPRM published on 05/02
- NPRM comment period extended on 08/02

Deepwater Ports

Changes resulting from DWP Mod Act

- Streamlined licensing process
  - Sec DOT to approve or deny license (“one-stop shopping”)
  - Only 1 year to process application
- Application processed by USCG & MARAD
  - Sec DOT delegated this to USCG & MARAD
  - USCG & MARAD to coordinate with other agencies and adjacent coastal State

Deepwater Ports

Marine Transportation Security Act of 2002

- Natural gas now included in DWP Act
- DWPs less risky than onshore facilities
- Beneficial for Nation’s energy policy

- Much interest by industry
- 2 applications already received (Chevron-Texaco, El Paso)

Deepwater Ports

Changes resulting from MTSA

- NEPA applies (full EIS not automatic)
- "Managed Access" restriction removed
  (Natural Gas DWPs only)
- Multiple DWPs allowed in Single Geographic Area
  (Natural Gas DWPs only)
- DWP regs to include specific requirements for Natural Gas
- Sec DOT can promulgate regs as Interim Final Rule (no public comment period)

USCG Update

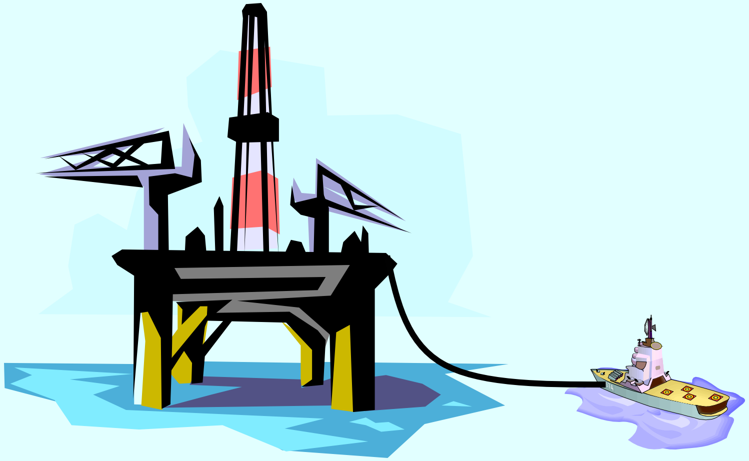
- Deepwater Ports
- Dynamic Positioning ←
- Offshore Security
- Questions/Answers

UNITED STATES COAST GUARD
1790

Dynamic Positioning

<u>For Oil/HAZMAT Transfers</u>

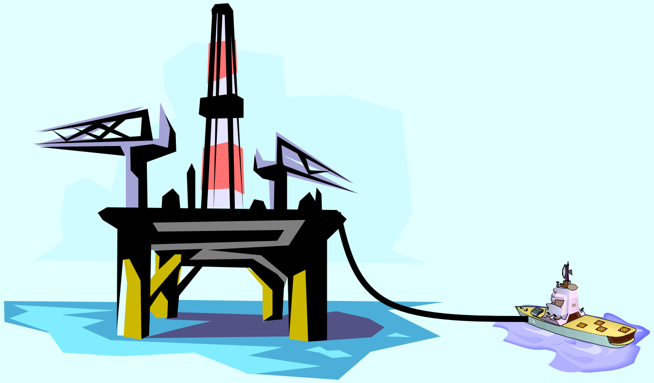
- 33 CFR 156.120(a): Vessel’s moorings strong enough to hold during all expected conditions of surge, current, and wind
- Implies mooring lines
- DP not addressed
- OSV industry prefers DP (vs. mooring lines)



Dynamic Positioning

Local policy (for GOM) with 4 options

1) IMO Class 2 or 3 DPS, or
2) Class "equivalent" to IMO Class 2 or 3 DPS, or
3) USCG minimum requirements for DPS (IMO "Class 1+"), or
4) Break-away fitting with quick-closing valves



USCG Update

- Deepwater Ports
- Dynamic Positioning
- **Offshore Security** ←
- **Questions/Answers**

Reporting Terrorist Activity

National Response Center (NRC)

1-800-424-8802 (24 hr/day)

- Contact point for all oil/HAZMAT spills
- “Clearinghouse” for reports of terrorist activity
- Works with FBI Strategic Intelligence & Ops Center (SIOC)
- FBI will assess credibility of threat
- On scene assessment *may* be made by FBI or other agencies (federal, state, or local)

Offshore Security

Current security guidelines

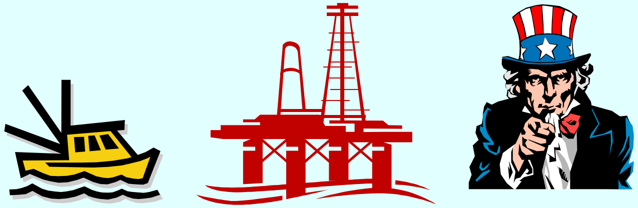
- NVIC 10-02: Security Guidelines for Vessels
- NVIC 09-02: Security Guidelines for Ports
- NVIC 04-02: Security Guidelines for Passenger Vessels & Passenger Terminals

Website: http://www.uscg.mil/hq/g-m/nvic/

Offshore Security

Gulf Safety Committee (GSC)

- Forum to improve communication and cooperation for stakeholders on GOM
- Mainly composed of reps from:
  - Fishing industry
  - Oil and gas industry
  - Government agencies (federal & state)



- Offshore Security has been “hot topic”

Offshore Security

GSC’s Security Subcommittee

- Headed by USCG (Guy Tetreau)
- Collaborate with offshore industry
- Focus on higher risk facilities
  (high production, thru-put, and/or POB)
- Develop voluntary consensus security guidelines for offshore facilities
- USCG to promulgate as “best practice”

USCG Update

- Deepwater Ports
- Dynamic Positioning
- Offshore Security
- **Questions/Answers** ←

Questions/Answers

Docket Management System:

- http://dms.dot.gov
- Select “Simple Search”
- Enter Docket Number: ____

Subchapter NN (DWP regs): Docket No. 3884

Chevron-Texaco DWP application: Docket No. 14134

El Paso DWP application: Docket No. 14294.

Questions/Answers

DWP questions - COMDT (G-MSO-2)

- CDR Mark Prescott
- (202) 267-0225
- email: MPrescott@comdt.uscg.mil

Offshore Compliance - 8th District (New Orleans)

- LCDR John Cushing
- (504) 589-6260
- email: JCushing@d8.uscg.mil

Questions/Answers

Offshore Security - 8th District (New Orleans)

- Mr. Guy Tetreau
- (504) 589-4686
- email: GTetreau@d8.uscg.mil

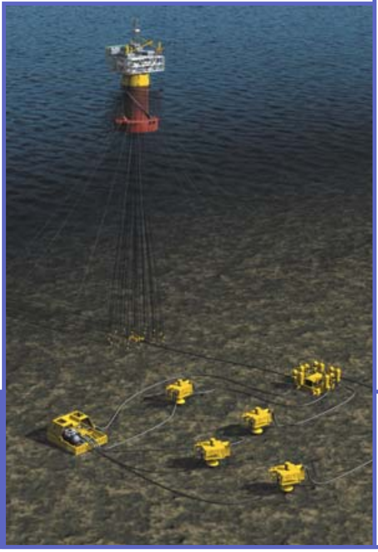
GSC Website:

http://www.uscg.mil/hq/g-m/harborsafety/Gulf%20Safety%20Committee.htm

Eighth Coast Guard District
“Guardians of the Heartland”

Minimum Facility Floaters

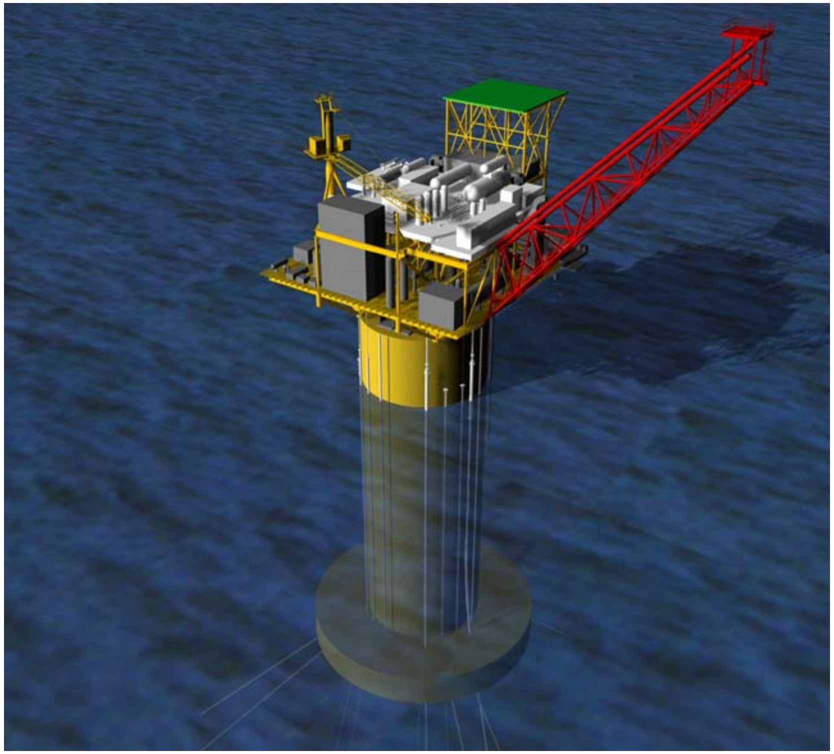
A Tool for Economic Deepwater Development To 10,000 Feet



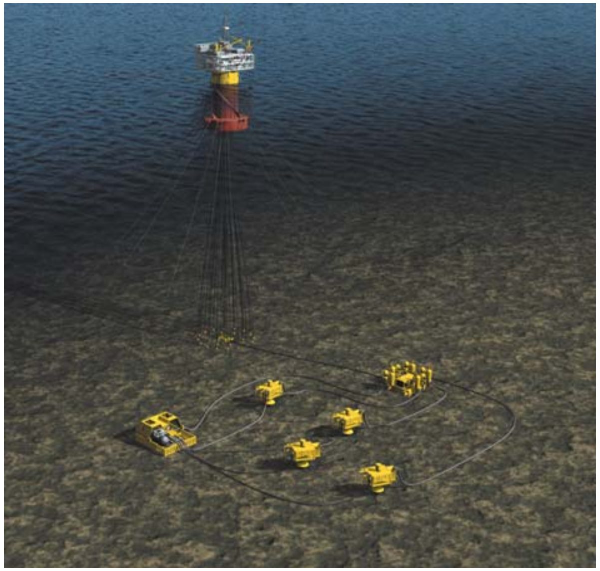
Clay Anderson / ABB Offshore Systems, Inc.

Minimum Facilities SCF Floater

- Field Economics Drivers
- Minimum Facility Concepts
- Example Development Scenarios
- Key Technical Issues



Minimum Facility
Single Column Floater (MF SCF)

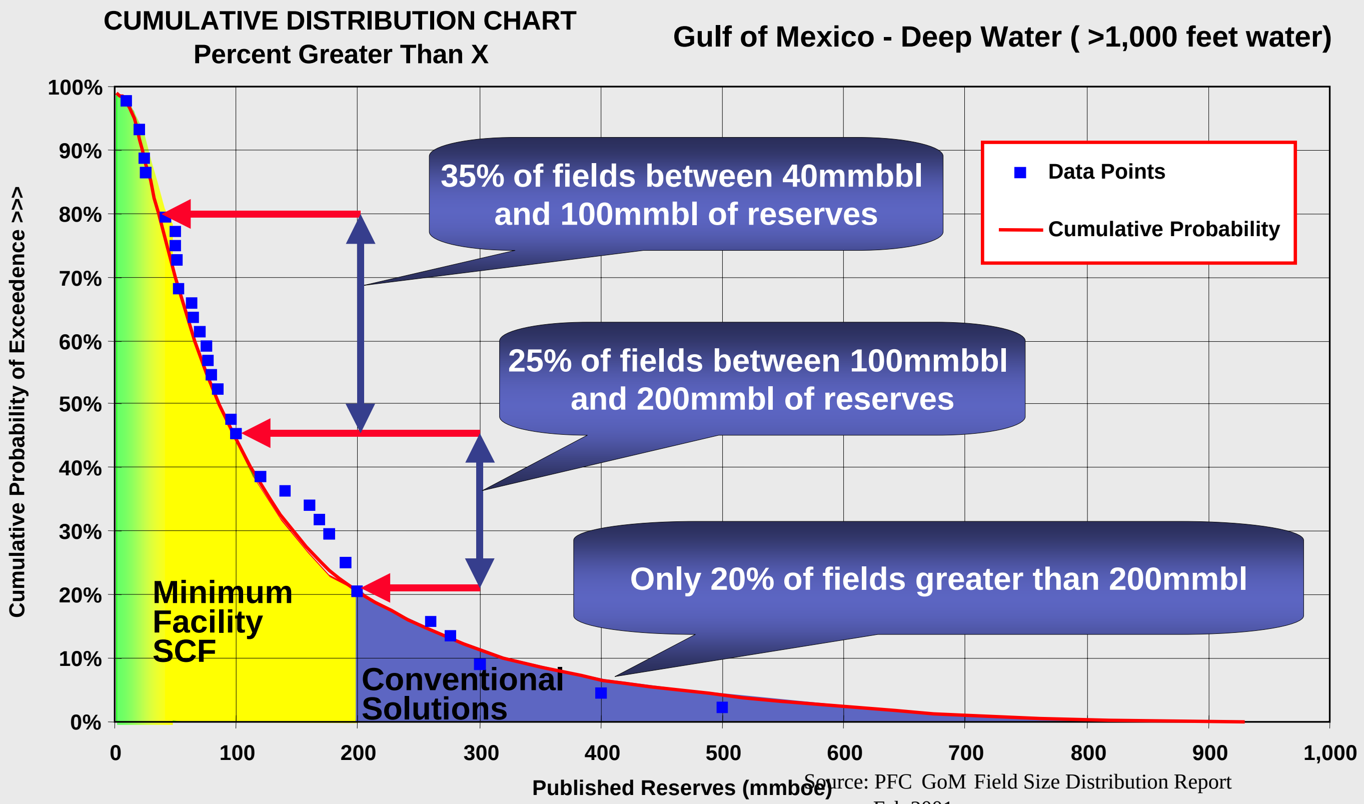


ABB

Conventional Development Solutions

GOM Field Size Distribution

Fields in water depths exceeding 1,000 feet



35% of fields between 40mmbbl and 100mmbl of reserves

25% of fields between 100mmbbl and 200mmbl of reserves

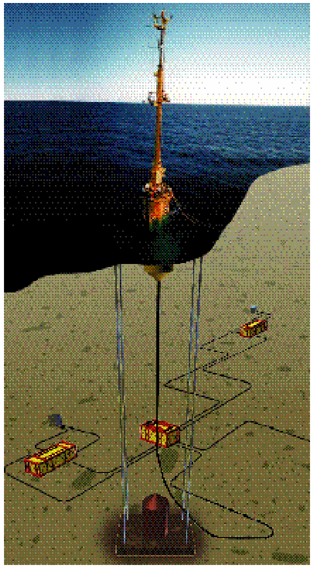
Only 20% of fields greater than 200mmbl

Source: PFC GoM Field Size Distribution Report Feb 2001

Minimum Facilities

Minimum Facilities Floater

An Infield, Unmanned or Minimally Manned Platform Used to Support a Deepwater or Ultra-Deepwater Subsea Field Development.



- Control Buoys used for Shallow Water Subsea :
  - East Spar Buoy, East Spar Field, NW Shelf Australia
  - MossGas Buoy, E-M field, Mossel Bay, South Africa
- Normally Unmanned Facilities are Common for Shelf Applications

- However, the Normally Unmanned Deepwater Floating Facility has not been used Yet

ABB

Minimum Facilities Floaters

A “Spectrum” of Solutions

“Mini-” & Full Deepwater Facilities

Control Buoys

- Replace Umbilical
- Control Wells
- Store & Distribute Chemicals

Minimum Facilities Buoys

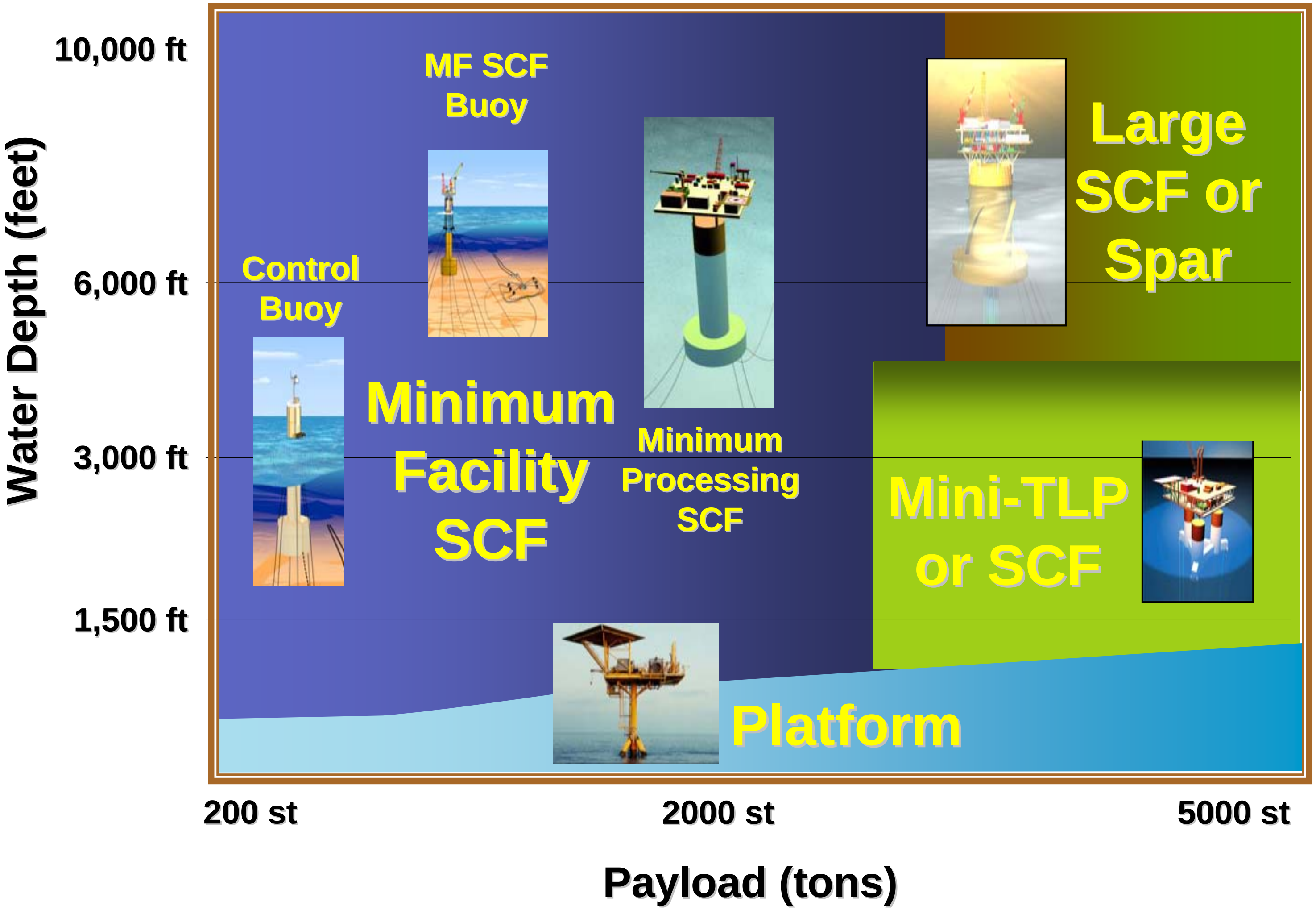
- Eliminate 2nd Flowline/ Pigging from Buoy
- Electrical Power Distibution for Subsea
- Support Subsea Pumping / Processing

Minimum Process Facility

- Subsea / Wet Trees
- “Local” Hub Facility
- Process Out Bulk Water
- Produced Water Treatment
- Pumping / Compression
- Mitigate Flow Assurance Risk
- Flexibility for Reservoir Risk

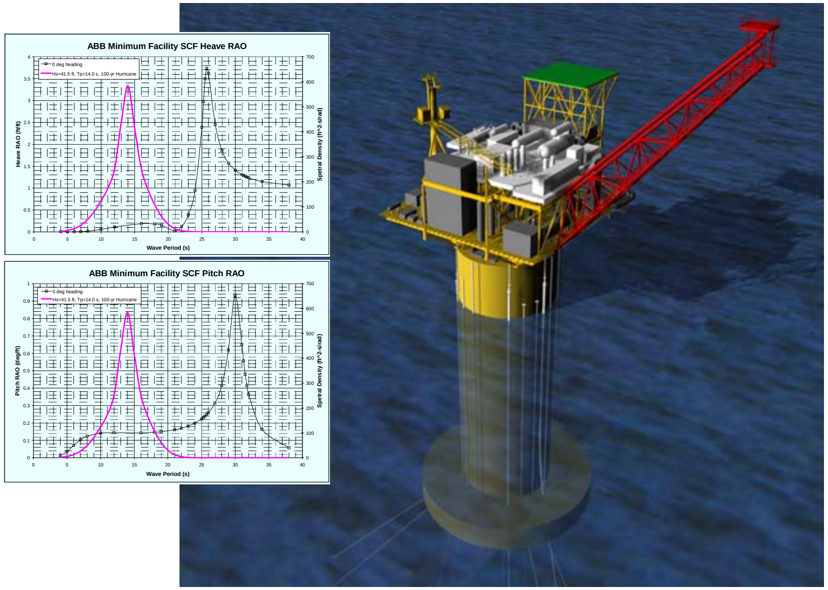
Minimum SCF Facilities

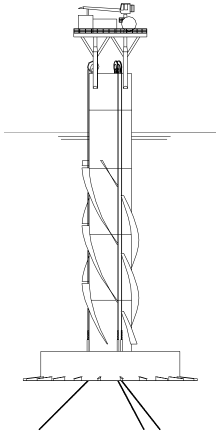
Indicative Hull Applicability Ranges



ABB

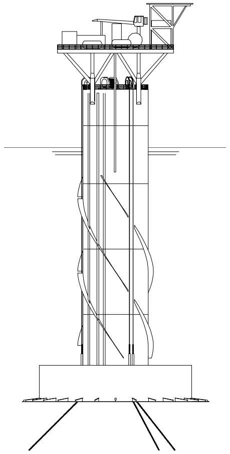
Minimum SCF Facilities





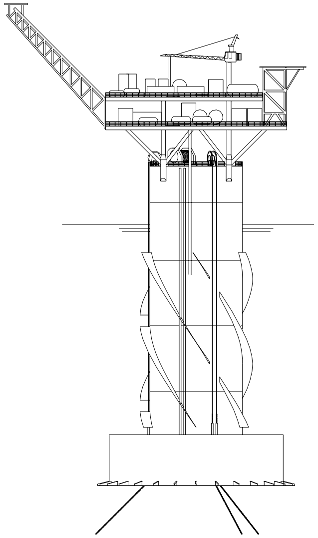
Min. Facilities Buoy

Topsides	200 tons
Draft	170 ft
Freeboard	40 ft
Column	25-32 ft dia.
Base Tank	90-100ft dia.



Min. Processing SCF

Topsides	1000 tons
Draft	175 ft
Freeboard	40 ft
Column	43-47 ft dia.
Base Tank	105-110ft dia.

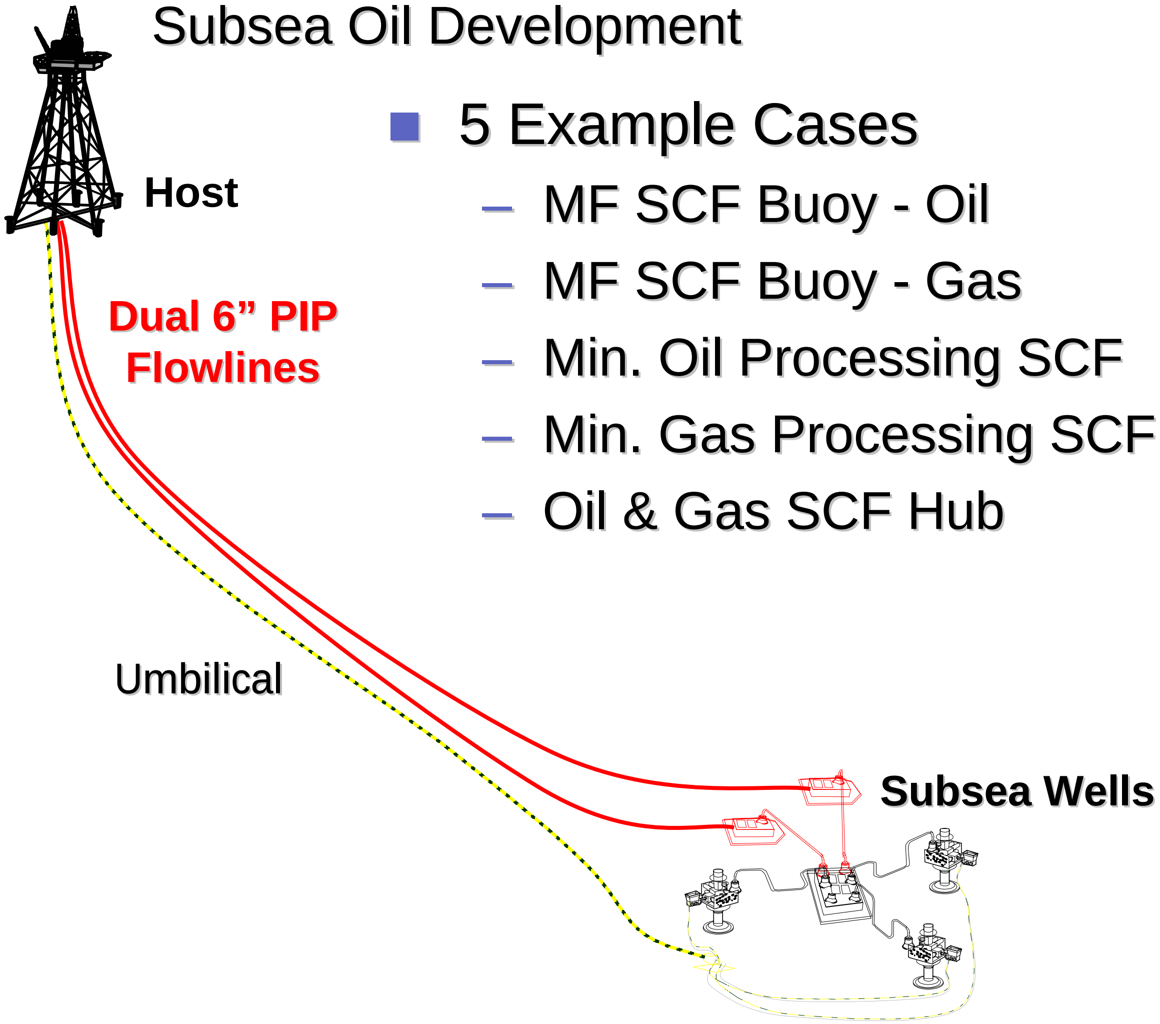


Min. SCF Oil & Gas Processing Hub

Topsides	2500 tons
Draft	180 ft
Freeboard	40 ft
Column	65 ft dia.
Base Tank	125 ft dia.

Example Development Scenarios

Subsea Oil Development



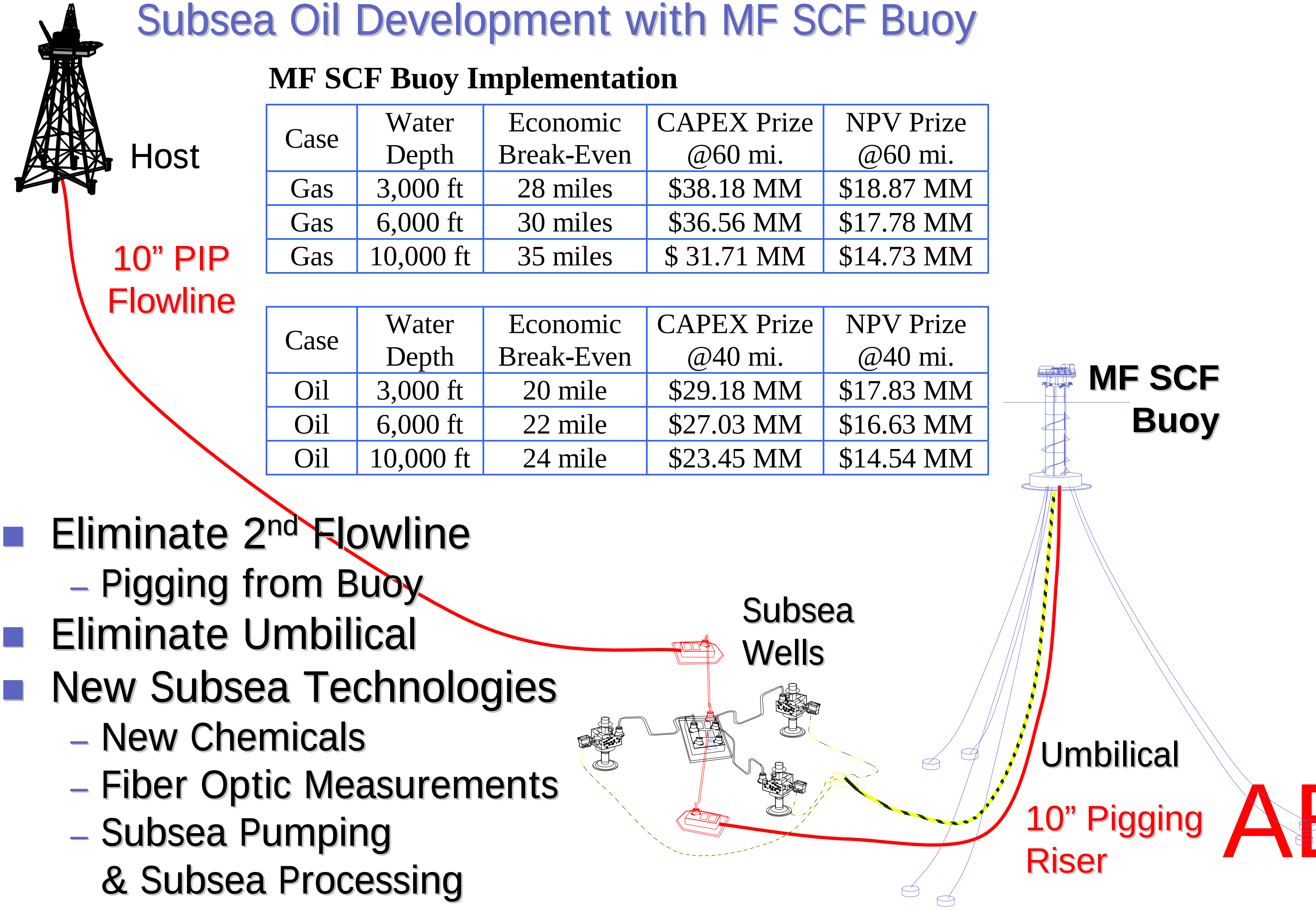
- 5 Example Cases
  - MF SCF Buoy - Oil
  - MF SCF Buoy - Gas
  - Min. Oil Processing SCF
  - Min. Gas Processing SCF
  - Oil & Gas SCF Hub

- 3 Water Depths
  - 3,000 feet
  - 6,000 feet
  - 10,000 feet

- 3 Offsets
  - 20 miles
  - 40 miles
  - 60 miles (Gas Only)

MF SCF Buoy

Subsea Oil Development with MF SCF Buoy



MF SCF Buoy Implementation

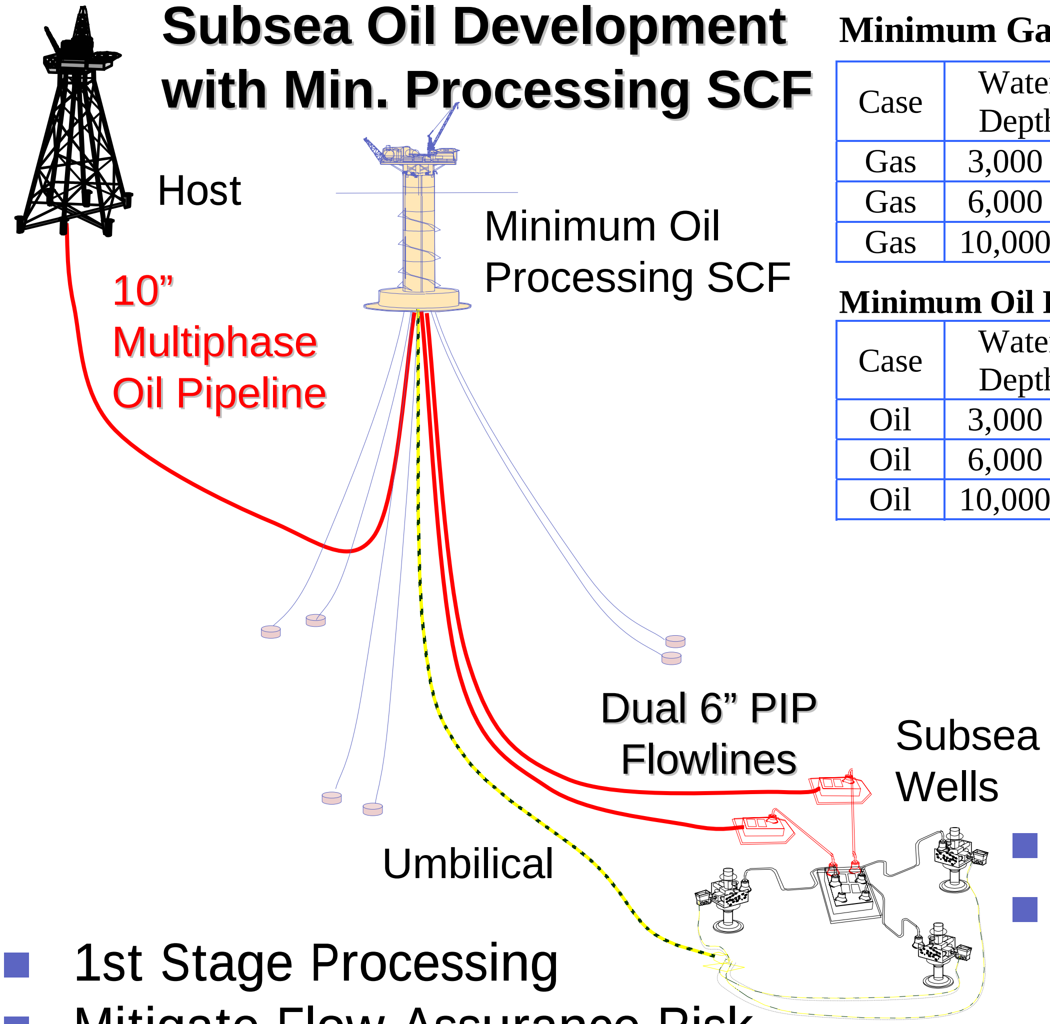
Case	Water Depth	Economic Break-Even	CAPEX Prize @60 mi.	NPV Prize @60 mi.
Gas	3,000 ft	28 miles	$38.18 MM	$18.87 MM
Gas	6,000 ft	30 miles	$36.56 MM	$17.78 MM
Gas	10,000 ft	35 miles	$ 31.71 MM	$14.73 MM

Case	Water Depth	Economic Break-Even	CAPEX Prize @40 mi.	NPV Prize @40 mi.
Oil	3,000 ft	20 mile	$29.18 MM	$17.83 MM
Oil	6,000 ft	22 mile	$27.03 MM	$16.63 MM
Oil	10,000 ft	24 mile	$23.45 MM	$14.54 MM

- Eliminate 2nd Flowline
  - Pigging from Buoy
- Eliminate Umbilical
- New Subsea Technologies
  - New Chemicals
  - Fiber Optic Measurements
  - Subsea Pumping & Subsea Processing

Minimum Oil Processing SCF

Subsea Oil Development with Min. Processing SCF



Minimum Gas Processing Hub Implementation

Case	Water Depth	Economic Break-Even	CAPEX Prize @60 mi.	NPV Prize @60 mi.
Gas	3,000 ft	39 mile	$15.47 MM	$12.08 MM
Gas	6,000 ft	41 mile	$12.84 MM	$10.38 MM
Gas	10,000 ft	46 mile	$9.07 MM	$7.98 MM

Minimum Oil Processing SCF

Case	Water Depth	Economic Break-Even	CAPEX Prize @40 mi.	NPV Prize @40 mi.
Oil	3,000 ft	31 mile	$17.31 MM	$10.57 MM
Oil	6,000 ft	33 mile	$14.02 MM	$8.68 MM
Oil	10,000 ft	36 mile	$7.35 MM	$4.71 MM

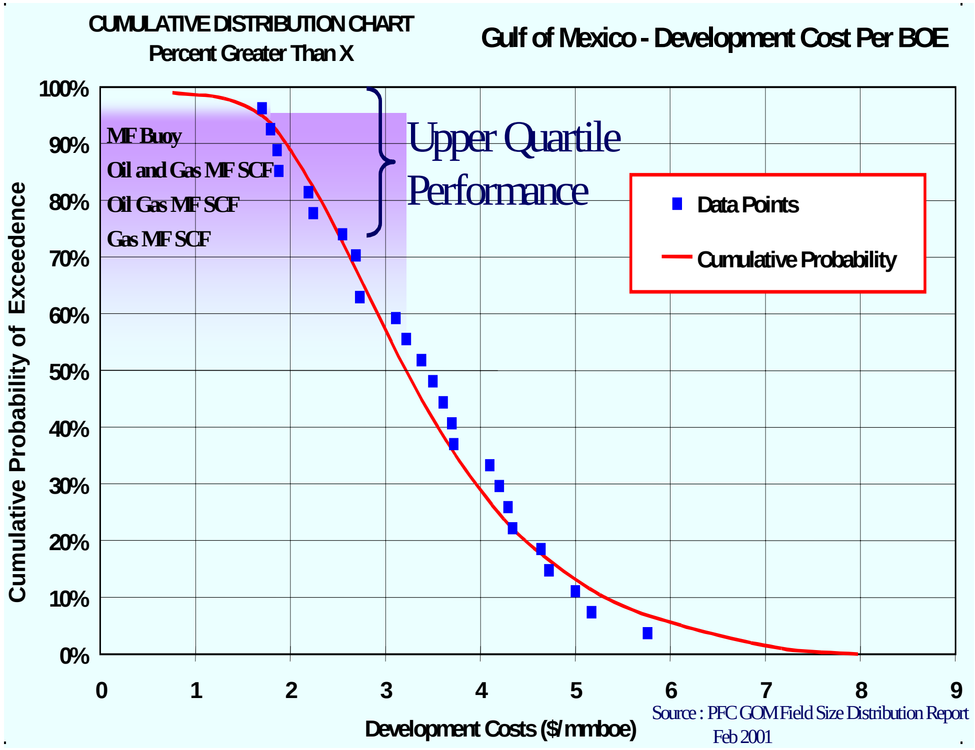
- Increased Offset
- Mitigate Life of Field Risks

- 1st Stage Processing
- Mitigate Flow Assurance Risk
- Red. Thermal Insulation

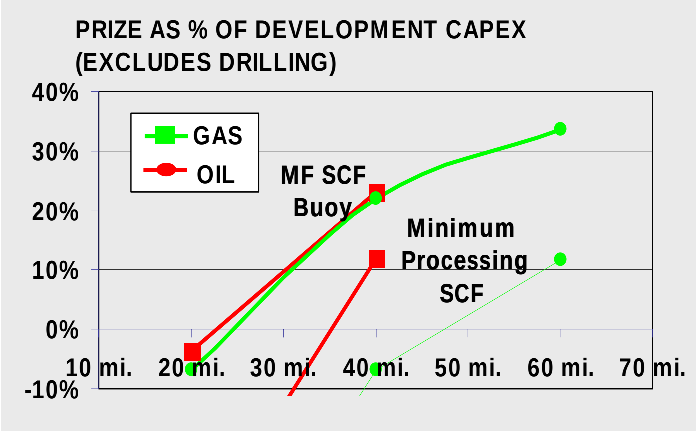
Comparative Economics for Examples

- How do the Economics Compare?

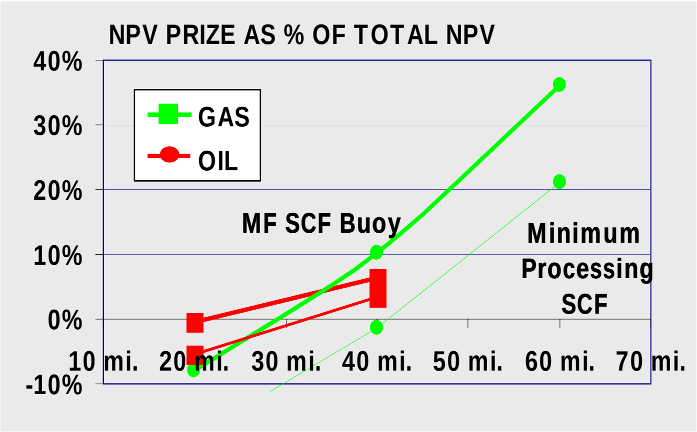
Development Costs



Source : PFC GOM Field Size Distribution Report Feb 2001



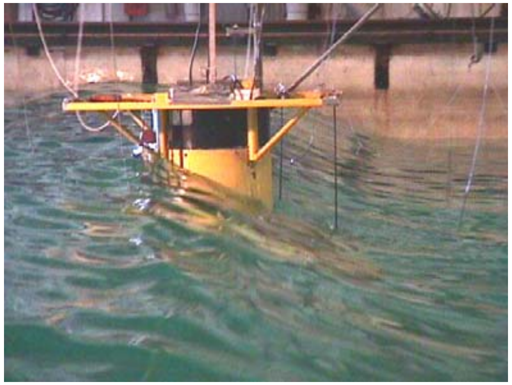
Compared with Subsea



Key Technical Issues

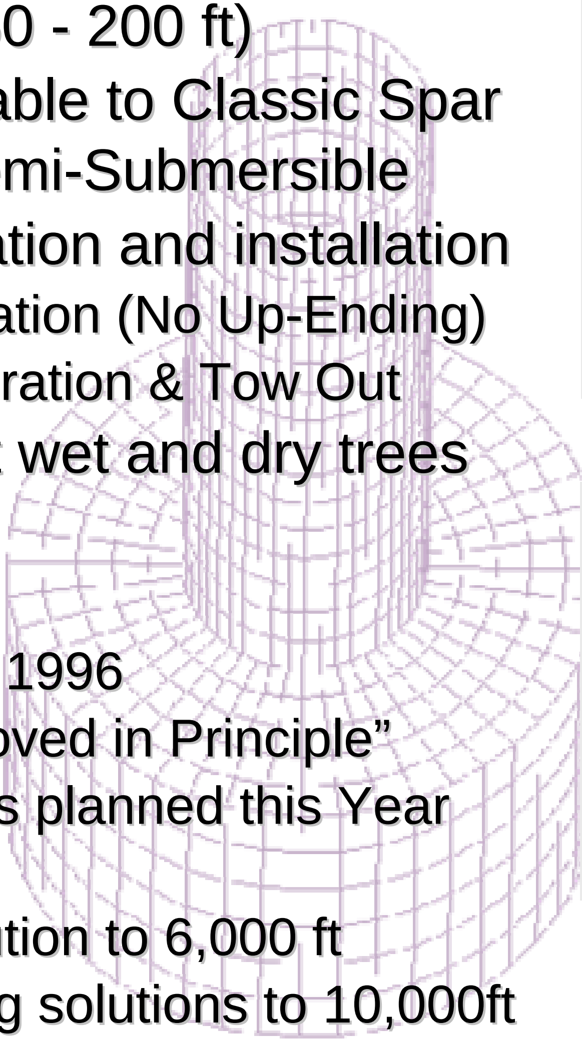
- Compact Structure & Compact Equipment
  - Work Up from Bare Structure
    (Not Down from Larger Structure)
- Efficient Hull Form
- Compact / Lightweight Topsides
- Moorings / Synthetic Moorings
- Riser Loads
- Unmanned / Minimally Manned Platform
  - Automation
- Power Generation / Power Requirements
- Ease of Installation
- Delivery Schedule
- Resupply, Operations & Maintenance

In-Place



Tow Out

Single Column Floater Hull Form

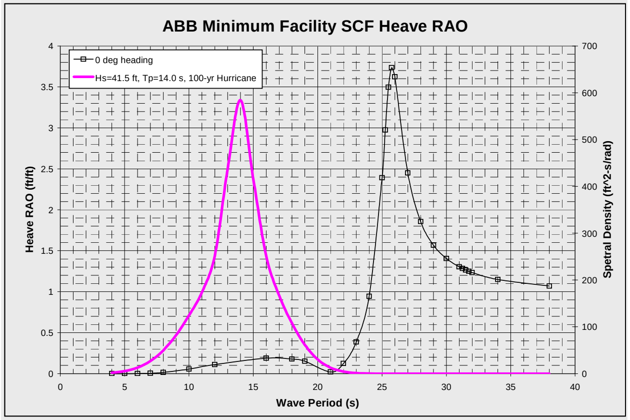


- Shallow draft (150 - 200 ft)
- Motions comparable to Classic Spar or Deep Draft Semi-Submersible
- Simplified fabrication and installation
  - Vertical Fabrication (No Up-Ending)
  - Quayside integration & Tow Out
- SCF can support wet and dry trees

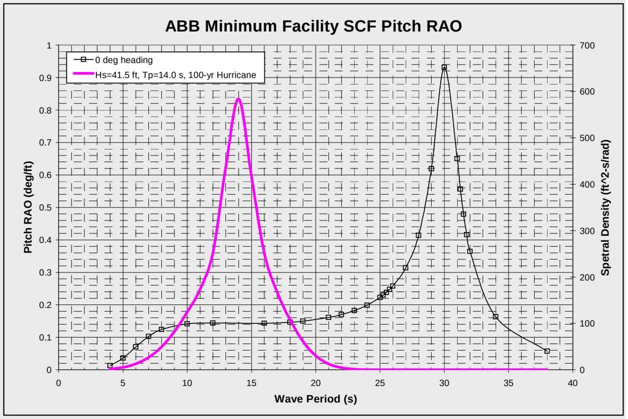
Current Status

- First Developed in 1996
- ABS & DnV “Approved in Principle”
- Further model tests planned this Year and Early 2003
- “Off the Shelf” solution to 6,000 ft
- Risers and mooring solutions to 10,000ft

Heave Motion RAO

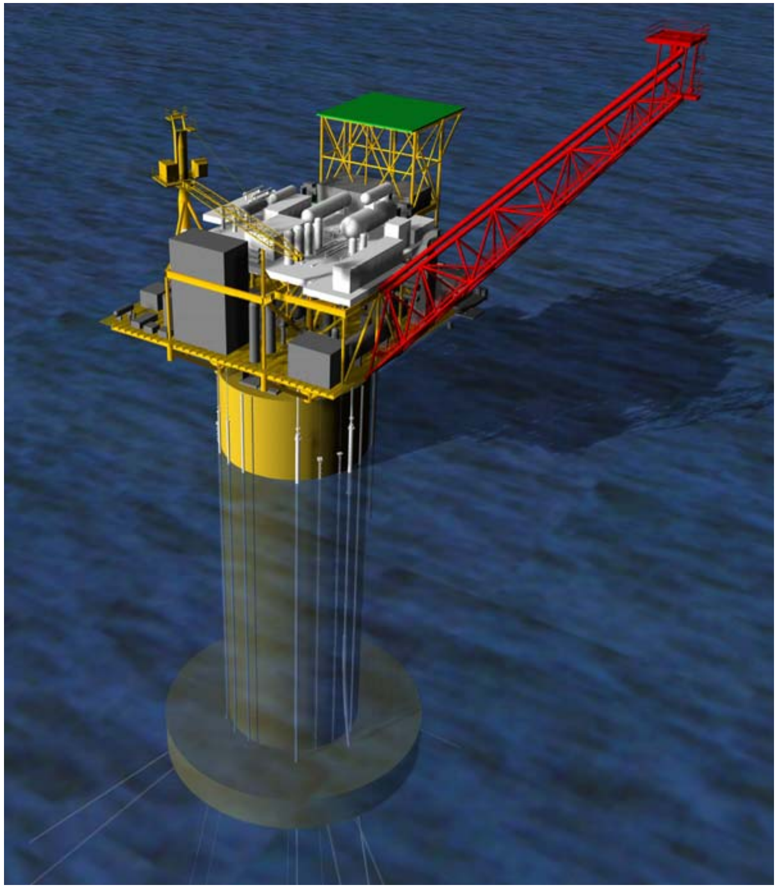


Pitch Motion RAO



Compact Topsides

Challenging the Limits

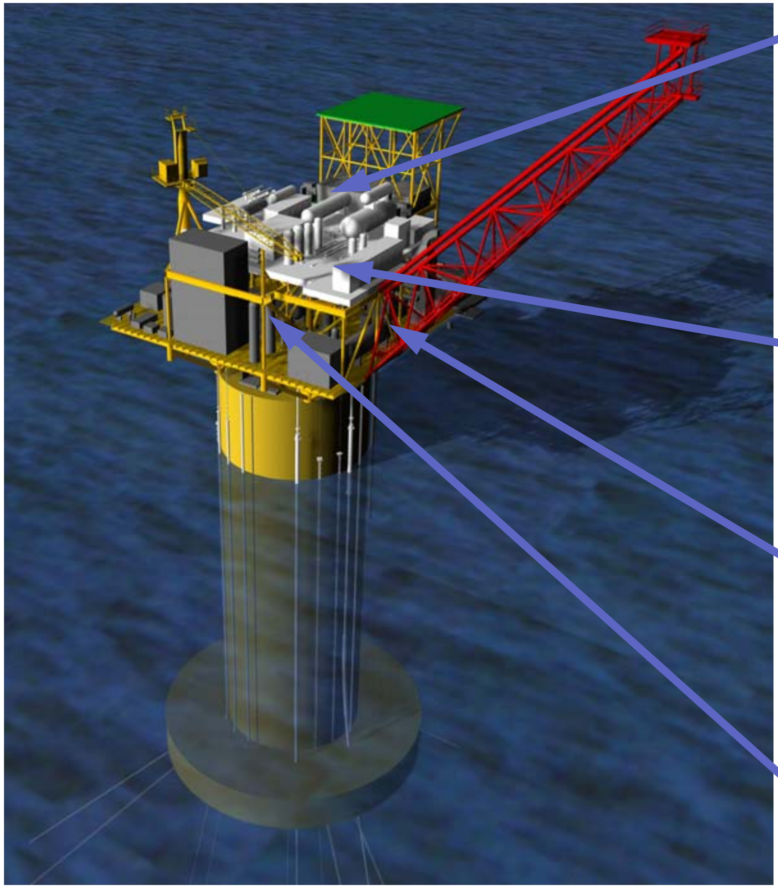


- Can we “wring” more out of compact separation?
- Software and hardware changes?

ABB

Compact Topsides

Challenging the Limits

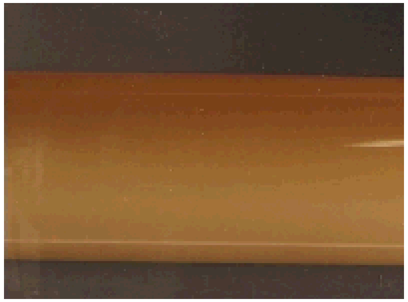


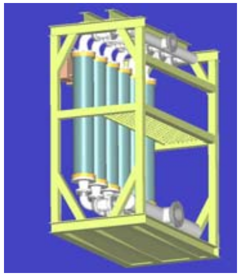
- Reduce slugging volume in 1st stage separator, but introduce active control.
- Remove test separator, use multiphase flow meters
- Fast stabilizing in 2nd stage.
- Compact produced water treatment

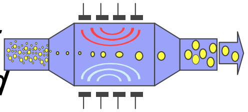
Compact Topsides

- CoSep™ : Compact Separation Program

IEC - In-Line Electrostatic Coalescer

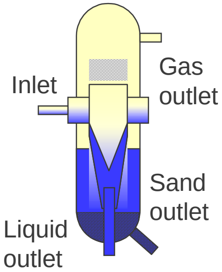






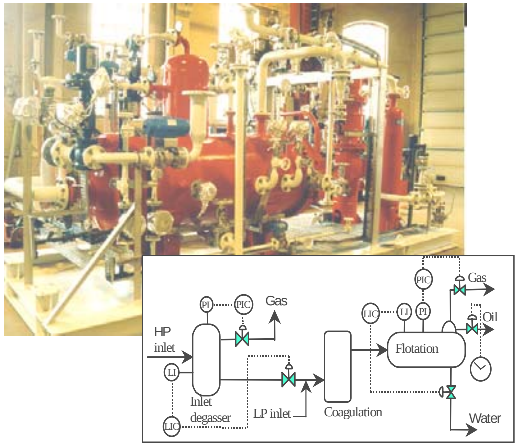
Water falls out after 2 seconds in HV field

Compact 4C Separator



Footprint Reduced 10-15%!!

Weight Reduced 40%!!



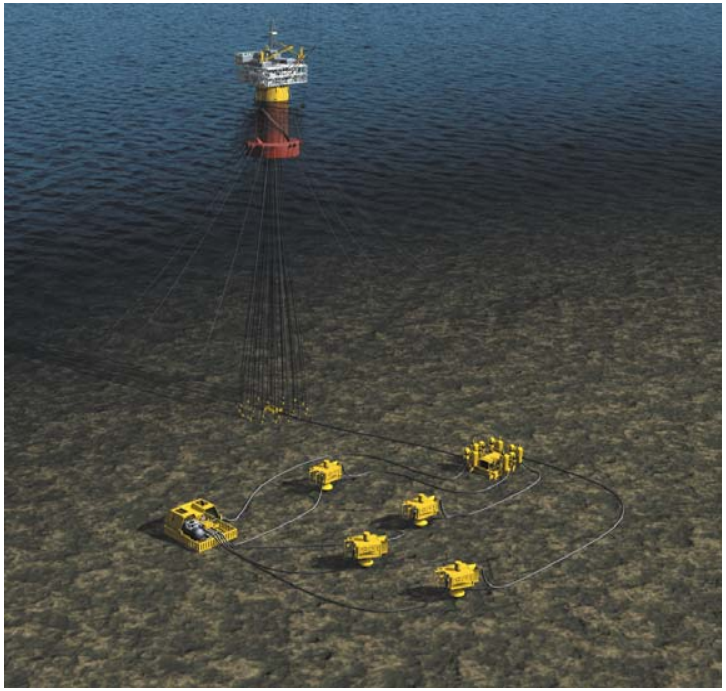
CODEFLO™ Compact Produced Water Treatment

Advanced Process Control

- OPTIMIZE^{IT} Active Flow Control
- Well Management System

Concluding Remarks

- Minimum Facilities, such as the ABB MF SCF, Represents a Breakthrough for:
  - Subsea Developments / Small Fields
  - Long Offset Fields
  - Deepwater Fields
  - Reduction in CAPEX & Risk
  - Enable Emerging Subsea Technologies



- The Concept is Ready for Use:
  - Oil & Gas Buoys
  - Minimum Oil Processing
  - Minimum Gas Processing
  - Local Hub Developments

ABB

MMS ITM Conference New Orleans

Deepwater Session - Jan 15th 2003

Subsea Production Trends:

Achieving the Potential of Subsea Processing

Ian G Ball
Subsea Systems Development Advisor
Shell International EP Inc
New Orleans

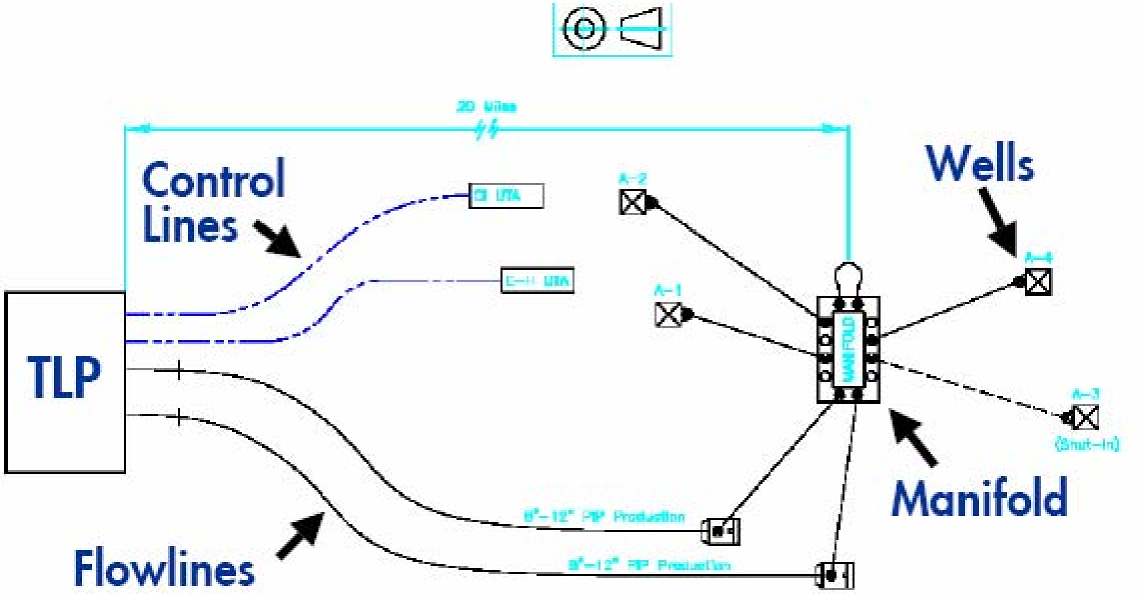
Achieving the Potential of Subsea Processing

We will touch upon:

- What is “subsea processing” anyway?
- How is that different from conventional subsea production?
- What are the potential benefits for the stakeholders?
- What is the current state of the art?
- How can we make it happen faster?

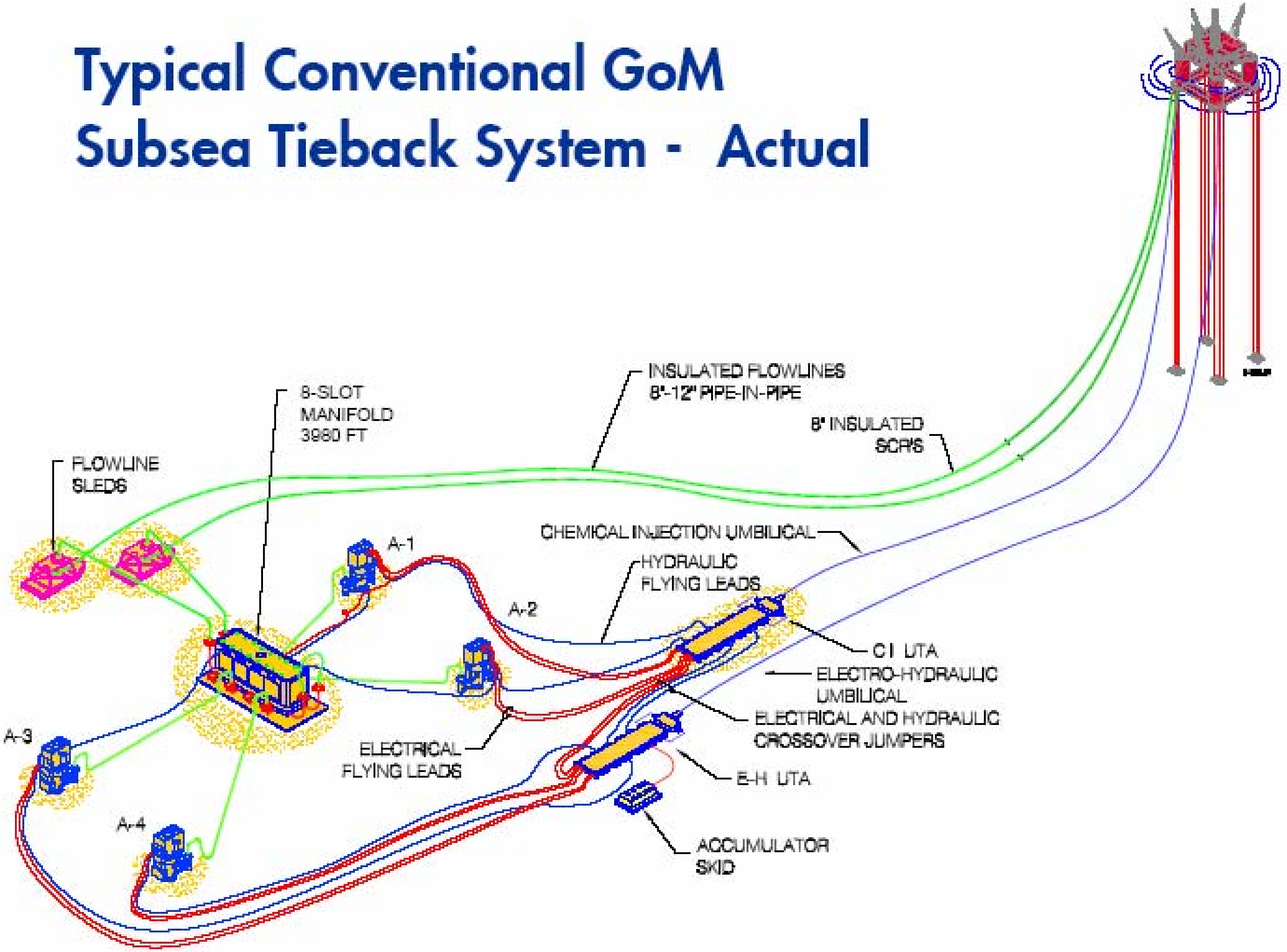
All I say will be:

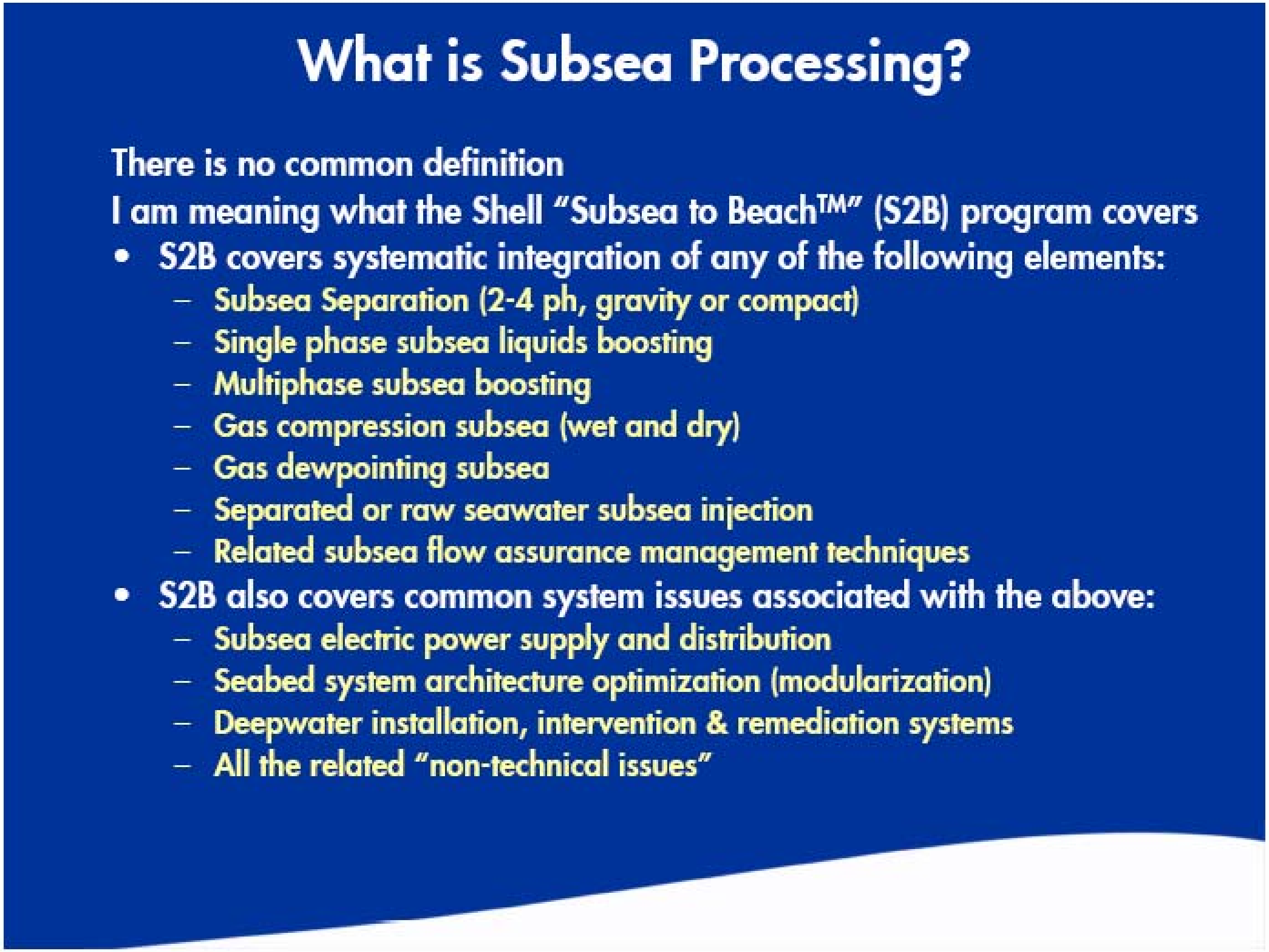
- from my personal perspective and
- about the industry in general



Typical GoM Subsea Tieback - Schematic

Typical Conventional GoM Subsea Tieback System - Actual





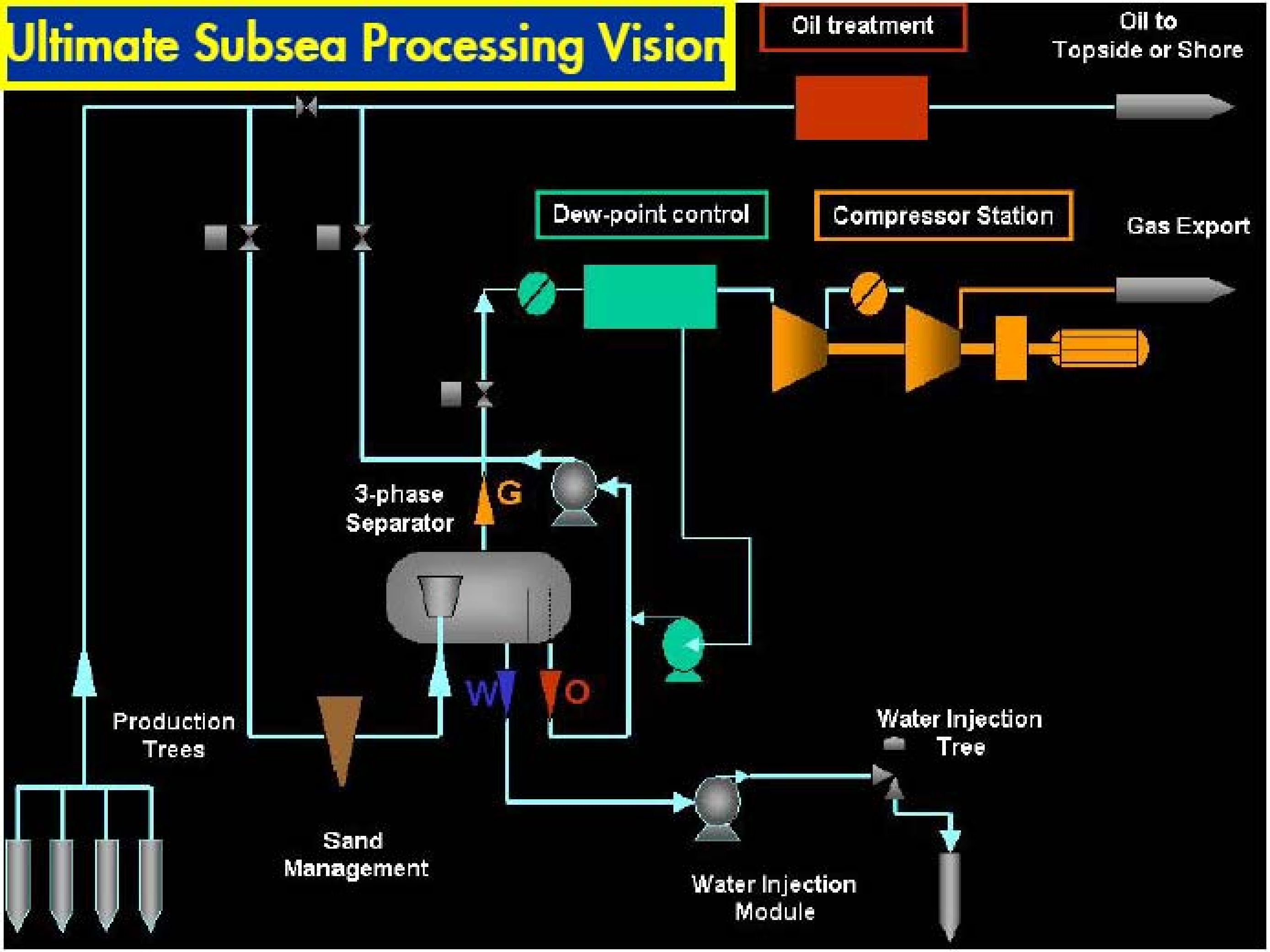
What is Subsea Processing?

There is no common definition

I am meaning what the Shell "Subsea to Beach™" (S2B) program covers

- S2B covers systematic integration of any of the following elements:
  - Subsea Separation (2-4 ph, gravity or compact)
  - Single phase subsea liquids boosting
  - Multiphase subsea boosting
  - Gas compression subsea (wet and dry)
  - Gas dewpointing subsea
  - Separated or raw seawater subsea injection
  - Related subsea flow assurance management techniques
- S2B also covers common system issues associated with the above:
  - Subsea electric power supply and distribution
  - Seabed system architecture optimization (modularization)
  - Deepwater installation, intervention & remediation systems
  - All the related "non-technical issues"

Ultimate Subsea Processing Vision



Shell S2B Program Goals (to 2005+)

- Create value for OUs…
  - Accelerate production and increase reserves
  - Reduce/defer capex – extend feasible offsets, phasing, topside debottlenecking
  - Manage uncertainty – flexible deployment, reponsive to reservoir behaviour
- …by developing/maturing subsea processing technologies …
  - Mudline pressure boosting
  - Subsea separation (2-4 phase)
  - Novel flow assurance approaches
  - Subsea power distribution
  - Modular architecture
  - Metering, electrical controls and communication
- …and promoting applications with Assets & Regulatory Authorities …
  - Global portfolio study
  - Regional planning studies
  - Deepstar/MMS liaison (+ global equivalents)
  - Create win-win outcome for all

10 mile offset - WI
OU-specific pvt and economics
330 MMbbl oiip

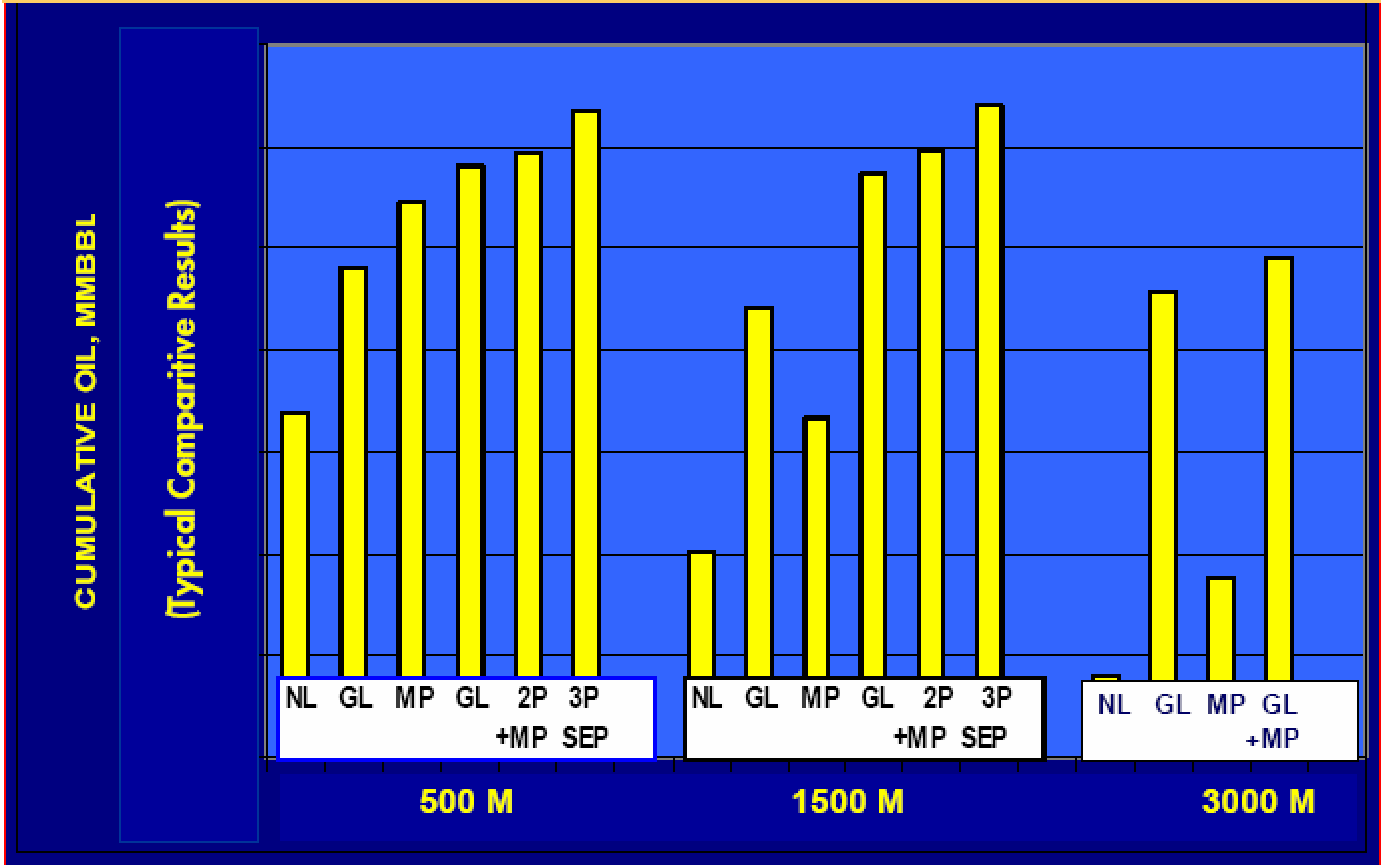
NL – no lift

GL – gas lift

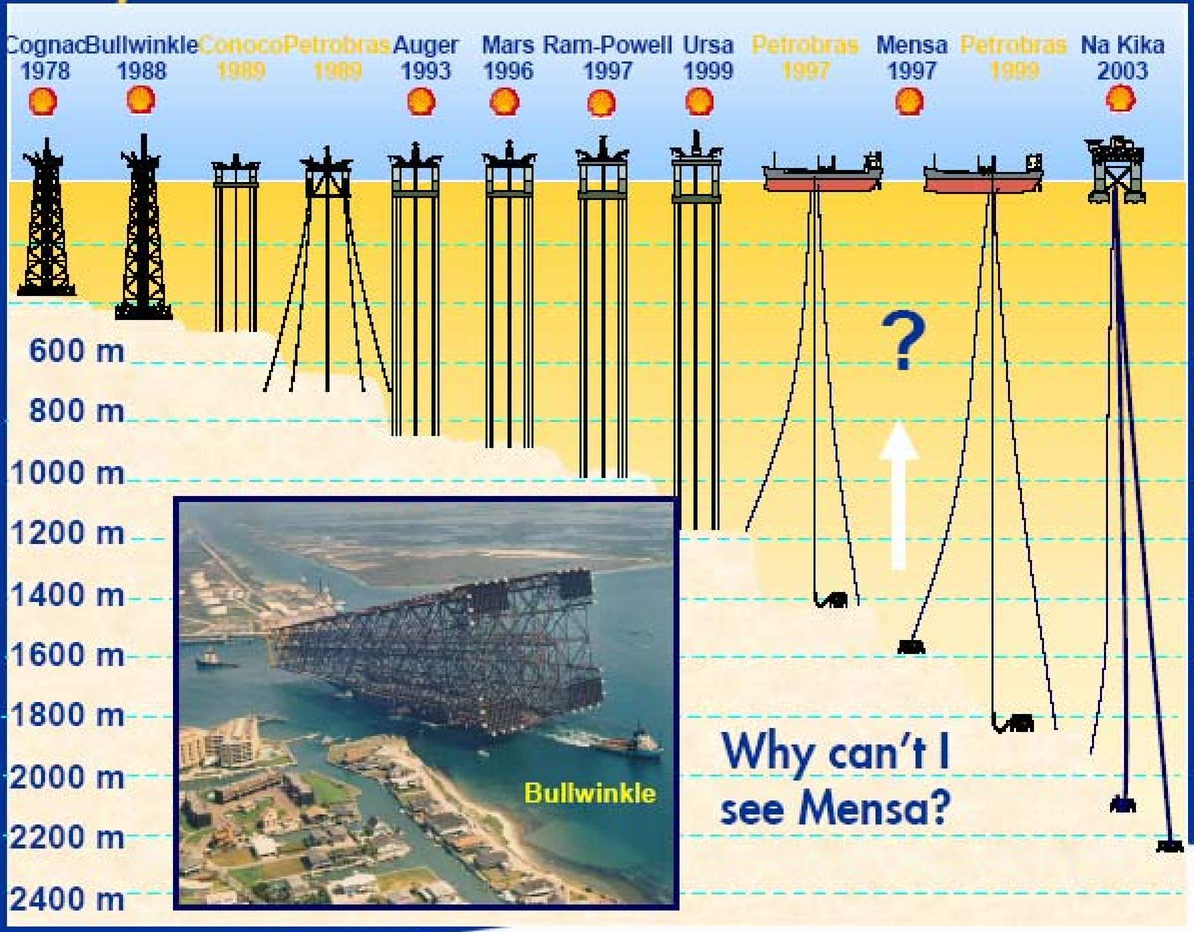
MP – multiphase pumping with1000 psi dp

GL+MP – both

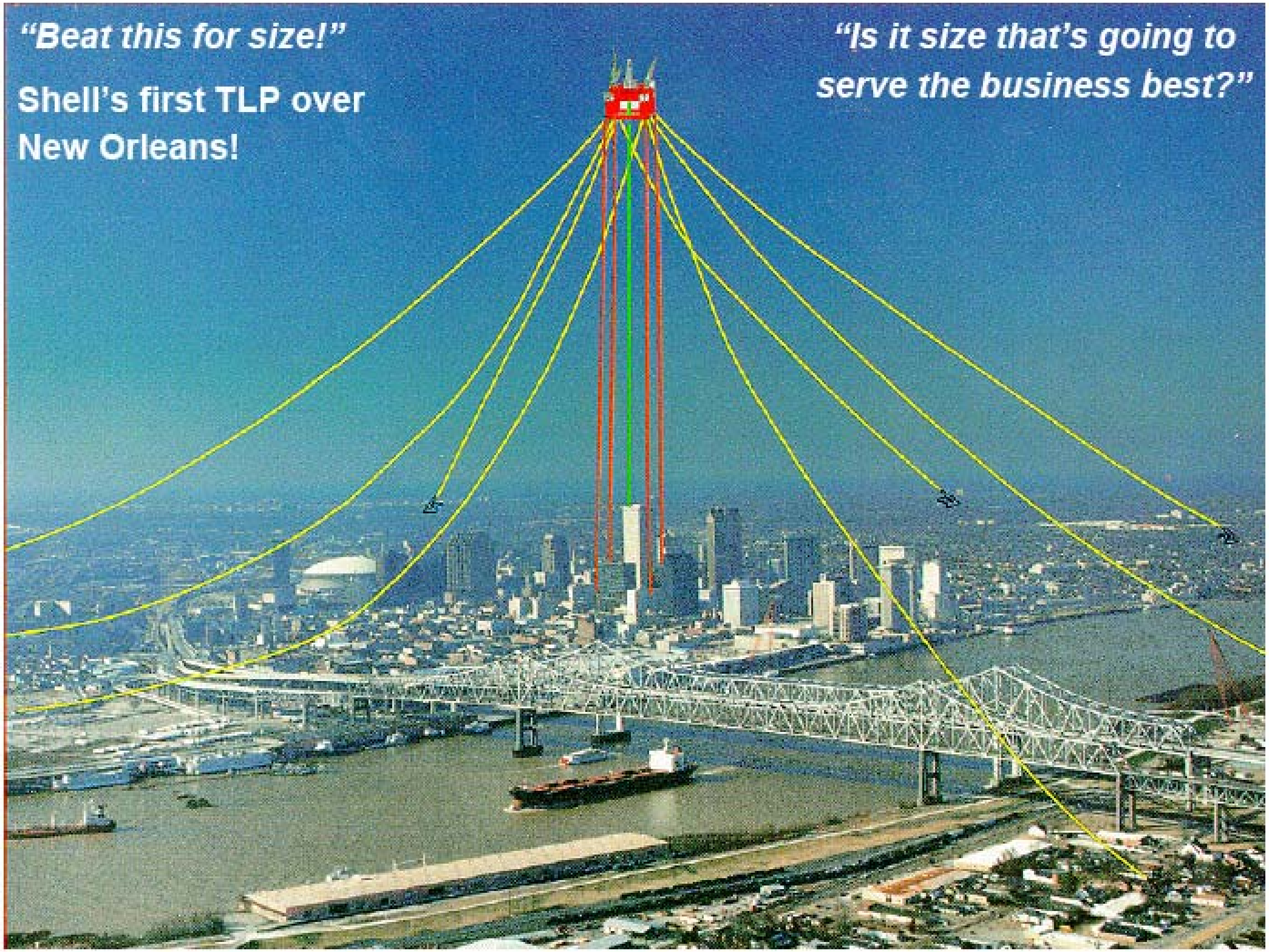
2P or 3P SEP – two/three ph separation, up to 2000 psi dp oil phase



Deepwater Milestones



Why can't I see Mensa?

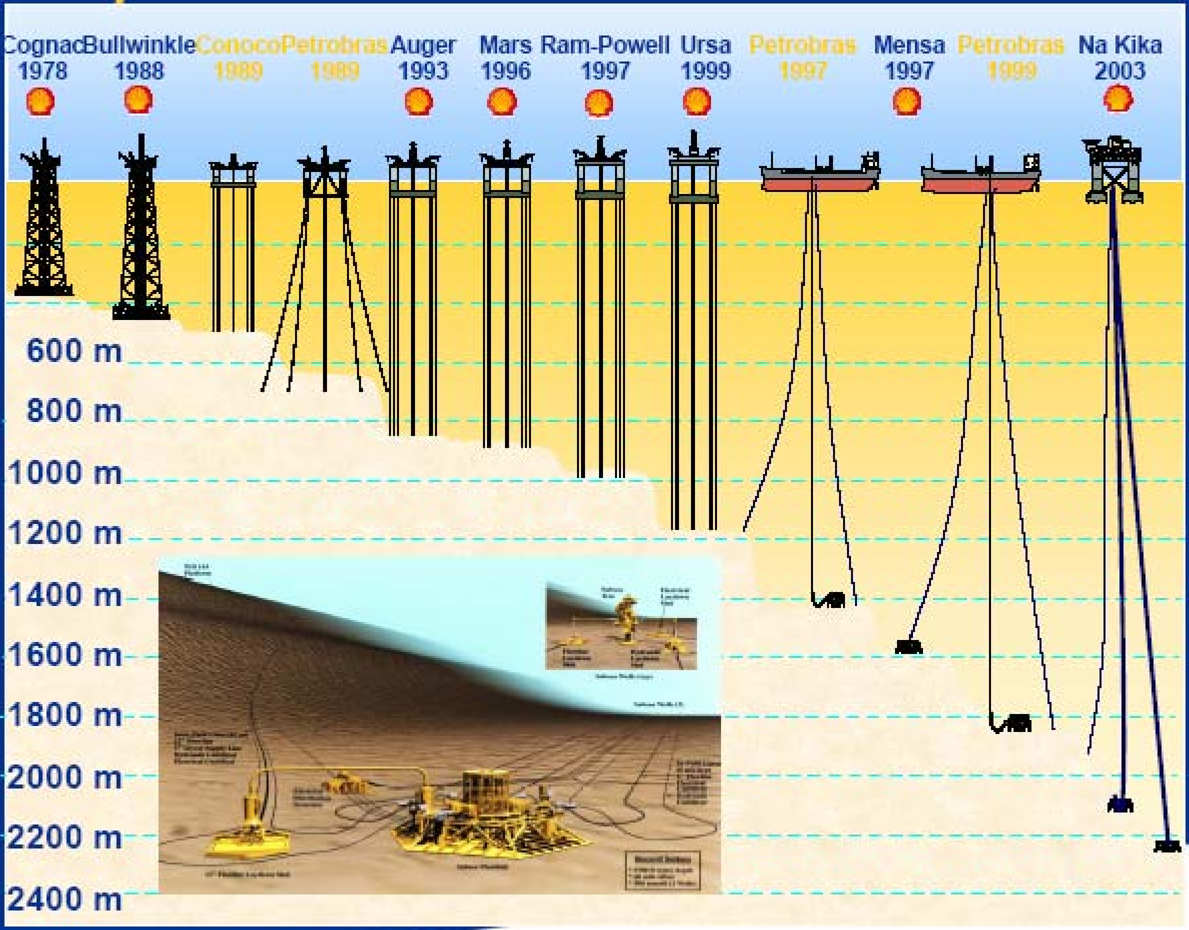


“Beat this for size!”

Shell’s first TLP over New Orleans!

“Is it size that’s going to serve the business best?”

Deepwater Milestones



Troll

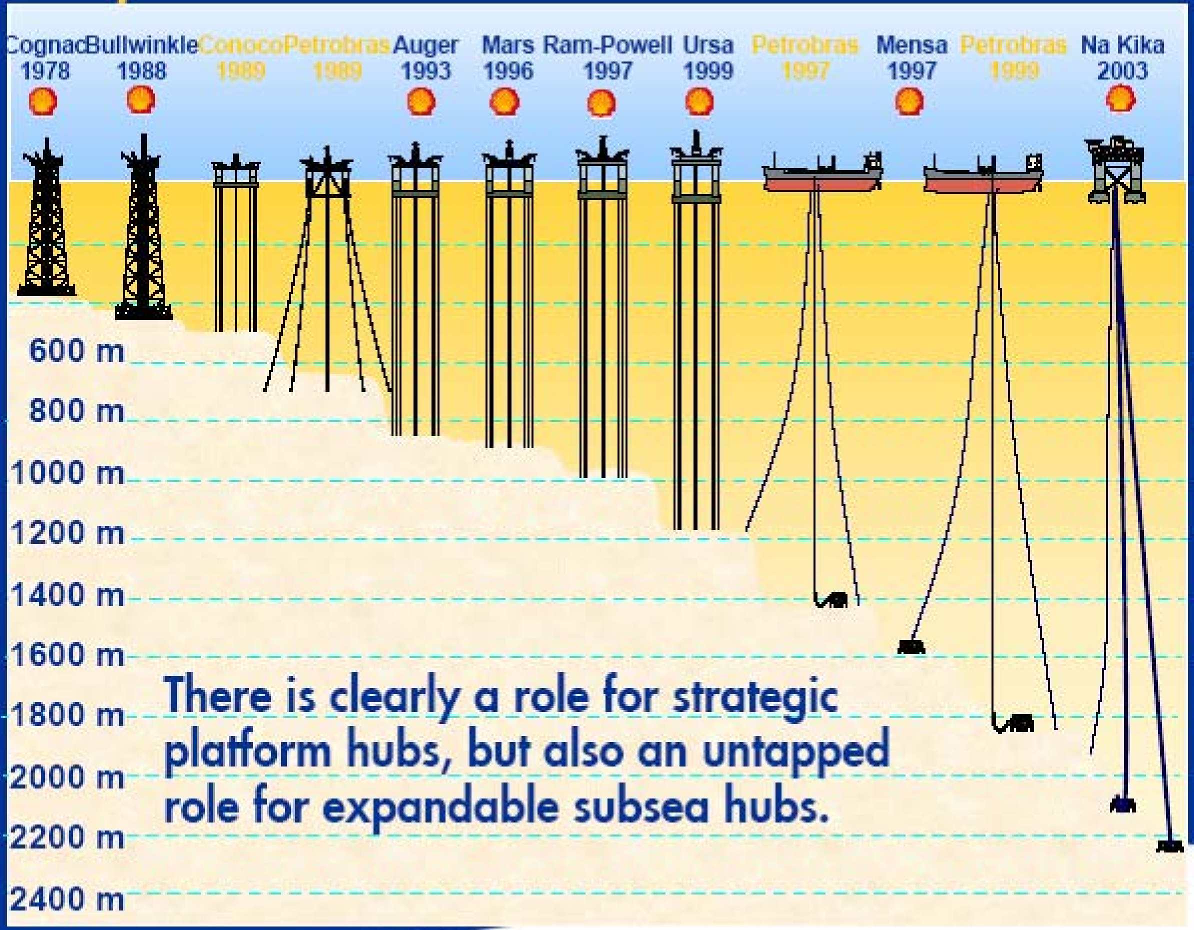
Brutus

“We have a wealth of global experience building huge structures”

Bonga

Malampaya

Deepwater Milestones



There is clearly a role for strategic platform hubs, but also an untapped role for expandable subsea hubs.

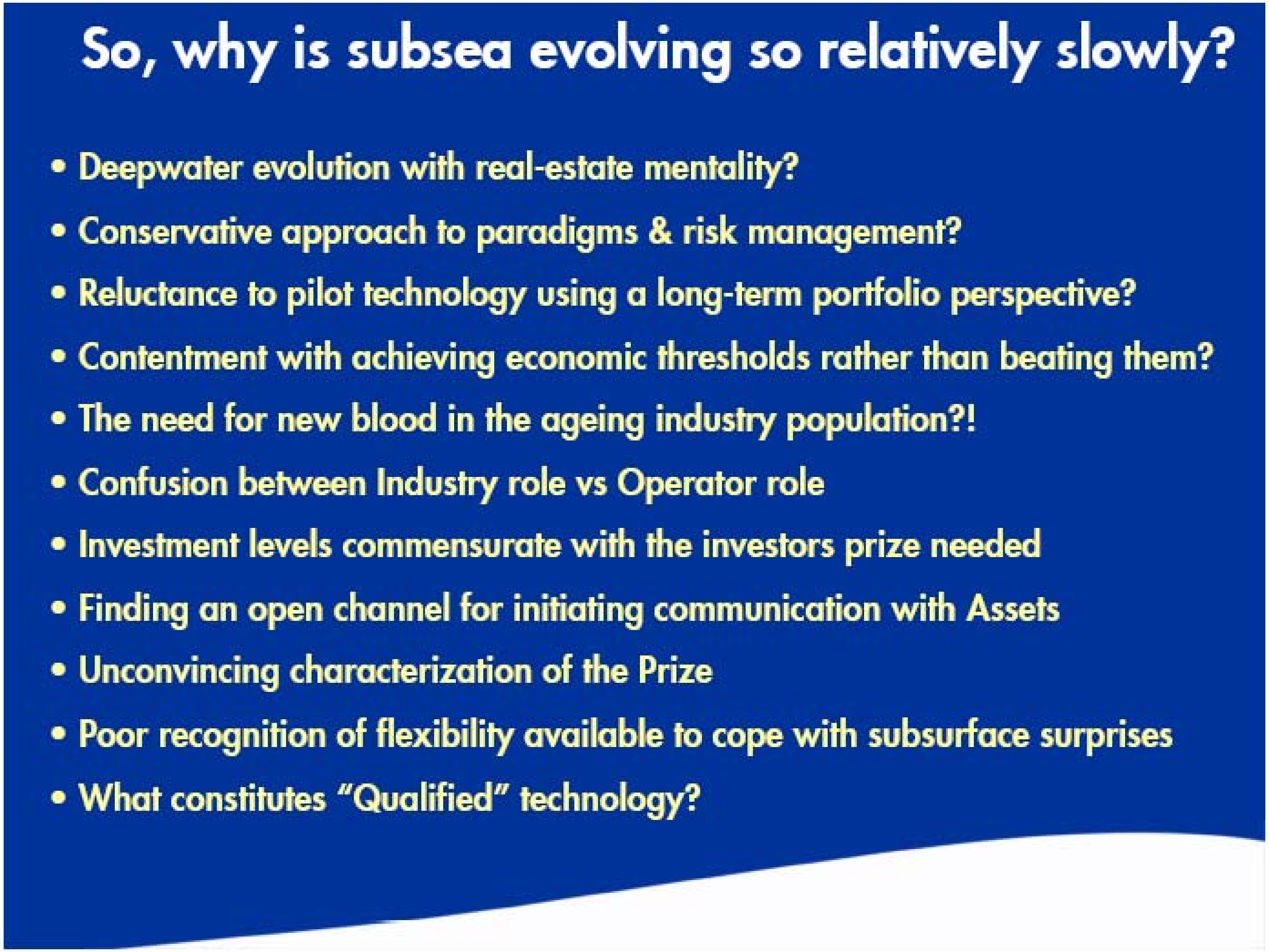
Impressive Subsea Progress this past 20 years?

- <u>1960's/70's</u>: One-atmosphere manned intervention enclosures for seabed wells and manifolds installed & used safely
- <u>1968</u>: all-electric subsea tree installed in GoM
  - Autonomous Power Supply recharging batteries
  - Electrically actuated tree valves
  - Acoustic control capability
  - Weak link was pin-type underwater electrical connectors
- <u>1976</u>: Shell/Esso UMC project initiated in N Sea
  - 9 wells – several still supporting Cormorant Alpha hub
  - 95+% availability over first 8 years
  - Remotely controlled maintenance & TFL systems
  - Successful debut of inductive wet-mateable electrical couplers

Cormorant UMC 1982 – Happy 20th Birthday!

- 9-wells fully TFL from platform
- Still producing today in N Sea
- Availability averaged over 95% in first 8 years

Load-out in Rotterdam



So, why is subsea evolving so relatively slowly?

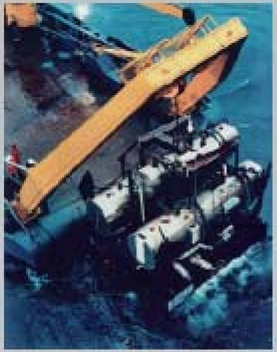
- Deepwater evolution with real-estate mentality?
- Conservative approach to paradigms & risk management?
- Reluctance to pilot technology using a long-term portfolio perspective?
- Contentment with achieving economic thresholds rather than beating them?
- The need for new blood in the ageing industry population?!
- Confusion between Industry role vs Operator role
- Investment levels commensurate with the investors prize needed
- Finding an open channel for initiating communication with Assets
- Unconvincing characterization of the Prize
- Poor recognition of flexibility available to cope with subsurface surprises
- What constitutes "Qualified" technology?

Actual Seabed Separation projects - 1969 on

ZAKUM (1969 -1972)

Exxon **SPS** (1972 -1974)

Kværner Booster Station
(Mid 80's)



BOET (1986 -1989)

GASP
(1986 -1990
successfully
tested)

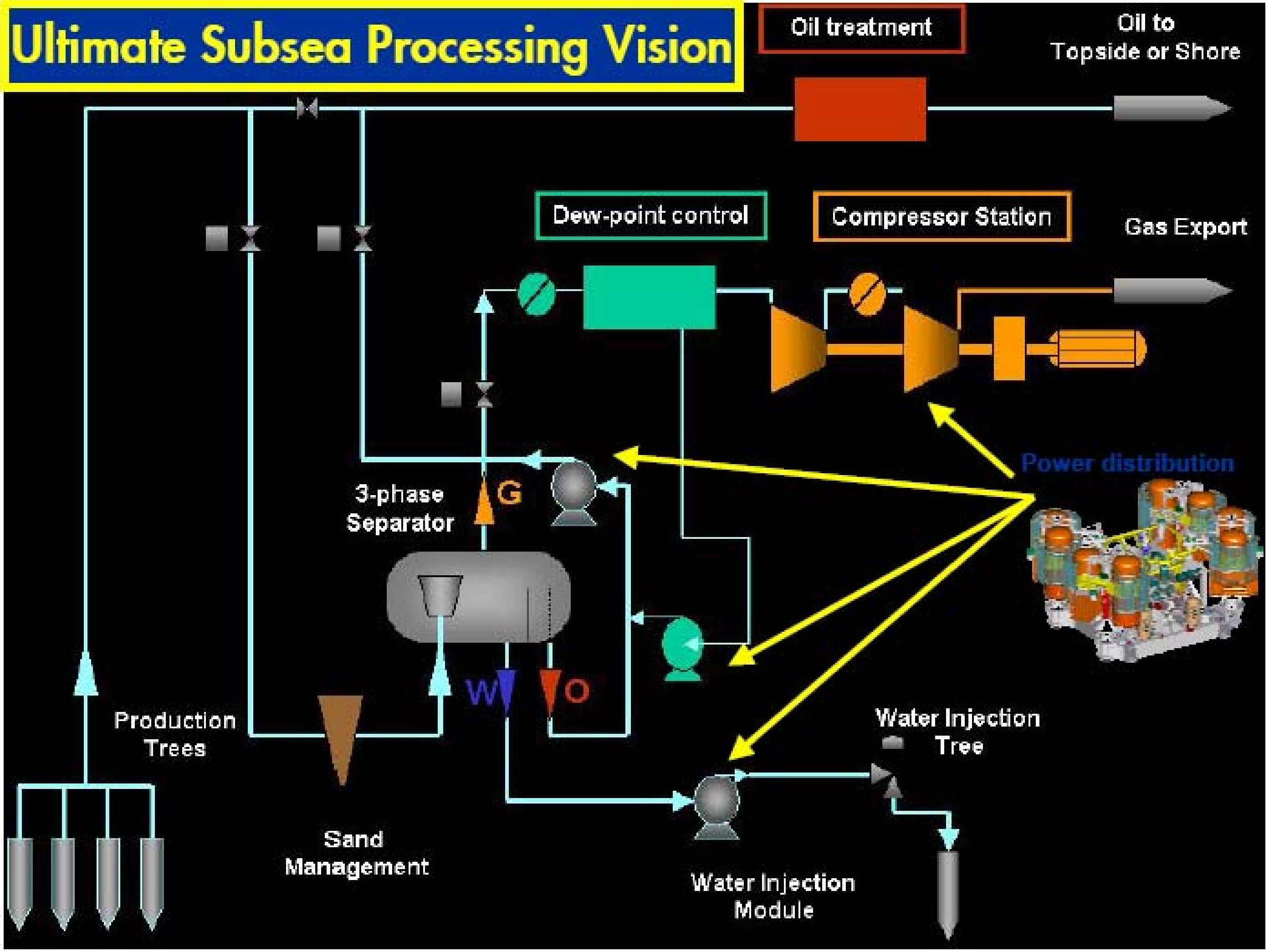
Texaco
Highlander
(1986 & still
operating)

AESOP (1999 -2000
successfully tested
via onshore JIP)

SUBSIS
(2000 - ongoing
Troll Pilot)

VASPS
(2000 - ongoing)

Ultimate Subsea Processing Vision



Oil treatment

Oil to
Topside or Shore

Dew-point control

Compressor Station

Gas Export

Power distribution

3-phase
Separator

G

W

O

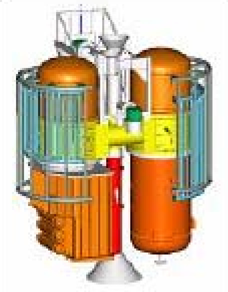
Production
Trees

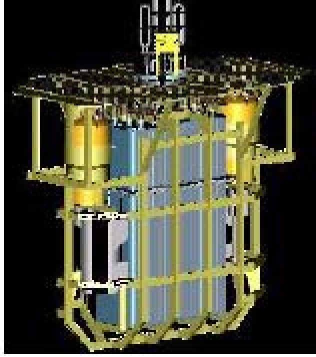
Sand
Management

Water Injection
Tree

Water Injection
Module

Technology Shell Is Qualifying



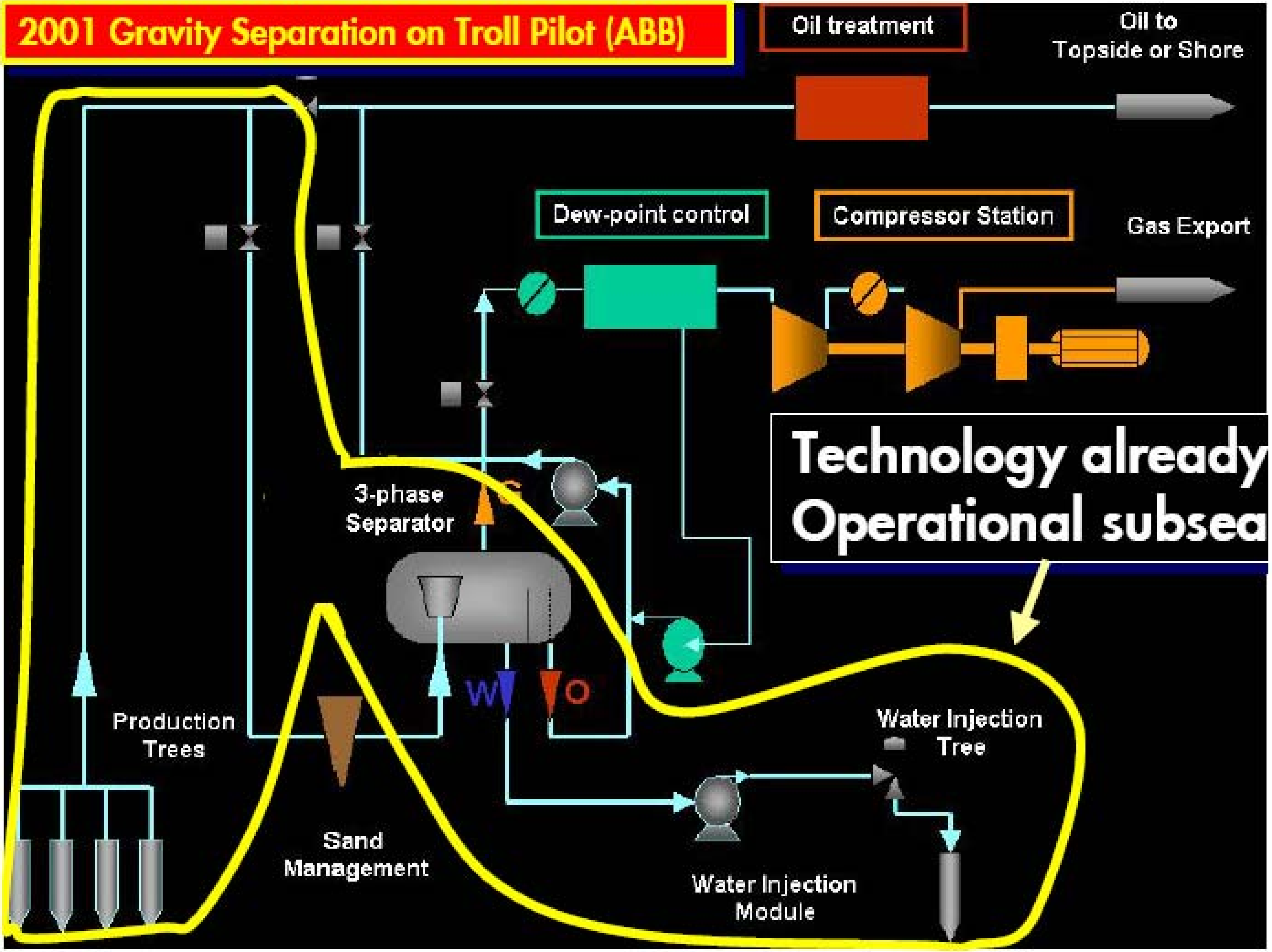


Subsea Power Distribution

2000 M, 4 loads, 10 MW total

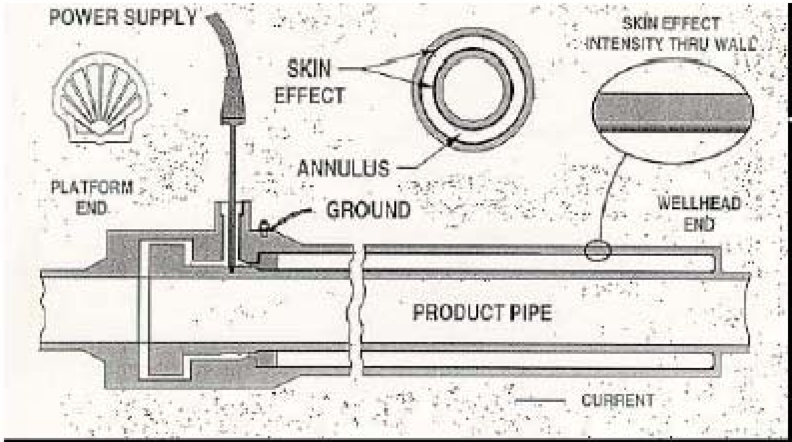
Available 2003

2001 Gravity Separation on Troll Pilot (ABB)



Technology already
Operational subsea

Electric flowline heating



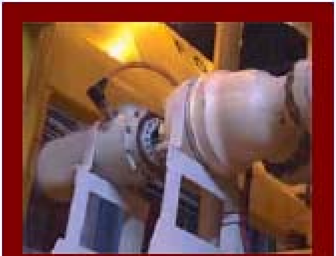
Serrano & Oregano 8km to Bullwinkle – always available - fully operational

Na Kika 20km 7200ft WD - Being installed as EH-ready

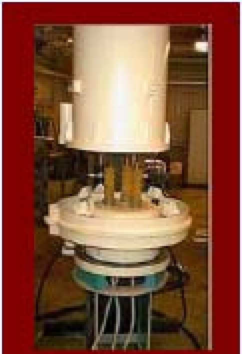
Kvaerner IPU Development

Underwater testing of AlphaPRIME™
System-Module during Shell-sponsored JIP in 2000

Modular Deployment and Electrical Components



PROACT™
Fast actuator
3000 m



ELEx™
Connector
1500 m

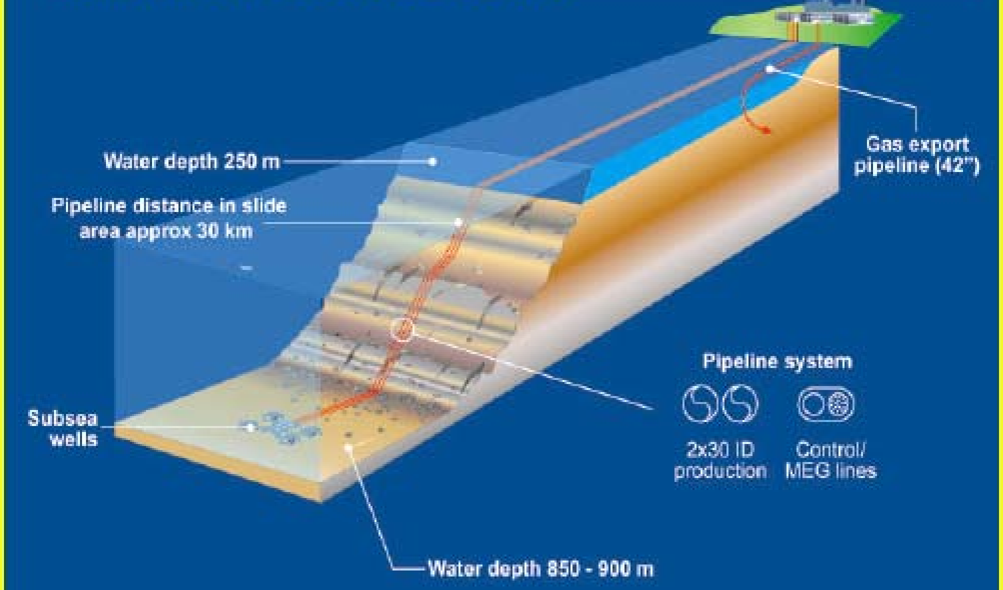
REACT™
Failsafe
actuator
3000 m

AlphaPrime™
& KeyMan Systems
1500 m

The Ormen Lange Project in Norway – first gas 2007

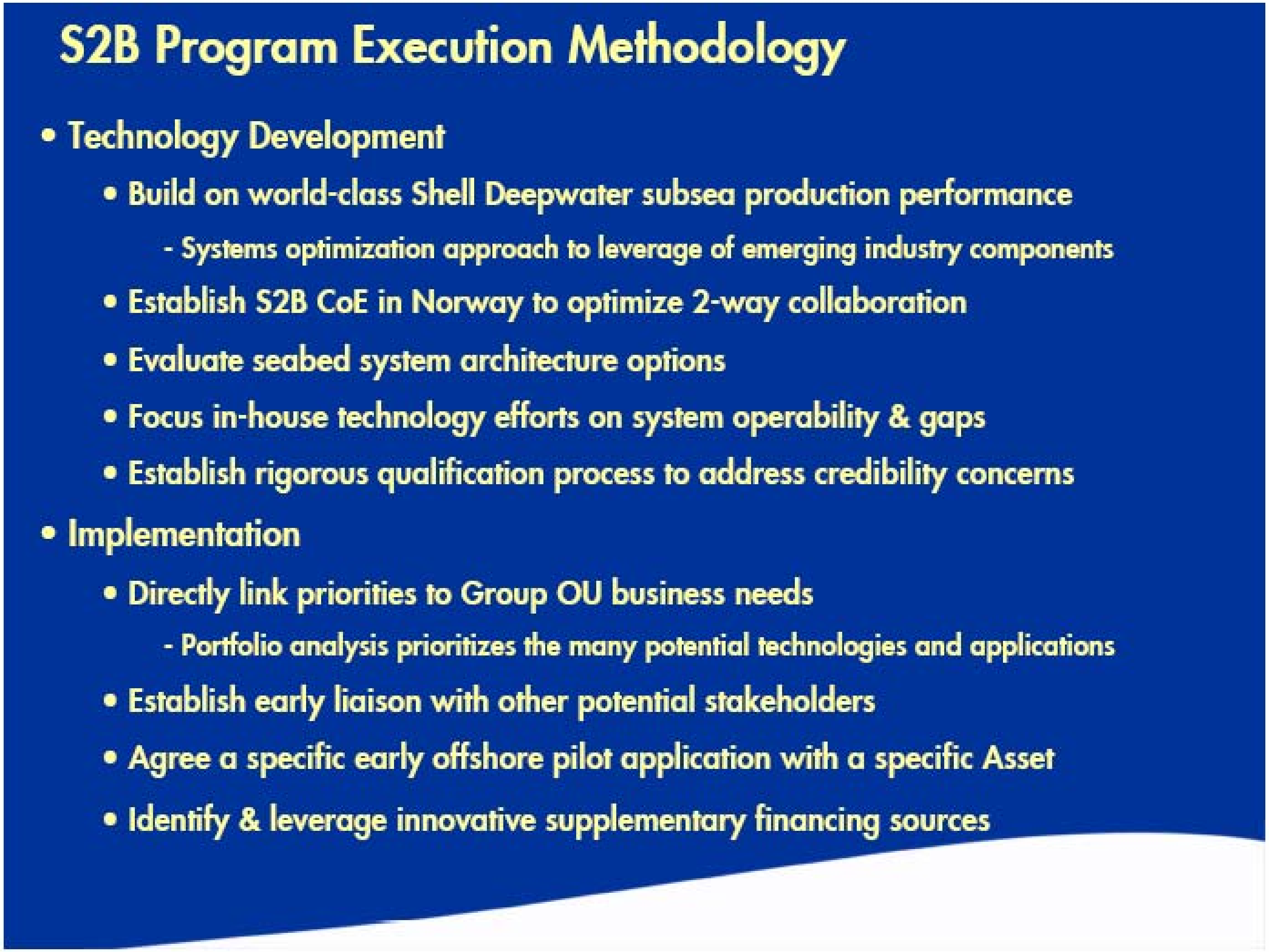
Adopted Sub-sea to the Beach – 100 miles away

Shell is Production Operator



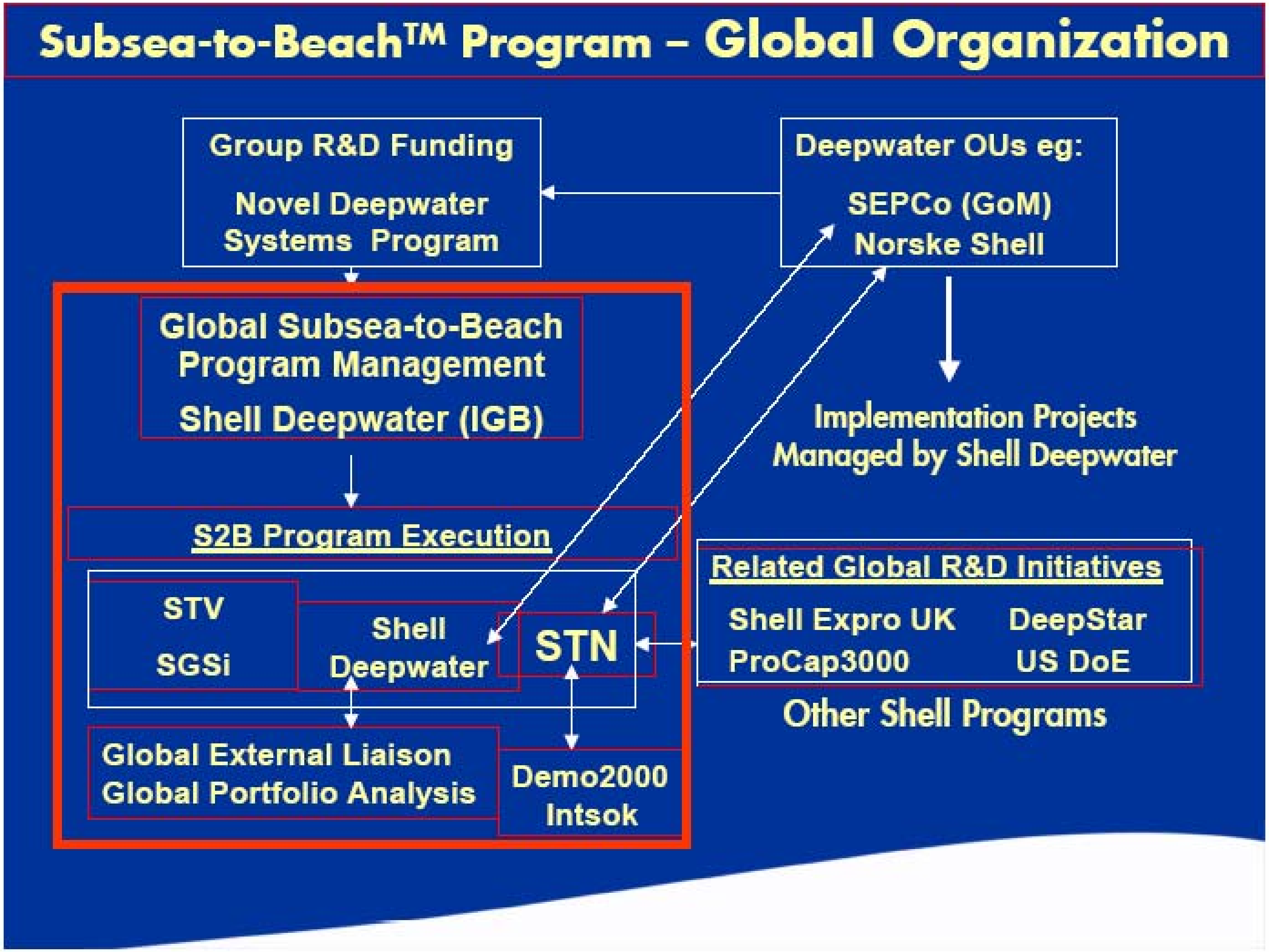
Developing a Strategy

- Am I going to be a Leader or Follower?
- Prospect Portfolio fit & drive vs Project crisis drive
- Broad industry collaboration vs early single sourcing
- Competition vs Duplication
- Who provides the upfront investment funds
- How to achieve internal Confidence Building
- Facilitating Technology Pilots (the Asset managers dilemma)
- Helping the Regulatory Authorities understand the issues



S2B Program Execution Methodology

- Technology Development
  - Build on world-class Shell Deepwater subsea production performance
    - Systems optimization approach to leverage of emerging industry components
  - Establish S2B CoE in Norway to optimize 2-way collaboration
  - Evaluate seabed system architecture options
  - Focus in-house technology efforts on system operability & gaps
  - Establish rigorous qualification process to address credibility concerns
- Implementation
  - Directly link priorities to Group OU business needs
    - Portfolio analysis prioritizes the many potential technologies and applications
  - Establish early liaison with other potential stakeholders
  - Agree a specific early offshore pilot application with a specific Asset
  - Identify & leverage innovative supplementary financing sources



Subsea-to-Beach™ Program – Global Organization

Group R&D Funding

Novel Deepwater Systems Program

Deepwater OUs eg:

SEPCo (GoM)
Norske Shell

Global Subsea-to-Beach Program Management

Shell Deepwater (IGB)

Implementation Projects Managed by Shell Deepwater

S2B Program Execution

STV
SGSi

Shell Deepwater

STN

Related Global R&D Initiatives

Shell Expro UK	DeepStar
ProCap3000	US DoE

Other Shell Programs

Global External Liaison
Global Portfolio Analysis

Demo2000
Intsok

Concluding Remarks – Personal View on Key Issues

- How much longer can our industry afford to view Big as Beautiful?
  - Subsea field development is rapidly overtaking conventional solutions
- Let's all put <u>serious effort</u> into attracting bright youngsters in
  - Requires there to be a fundamentally more attractive culture visible
- Standardization needs constant renewal to remain smart
  - The biggest long-term business risk is – never taking any
- Government-led efforts in Norway have really made the difference
  - Are other National bodies going to play a similar role
- Subsea Processing has huge latent value for Operators & Nations
  - But where is the commensurate investment to deliver that value?
- Collaborative efforts will be crucial in resource-starved times ahead
  - Sensible orchestration to share burden of achieving commerciality
- Shell is among the few that are really starting to take it seriously
  - Vendors profit margins alone might not get us there!

Thanks for listening!

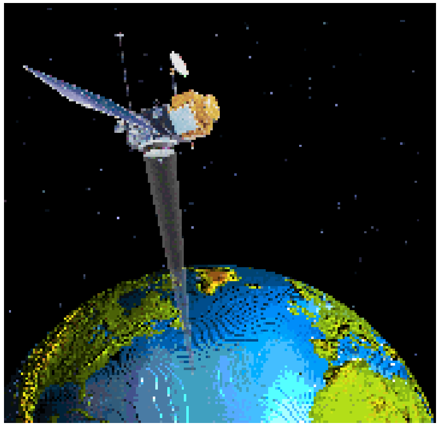
What do you think?
Don’t be bashful – good or bad!
Please let me know now, or later at:

Ian.Ball@Shell.com

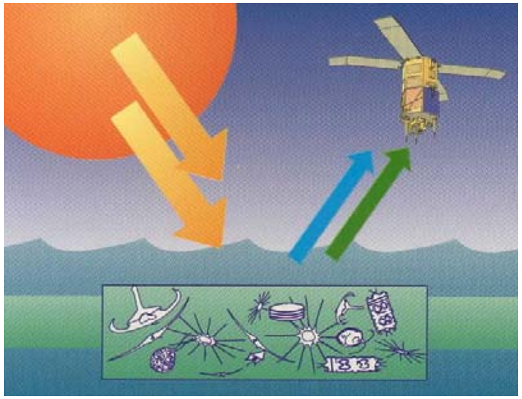
Ship and Satellite Studies of Sperm Whale Habitat

DC Biggs, MK Howard, AE Jochens, SF DiMarco (Texas A&M University)
Robert Leben (University of Colorado)
Chuanmin Hu (University of South Florida)

R/V *GYRE*



TOPEX/Poseidon



SeaWiFS

Summer 2002 Sperm Whale Seismic Studies (SWSS):

SWSS Leg 1: 20 June - 8 July 2002

SWSS Leg 2: 22 August - 15 September 2002

- **Texas A&M University**

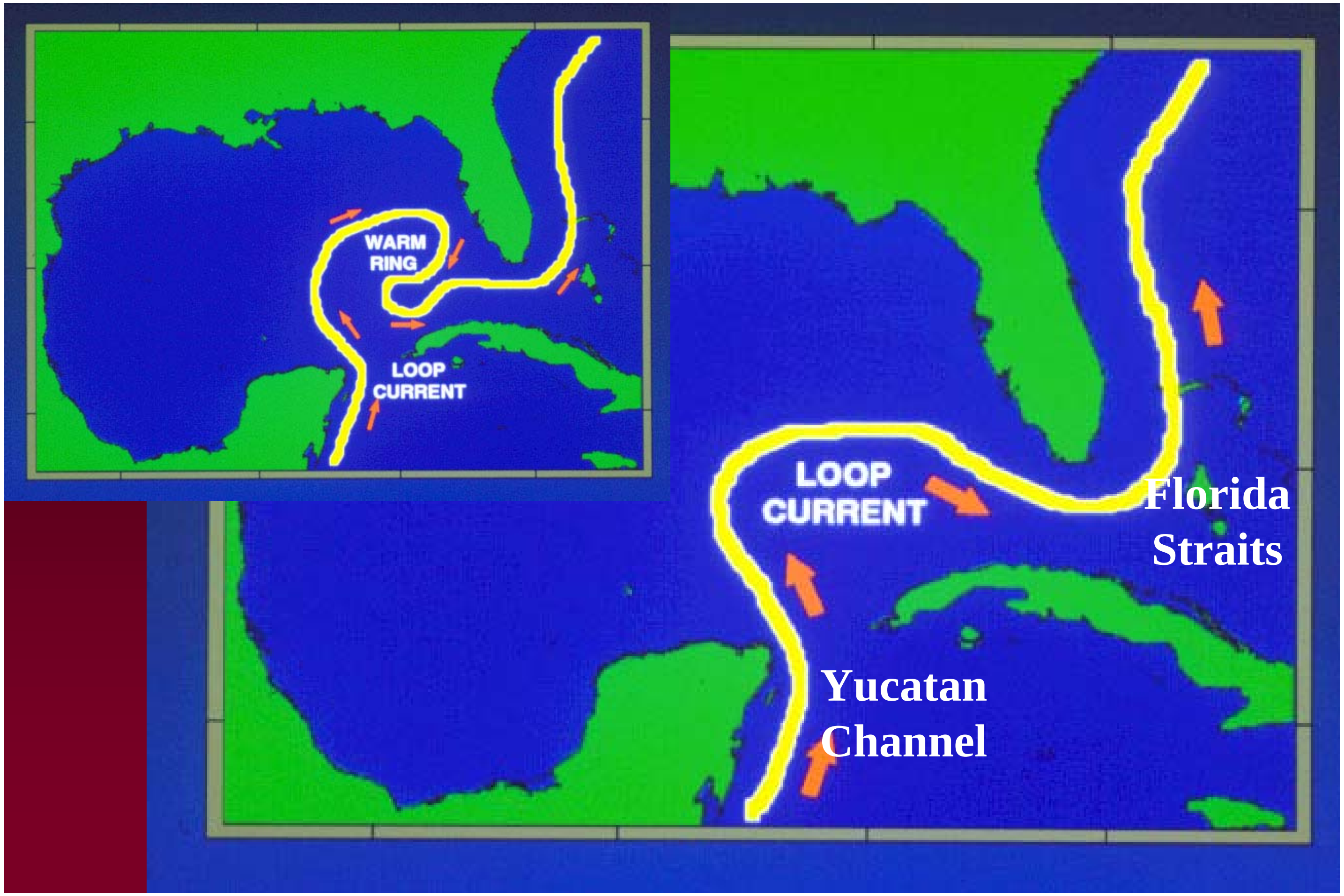
  oceanographic data from R/V *GYRE* :
  - **Temperature, salinity at z = 3 m**
  - **In vivo CHL fluorescence at z = 3 m**
  - **XBT**
  - **ADCP**

  and CTD casts to profile sound velocity

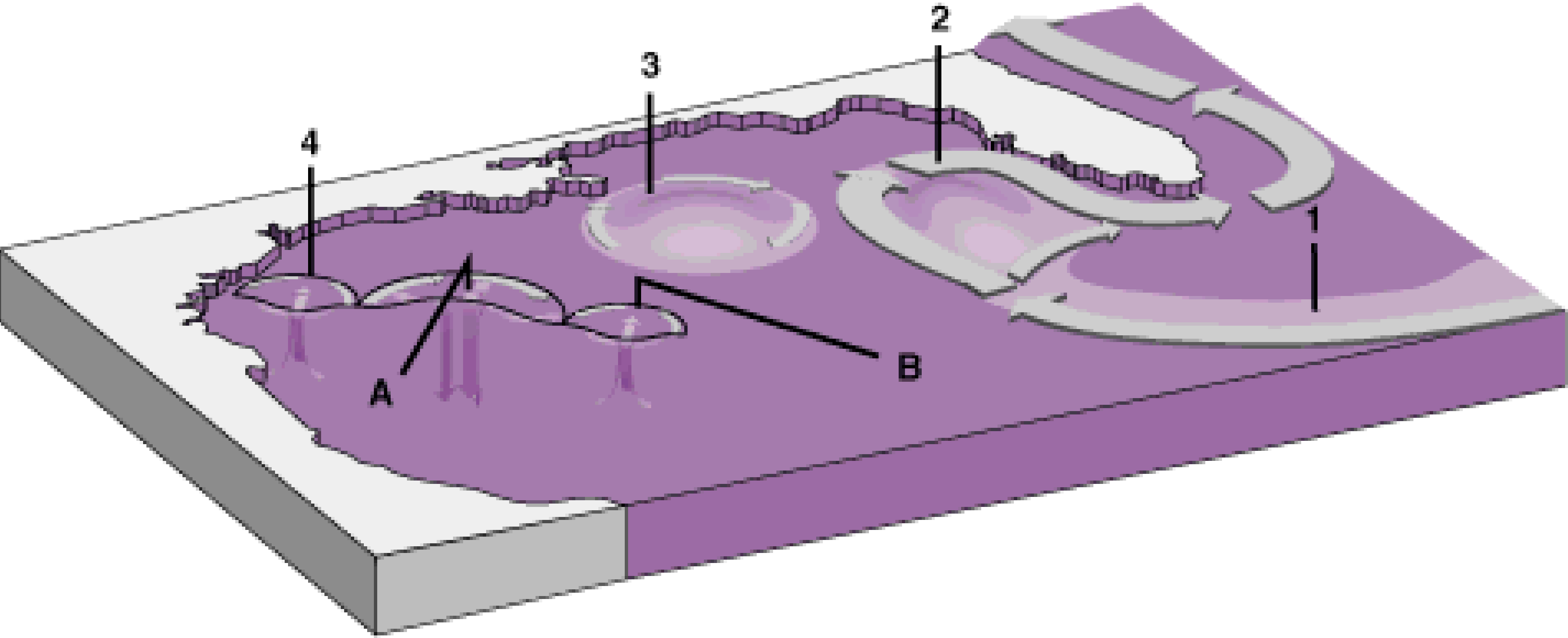
- **University of Colorado**
  Center for Astrodynamics Research (CCAR):
  SSH altimetry from tandem measurements by
  NASA TOPEX/Poseidon and ERS-2 altimeters

- **University of South Florida**
  Institute for Marine Remote Sensing (IMaRS):
  ocean color from NASA SeaWiFS satellite

Gulf of Mexico: General Circulation



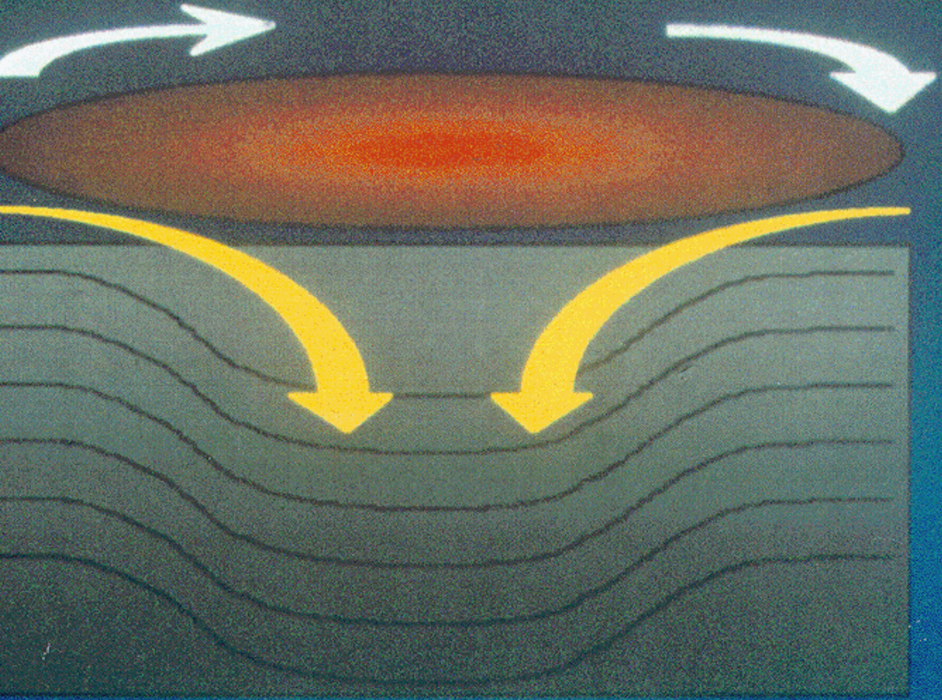
1) Loop Current inflow; 2) Anticyclonic excursion; 3) Separation of LCE; 4) bottom friction causes LCE to shed vorticity, and in doing so this anticyclonic eddy (A) can create companion cyclones (B).



Anticyclonic versus Cyclonic Rings

Warm Core Ring

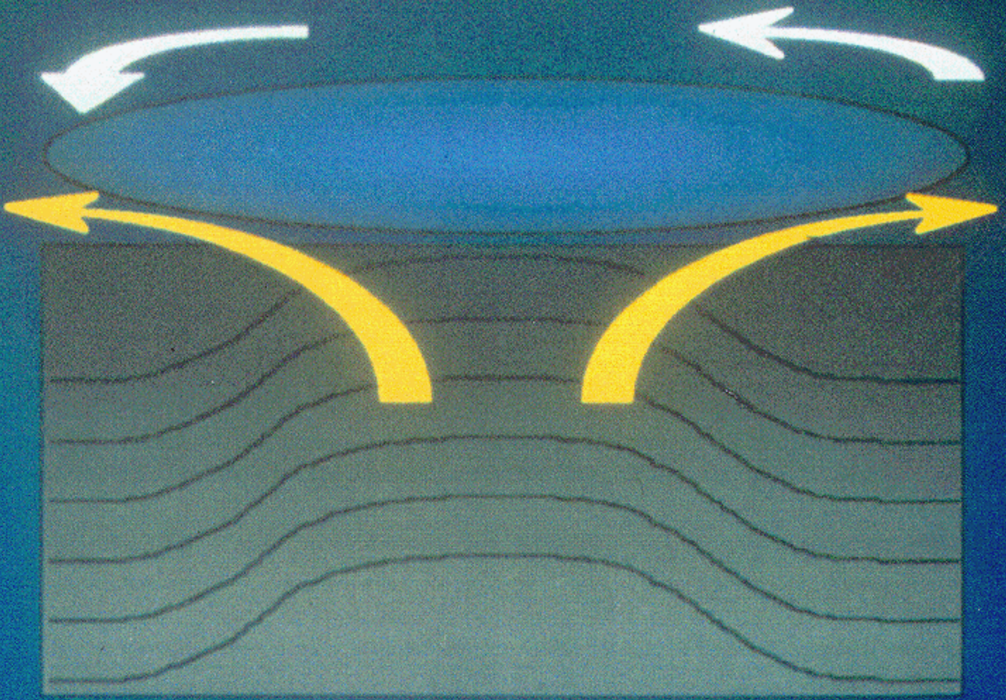
Anticyclonic Circulation
Convergence Zone



Temperature Depth Profile

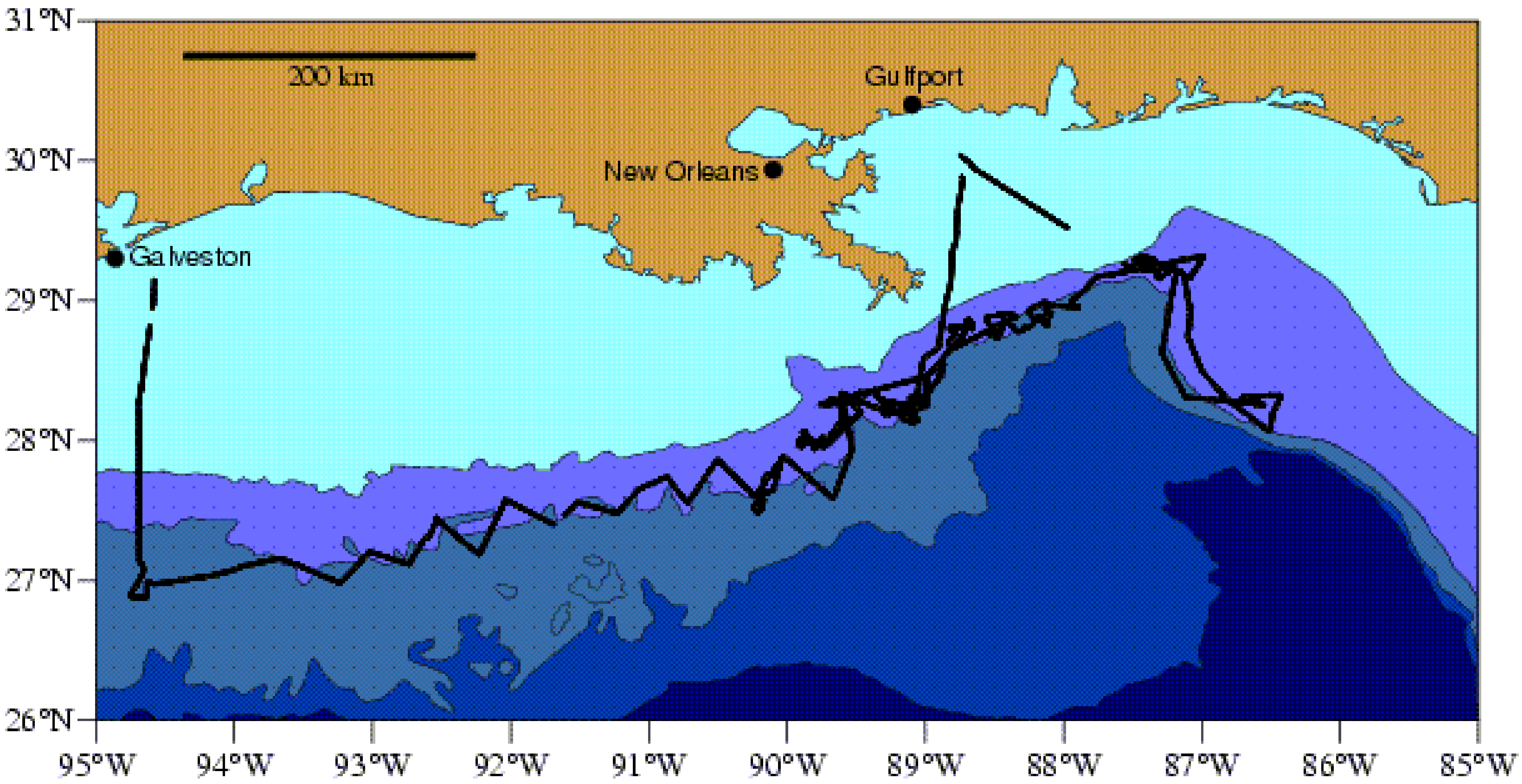
Cold Core Ring

Cyclonic Circulation
Divergence Zone



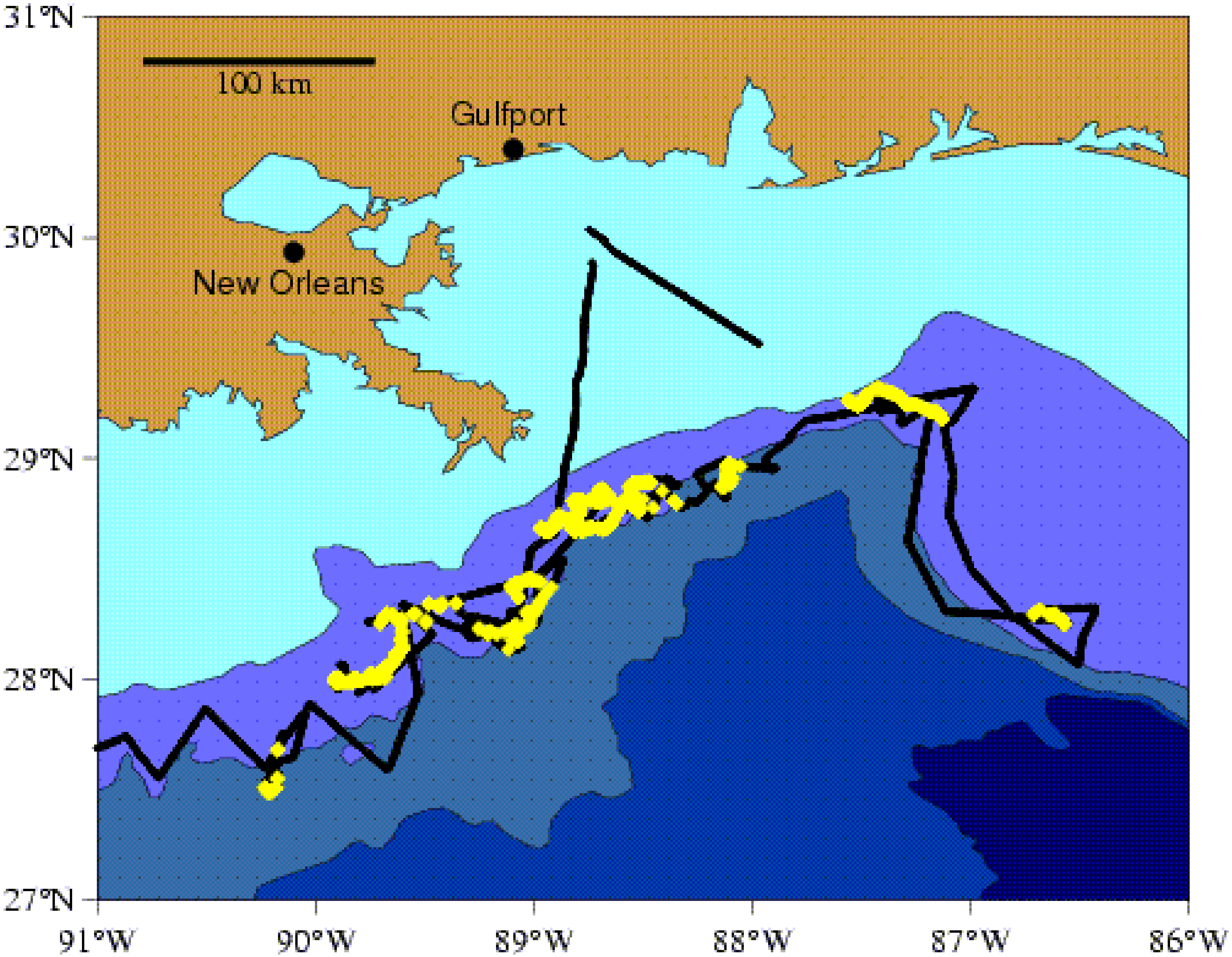
Temperature Depth Profile

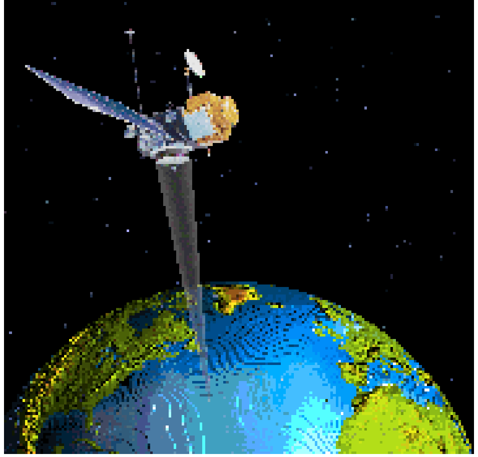
Summer 2002 Fieldwork: SWSS Leg 1



Bold line indicates S-Tag cruise track.
Depth contours shown: 200m, 1000m, 2000m, and 3000m.

Sightings of sperm whales on Leg 1

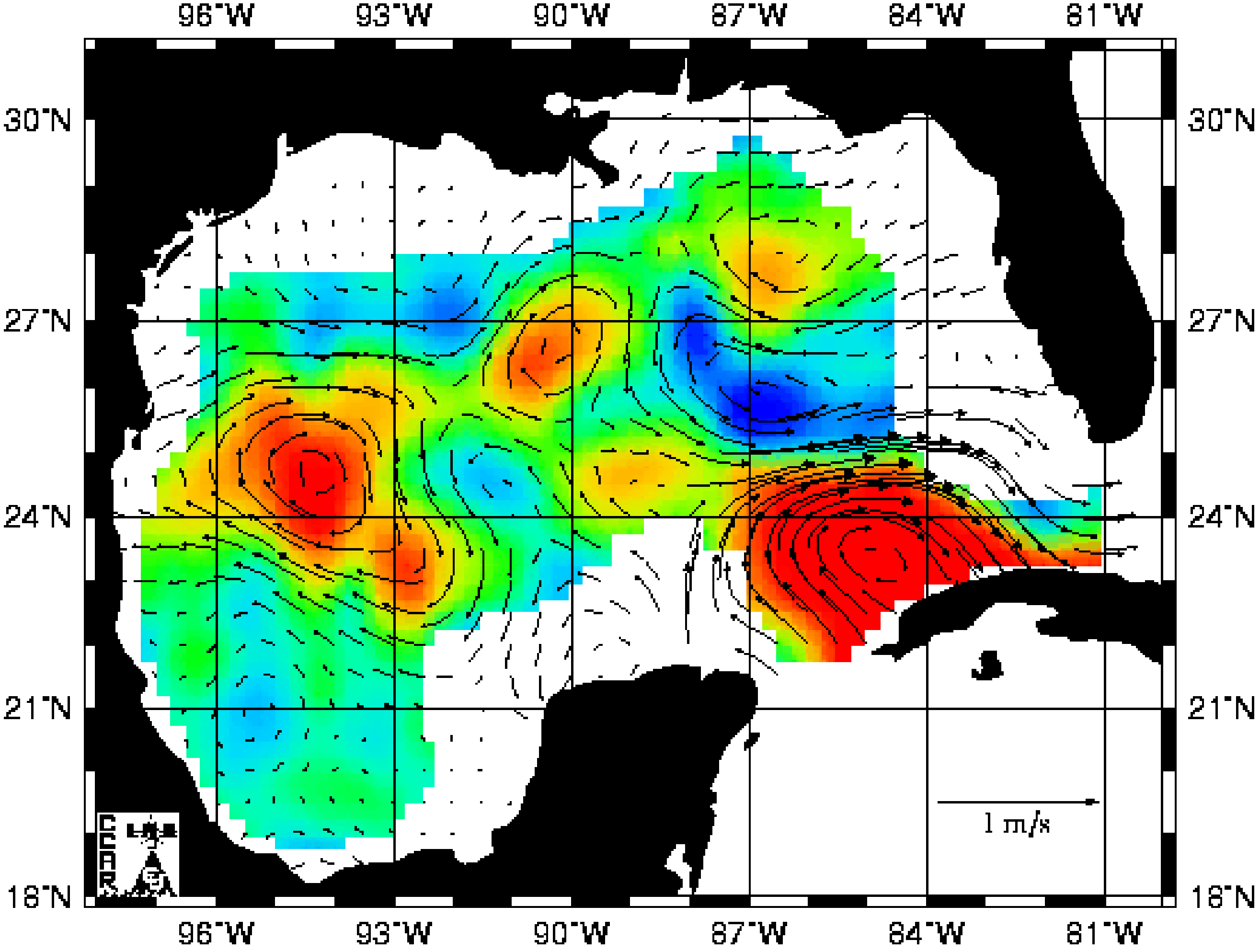




Radars measure satellite height above the ocean; But since the satellite orbit is known with high precision, these radar measurements tell us the sea surface fine structure (how high, or how low, relative to long-term average height).

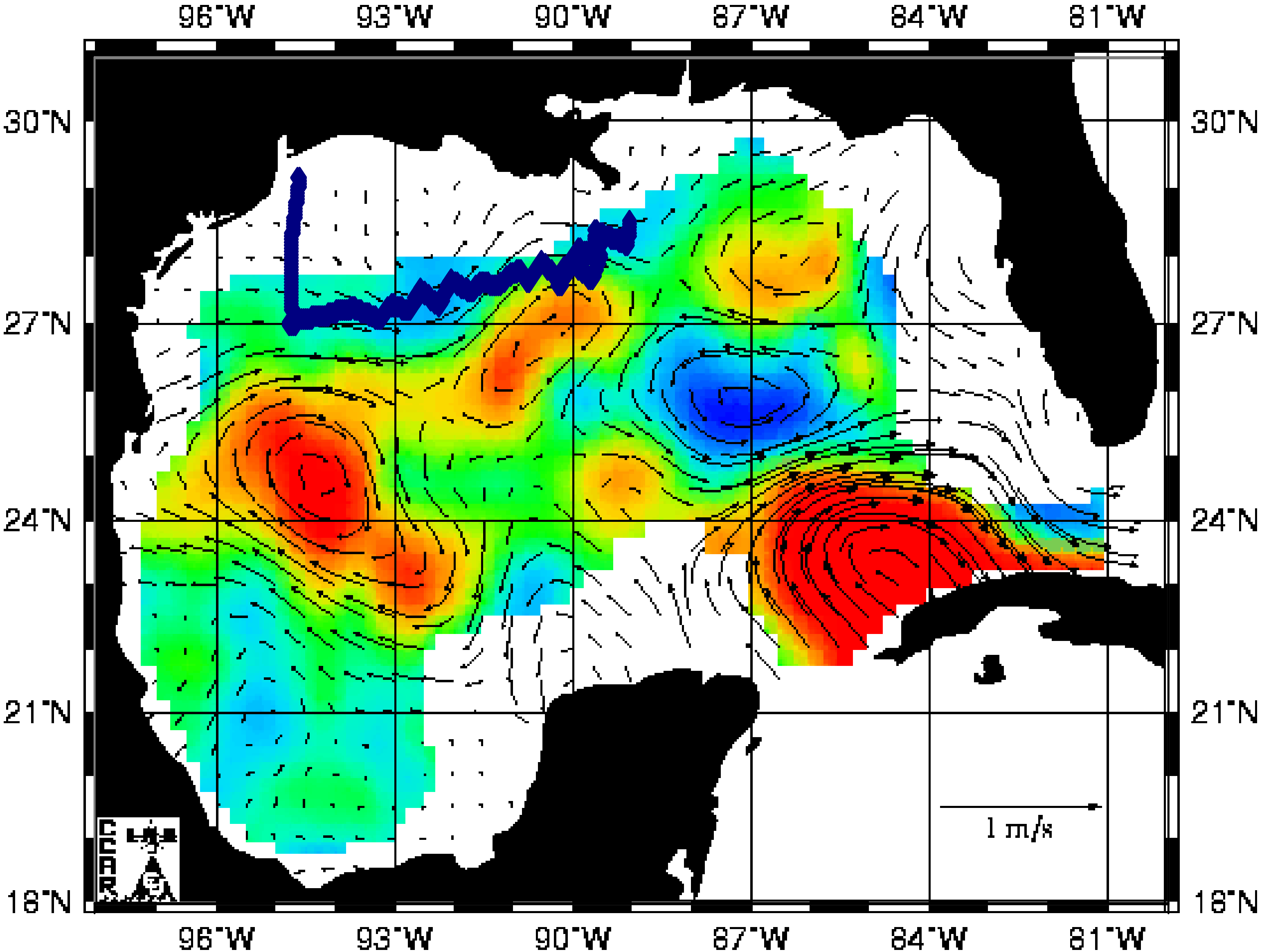
TOPEX/ERS-2 Analysis Jun 19 2002

This was eddy field the day R/V *Gyre* sailed for sea



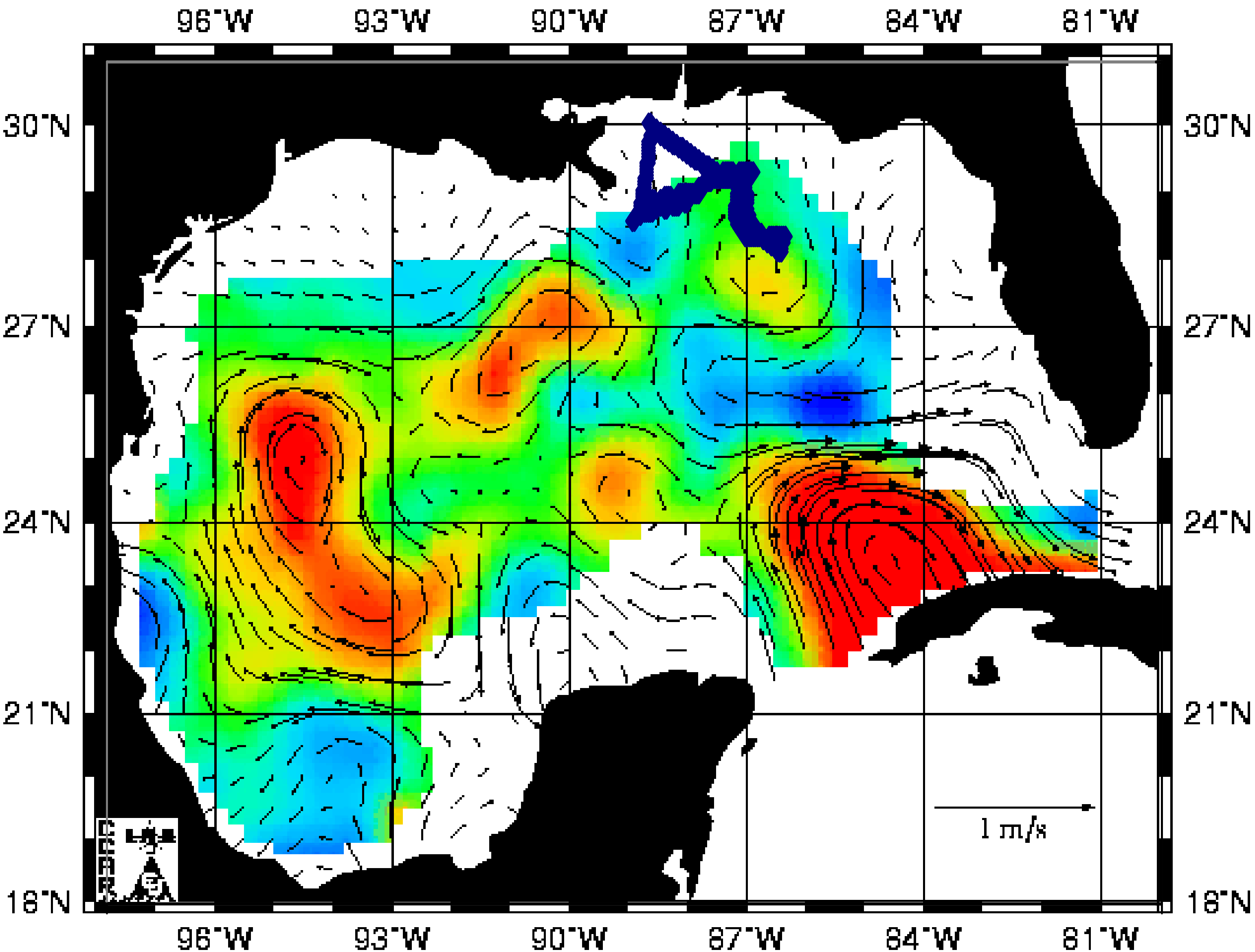
TOPEX/ERS-2 Analysis Jun 26 2002

with Leg 1 shiptrack 20-26 June



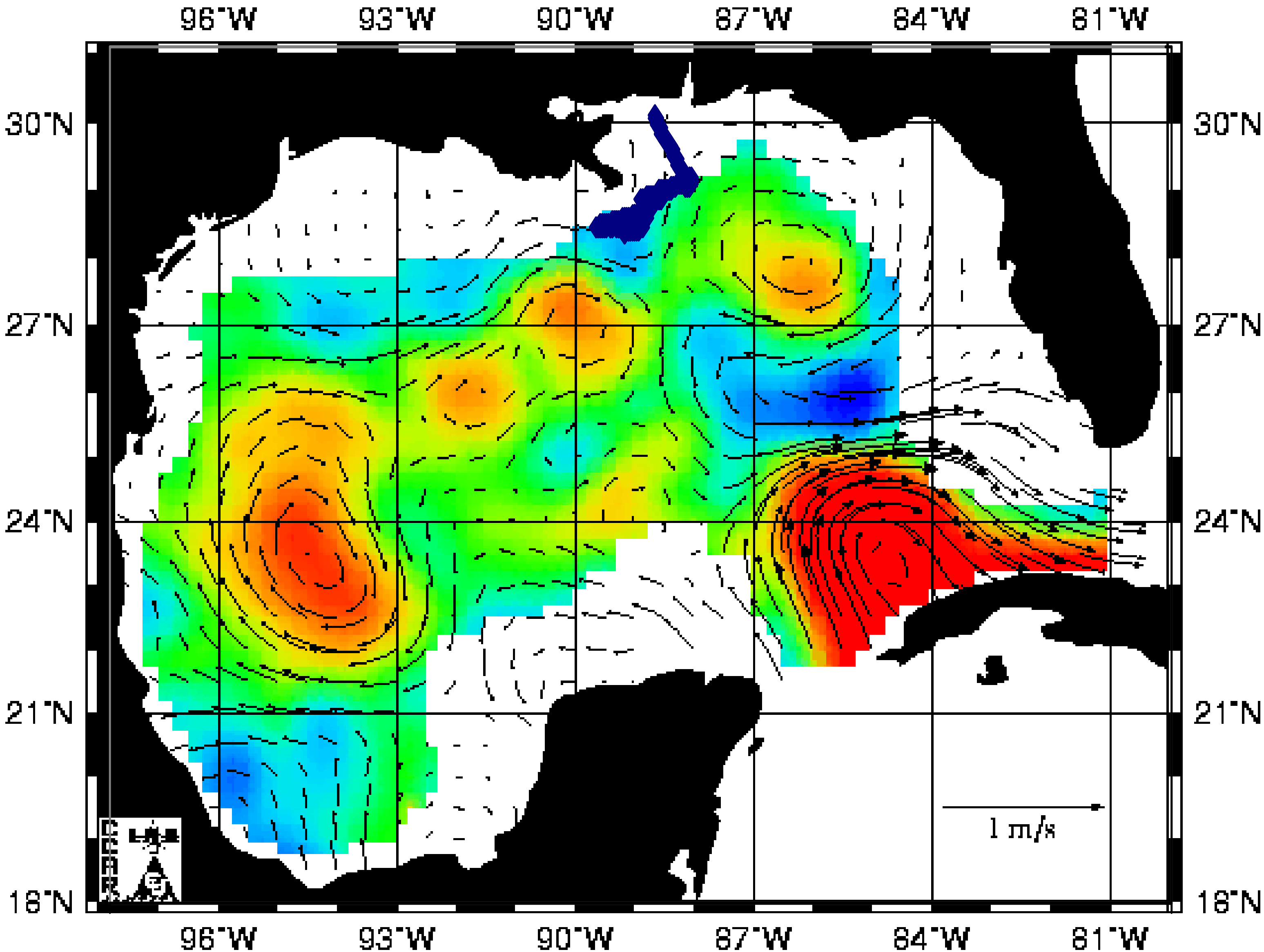
TOPEX/ERS-2 Analysis Jul 3 2002

with Leg 1 shiptrack 27 June - 3 July

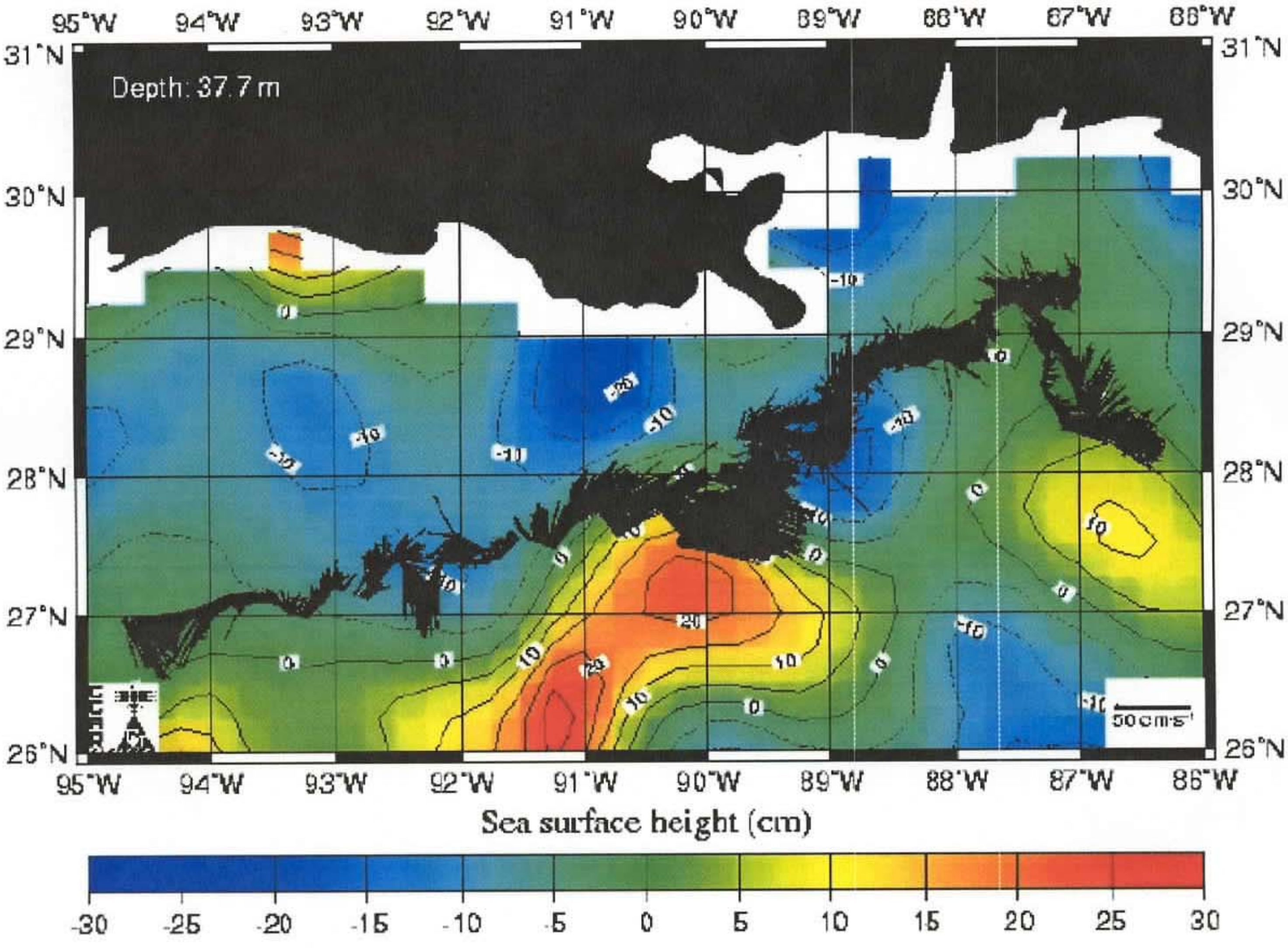


TOPEX/ERS-2 Analysis Jul 10 2002

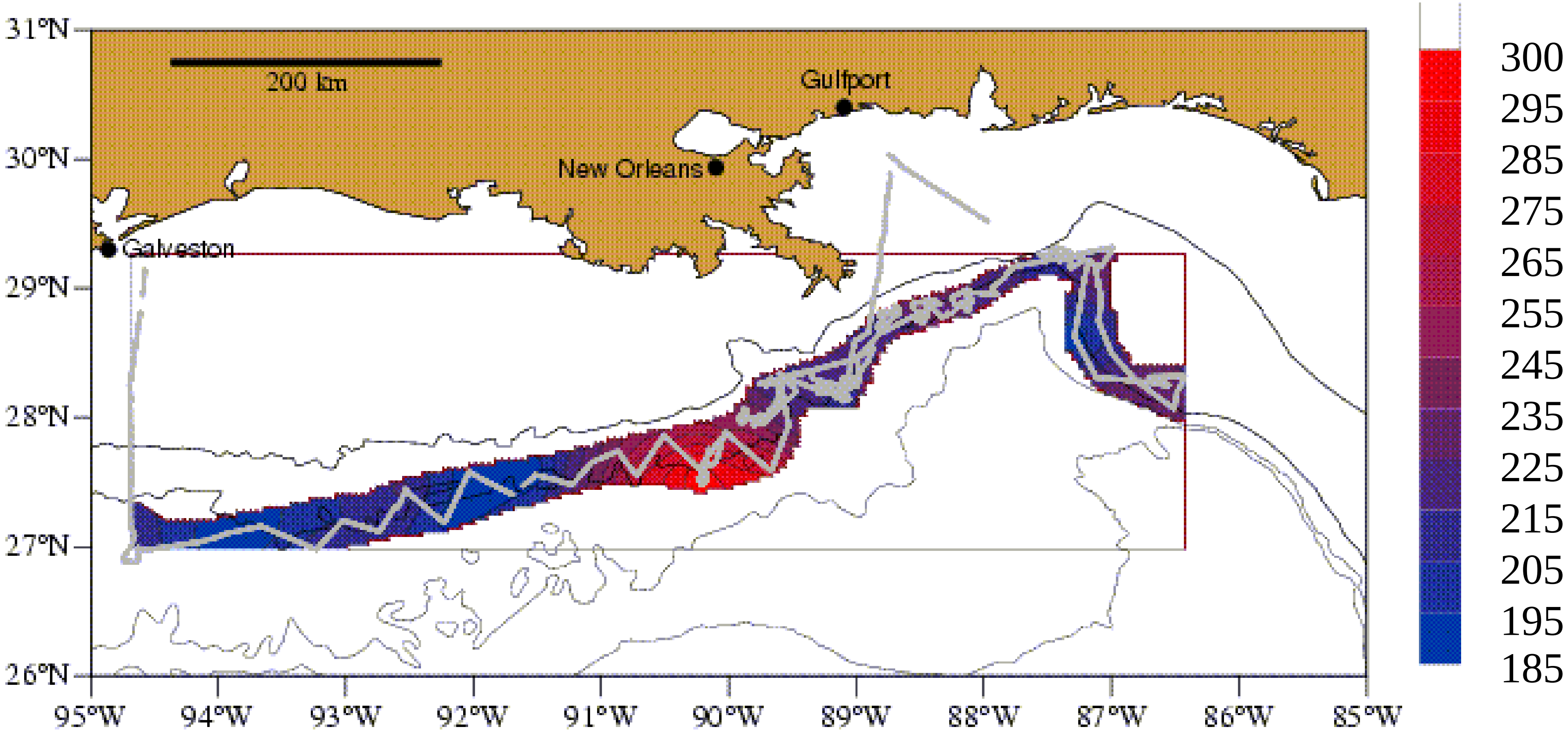
with Leg 1 shiptrack 4-9 July



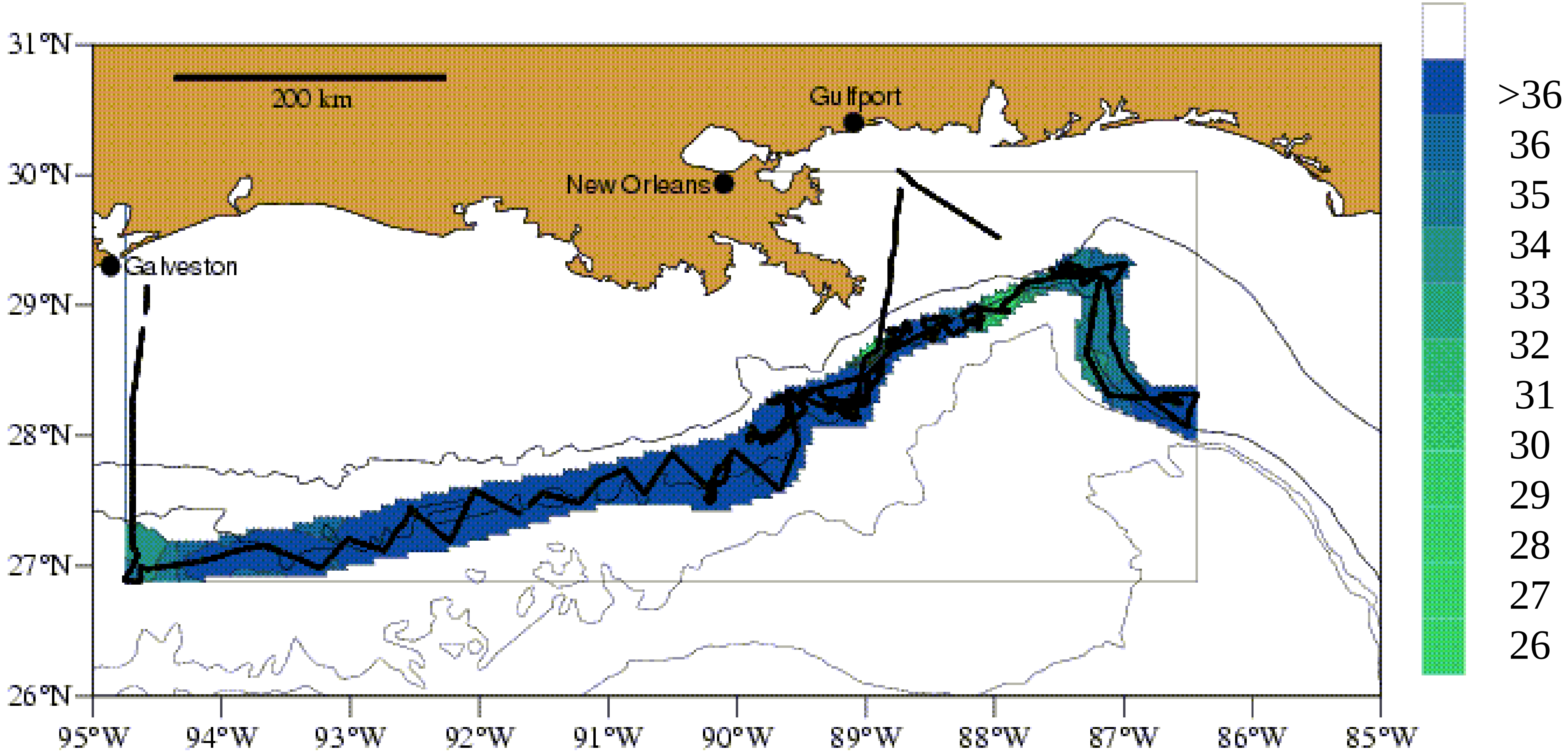
Current velocity from hull-mounted ADCP on R/V *GYRE*



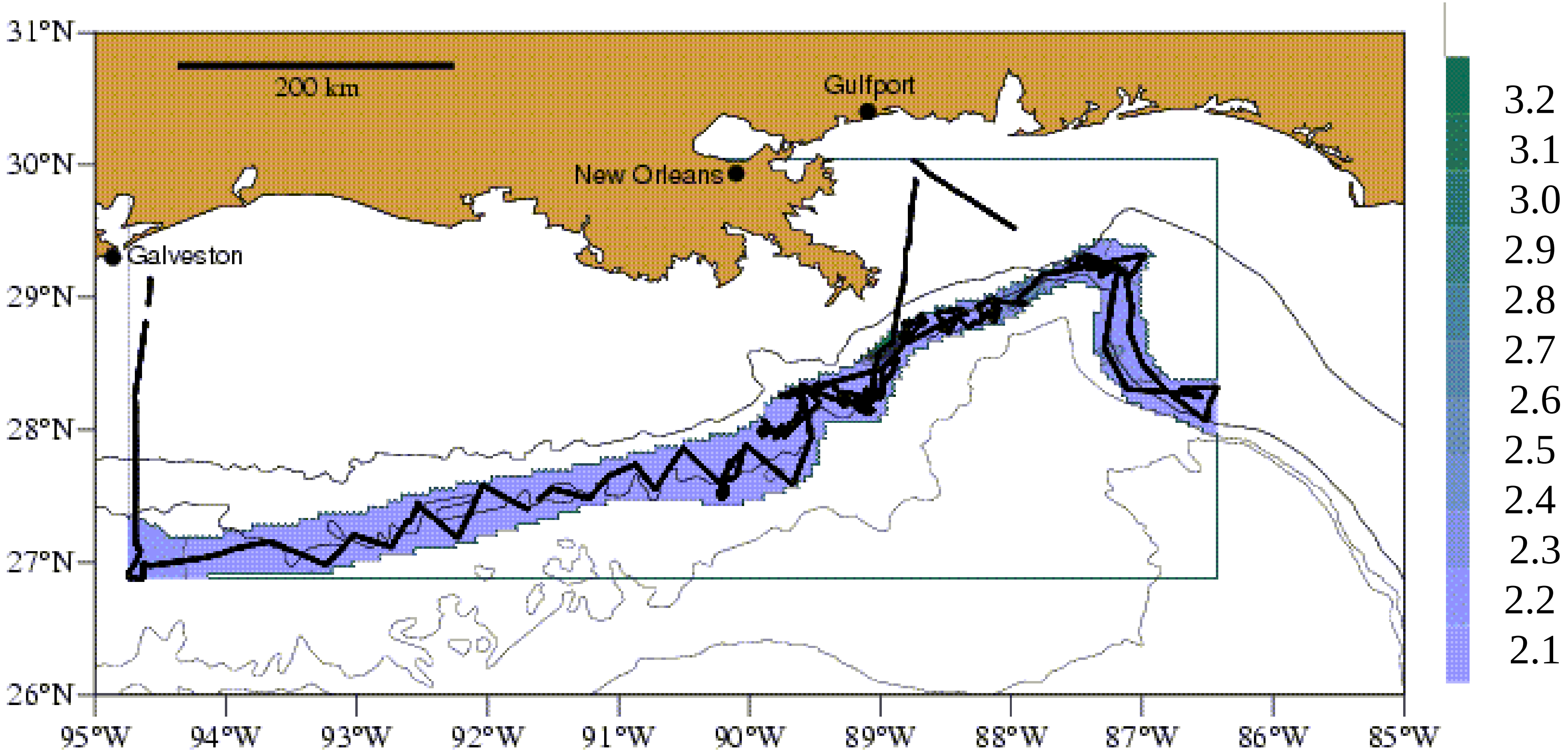
Depth (m) of the 15^{o}C isotherm along cruise track of SWSS Leg 1



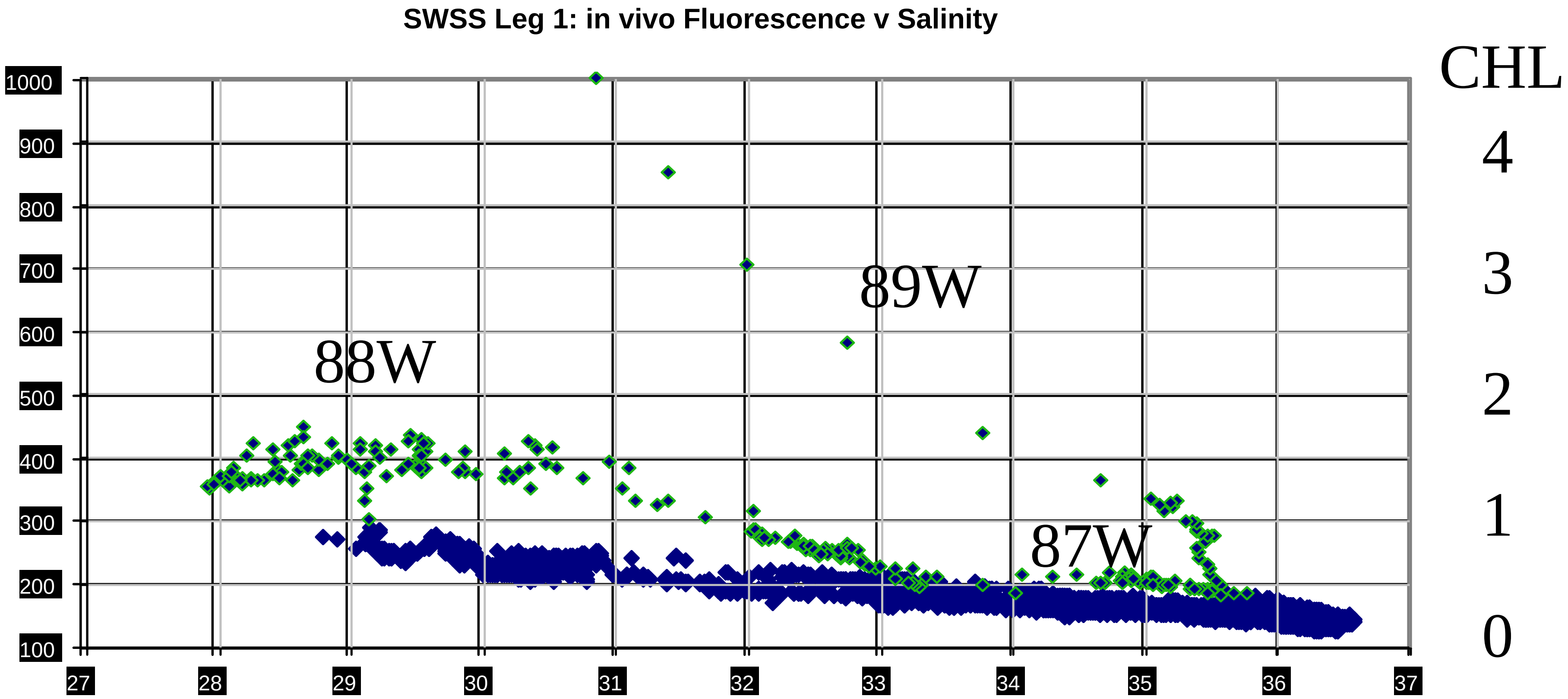
Salinity at z = 3 m along cruise track of SWSS Leg 1



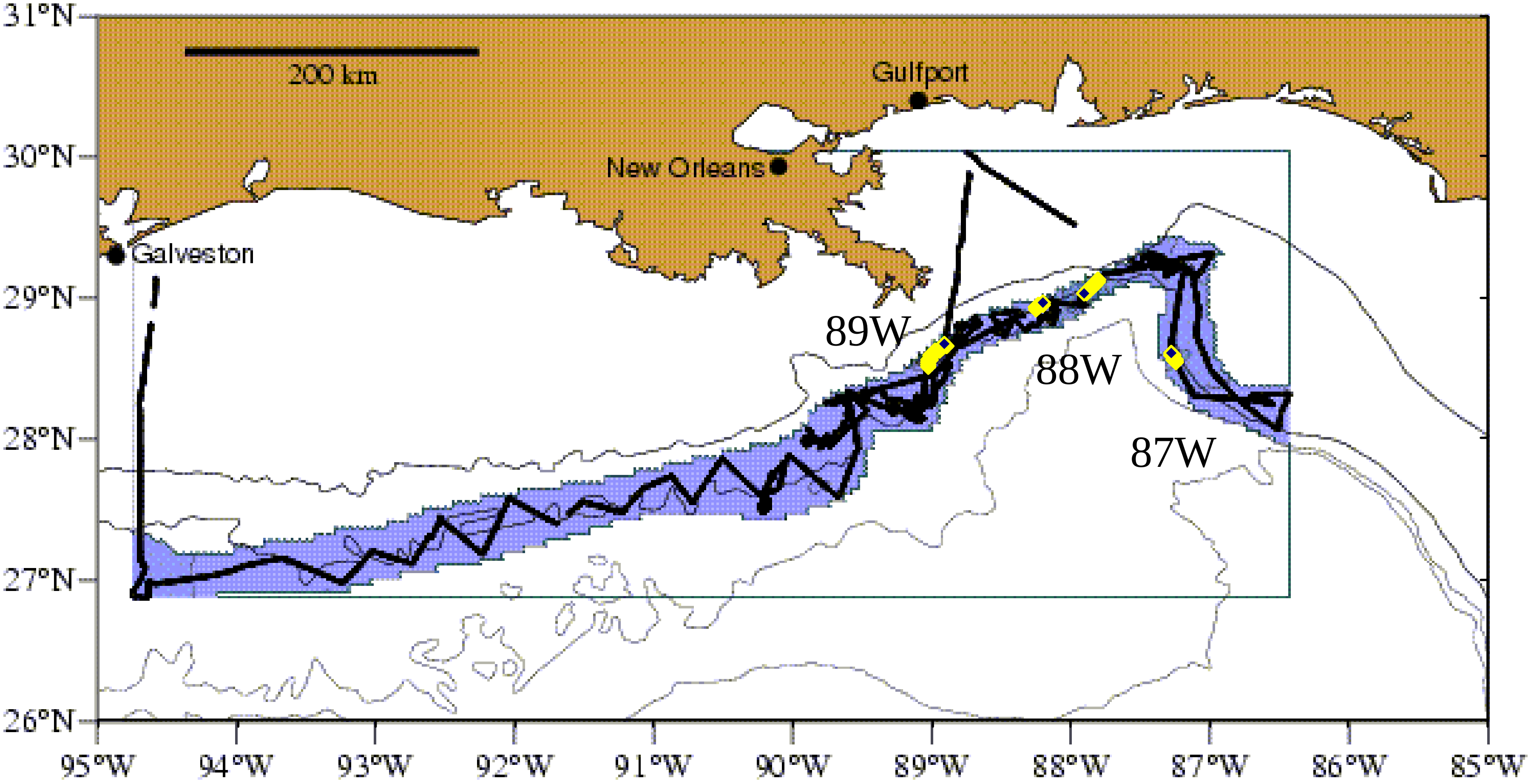
In vivo fluorescence (mvolts, log-transformed) at z = 3 m along track



SWSS Leg 1: In vivo fluorescence versus Salinity

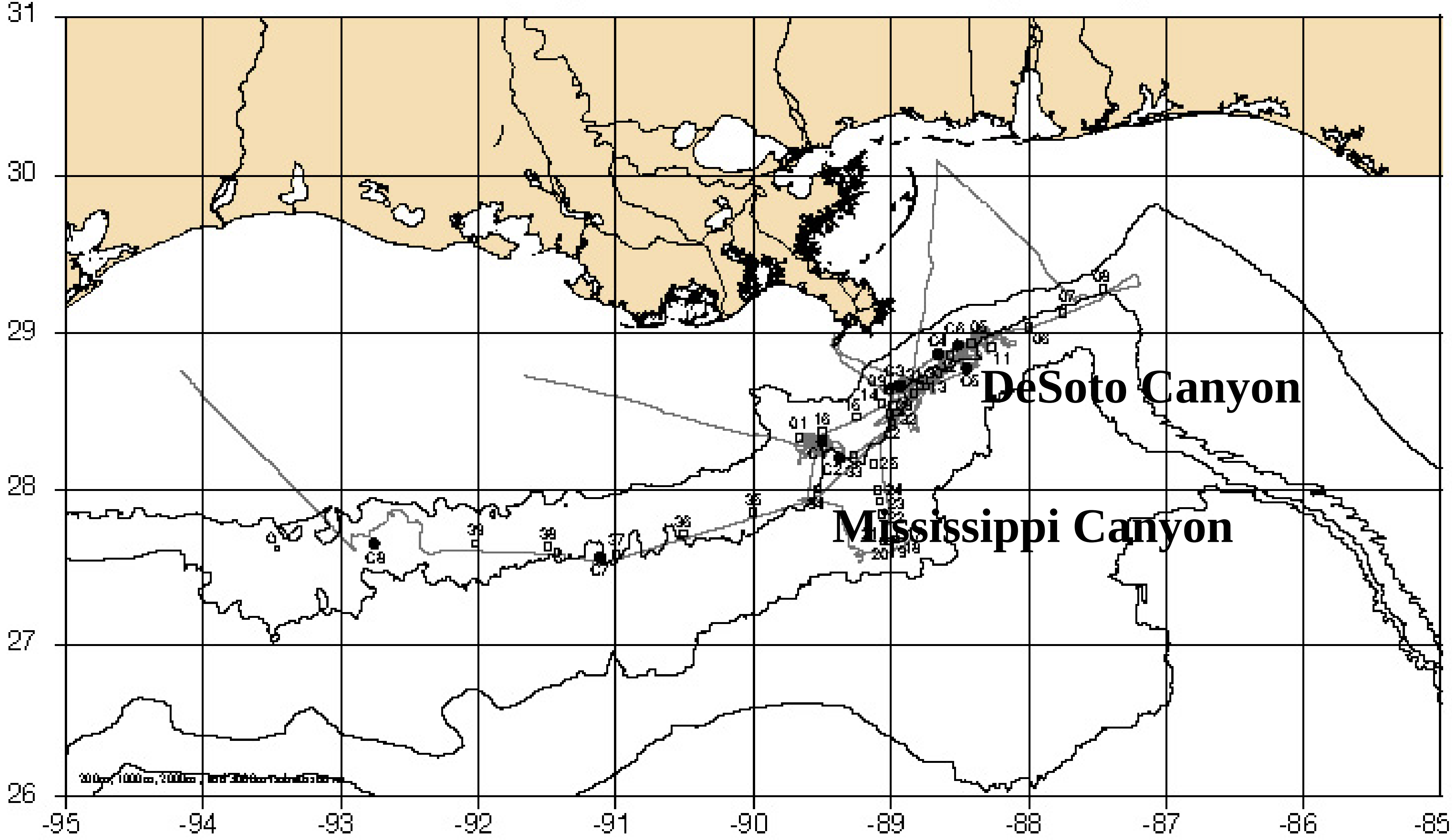


In vivo fluorescence (proxy for CHL) at z = 3 m along track of SWSS Leg 1

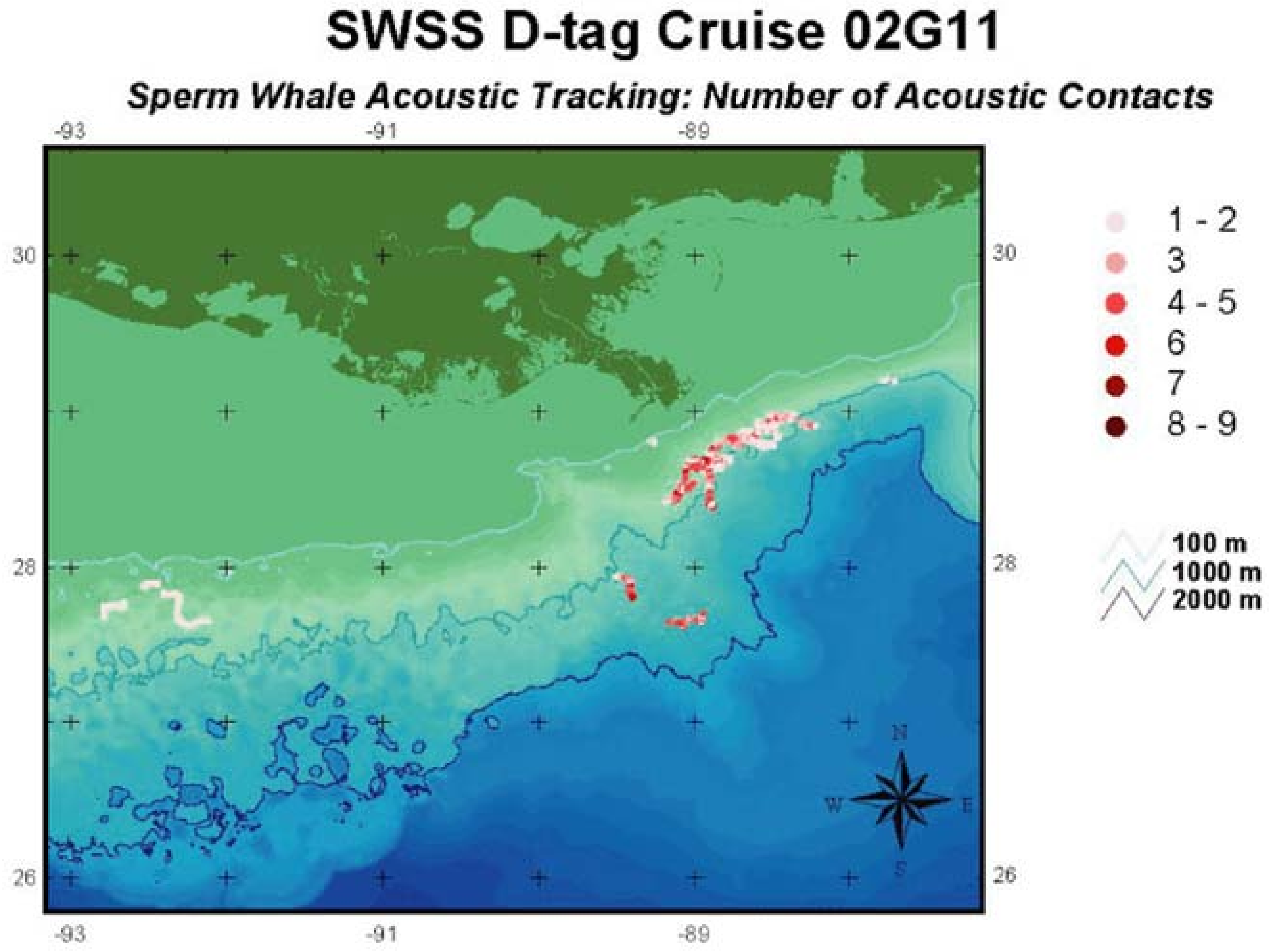


Summer 2002 Fieldwork: SWSS Leg 2

CTD and XBT Deployment Locations During D-Tag Cruise



Acoustic contacts with sperm whales on Leg 2



SWSS D-tag Cruise 02G11

Sperm Whale Acoustic Tracking: Number of Acoustic Contacts

Figure 11. Basemap showing numbers of acoustic contacts during the D-tag cruise.

Visual contacts with sperm whales on Leg 2

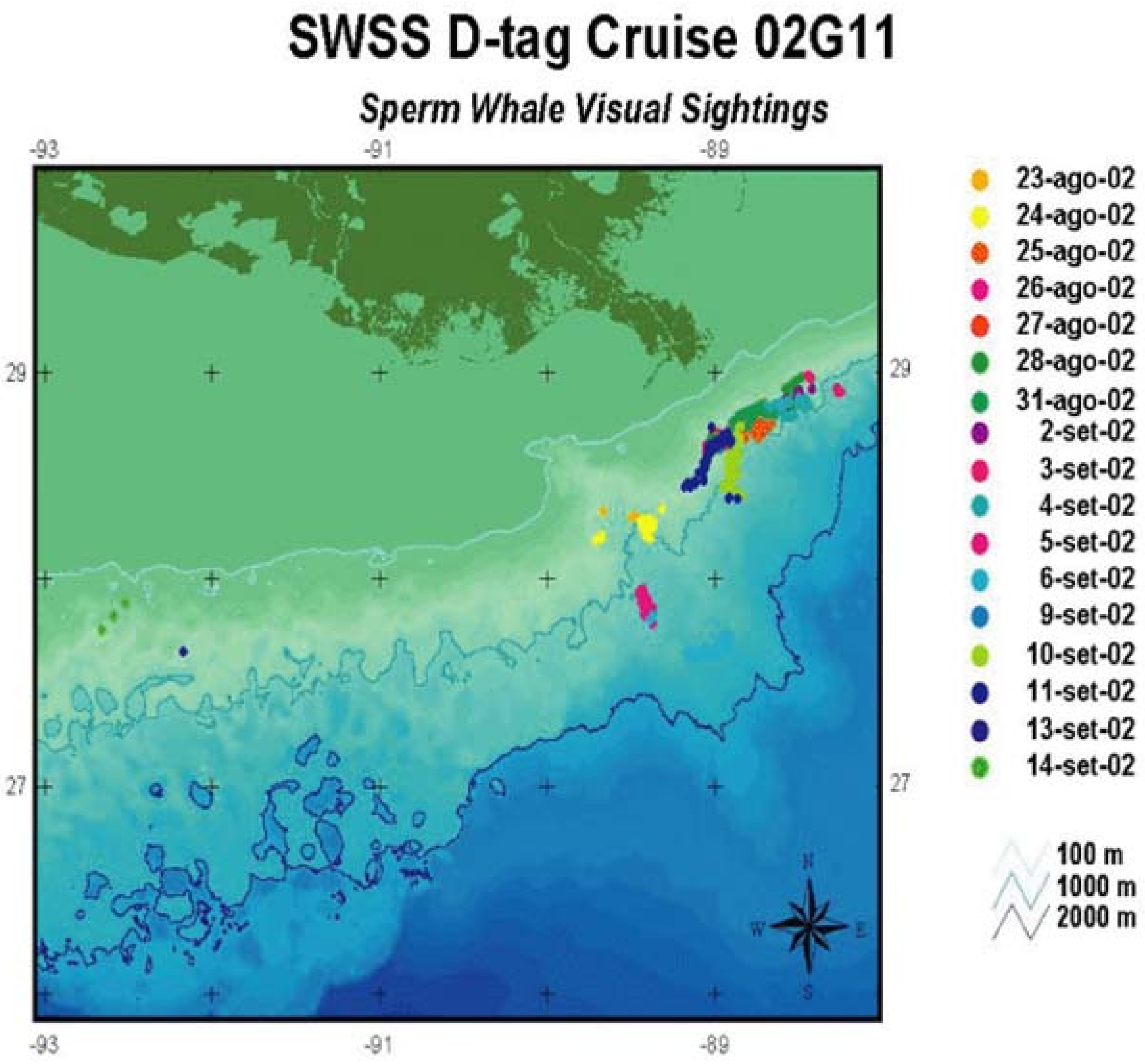
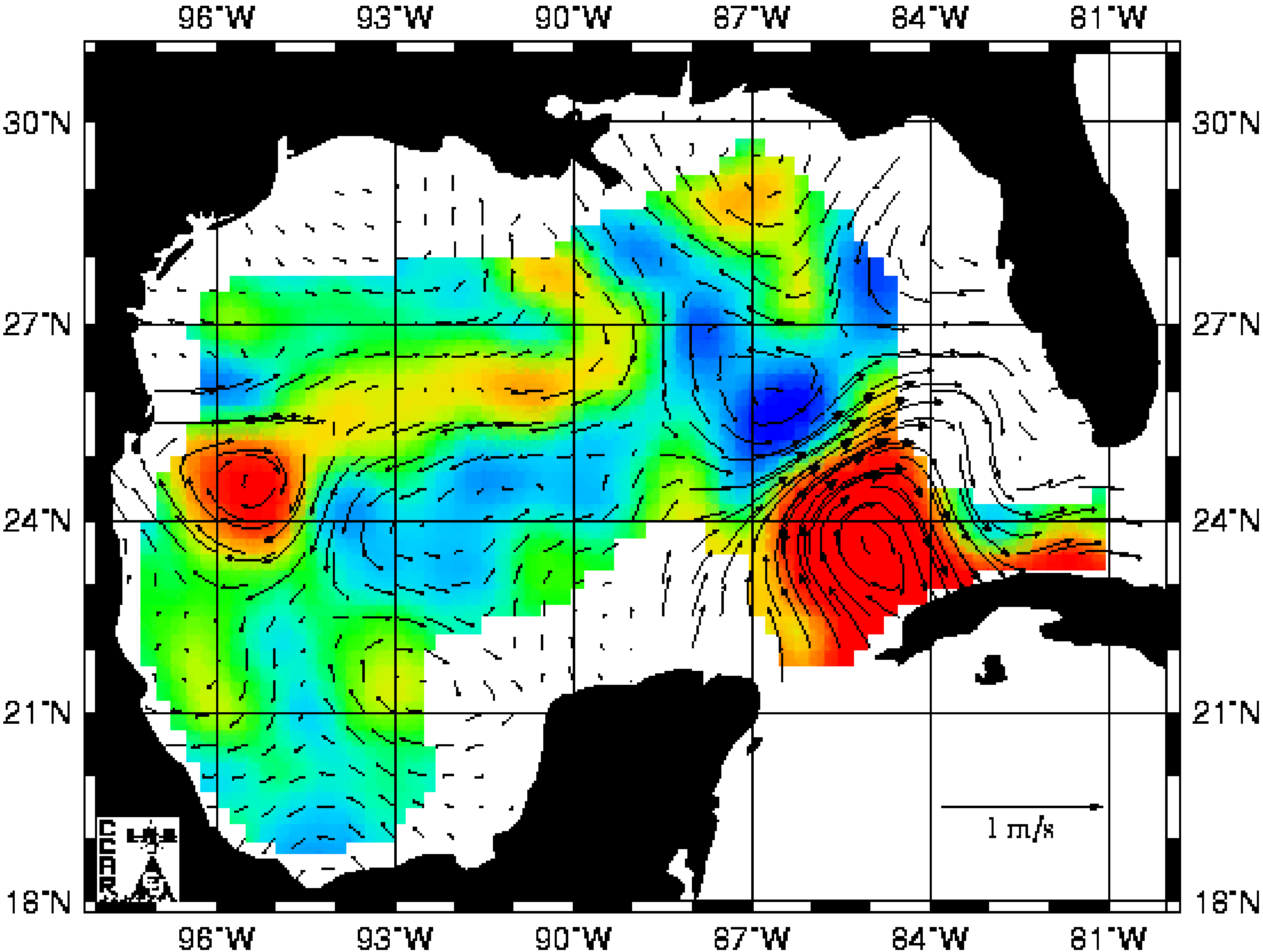


Figure 4. Locations of visual sightings of sperm whales during the D-tag cruise.

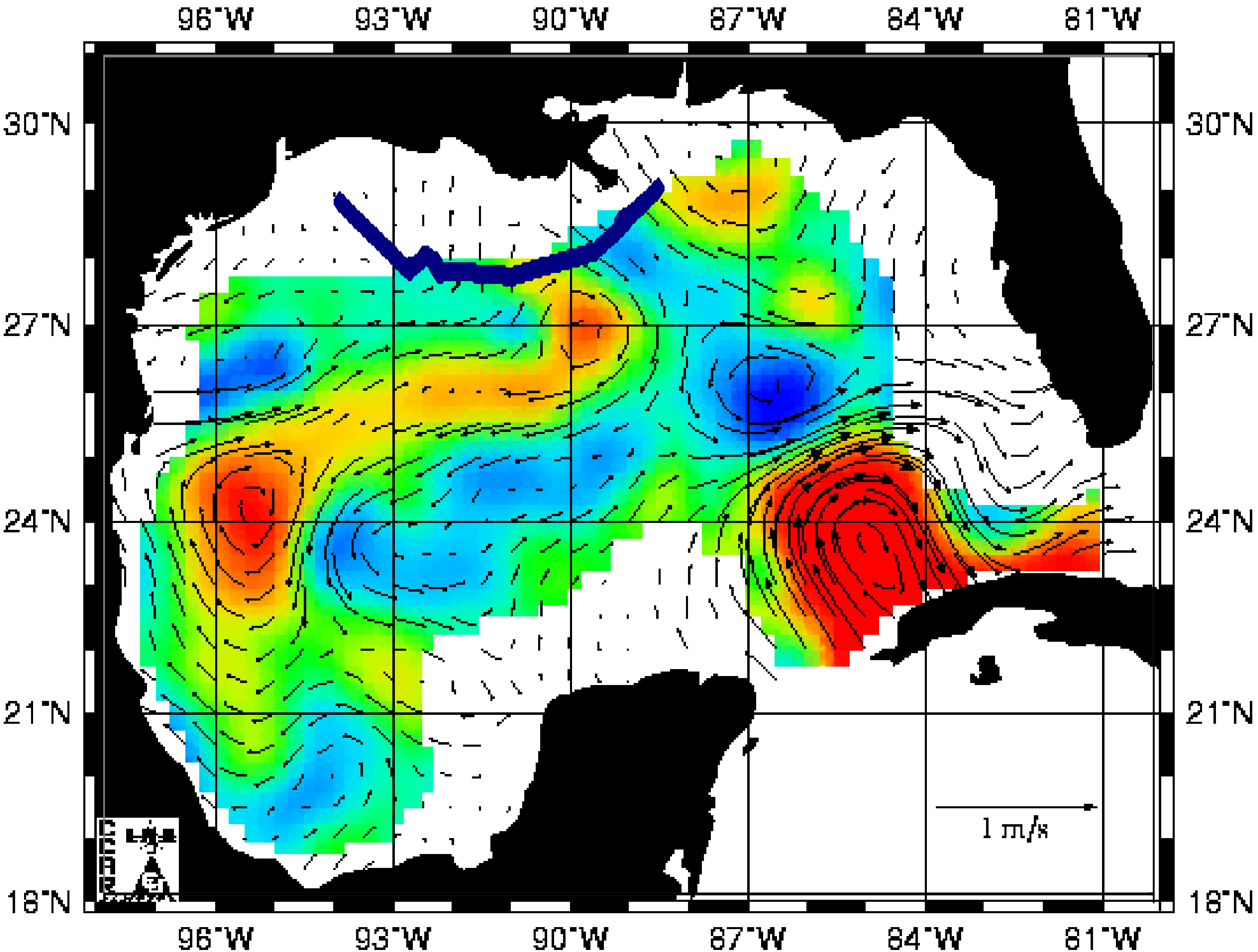
TOPEX/ERS-2 Analysis Aug 21 2002

This was eddy field when R/V *Gyre* sailed for sea



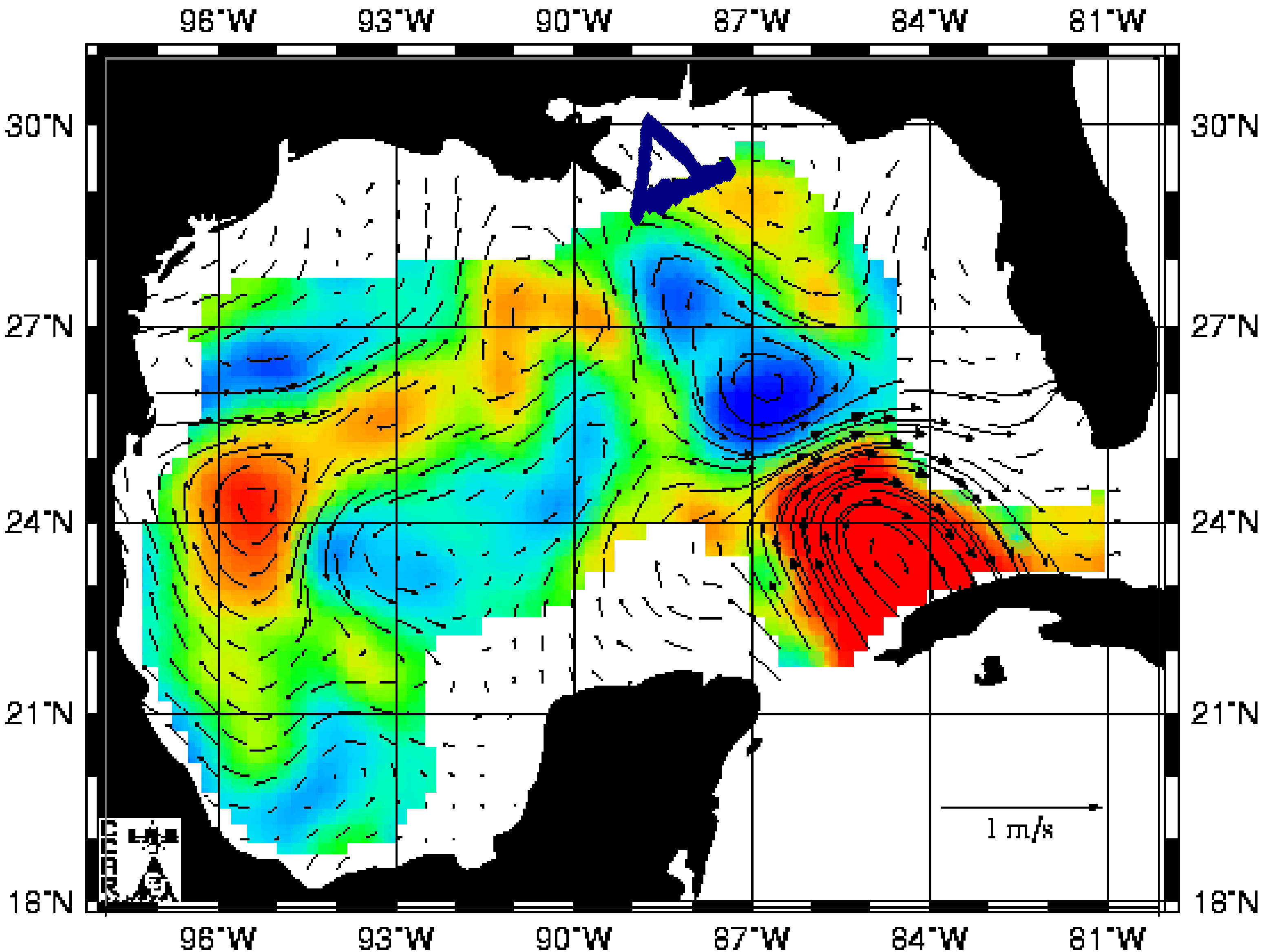
TOPEX/ERS-2 Analysis Aug 28 2002

with Leg 2 shiptrack 22-28 Aug



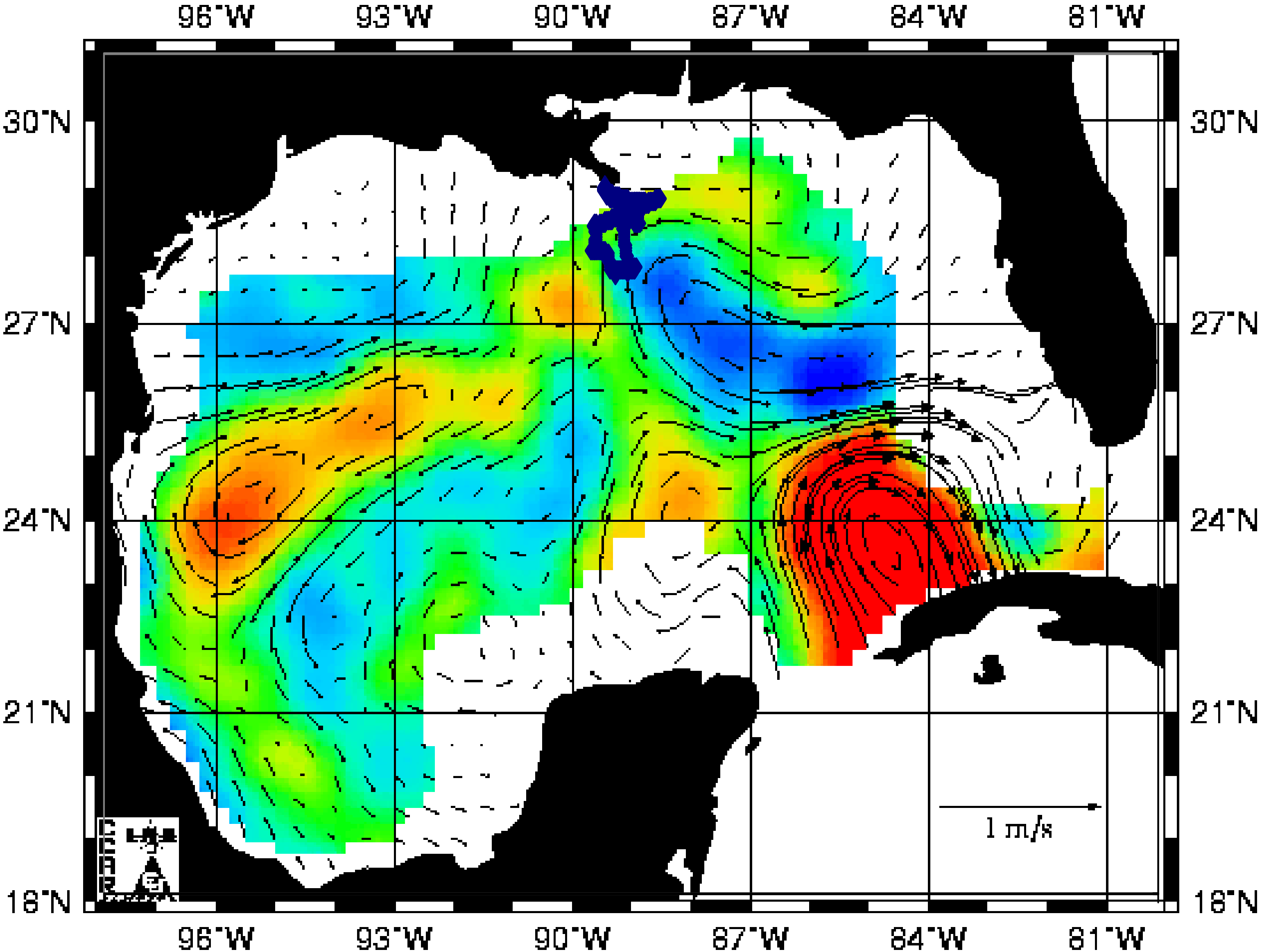
TOPEX/ERS-2 Analysis Sep 4 2002

with Leg 2 shiptrack 29 Aug - 4 Sep



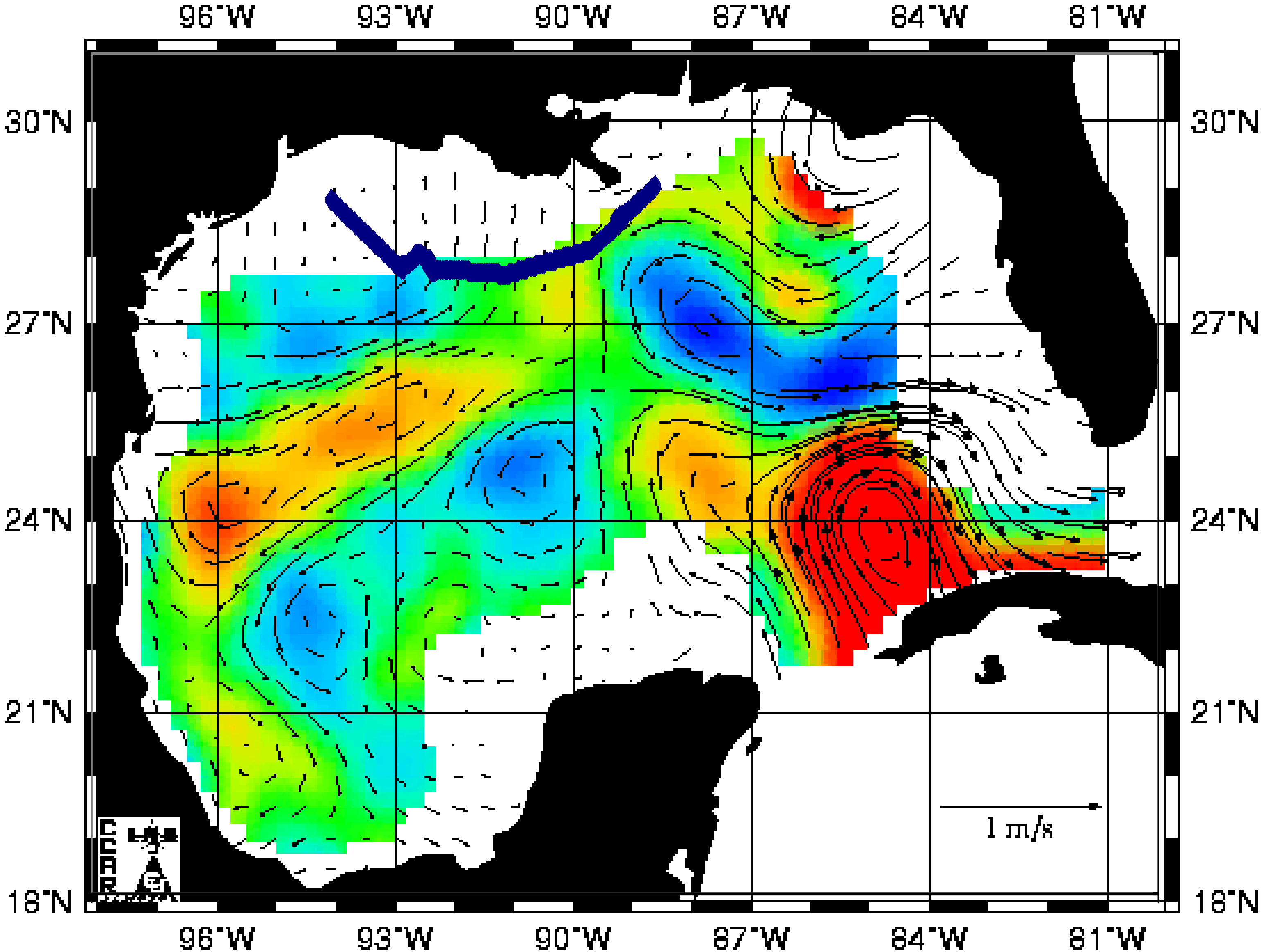
TOPEX/ERS-2 Analysis Sep 11 2002

with Leg 2 shiptrack 5-11 Sep



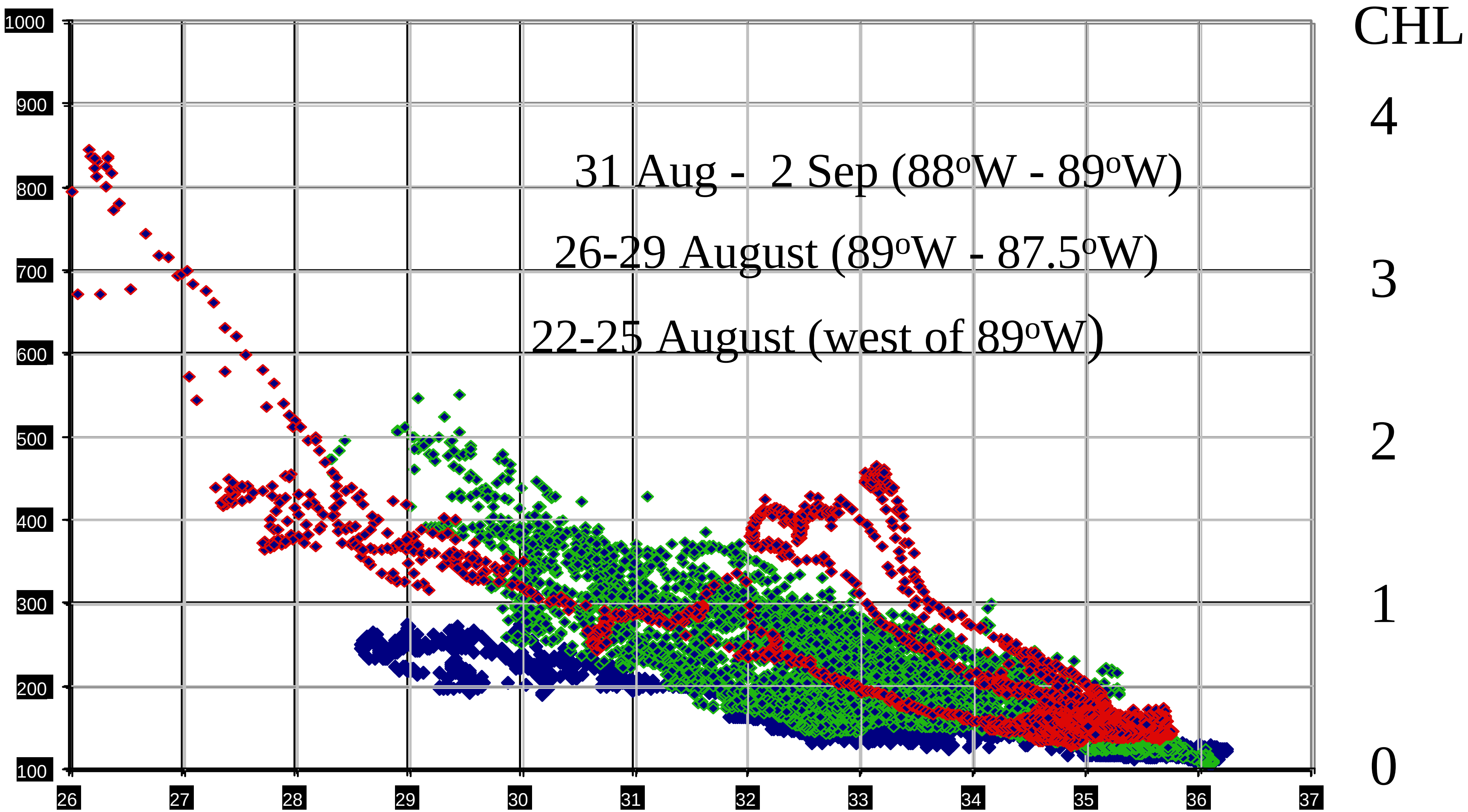
TOPEX/ERS-2 Analysis Sep 18 2002

with Leg 2 shiptrack 12-15 Sep



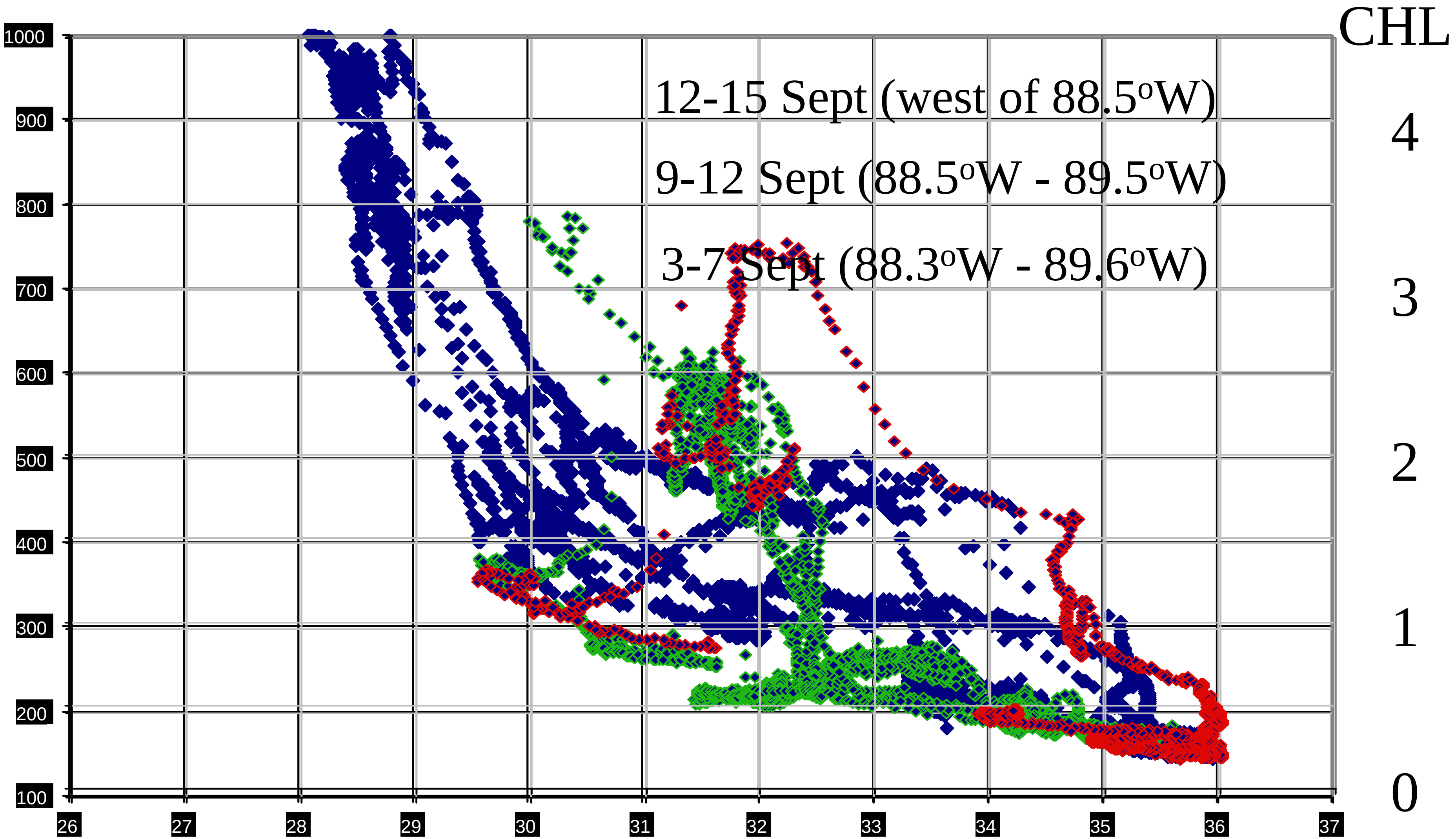
SWSS Leg 2: in vivo Fluorescence versus Salinity

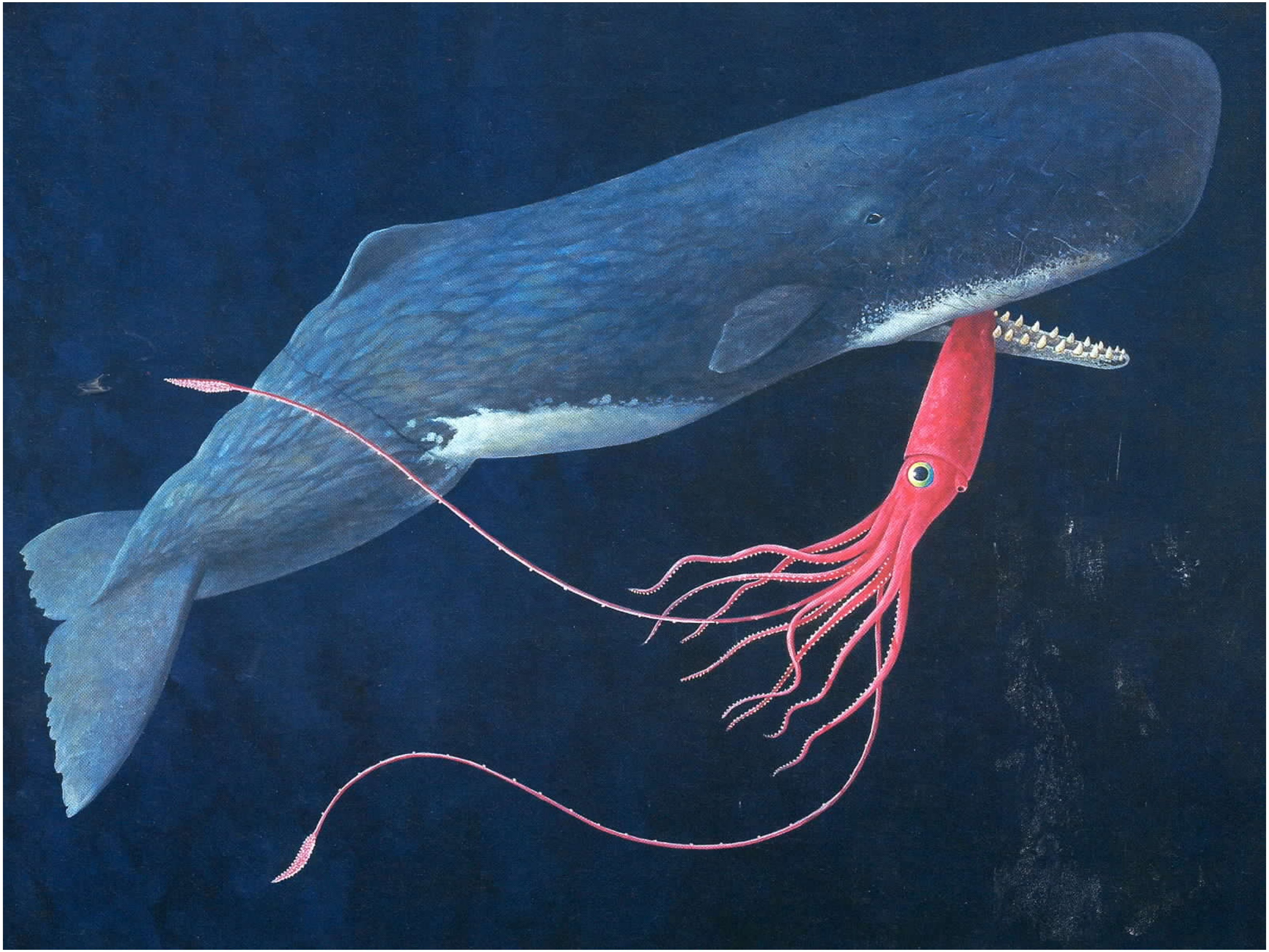
plot Fluor v Salin for 22-25 August



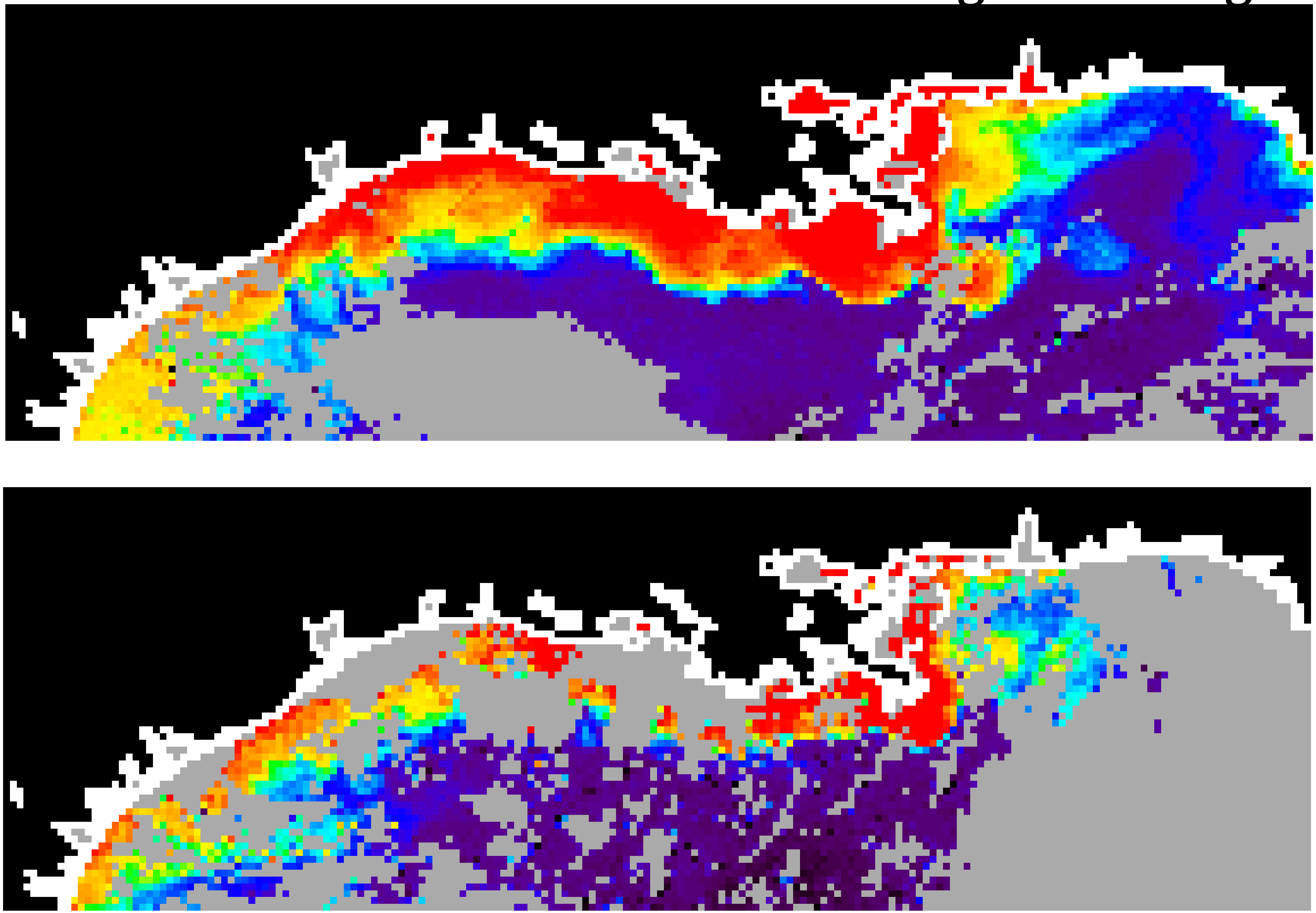
SWSS Leg 2: in vivo Fluorescence versus Salinity (continued)

plot Fluor v Salin for 3-7 September

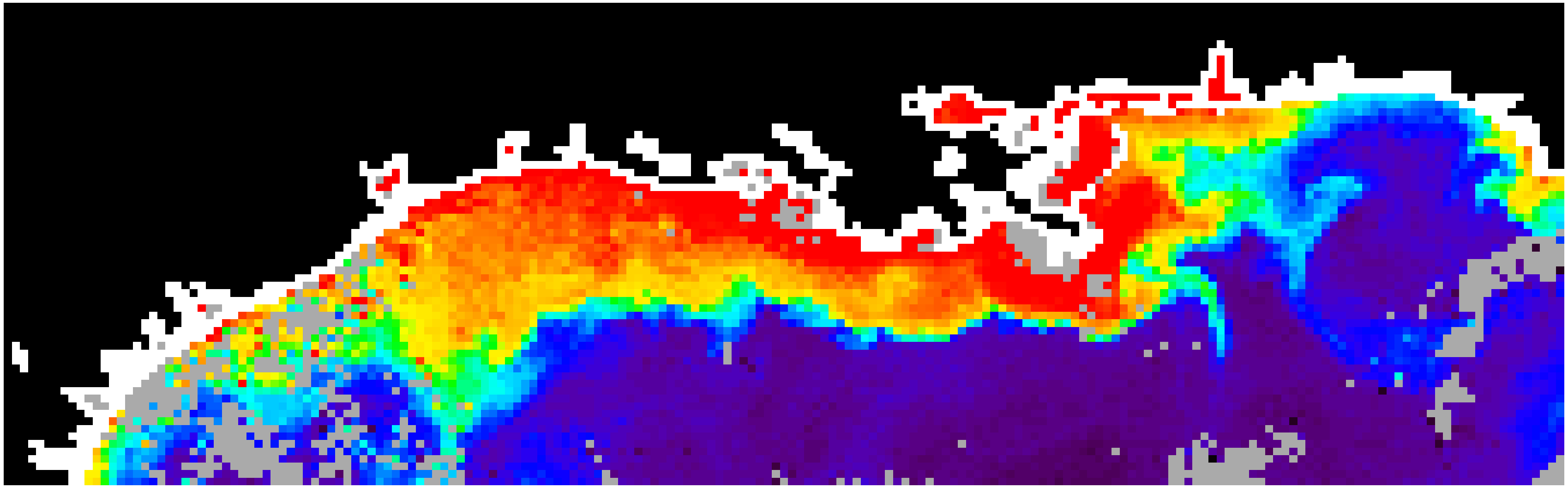


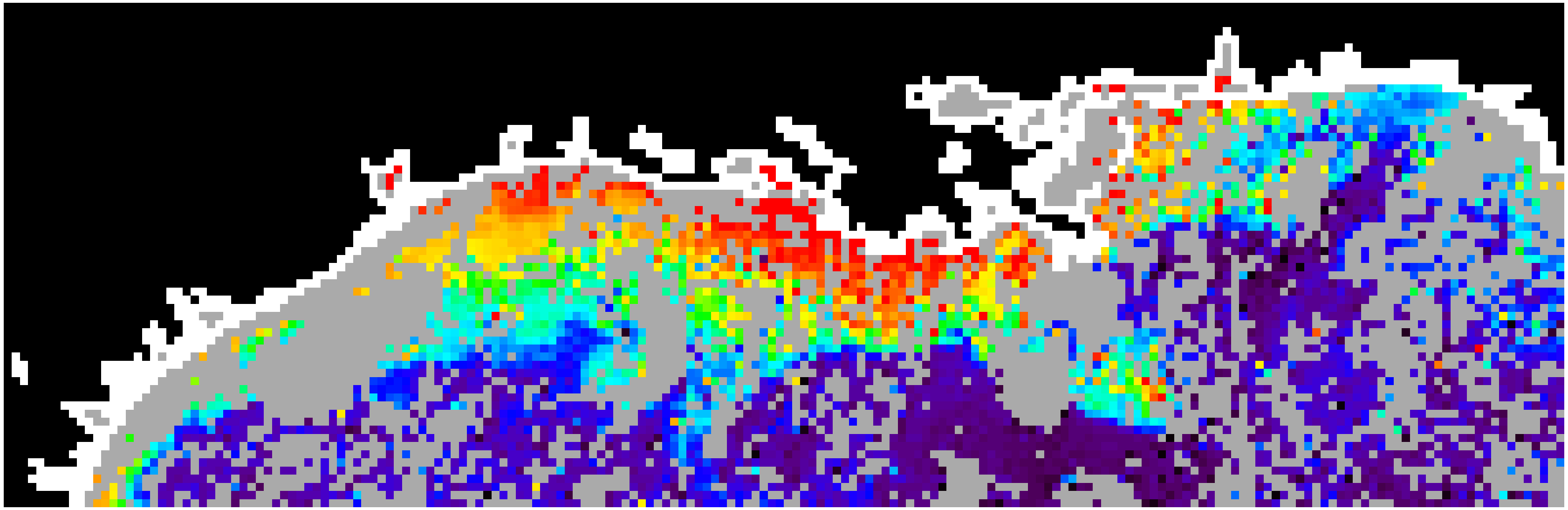


SeaWiFS ocean color before and during SWSS Leg 1

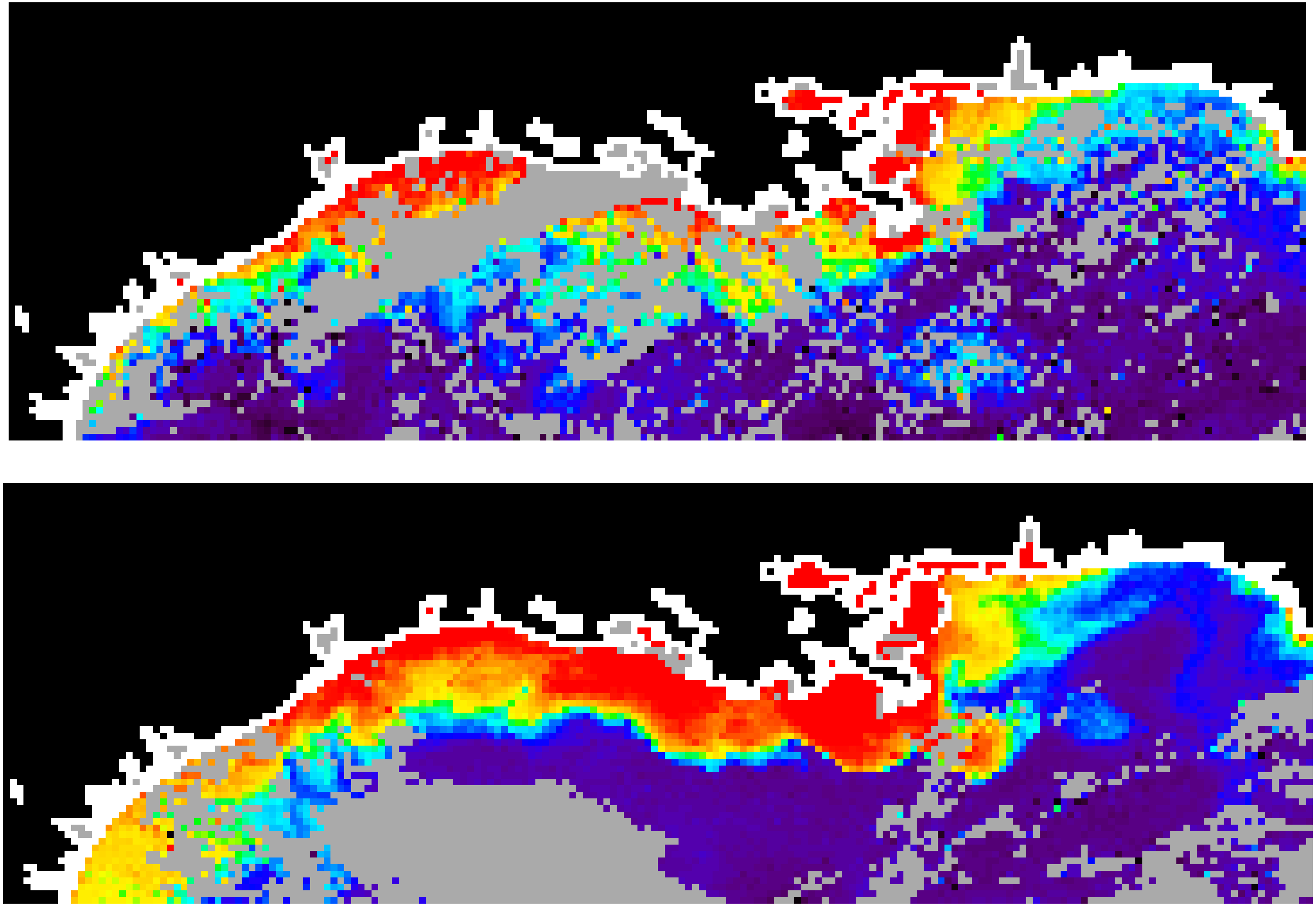


SeaWiFS ocean color between SWSS cruises

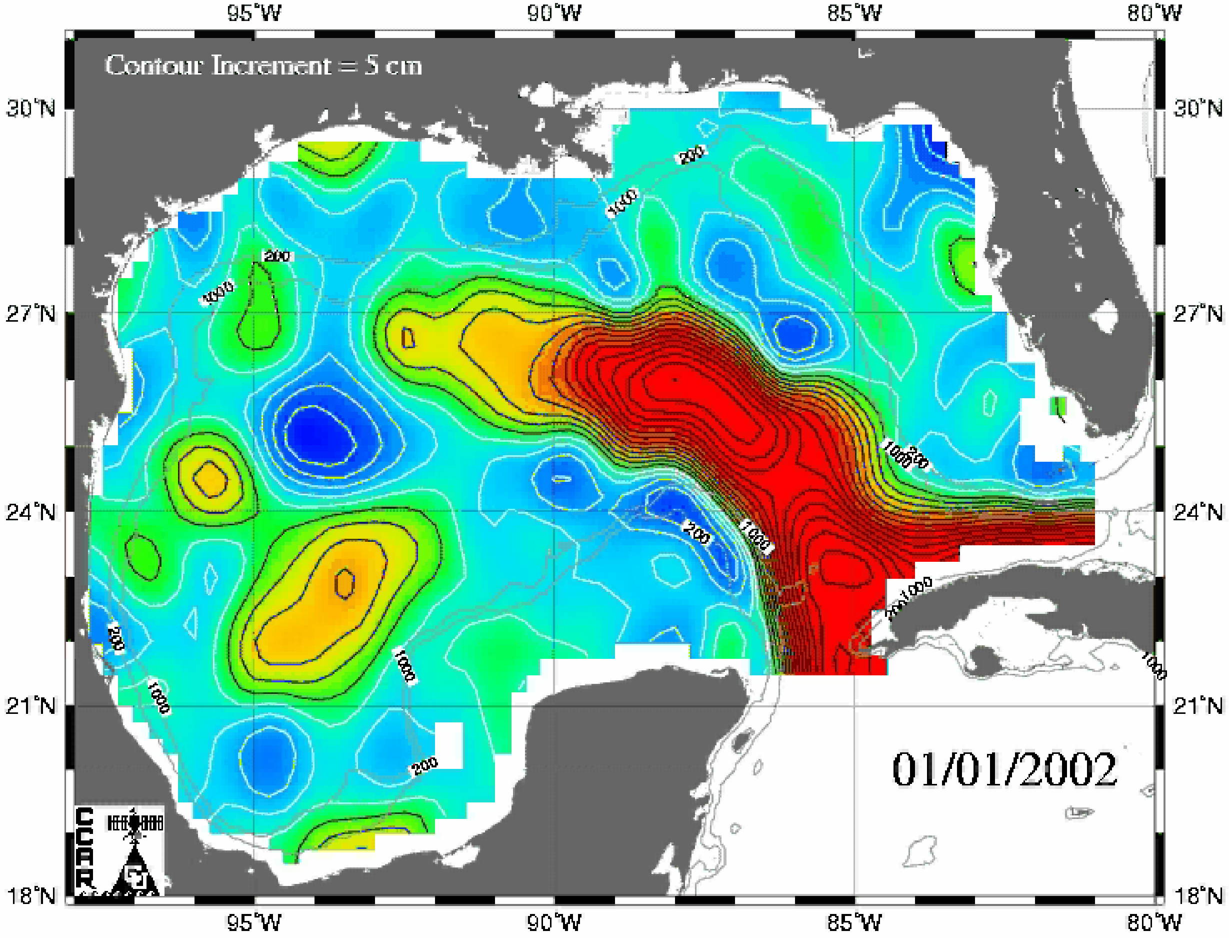




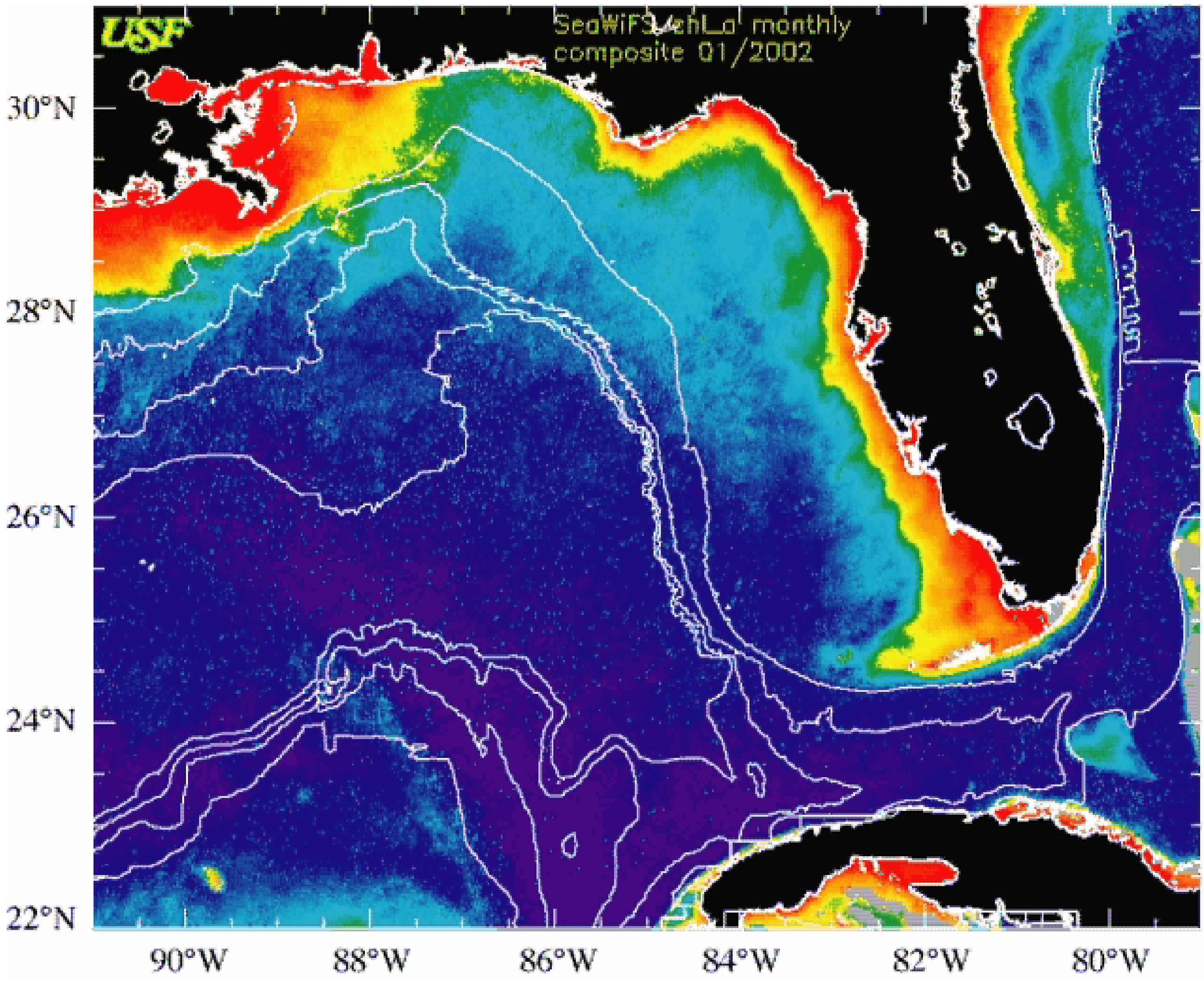
SeaWiFS ocean color during SWSS Leg 2



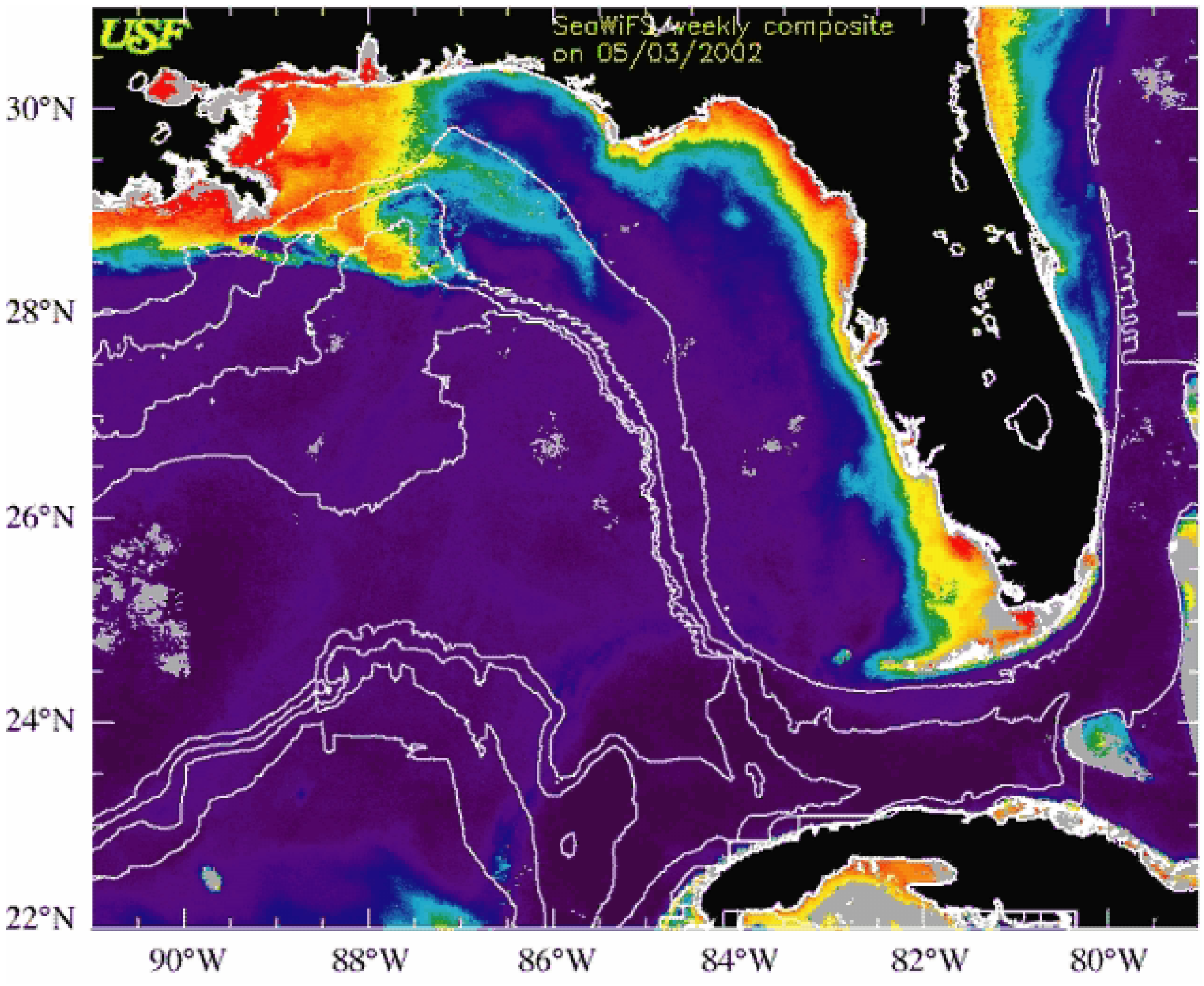
Animation of Sea Surface Height anomaly
Nine months: Jan - Sep 2002



Animation of monthly mean ocean color
Nine months: Jan - Sep 2002



Higher-resolution animation of ocean color
Weekly means: Apr - Sep 2002



Conclusions

- Cyclonic and anticyclonic eddies contribute biological and physical heterogeneity along the continental margin of the northern Gulf of Mexico.

- Temporal and spatial variations in the geometry of the eddy field along the 800-1000 m isobath determine whether low salinity “green water” flows off margin or if high salinity “blue water” flows on margin.

- “Green water” is biologically rich and will support more food for the squid upon which whales prey.

Conclusions

- Locally high CHL can also develop when or where nutrient-rich water domes upward in cyclonic eddies.

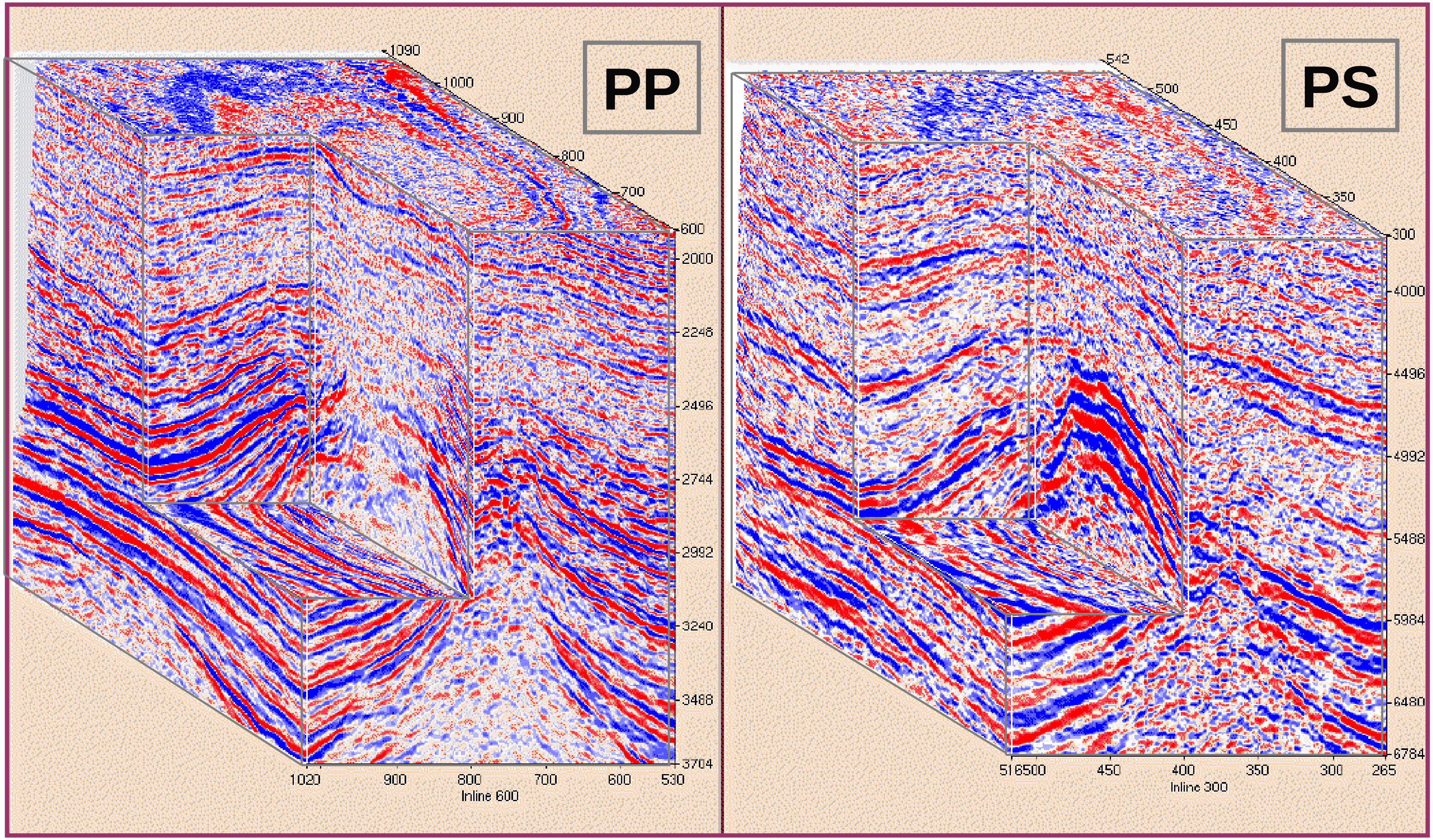
- Cyclonic eddies and other nutrient-rich features that persist for 3-4 months in time may be important feeding grounds for sperm whales along the GOM continental slope.

For more information: http://seawater.tamu.edu/swss

Seismic Surveys and Marine Mammal Protection

Philip M. Fontana
Geophysical Manager, Marine Data Acquisition – Veritas DGC
MMS Information Transfer Meeting, New Orleans
January 15, 2003

3D Seismic


PP
1090
1000
900
800
700
600
2000
2248
2496
2744
2992
3240
3488
3704
1020
900
800
700
600
530
Inline 600
PS
542
500
450
400
350
300
4000
4496
4992
5488
5984
6480
6784
516
500
450
400
350
300
265
Inline 300

Misconceptions

COURT ORDER BLOCKS WHALE KILLING IN GULF OF CALIFORNIA

On Monday, 10-28-02, the Center for Biological Diversity won a temporary restraining order stopping a government/university research project linked to the killing of beaked whales in the Gulf of California. The order not only protects one of the largest and most important beaked whale populations in the world, it will help establish once and for all that U.S. environmental laws apply to U.S. funded projects killing wildlife in other nations.

Geographers from the National Science Foundation, Columbia University, and the Georgia Institute of Technology have been using **acoustic cannons** to bombard the Gulf with **mind-numbing** **220 decibel sound blasts**. Their goal is to map portions of the sea floor, but the **ear-shattering noise** **appears to be killing beaked whales** as well. Scientists from the National Marine Fisheries Service found two dead whales near the research area and believe they were killed by the deafening noise. It is likely that more whales have been killed, but no surveys have been conducted.

Dozens of beaked whales in the Bahamas have been killed by similar sound levels blasted into the ocean by the U.S. Navy. Nevertheless, the National Science Foundation refused to stop the deadly research project, claiming there was no "credible evidence" linking the acoustic cannons to the whale deaths. With **no other option to save the whales**, the Center went to court winning today's restraining order.

What's at Stake ?

Following are recommendations from the National Resource Defense Council for regulation of marine seismic activities in US Waters:

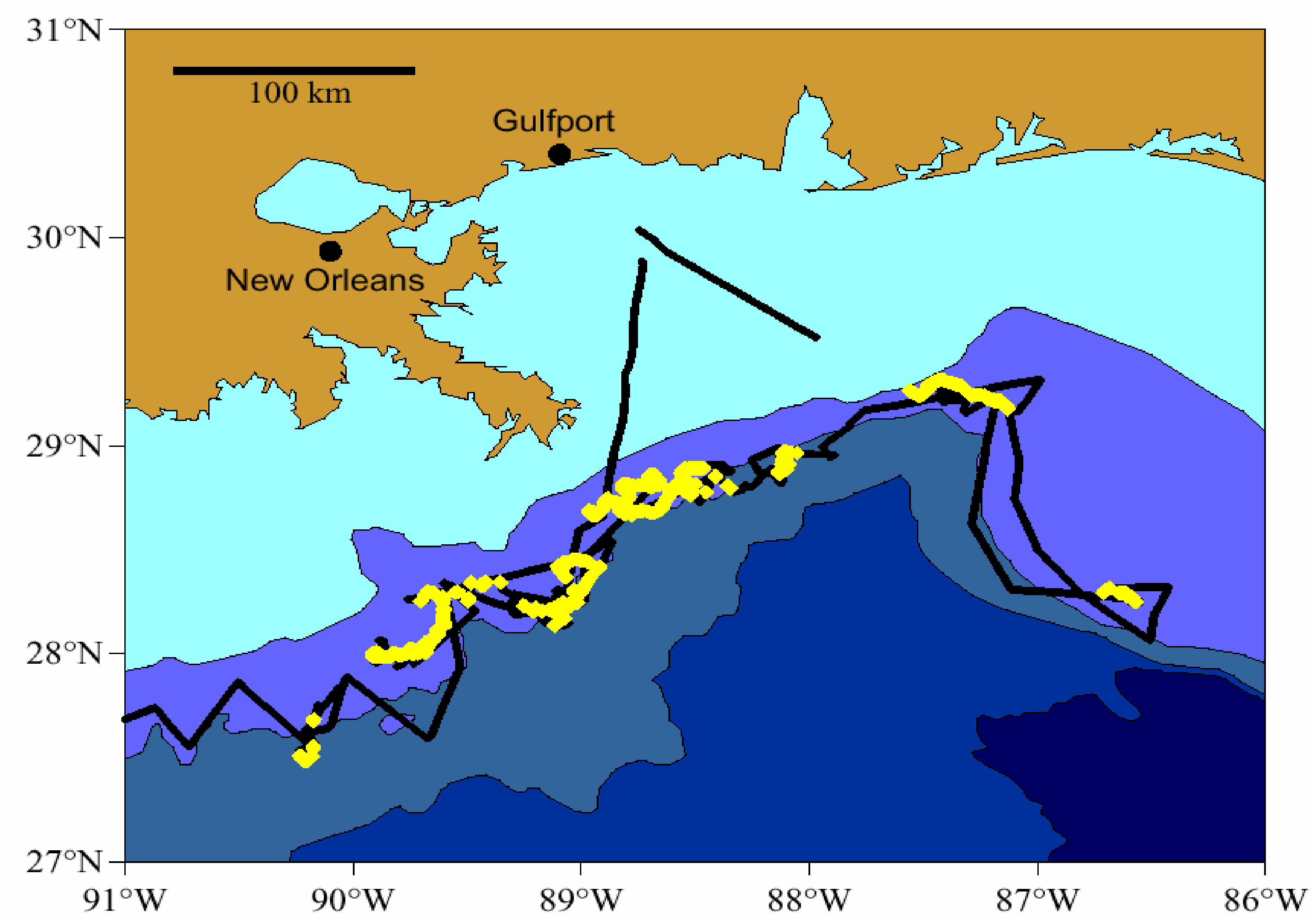
"The Minerals Management Service (MMS), the federal agency charged with regulating the industry, should face the issue first within its five-year leasing plan – by **identifying acoustic "hotspots" in which operations will be restricted or excluded** ."

"Mitigation for seismic surveys should include visual and acoustic monitoring, with a **cessation of activity at night and on foggy days**; shut-down procedures to avert the exposure of marine animals to acoustically damaging sound; and the funding of research on the biological effects of impulsive noise."

"Given the competitive nature of the oil industry, it frequently happens that the same lease site is surveyed several times by different companies, multiplying the impacts. **The industry should be required to share data or to use, as some companies do, a common surveyor**."

From NRDC Report "Sounding the Depths ; Supertankers, Sonar, and the Rise of Undersea Noise "

“identifying acoustic "hotspots" in which operations will be restricted or excluded”

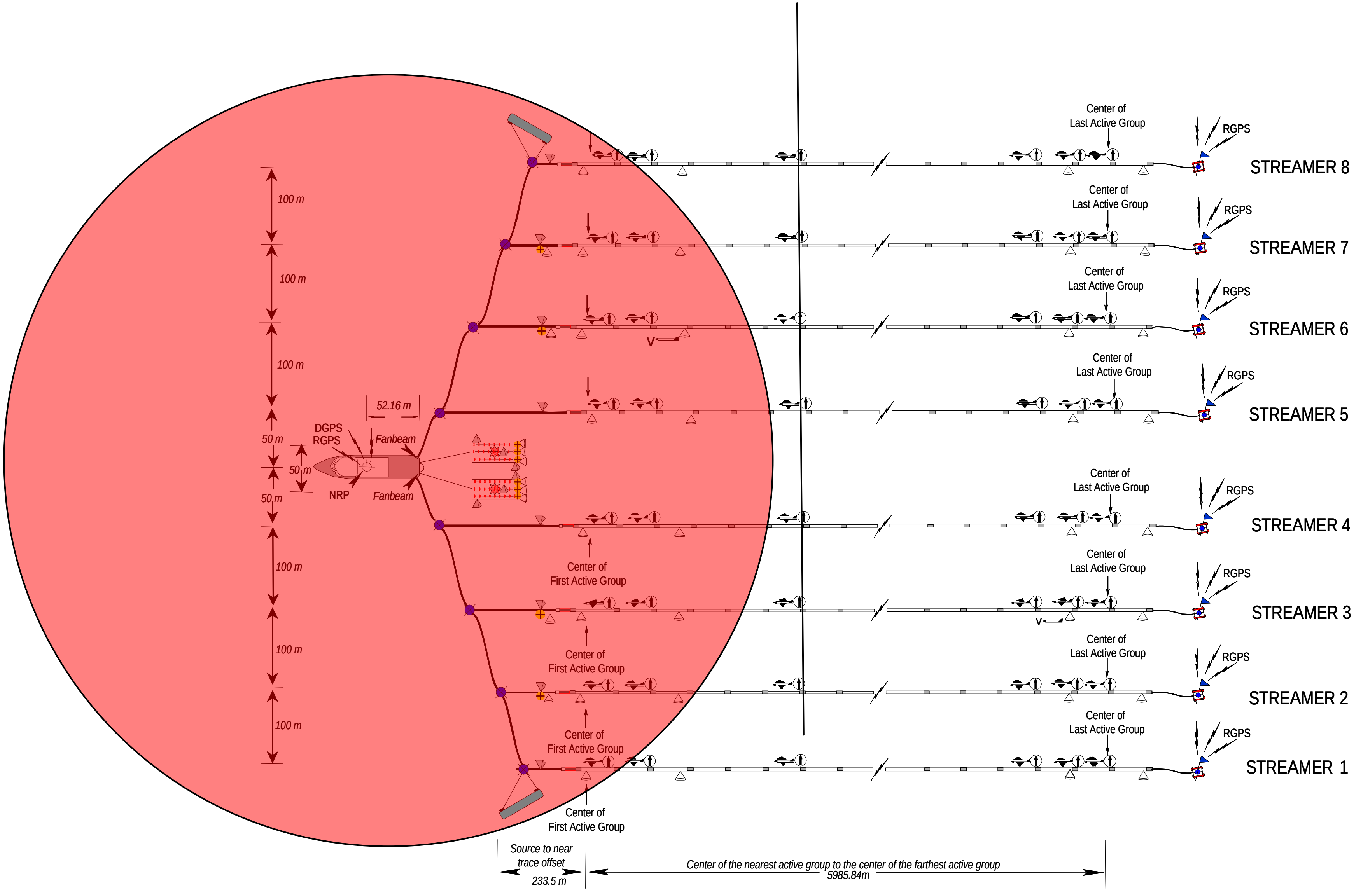


Location of sperm whale sightings – SWSS S-Tag Cruise, Summer 2002
Bold line indicates cruise trackline. Depth contours shown: 200m, 1000m, 2000m, and 3000m.

“shut-down procedures to avert the exposure of marine animals to acoustically damaging sound”

	Proposed Stipulations	**Current NTL**
1.	180 dB “Impact” Zone	500m “Exclusion” Zone
2.	Soft Start Airgun Array	Soft Start Airgun Array
3.	No night-time start-ups	Maintain 160 – 170 dB minimum level
3.	NOAA approved observers	NOAA approved training for crew members

500m Exclusion Zone



Soft Start : 20*log(2) = 6.02 dB

Number of Array Elements	Signal Level	Time of Procedure
1	0 dB (base reference)	0 minutes
2	+6dB	5 minutes
4	+12dB	10 minutes
8	+18dB	15 minutes
16	+24dB	20 minutes
32	+30dB	25 minutes

180 dB Acoustic “Take” Threshold

180 dB value is a consensus opinion of researchers attending High Energy Seismic Source (HESS) workshop at Pepperdine University in 1997.

Value **is** key parameter in NOAA Fisheries mitigation rule making.

Value **is not** based upon any empirical dataset.

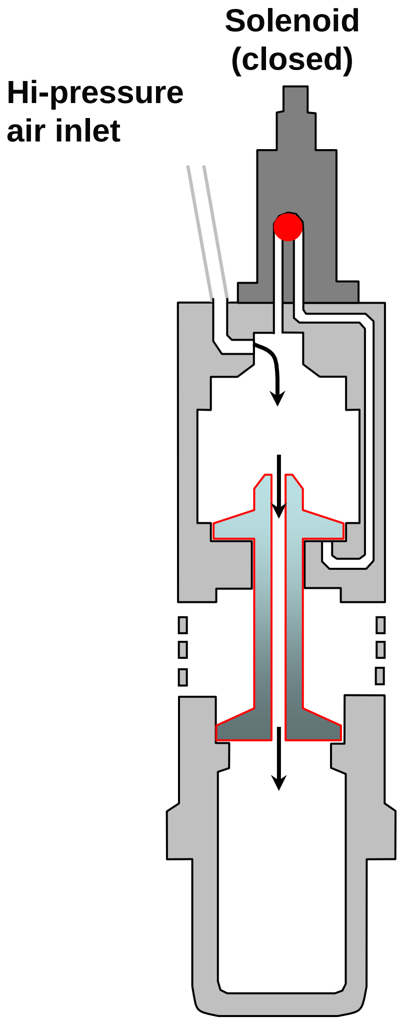
Value **is not** referenced to frequency bandwidth.

Value **is not** referenced to duration of sound exposure.

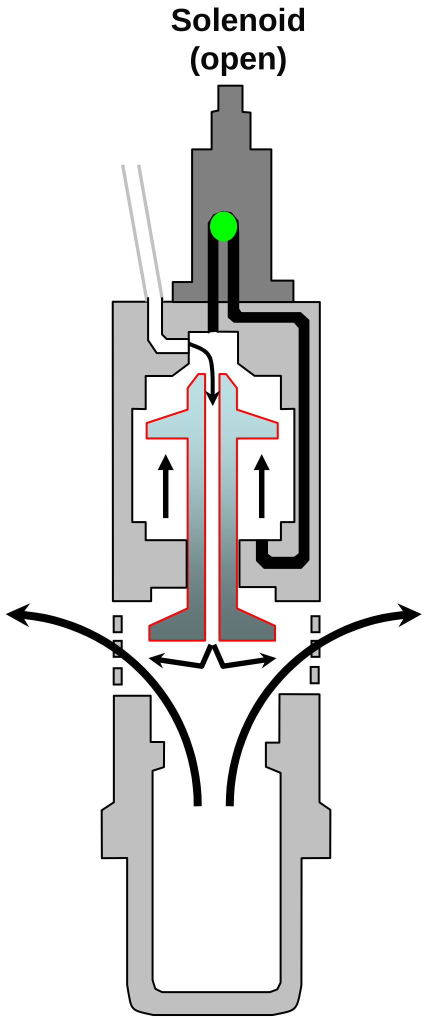
So, what does it mean in terms of airgun emissions ?

Airguns

Exploded’ view & operation of a marine airgun



charge

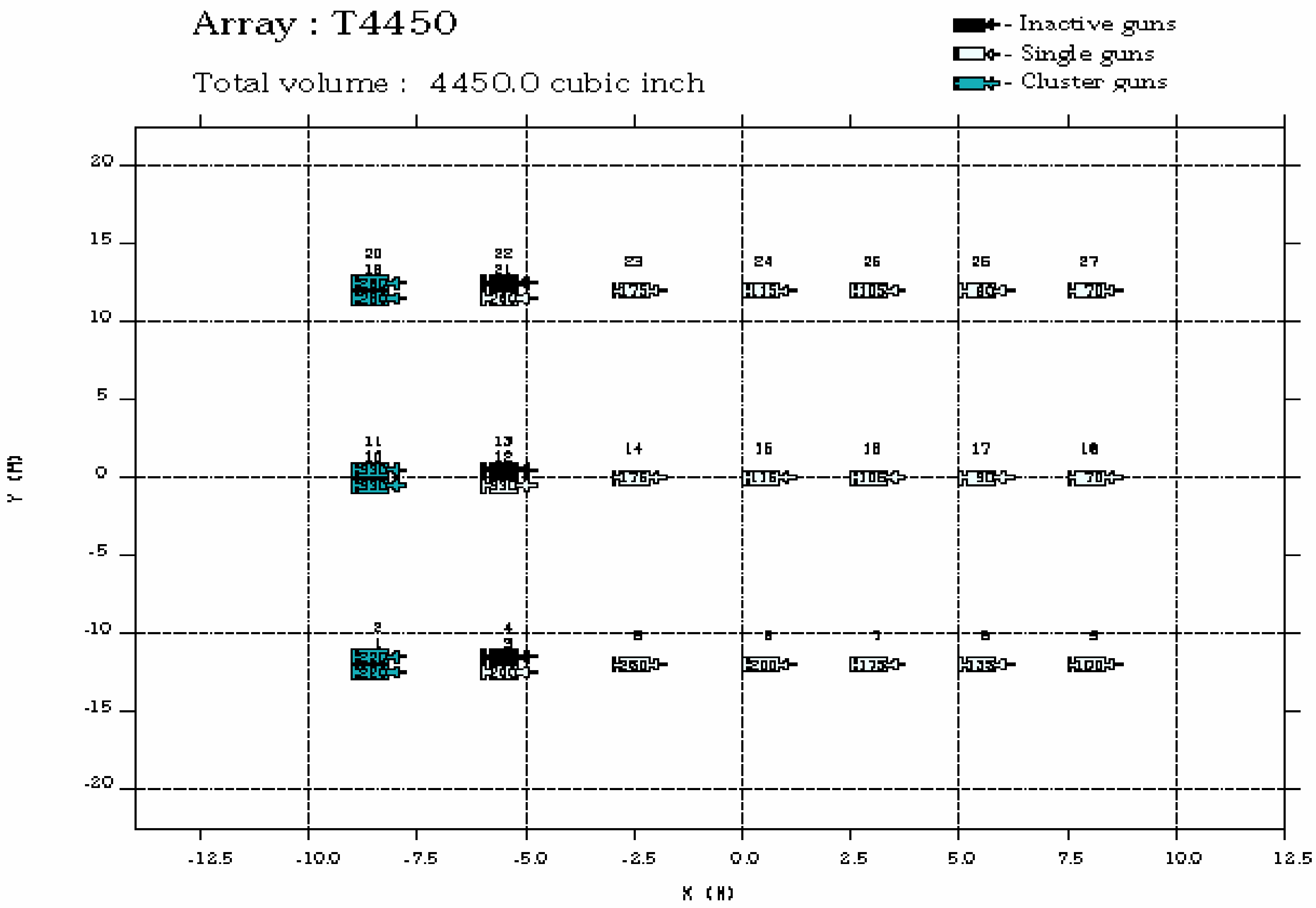


discharge

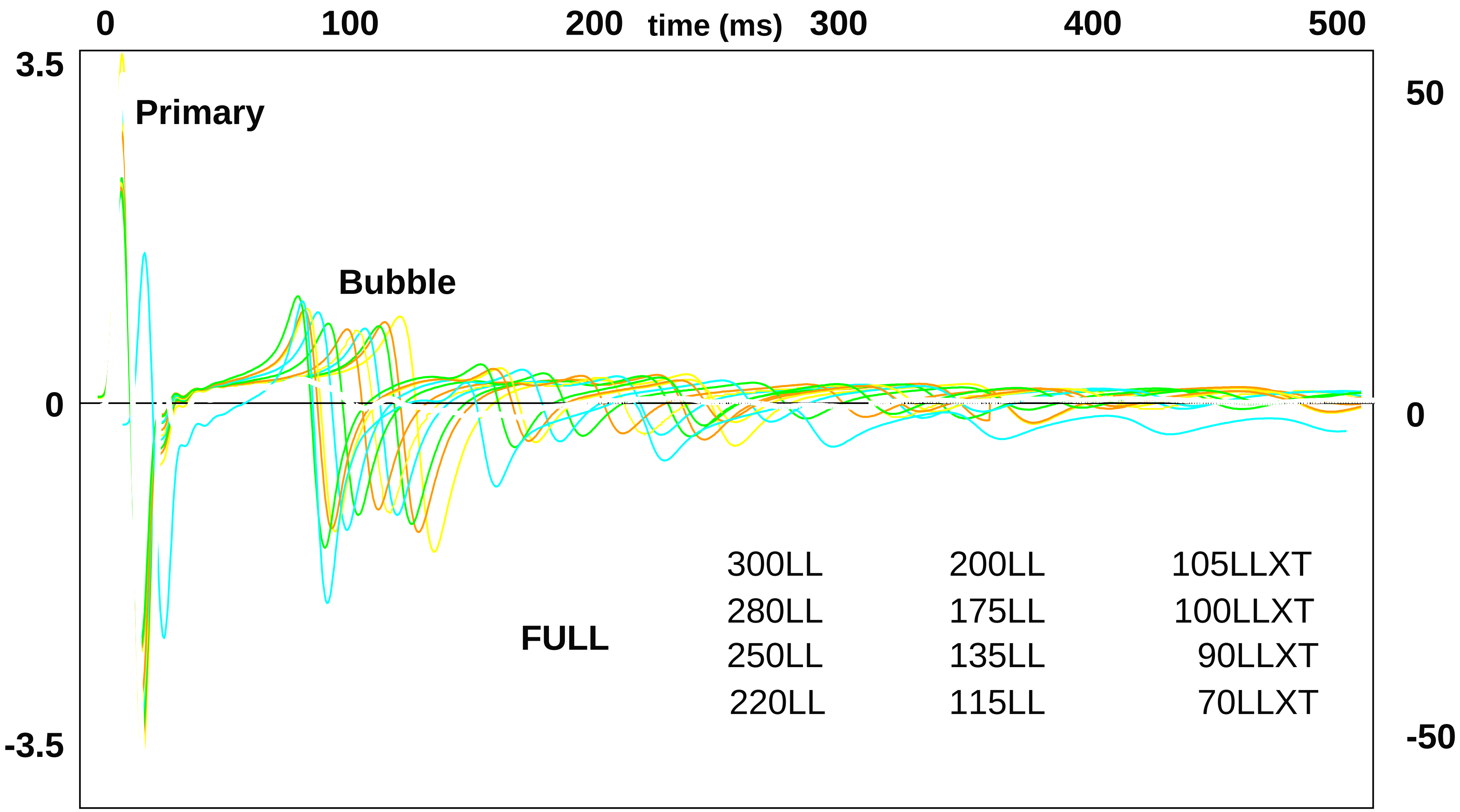
Airgun

Single Airgun Pressure Signature

Airgun Array Layout – Plan View



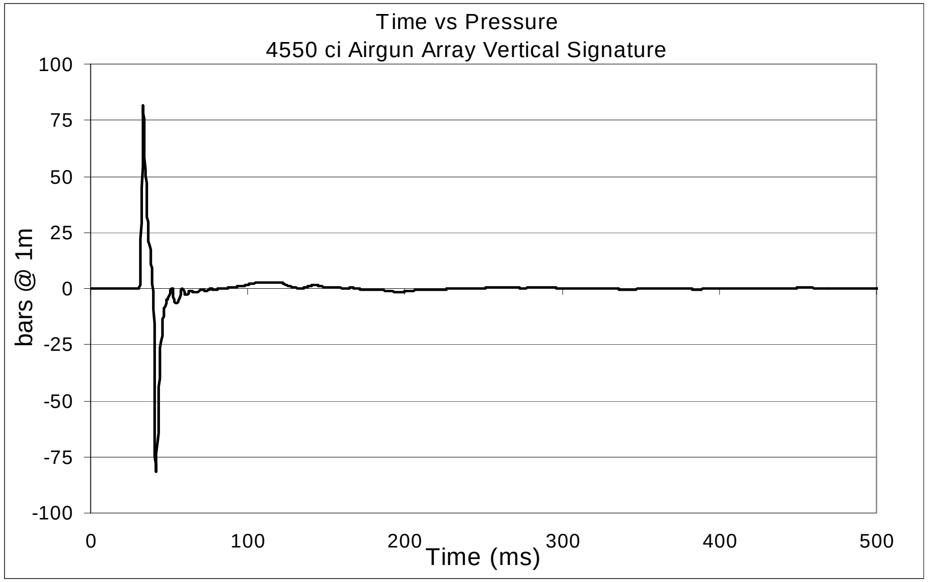
Airgun Array

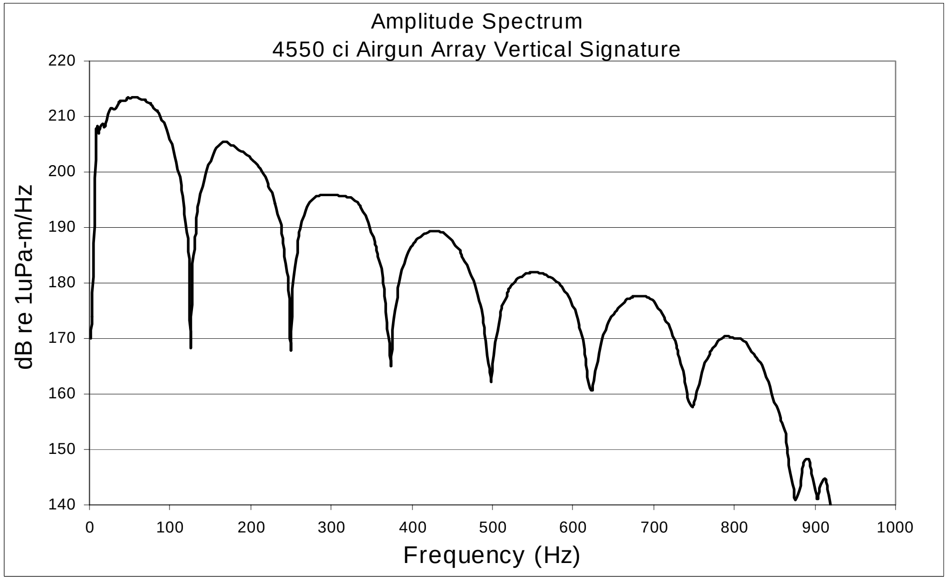


4150 cu.in array : modeled far-field signature @ 6m water depth

Airgun Array Signatures

Typically the output of an airgun array is referenced to **an imaginary point 1m below the center of a theoretical point source.**



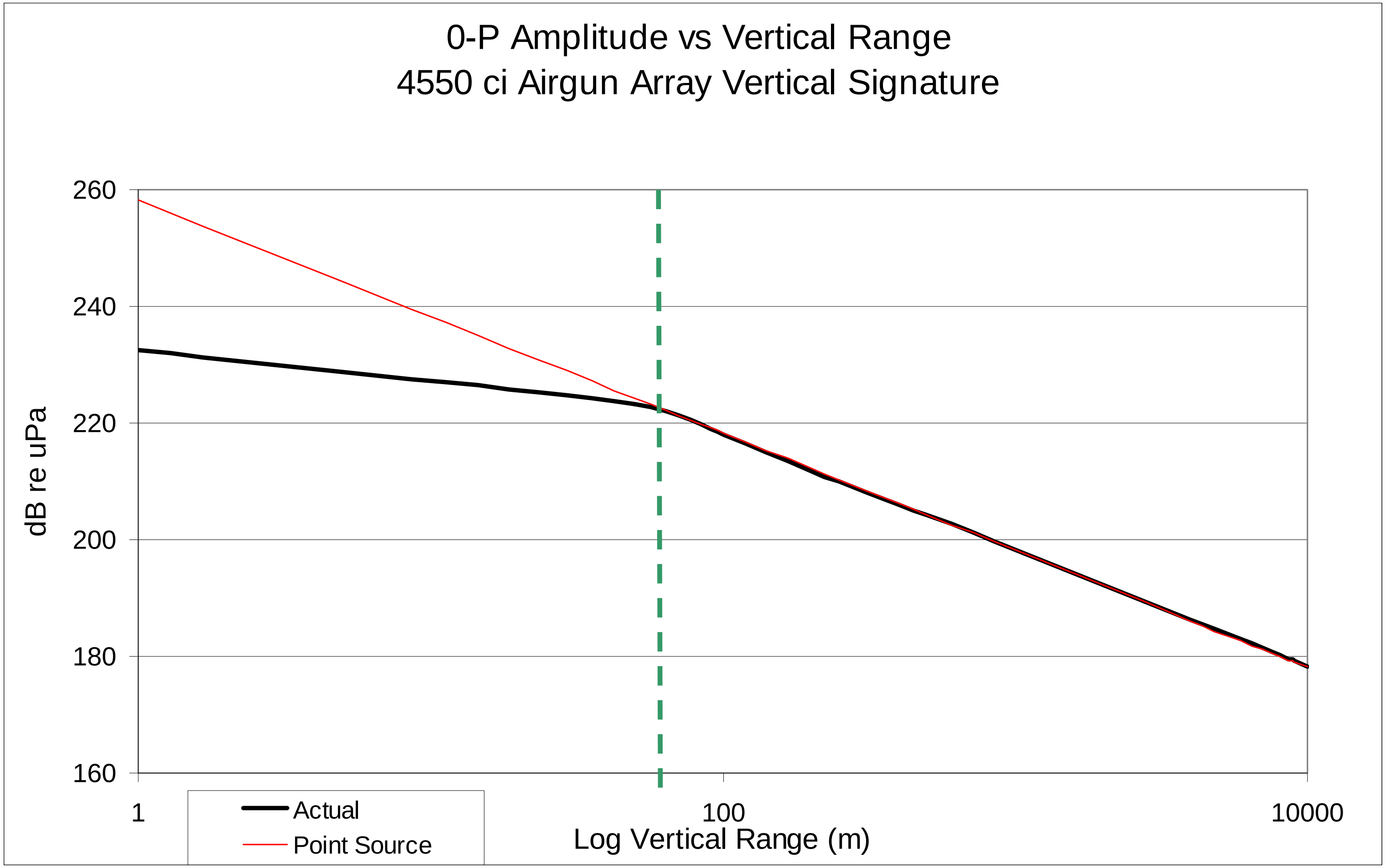


0-P source level = 80 bar-m (258 dB re 1 uPa-m at 3 – 800 Hz)
= 57 bar-m (255 dB re 1 uPa-m at 3 – 128 hz)

The pressure of the quoted source level is never realized at any point in the water column.

Airgun Arrays

In the far-field, the output of the array decreases inversely with the distance (1/r) …..

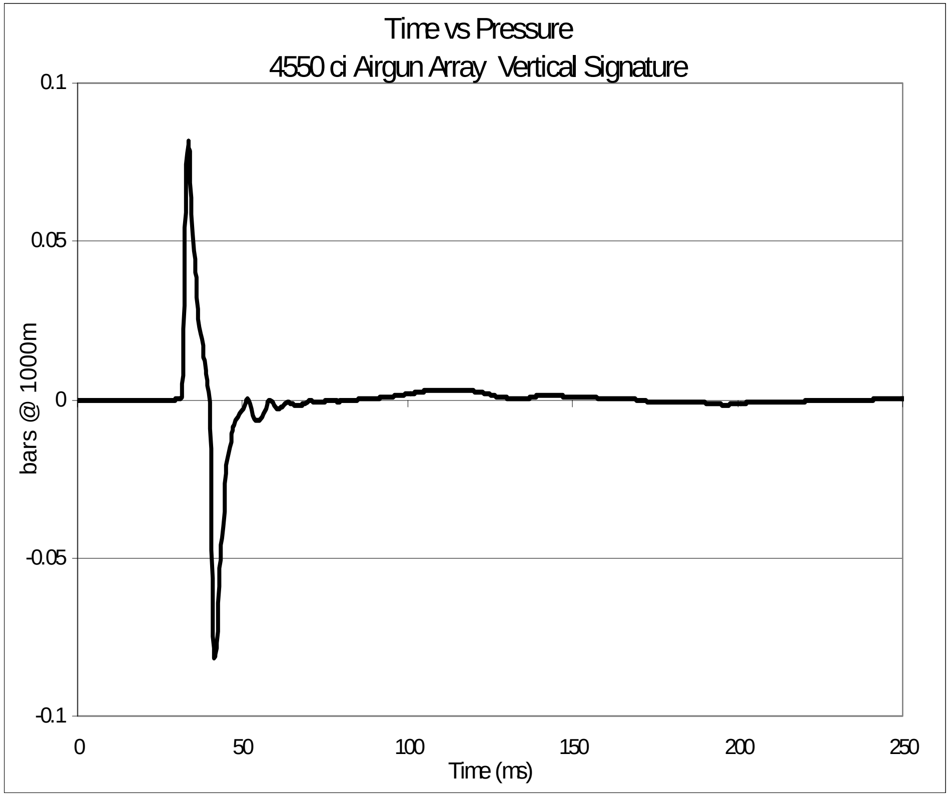


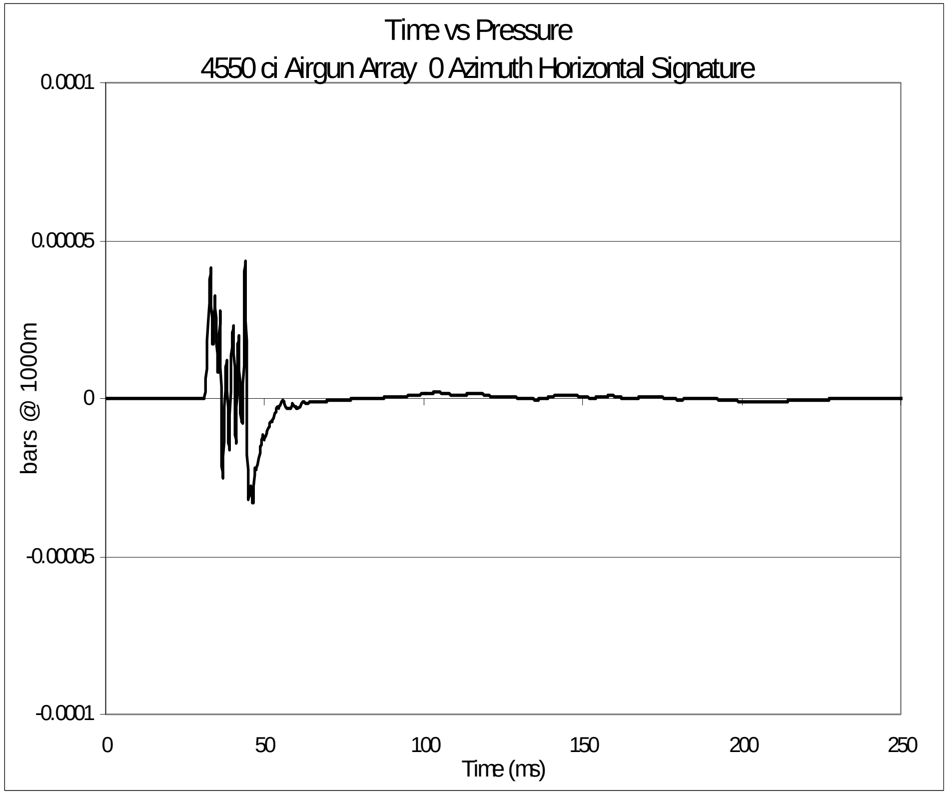
However, the maximum pressure in the water is around 20 dB (i.e 1/10) less than predicted by the point source assumption.

Airgun Array Directivity

Peak = 0.082 bars
= 198 dB re 1 uPa

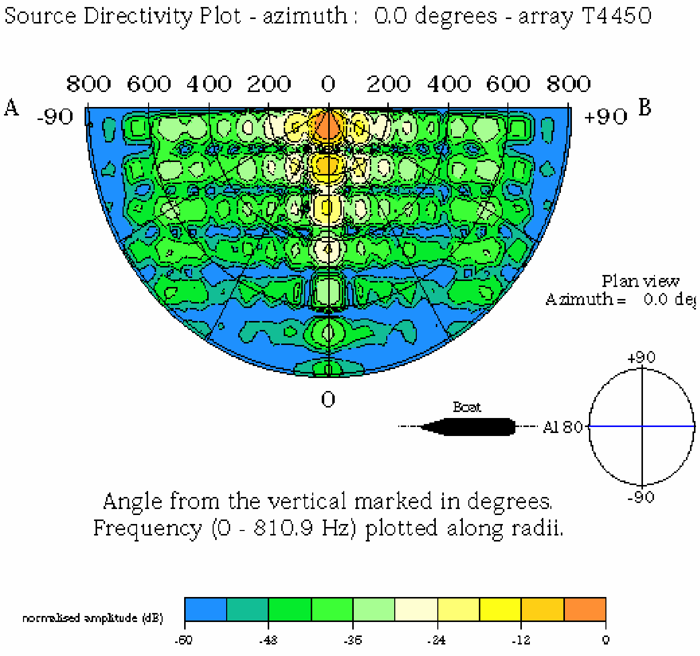
Peak = 0.0000043 bars
= 113 dB re 1 uPa



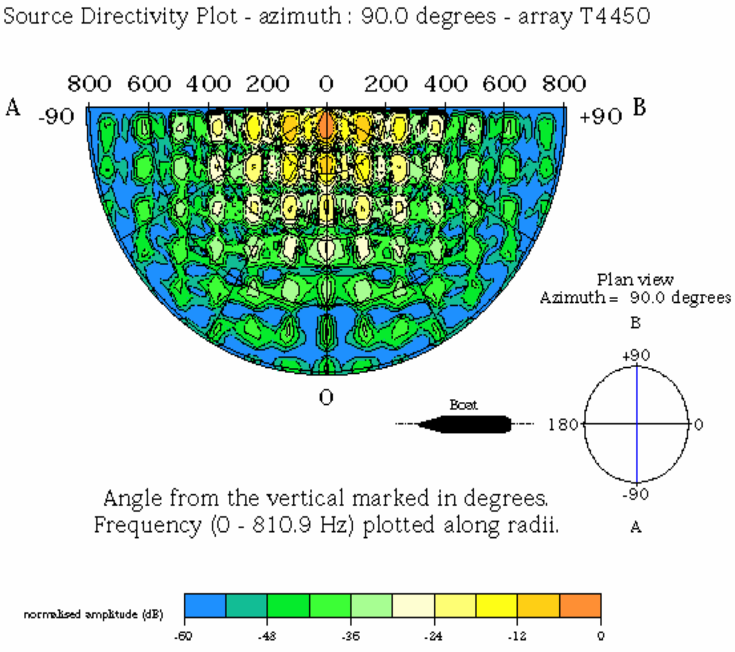


The difference in output pressure between the horizontal and vertical signatures is on the order of .00005 or –85 dB

Airgun Array Directivity



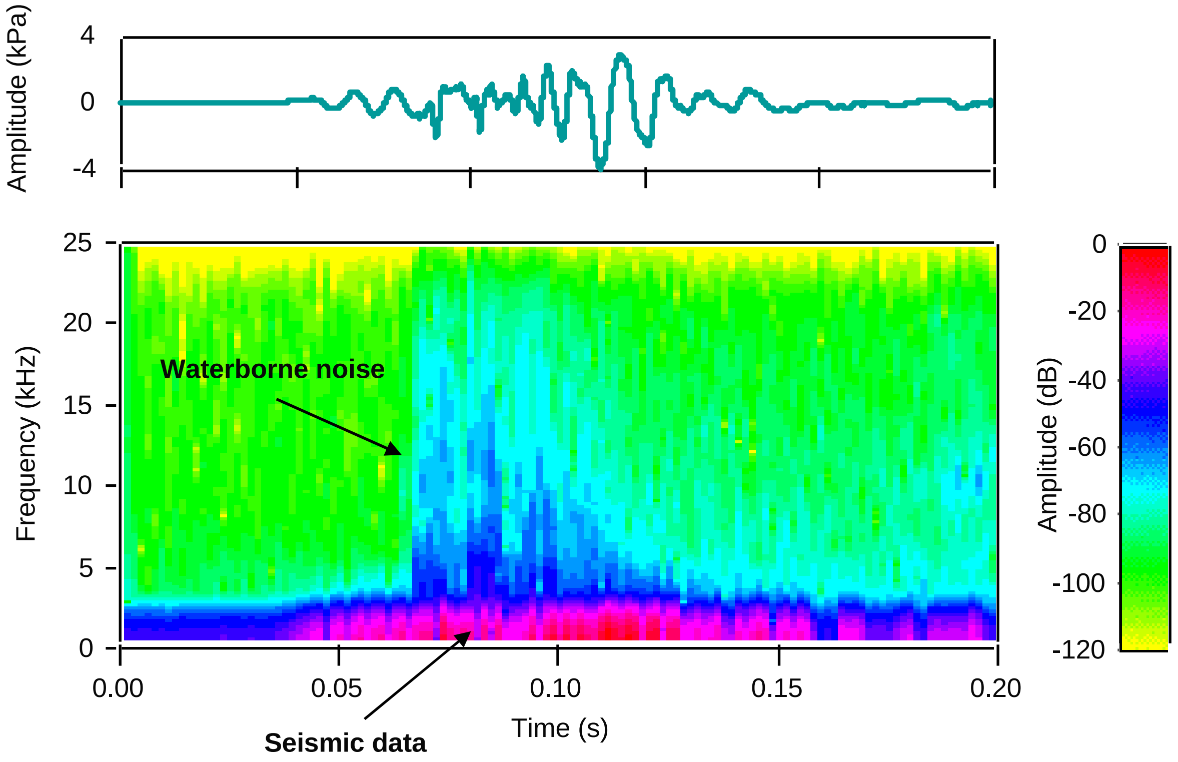
In-Line



90 Degree Azimuth

High Frequency Emissions from Airgun Arrays

Observations - Acoustic event from seismic exploration
Gabor transform (time - frequency analysis) of first arrival



Survey type: standard North Sea
Water-depth: 40 m
Observation distance: 500 m

Slide Courtesy of Peter Van der Sman-SIEP

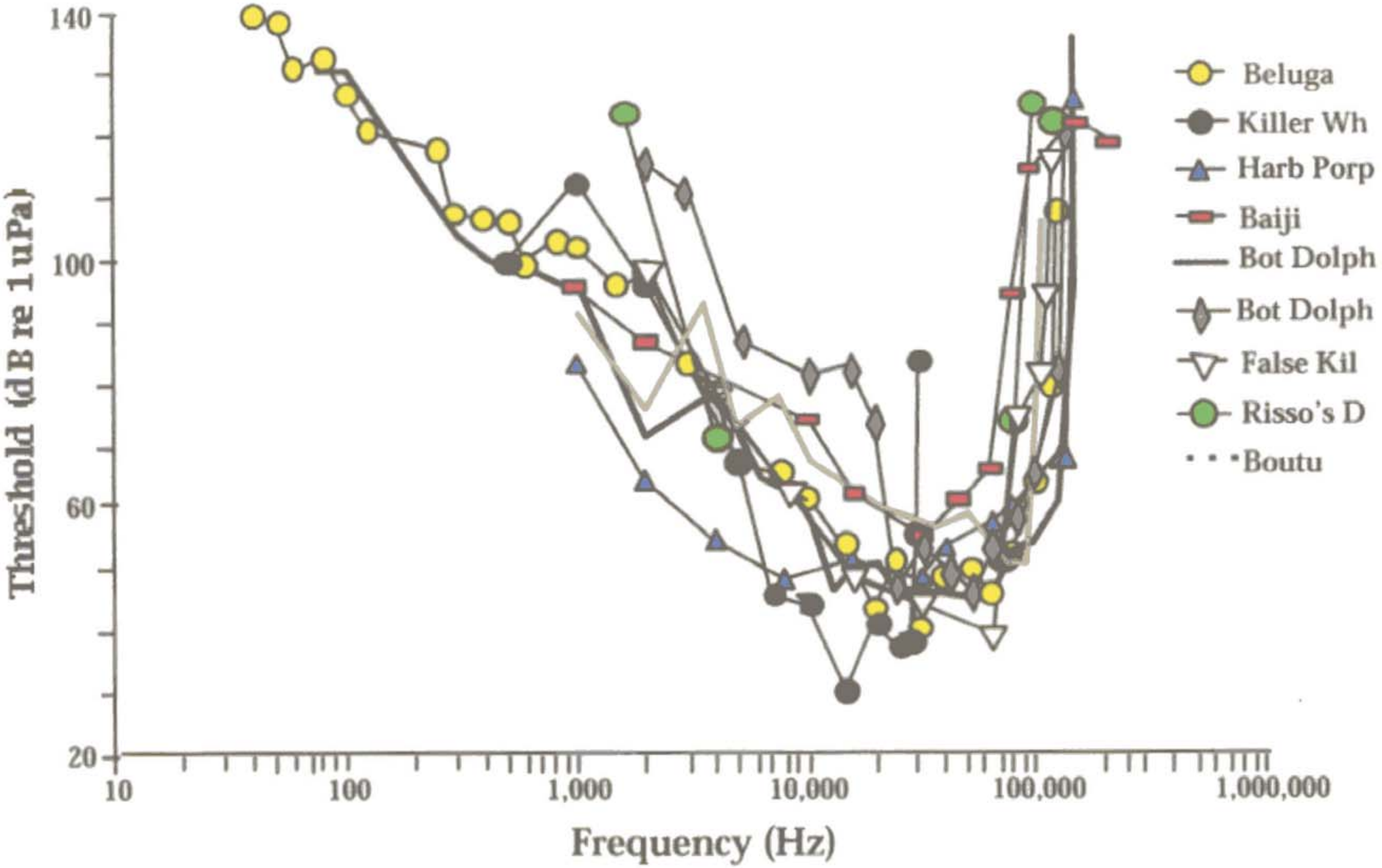
Issue – Frequency Content

“The consensus of the data is that virtually all marine mammal species are potentially impacted by sound sources with a frequency of 500 HZ or higher. Relatively few species are likely to receive significant impact for lower frequency sources.”

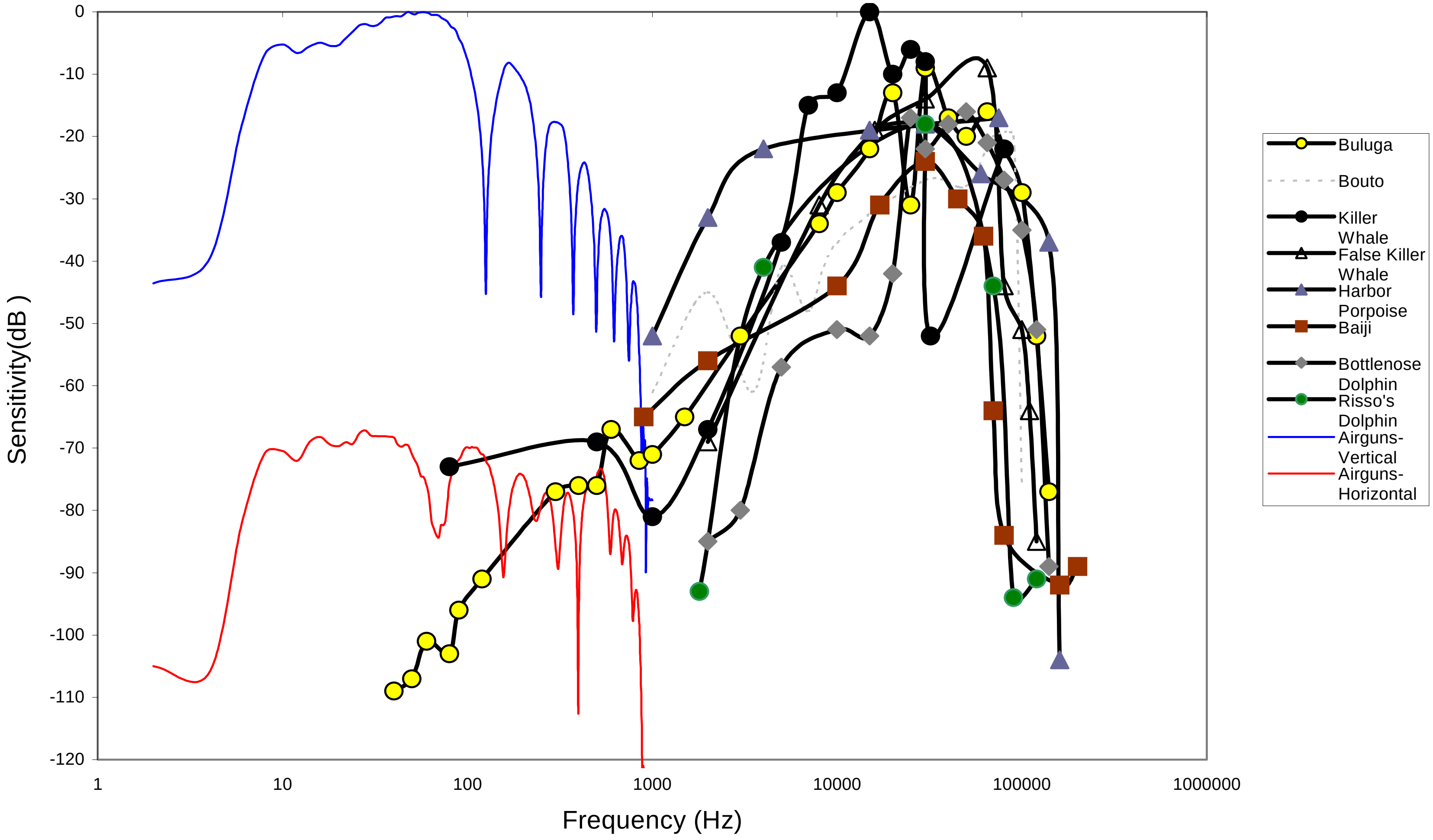
Ketten, D.R., 1998
Marine Mammal Auditory Systems:
A Summary of Audiometric and Anatomical Data
And Its Implications For Underwater Acoustic Impacts
NOAA Technical Memorandum
NOAA-TM-NMFS-SWFSC-256

Audiogram for 8 Species of Tooth Whales

Slide Courtesy of Texas A&M University

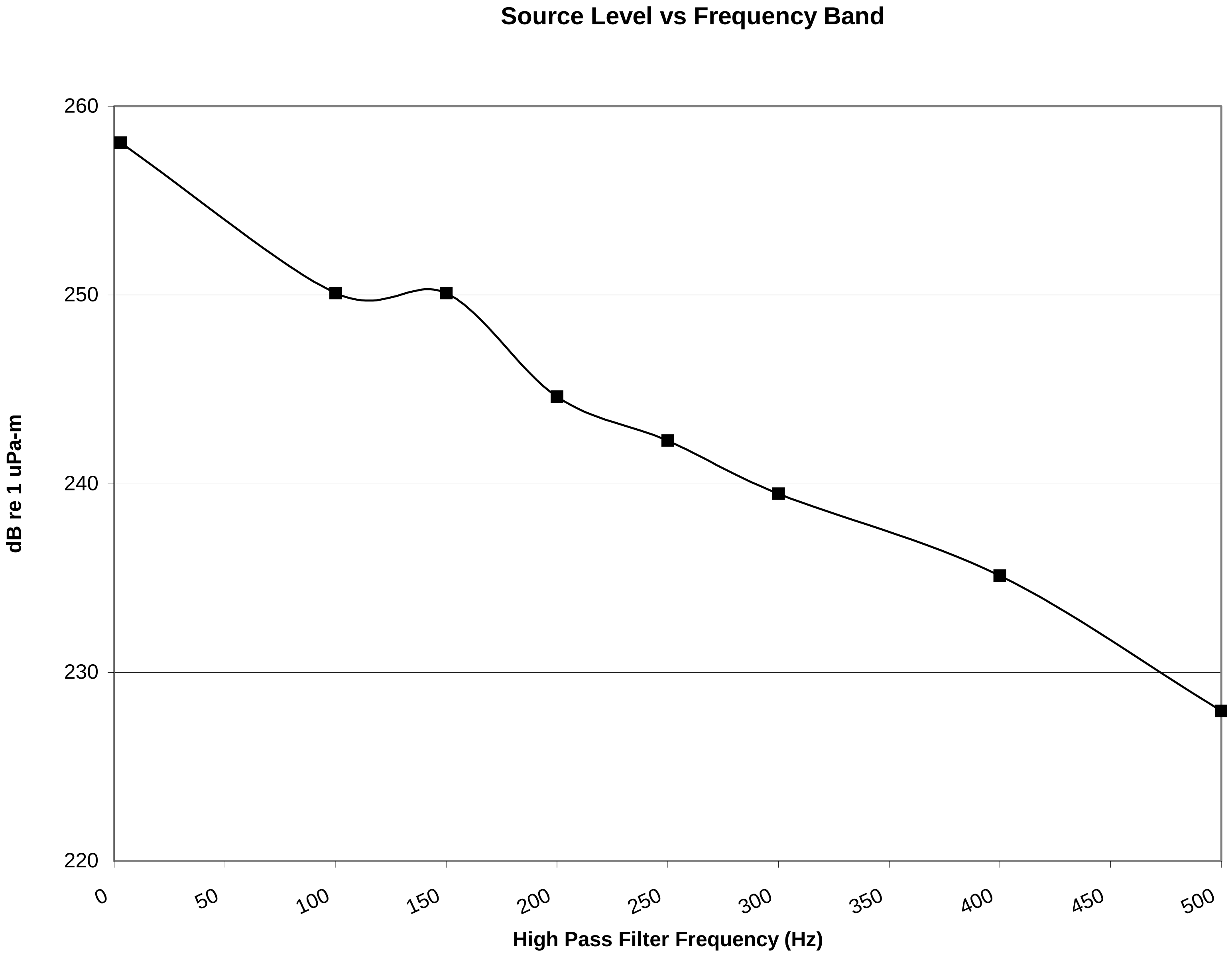


Comparison of Normalized Sensitivity Spectra for Toothed Whales Relative to Acoustic Output from a Typical Deep Water 3D Airgun Array

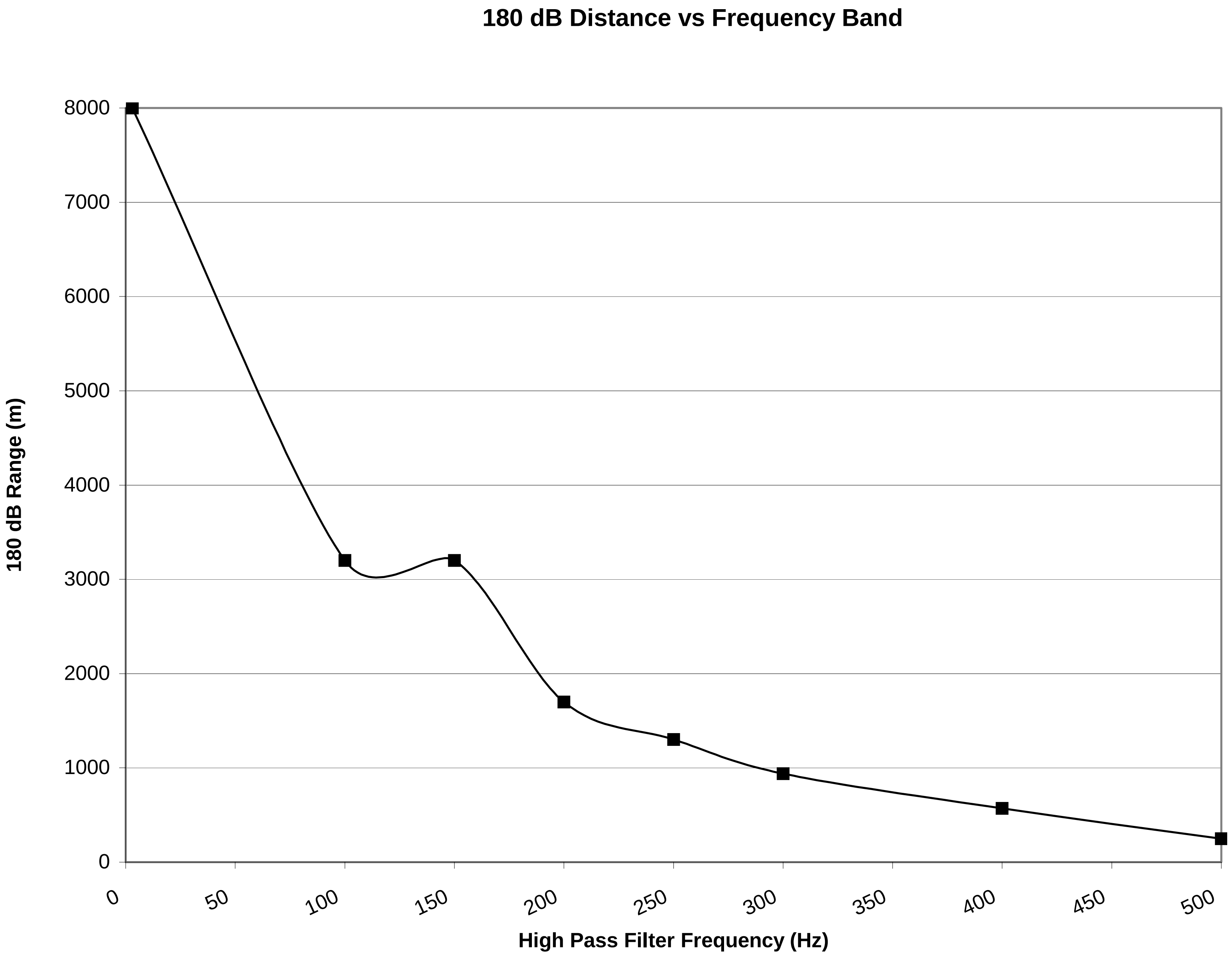


Spectal Overlap
Odontocete versus Airgun Array

Source Level versus Frequency Content



180 dB Distance versus Frequency Content



Sperm Whale Seismic Study (SWSS) 2002

SPERM WHALE SEISMIC STUDY
CRUISE REPORT - 2002 LEG 2

SWSS

August 19
September 15

Gulf of Mexico Sperm Whale Research - 2002

IAGC was directly involved in two specific aspects of this year’s work: S-Tag and D-Tag studies.

As part of the S-Tag effort, the IAGC is compiling positioning and activity information for all active seismic crews in the GOM. These data will be used to correlate against the S-Tag data to investigate any long term, large scale response between sperm whale movements and seismic activities.

As part of the D-Tag effort, the IAGC provided a dedicated seismic source vessel for use in the second stage of a four-week, controlled-exposure experiment (CEE).

Advantages of Industry Participation

There are several advantages for IAGC to participate in the 2002 studies.

As an active partner with MMS IAGC had input to experimental priority and design.

IAGC will participate in data analysis, interpretation, and publication.

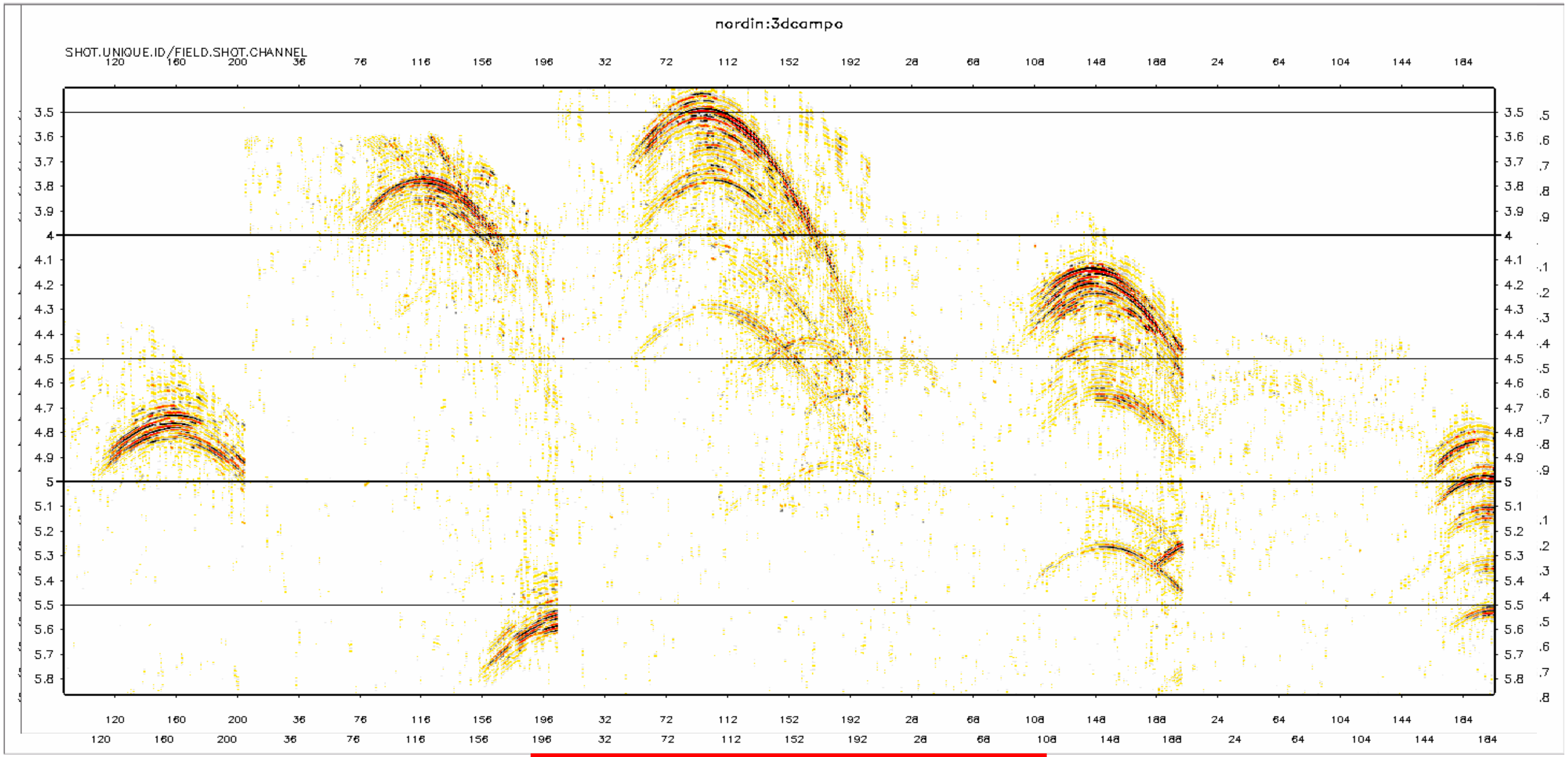
Although endangered, sperm whales inhabit all the world's oceans. Knowledge gained in the GOM can be applied in other E&P operating areas and with other national regulatory bodies.

Technologies and methodologies developed during the SWSS research can be applied to other species in other parts of the world.

Passing Through

Humpback whale approached to within 100m of Veritas Viking I.
Brazil – August 10, 2002

BM-C-19: seq.79 - Whale noise (?)



Risk versus Uncertainty

Risk **refers to hard mathematical odds.**

Uncertainty **refers to situations in which the odds are anybody's guess.**

Michael Kinsley – Time Magazine

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.