Action Plan for Harmful Algal Blooms and the Gulf of Mexico Coastal Ocean Observing System:

Results from a Regional Workshop

HAB-GCOOS

Acknowledgments

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For additional copies or information, please contact
NOAA Coastal Services Center
2234 S. Hobson Ave.
Charleston, SC 29405-2413
Telephone: (843) 740-1200
Fax: (843) 740-1224

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Executive Summary

A regional observing system for harmful algal blooms (HABs) in the Gulf of Mexico has the potential to greatly improve the ability to manage these events by providing updates to the locations of existing blooms, early alerts to new blooms, forecasts of bloom trajectories, and the probability that a new bloom could occur. Coastal managers and researchers in the region, from both the U.S. and Mexico, have been working towards this goal of providing a state-of-the-art monitoring and forecasting system through the Harmful Algal Blooms Observing System (HABSOS) and several related efforts. The organization of regional associations for the Integrated Ocean Observing System (IOOS), particularly the Gulf of Mexico Coastal Ocean Observing System (GCOOS), provides an opportunity to collaborate and improve the oceanographic observations required by both efforts. This workshop explored the needs of the user community with regard to HAB and ocean observations within the context of detecting, predicting, and forecasting HAB events. The resulting recommended actions were grouped into six functional categories:

- Harmful Algal Blooms Observing System (HABSOS)
- NOAA HAB Bulletin
- Ocean observations
- Models
- Standards and protocols
- Research and development

HABSOS — The goal of the Harmful Algal Blooms Observing System (HABSOS) is to develop an Internet-based data communications and management system for accessing and disseminating data and information for HAB management. The initial case study has raised important issues of data management among data providers and system users. HABSOS should be transitioned from a pilot project to a binational effort and continue its efforts to facilitate data access and exchange.

NOAA HAB Bulletin — The Harmful Algal Bloom Bulletin was developed by NOAA in cooperation with the U.S. Gulf states to address the need for quick delivery of concise information on the location, intensity, and expected development and movement of blooms of *Karenia brevis*. The bulletin has proven useful to state managers in their decisions of when and where to monitor the hundreds of miles of coast and associated shellfish beds for *Karenia brevis* toxins. Further development of this tool should include collaborating to incorporate appropriate research and technologies as they become available.

Ocean Observations — By participating with the Gulf of Mexico and Southeast ocean observation regional associations, members of the HAB community will have opportunities to contribute their needs, priorities, and suggestions for further development of infrastructure for monitoring and for research efforts. HAB monitoring can be improved by the incorporation of sentinel stations and of observing stations placed in strategic HAB areas and instrumented with additional detection sensors, and development of a plan for these stations is a high priority. The HAB community will also benefit from the contribution of additional observing stations to improve coastal ocean forecasts, the foundations for HAB forecasts. To further their coordinated development and integration, the Environmental Protection Agency's Gulf of Mexico Program will serve as a point of contact for the regional associations.

Models — Oceanographic models are critical to the development of a forecast capability for HABs. Although there are several models available for the Gulf of Mexico, each model varies in resolution, geographic coverage, availability, and model output format. A coordinated effort to identify the model or model output that is needed and to address which models can be used in real time, near real time, or as forecasts is a high priority for developing an HAB forecast capability. A feedback system between the modelers, data providers, and users is critical to evaluating model forecast accuracy and utility.

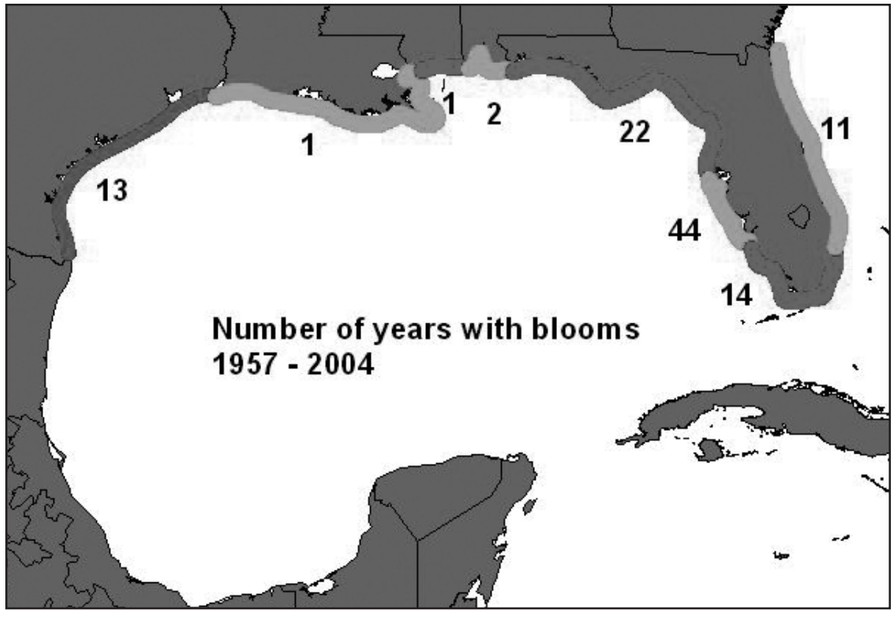
Standards and Protocols — The establishment of standards and protocols for data collection procedures and for routine monitoring will facilitate data exchange and research across the U.S. and Mexican states. The Gulf of Mexico States Accord, Gulf of Mexico Program, State of Florida, and others are committed to developing these standards and providing training to participants.

Research and Development — Improvements to detection technologies to make HAB detection faster and simpler in the field is a high priority. This technology will increase the efficiency with which managers can regulate shellfish beds and post advisories for beaches and may be appropriate for automated use on buoys, which would improve offshore monitoring. In order to obtain forecast capability, continued research on the ecosystem and biology of the HAB species is needed to incorporate biological processes into physical oceanographic models and to advance our knowledge of the initiation mechanisms of HAB events. The support for additional scientific research should be allied with increasing socioeconomic and public health impact studies.

Communication and collaboration between the U.S. and Mexico and academic, state, federal, and other entities is integral to the success of developing a regional capability for managing and ultimately forecasting HAB events.

Background

Concerns about harmful algal blooms (HABs) have increased over the last decade largely because of the perceived increase in the number and duration of events. The toxins produced by these species cause finfish and shellfish poisoning and mortality of marine animals, including mammals and birds. In the Gulf of Mexico, the red tide species, *Karenia brevis*, routinely occurs along the southwest coast of Florida in the late summer and early fall and can persist for up to three months. This type of bloom has occurred in the Florida panhandle, Texas, and as far north as the barrier islands of North Carolina. Aquatic organisms are affected either by the neurotoxin itself or by the reduced water quality that results from a bloom. In 1996, a bloom was responsible for the death of 10 percent of the manatee population. In addition, human health is compromised by the presence of dead and decaying fish in the waters and on the beach and by the production of aerosols that cause asthma-like symptoms. The blooms also impact fisheries and tourist industries by inducing neurotoxic shellfish poisoning. In the 2002–2003 HAB season, the Florida shellfish aquaculture and oyster industries lost $6 million in dockside sales alone, and up to 20 percent of the planted clams.



Map of Karenia brevis *bloom locations from 1957–2004. Blooms are defined as events that exceeded 5 x 10^3 cells l^{-1}. Map provided by Florida Fish and Wildlife Conservation Commission.*

Advance warning of HABs increases the options for managing these events. Through collaborations between many agencies, the Harmful Algal Blooms Observing System (HABSOS) was designed to integrate observations of environmental data that affect the initiation, movement, and demise of HABs. Scoped at a workshop in December, 2000, (report available at *www.hpl.umces.edu/projects/HABSOS.pdf*), the system will provide useful products and information to end users, including (but not limited to) state agencies responsible for public health, coastal zone management, environmental protection, and sustainable management of living

marine resources. Through this and many other efforts over the past few years, significant progress has been made to develop a regional observing system for HABs in the Gulf of Mexico. Florida investigators have received funding for in-depth research on HAB dynamics and have been working towards the goal of providing a state-of-the-art monitoring and forecasting system. The HABSOS case study (*www.ncddc.noaa.gov/habsos*) is developing further implementation plans to achieve its goal of developing an Internet-based data communications and management system for accessing and disseminating data and information to support

- Early HAB alerts (detecting new blooms),
- Frequent updates on the locations of existing blooms,
- Timely forecasts of HAB trajectories and the time and location of HAB land falls, and
- Probabilities that a bloom will occur based on environmental conditions.

Critical to this effort is partnership with existing research and monitoring capabilities, including the observations available through the Integrated Ocean Observing System (IOOS). The regional associations for the Gulf of Mexico area include the Gulf of Mexico Coastal Ocean Observing System (GCOOS) and the Southeast Coastal Ocean Observations Regional Association (SECOORA), which are providing oceanographic data and conducting research that will affect the management of harmful algal bloom events. Both GCOOS (*www.gcoos.org*) and SECOORA (*www.secoora.org*) are committed to establishing a sustained observing system for the Gulf of Mexico that will provide observations and products needed by users in this region. These associations are now in the process of developing governance structures and coordinated agendas for operational elements, pilot projects, and underpinning research in the form of business and strategic plans. The findings of this workshop provide important information regarding HAB observing requirements in the Gulf.

Given the goals of these two efforts, there is a mutual benefit in their coordinated development and integration. The purpose of the workshop was to explore these possibilities and to set in motion a planning process to achieve these goals. The workshop addressed current capabilities and the development of an HAB observing capability that will, in collaboration with the developing GCOOS, improve the efficacy of efforts to manage and mitigate the effects of HABs on public health, aquaculture production, and fisheries in the Gulf of Mexico. Participants included researchers from multidisciplinary teams currently developing regional products, researchers in applied modeling activities, individuals from private industry impacted by HAB events in the Gulf of Mexico, and representative users from various public agencies and institutions that are involved in HAB mitigation.

Workshop Objectives

- Review HAB data and information needs of state agencies, coastal zone managers, and scientists in the Gulf of Mexico.
- Assess current capabilities of the Harmful Algal Blooms Observing System (HABSOS) and related efforts to provide required data and information.
- Formulate an action plan to improve capabilities for the development of HAB observing system elements in the Gulf of Mexico as integral parts of the developing GCOOS.

Workshop Results

Through a series of presentations, panelists, and small group discussions, the needs of the management agencies and the capabilities of observation-based science were clarified regarding HAB events (see Agenda in Appendix A). Representatives from agencies around the Gulf, including those from Mexico, had the opportunity to discuss their needs for information. Members of the operational and research communities discussed the current capabilities and plans for systems that are based on ocean observations—models, remote sensing, and in situ sampling (see Participants in Appendix B). Although significant progress has been made to address HAB monitoring and forecasting issues, there is a need for communication and collaboration within the region and with the federal agencies to be more effective. The recommendations of this workshop aim to ensure that the development of regional observing systems can accommodate this user community and that the products developed from this system address the needs for monitoring and forecasting HABs using the best possible science.

HAB Data and Information Needs

The user groups for HAB data in the Gulf include a variety of state, federal, and international living resource managers, public health officials, and environmental regulators. Local governments involved in projecting cleanup needs, as well as the aquaculture industry, tourism, and local businesses, also have a vested interest. Other users of the systems include the media, the public, educators, students, and forecasters. The needs of U.S. and Mexican officials can be addressed by similar data and products.

Many of these user groups have expressed a need for decision-making capabilities in order to minimize risks and impacts. Some of the capabilities requested include advance notice of an HAB event (e.g., two weeks), the type of species or toxin that is present, the action levels for these species and toxins and the associated risks, marine animal mortality, the ability to forecast trajectory in time and space, data and information for control and mitigation, and data and information for adaptive sampling and rapid response. Users also stressed the need for relational databases and the timely availability of synthesized data and maps.

Most of the Gulf states conduct reactive sampling and shellfish closures based on the occurrence of HAB events. Long coastlines coupled with limited resources require an early warning system so that resources can be dispatched to the appropriate place for sampling. This response requires that the system contain a predictive capability to identify when and where blooms are likely to occur as well as when a bloom does occur. A warning system might include e-mail notification of a “likely event,” such as those provided by the NOAA HAB Bulletin, a predictive event warning, which would be similar to hurricane projection, and an early warning to allow managers to prepare for deployment of response. Also critical to the needs of a shellfish manager is information on the recovery from the event to pre-bloom water conditions.

In addition to managing closures and openings of natural shellfish harvest areas, the coastal agricultural resource manager is also involved in aquaculture issues. Historical databases and hindcast systems would be extremely useful in helping to site new aquaculture locations and programs. Detection, forecast, and predictive capabilities are critical for aquaculture. Business decisions such as pen relocations or early harvest can be made if appropriate HAB event information is made available early. If aquaculture managers know a bloom is projected for their area, they can reduce stock losses.

Although progress to provide state managers with relevant information has improved in the last few years, state managers throughout the Gulf do not consistently have adequate information to know when and where to sample for harmful algal blooms. Additional products are needed to provide more complete information

more quickly than traditional methods, many of which require surveying with a boat to acquire water samples that are then tested in the laboratory. Multiple pieces of information, including surface and water column measurements, are needed so that managers can pick and choose the information needed to make decisions that affect natural resources and human health. To simplify access, this array of information should be available from a single, user-friendly access site.

Current Capabilities of the Harmful Algal Blooms Observing System

The Harmful Algal Blooms Observing System (HABSOS) pilot project was developed through a partnership of federal, state, and academic organizations as a proof-of-concept for the development of a coastal observing system in the Gulf of Mexico. One of the first goals of HABSOS was to conduct a retrospective case study of red tide blooms in the northern Gulf of Mexico. The case study would provide a mechanism to design an HAB data management and communication system to assist state managers by establishing a network of coastal laboratories for rapid collection and dissemination of data and information on *Karenia brevis* events and related environmental factors. The case study reconstructed the regional environmental conditions and tracked the occurrence and trajectory of *K. brevis* events during 1996, 1997, and 2000.

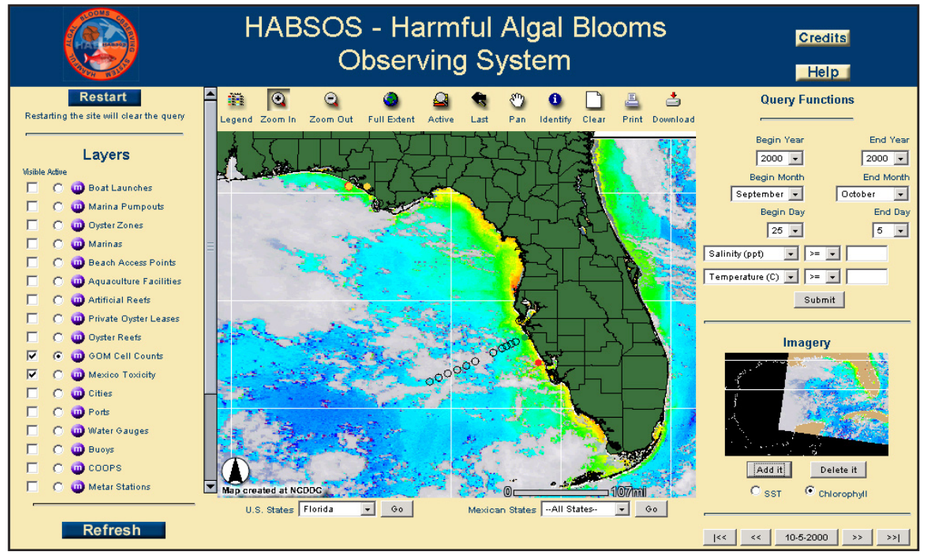
The effort to obtain relevant HAB cell counts and hydrographic and chemical data to demonstrate the benefits of regional data integration revealed that significant differences existed in the states’ data management capabilities. A problem proved to be the inconsistency of dedicated resources for regular monitoring and data management, resulting in an array of data holdings that proved difficult to locate and standardize for analysis. A list of data parameters cross-referenced by state/agencies and time period is included as Appendix C.

HABSOS On-Line Mapping Tool

An on-line mapping tool (*www.ncddc.noaa.gov/habsos*) provided data visualization, query, and analysis of conditions prior to, during, and following blooms. The dynamic mapping capabilities demonstrated the potential benefits of timely data collection, integration, and information dissemination. The case study working group developed the following requirements for the on-line mapping tool:

- Simple Web interface, including on-line mapping tools, for ease of use;
- Standard query to subset data by time period defined by user;
- Standard query to subset data by physical parameter and range as defined by user; and
- Integration of imagery data into the map for analysis.

A critical function of the HABSOS case study was to provide momentum for the design, costs, and development of the operational or near real-time HABSOS application. This purpose is being fulfilled and the design and development of the operational HABSOS is well under way with a clear demonstration of the ability of institutions to collaborate on regional issues.



Map of bloom event integrated with imagery.

Figure provided by the National Coastal Data Development Center.

Action Plan

Considerable resources exist within the research community to address the needs for managing HAB events. These resources include knowledge about the species and ecological system, hydrodynamic models, and observation and remote sensing techniques. Data and information requirements to improve management capabilities include improved nowcasts and forecasts of surface current and wave fields, real-time in situ sensing of HAB species, improved ocean color algorithms, and models. To determine how to best leverage these and other resources and incorporate the results into management tools, the management process was divided into three tasks: detecting a HAB, forecasting the movement and change in an existing bloom, and predicting the development of a bloom. The actions needed to incorporate the science into that task were then identified (see summary table). These actions were grouped functionally into six categories:

- Harmful Algal Blooms Observing System (HABSOS)
- NOAA HAB Bulletin
- Ocean observations
- Models
- Standards and protocols
- Research and development

Summary Table of Actions

	Detection	Forecasting	Prediction
Vision	The information on the present location and abundance of harmful species is quickly communicated to appropriate responders	The possible movement and development of an existing bloom is forecasted for the next three to five days	A two-week notice is provided to responders of the potential for bloom development
Strategies and Actions	Continue HAB Bulletin development and distribution	Establish a system to access forecast output from multiple models	Continue research on biology and ecosystem dynamics to advance knowledge of conditions leading to HAB events
	Facilitate data access and exchange	Develop a feedback system to validate model forecast accuracy and utility	Validate need for prediction through socioeconomic and public health impact studies
	Establish standard protocols for data collection	Develop a plan and mechanism for distributing forecast information	Support climatology database
	Establish standards and plan for routine monitoring	Promote increasing observations and measurements that improve coastal ocean forecasts	
	Augment GCOOS plan to incorporate HAB monitoring data		
	Promote development of new detection technologies		

Harmful Algal Blooms Observing System

The HABSOS case study findings indicate that currently the ability to assimilate and apply environmental data into a two-to-three day forecast of *K. brevis* events does not exist on a Gulf-wide basis. A primary obstacle to the study of regional environmental phenomena proved to be the difficulty in identifying, recovering and integrating relevant but disparate data into a useful format for display and analysis. Data assimilation and integration are time-consuming and generally under-funded tasks; however, through the case study activities, the capacity and infrastructure necessary was built to address this problem and support the eventual success of an operational HABSOS.

Facilitate data access and exchange – As an outcome of the HABSOS case study, efforts are ongoing to develop an automated data processing technique to reduce the time between essential measurements, incorporation into forecasts, and dissemination to state resource managers. Acquisition of timely information is critical if HABSOS is to evolve into a fully operational real-time system. The information gathered through the case study will be valuable in the development of standards and protocols to facilitate the exchange of data (see also Standards and Protocols below). The National Coastal Data Development Center has begun work to develop an online cell count entry tool that will facilitate data access for agencies that do not already have a system in place.

Integrate data – Efforts to obtain and access data that are consistent with the developing Ocean. US data management and communication plan (DMAC plan) will assist HABSOS in transitioning from a retrospective analysis. A system that can efficiently link current observations (in situ and remote) to models and data products and can provide access to historical data will provide the greatest flexibility to satisfy the multitude of users of this type of information.

The ability to visualize the spatial characteristics and dynamics of a bloom is critical, and integration of the various data types into a single tool is an important step towards this capability. Ocean color data have proved valuable; however, the license restrictions imposed on color imagery have limited their utility. Development and integration of MODIS imagery into a real-time map server will be a valuable analysis tool. Also integration of real time data such as winds and currents could be used to estimate the surface displacement of the blooms from day to day in near-real time and would supplement and support oceanographic models

Provide Gulf-wide coverage – Information should be expanded to include the Mexican Gulf states, allowing for a binational HAB collaboration and monitoring capability that will span international borders. Imagery and data should be provided for the entire Gulf when possible. To indicate the locations of blooms, all states in the U.S. and Mexico will need to provide data on cell concentrations and locations (only Florida now provides routine access to cell data). Interactions initiated through the Gulf of Mexico States Accord could improve the necessary communication.

Harmful Algal Bloom Bulletin Development and Distribution

The Harmful Algal Bloom Bulletin was developed by the National Oceanic and Atmospheric Administration (NOAA) in cooperation with the U.S. Gulf states to address the need for quick delivery of concise information on the location, intensity, and expected development and movement of blooms of the *Karenia* species. The bulletin contains satellite ocean color imagery of the chlorophyll concentration in the region with potential HAB areas identified, meteorological data coupled with a simple drift

transport model, and observational data from state and research investigators. Because states have liability concerns, distribution of the bulletin is limited to users with natural resource management responsibilities. After a delay of several days, it is posted to a Web site for general access. The bulletin has proven useful to state managers in making decisions on when and where to monitor the hundreds of miles of coast and associated shellfish beds for *Karenia brevis* toxins, but further development is needed to address management needs.

Improvements to the bulletin are in progress within NOAA's National Ocean Service (NOS), and comments from this workshop are being incorporated with those changes. Future developments and revisions will be integrated in partnership with representatives from the region. As improvements and changes to the bulletin are made, they will be communicated to subscribers through e-mail announcements and at conferences and meetings.

Provide Gulf-wide coverage – As mentioned above, a binational capability is needed. Improved analysis for Mexican waters will require developing new communication pathways between bulletin analysts and Mexican authorities and scientists for data exchange and validation. Interactions initiated through the Gulf of Mexico States Accord will improve the necessary communication.

Distribute routinely – Recommendations have called for the bulletin to be issued every three to five days when a bloom is in progress and weekly when there are no reported events. The bulletins will be coded such that the importance (high, medium, low) of information about bloom events will be clear.

Provide open access to data and methods – Data provided in the bulletin that are not subject to licensing restrictions are available for download in a geographic information system (GIS) format from an Internet map service (*www.csc.noaa.gov/crs/habf*). This site will be merged with the HABSOS site (*www.ncddc.noaa.gov/habsos/*) to provide a single, near-real-time mapping service. Collaboration with the research community needs to be emphasized and encouraged within the NOAA process.

Provide access to improved nowcast and forecast information – The bulletin can and should improve as a mechanism to communicate concise information on the expected movement of a bloom. Current efforts that use a rudimentary two-dimensional wind drift model to estimate movement are insufficient. As model collaborations develop (see Model section below), the bulletin will serve as a means to convey top-level information on forecasts. A product containing full output from multiple models and information about the error in predictions would complement the information provided by the bulletin.

Ocean Observations

As the regional associations gain organization and capabilities, members of the HAB community will have opportunities to contribute their needs, priorities, and suggestions for further needed operational activities. To maximize the capabilities of GCOOS, SECOORA, and HABSOS, and to further their coordinated development and integration, communication between the efforts is a priority.

Communicate HAB needs to regional associations – An opportunity to provide input on the highest priority enhancements to the national backbone from the Gulf of Mexico Regional Association was offered by Ocean.US within weeks following the workshop. Those enhancements

were included in the priorities expressed to the Ocean.US by GCOOS (see Appendix D). In future communications, the Environmental Protection Agency's Gulf of Mexico Program will serve as a point of contact to the regional associations on HAB-related observations.

Facilitate access to remote sensing data – Remote sensing data are available from a variety of sources in the Gulf and across the nation. There are several sensors providing data that can contribute to HAB work, and improved products and access to these data sources are important components to understanding the regional dynamics of the Gulf of Mexico and to providing the HAB products. Support for enhancements to increase the spatial and temporal resolution would improve their application to HAB events. Additionally, support is needed to ensure continuity of imagery into the future.

Improve coastal ocean forecasts – HAB forecast models depend on oceanographic models that, in turn, rely on weather forecasts. Improved HAB forecasts in the nearshore regions will require improved coastal ocean forecasts, driven by local winds.

Provide for improved measurement of nearshore currents – Ocean.US has initiated a planning effort to instrument the U.S. coastline with high-frequency (HF) radar as part of the national backbone of the IOOS. This plan, if implemented, will improve measurement of surface currents, needed particularly for nearshore environments. It is expected that regional ocean observing system associations will help determine where HF radars will be located within their region.

Increase moored observations – To support many of the efforts, including improved coastal ocean forecasts, an increase in the number and type of observations will be needed. Any model to forecast the movement of an existing bloom will be improved by measured information on winds and currents, as well as temperature and salinity.

- Increase meteorological observations in the coastal ocean by instrumenting buoy and land-based platforms
- Improve and increase measurements of physical oceanographic data such as currents, temperature, and salinity

Add biological sensors to a system of sentinel stations – Biological sensors such as chlorophyll, oxygen, and various optical instruments would improve the observation system for HAB applications. Extant stations may be augmented with additional instrumentation, or new platforms may be added. Both surface and subsurface monitoring is envisioned. The specific locations and instrumentation for the sentinel stations need to be developed in partnership among all users of HAB information and the regional associations.

Coordinate cross-shelf transects – Cooperation between the U.S. and Gulf states, through the Gulf of Mexico States Accord (GOMSA), to coordinate a regular serial transect across the Gulf would provide a foundation for working binationally to address the HAB issue. The data collected on these transects would be valuable for HAB research, particularly for calibration and validation of remote sensing algorithms. It also would establish the communications and resources necessary to develop a regional response for offshore monitoring when needed. Each state would be responsible for organizing and sponsoring a cruise, and cruises would occur once a month (biweekly would be preferred August through October when *K. brevis* is most common). The following sampling plan was proposed:

- Sampling at standard station locations
- Collections at standardized sample depths: surface, pycnocline (or mid-depth), and near bottom
- Routine detection parameters: cell counts (target toxic species), chlorophyll, temperature, salinity, dissolved oxygen, fluorescence, suspended sediments, colored dissolved organic matter (CDOM), nutrients, pigments, and toxins
- Standard data management practices for access to data and metadata

Model Development

Oceanographic models are critical to the development of a forecast capability for HABs. There are several models available for the Gulf of Mexico. Each model varies in resolution and geographic coverage, and both two- and three-dimensional models are being used. Many of the models presented appear to have direct application to modeling HAB trajectories for the purposes of predicting movement and landfall; however, there is no coordinated effort to evaluate these various models.

Verify and validate forecasts – Two-dimensional wind drift models are being used by NOAA in an experimental model to explore their accuracy in predicting surface trajectories. An important component to this and future efforts is to develop feedback from states for verification and validation of model product utility. This process will rely largely on obtaining feedback, including data collection, from users when a forecast is issued. NOAA will work with the states to provide these data and information to the larger modeling community in a usable form. In addition, NOAA will work with the states to understand the sensitivities of issuing HAB forecasts and to develop a plan for distributing them. This plan will be made available to the larger community.

Facilitate access to output from multiple models – Similar to the efforts of hurricane forecasts, access to output from multiple models is an important component of accurate HAB forecasts. This approach will provide a range of forecasts using all available models as a means of showing the range of possible trajectories. A platform that allows the display of multiple models' outputs and their codes and that provides for research comparison will facilitate a comprehensive performance analysis of the models. This effort will require extensive collaboration across federal and academic programs and may be accomplished with the following steps:

- Standardize existing model output formats. This step will allow model output to be easily ingested into a common tool for comparison of outputs. Although IOOS does not require standardized outputs, it encourages sharing model codes to facilitate model comparison and validation.
- Build a display capability for the use of multiple models allowing for trajectory overlay.
- To improve coverage and resolution, nest higher-resolution models into lower-resolution models and focus these efforts on three-dimensional coastal models.
- Incorporate particle tracking capabilities into existing models.
- Integrate ocean color remote sensing for improved visualization of HAB coverage and movement.

Leverage industry capabilities – There are several industries in the Gulf of Mexico with extensive observation and analytical capacities in place that should be considered in development of the HABSOS in the region. For example, the oil industry now plans to openly share current measurements from some 40 locations in the Gulf. Shipping through the Gulf provides additional platforms for in-water detection, and discussions with regional shipping companies might facilitate deployment of sensors such as those that have been carried on ferries. Routine federal weather or training overflights might also provide vehicles for airborne detection of surface characteristics. Discussions with the Coast Guard or state National Guard units might provide periodic sampling opportunities.

Improve biophysical models – Most of the models presently available are physical oceanographic models that can easily incorporate passive tracers. For use with HABs, the biological processes are important drivers, and additional research and development is needed to incorporate the coupled physical and biological processes into a model that is viable in an operational environment. There have been substantial advances in general understanding of the physiology and behavior of several Gulf HAB species in the past decade. Current physical models might now more routinely consider algorithms for vertical migration behavior and diel division cycles, which are now better understood and more quantifiable than in the past. The inputs and biogeochemistry of nitrogen and phosphorous are better described for Florida's shelf and these inputs could assist in better characterization of nutrient supplies for the transported HAB taxa. The inclusion of these formulations should be a priority as the models are moved towards operational forecasts.

Incorporate satellite imagery – The combination of imagery (SST and chlorophyll) with surface circulation models creates a visualization tool with many applications. Visualizing water masses moving through the Gulf using chlorophyll or temperature imagery is an intuitive approach to visualizing the surface movement and flow of blooms. Adding tracers to the visualization to mimic known bloom locations and their trajectories improves this capability.

Common Standards and Protocols

Establishing standards and protocols will facilitate data acquisition and data access to improve monitoring, forecasting, and prediction activities. Standard methods are needed for many parameters, including biological, chemical, and optical. Standards for collection and quality assurance/quality control of most oceanographic data are in common use. Work is needed to outline materials, methods, and approaches for collecting, organizing, reporting, and disseminating other types of data. Standard operating procedures and quality assurance plans exist for a variety of federal activities, such as the Environmental Monitoring and Assessment Program (EMAP), that could be used as templates. However, since some of the potential sensors for species and toxins are still in the research and development phases, and since different U.S. and Mexican states have different data collection and reporting methods, whatever standards and protocols are outlined should be under continuous evaluation for modification.

The common denominator under any standards and protocol guidelines is basic quality control and a minimum set of standards to meet. The first step to addressing standards and protocols is to survey the current capacity for data collection and reporting; a large portion of this information is available from the HABSOS case study results. Meetings to coordinate collections and reporting should then be a priority

to establish integrated procedures. Inter- and intrastate communication and collaboration is essential. Standards and protocols may differ based on the level of complexity and on-site assessment and, therefore, a two-tiered or multitiered approach may be needed to meet all the user needs.

Improve data management – Reporting should be standardized so that multiple databases are compatible and can be integrated. There will necessarily be multiple levels of measurement, reporting, and retrieving. Depending on the user—scientist or manager—the formatted data may be presented as a table, graph, or map for best use and application. In the reporting and dissemination of data, it will be critical to have complete metadata files that follow federal guidelines. Eventually, a summary or aggregate of data should be available for the public via a Web site.

Implementation of the IOOS data management and communication (DMAC) plan will facilitate the capability of state agencies to access and exchange data. In some cases, assistance with resources to obtain hardware and software may be needed. Assistance with installation and training and consultation services may be required to maintain data communication. Orientation of state data managers to the DMAC could be held in conjunction with regional association meetings.

Provide training and outreach – Standards and protocols per se need to be augmented by training in established and new technologies such as hydrographic variables and species and toxin detection, by providing recommendations for equipment and level of detection, by providing or training personnel in database management and communication systems, by providing models or access to modeling personnel, and by providing education and outreach materials.

Research and Development

There are many opportunities for research and development to support HAB monitoring and forecasting. An understanding of the organisms, ecology, and physical environment is important to improving monitoring techniques and critical to developing forecasting and prediction tools.

Support climatology database – A high-quality historical database for *Karenia brevis* occurrence and the oceanographic variables associated with blooms, including ocean color imagery, would improve the ability to look at many questions. For example, a correlation between high rains and the formation of red tides is hypothesized, but the database to quantitatively examine correlations is difficult to assemble.

Quantify biological processes – As mentioned above, the incorporation of basic biological rates into physical models will allow for improved modeling of bloom initiation and intensification in addition to transport. Information on physiology will allow the behavior of HAB species to be separated from non- HAB species.

Study socioeconomic and public health impacts – Additional work on socioeconomic and public health impacts will improve the ability to quantify HAB impacts. At present the ability to extrapolate HAB monitoring to forecasts of impacts on public health impact is tenuous and needs to be strengthened. Monitoring programs for public health impacts are not routine and suffer from inadequate data. The availability of this information could assist in quantitatively justifying the effort spent on HAB research and applications. Funding through the Oceans and Human Health Initiative to institutes in the region (University of Miami) will bring additional resources to this effort.

Improve in situ observation technology – The capability to better detect *Karenia brevis* in its environment to monitor bloom development and movement will improve monitoring and forecasting. Support for improvements to technologies that discriminate *K. brevis* within the environment and that better measure physical oceanographic parameters is warranted.

The use of molecular probes to discriminate harmful species will improve monitoring techniques by making the identification of a particular species easier and faster than identification using microscopic techniques—with the goal of testing and validating these techniques on in situ, automated, real-time sensors.

Optical detection of *K. brevis* will allow for improved remote monitoring of blooms. This type of technology has been explored for satellites, buoys, and autonomous underwater vehicles (AUVs). A few AUVs are currently being used to provide measurements indicative of the gyroxanthin pigment found in *K. brevis*. Continued and expanded use of this type of AUV, for example, in areas that frequently are initiation sites, will allow remote detection of *K. brevis* cells below the surface and thus provide for better understanding of bloom initiation and transport processes. Optical detection from passive instrumentation shows promise, and continued research is needed.

Improve satellite remote sensing technology – Satellite remote sensing imagery is presently used to identify areas of high chlorophyll, which may be indicative of red tide. More rigorous optics-based methods need to be combined with climatological algorithms to improve detection. These algorithms need to be improved for use in coastal areas where chlorophyll detection is difficult. Imagery in coastal areas is affected by shallow bathymetry, the effects of the atmosphere, and sediment and dissolved organics in the water column. Long-term advancements in the temporal, spatial, and spectral resolution of satellite sensors will improve remote sensing in coastal areas where cloud cover can prevent image acquisition and features of interest in the coastal zone (e.g., circulation in bays and estuaries) may not be detectable because of the spatial resolution of the sensor (presently, 1 km). Continuity of imagery between ocean color sensors will provide a long-term capability and assist in research efforts to determine the extent and duration of blooms.

Research advances using airborne oceanographic LIDAR data show promise in coastal areas where sediments and dissolved organics complicate extraction of chlorophyll. A limited number of sensors are presently available, and the technology requires trained personnel to extract data. Additional research and process is needed to leverage these capabilities for use as a monitoring tool.

Appendices

Appendix A – Workshop Agenda

Integrating Harmful Algal Bloom Observations into the Gulf of Mexico Coastal Ocean Observing System

April 12–15, 2004
Florida Marine Research Institute • St. Petersburg, Florida

MONDAY, APRIL 12

6:00–7:30 p.m. **Welcome Reception**
Bayboro Room, Hilton Hotel, St. Petersburg
Convener – Mary Culver, NOAA Coastal Services Center

TUESDAY, APRIL 13

8:30 a.m.	**Welcome and Introductions** Bryon Griffith, EPA Gulf of Mexico Program Office Kevin Sellner, Chesapeake Research Consortium	
9:00	**GCOOS – A Regional Component of the Integrated Ocean Observing System** Worth Nowlin, GCOOS Advisory Committee and Texas A&M University	
9:30	**HABSOS Case Study Results** Sharon Mesick, NOAA National Coastal Data Development Center	
10:15	Break	
10:30	**Session 1: Decision-Support System Requirements** Karen Steidinger, Lead	
	Bruce Champion David Heil	Jorge Nicolas Chantiri Perez Jim Simons
12:00 p.m.	Lunch	
1:00	**Session 2: Applied Research Programs Update: Remote Sensing Development** Bob Arnone, Lead	
	Chris Brown Dave Koler Remy Luerssen	Jennifer Patch-Cannizarro Rick Stumpf
3:00	Break	
3:15	**Session 3: Applied Research Programs Update: Model Development** Kevin Sellner, Lead	
	Tom Gross Rob Hetland	Ruth Preller Bob Weisberg
5:00	Adjourn	

WEDNESDAY, APRIL 14

8:30 a.m.	Review	Co-chairs
9:00	**Session 4: Applied Research Programs Update: *In situ* Monitoring** Gary Kirkpatrick, Lead	
	Norman Guinasso Cindy Heil	Hugh MacIntyre Cynthia Moncreiff
10:30	Break	
10:45	**Session 5: Data Management and Communications Requirements** Darlene Haverkamp, Lead	
	Steve Collins Mark Luther	Tim Orsi Larinda Tervelt
12:00 p.m.	Lunch	
1:00	**Concurrent Workgroups–** Development of Pilot Projects Formulate a plan for a pilot project that identifies user groups, specifies data and data products, and presents elements of an end-to-end system that provides the required data and data analysis to detect and predict changes in the physical environment and HABs.	
3:00	Break	
3:20	**Workgroup Presentations**	
5:00	Adjourn	

THURSDAY, APRIL 15

9:00 a.m.	**Session 6: HAB-GCOOS Integration** Tom Malone, Lead	
	Mary Culver Quay Dortch Bryon Griffith	Worth Nowlin Kevin Sellner Karen Steidinger
10:30	Break	
10:45	Agreement on Follow-up Actions, Commitments, and Schedule *Co-Chairs*	
12:00 p.m.	**Workshop Adjourned**	

Appendix B – Workshop Participants

Bob Arnone
Naval Research Laboratory
Ocean Color Section 7243
Naval Research Lab, Bldg. 1105
Stennis Space Center, MS 39529
(228) 688-5268
Bob.Arnone@nrlssc.navy.mil

Rosa Aurora Azamar
Regulacion y Fomento Sanitario
Servicios de Salud de Veracruz
Soconuso No. 31 Col. Aguacatal
Xalpa, Veracruz, MEXICO 91130

Christopher Brown
NOAA Cooperative Institute for
Climate Studies
2207 Computer and Space Sciences
Building
University of Maryland
College Park, MD 20742-2465
(301) 405-8031
Christopher.W.Brown@noaa.gov

Bruce Champion
Louisiana Dept. of Health and Hospitals
Molluscan Shellfish Program
6867 Bluebonnet Blvd., Box 16
Baton Rouge, LA 70810
(225) 763-3554
bchampion@dhh.state.la.us

Jorge Nicolas Chantiri Perez
Director de Regulacion y Fomento
Sanitario
Servicios de Salud de Veracruz
Soconuso No. 31 Col. Aguacatal
Xalpa, Veracruz, MEXICO 91130
jnchantiri@ssaver.gob.mx

Steve Collins
NOAA National Data Buoy Center
Bldg. 1100
Stennis Space Center, MS 39529
(228)688-2822
Steve.Collins@noaa.gov

Mary Culver*
NOAA Coastal Services Center
2234 S. Hobson Ave.
Charleston, SC 29405-2413
(943) 740-1250
Mary.Culver@noaa.gov

Carol Dorsey
Alabama Dept. of Public Health
757 Museum Drive
Mobile, AL 36608
(251) 344-6049
caroldorsey@adph.state.al.us

Quay Dortch*
NOAA Center for Sponsored Coastal
Ocean Research
N/SCI2 SSMC4 1305 East-West Hwy
Silver Spring, MD 20910-3281
(301) 713-3338 x137
Quay.Dortch@noaa.gov

Bryon Griffith**
EPA Gulf of Mexico Program Office
Stennis Space Center, MS 39529-6000
(228) 688-3726
Griffith.Bryon@epa.gov

Tom Gross
NOAA NOS Coast Survey
N/CS1, 1315 East-West Hwy.
Silver Spring, MD 20910-3282
(301) 713-2809 x139
Tom.Gross@noaa.gov

Norman Guinasso
Texas A&M University
3146 TAMU
College Station, TX 77843-3146
(979) 862-2323
guinasso@tamu.edu

Callie Hall
NASA Earth Science Applications
Directorate
Mail Code MA10
Stennis Space Center, MS 39529-6000
(979) 862-2323
Callie.Hall@ssc.nasa.gov

Darlene Haverkamp
Florida Wildlife Research Institute
100 Eighth Ave. SE
St. Petersburg, FL 33701-5095
(727) 896-8626
Darlene.Haverkamp@fwc.state.fl.us

Cindy Heil
Florida Wildlife Research Institute
100 Eighth Ave. SE
St. Petersburg, FL 33701-5095
(727) 896-8626
Cindy.Heil@fwc.state.fl.us

David Heil
Florida Dept. of Agriculture and
Consumer Services
1203 Governor's Square Blvd. 5th Floor
Tallahassee, FL 32399-3000
(850)488-5471
heild@doacs.state.fl.us

Rob Hetland
Texas A&M University
3146 TAMU
College Station, TX 77843-3146
(979) 458-0096
rhetland@ocean.tamu.edu

Juan Manual Irigoyen
Consejo de Desarrollo del Papaloapan
Palacio de Gobierno, I. Zaragoaz s/n
Xalpa, Veracruz, MEXICO 91000
codepap@codepap.gob.mx

Bela James
Shell Exploration and
Production Company
3333 Highway 6 South
Houston, TX 77082
(281) 544-6154
Bela.James@shell.com

Sharon Ketchen
Florida Dept. of Health
4052 Bald Cypress Way, Bin #C-22
Tallahassee, FL 32399-1742
(850) 245-4444
Sharon.Ketchen@doh.state.fl.us

Shana Kinsey
Florida Dept. of Environmental Protection
3900 Commonwealth Blvd. MS 47
Tallahassee, FL 32399-3000
Shana.Kinsey@dep.state.fl.us

Gary Kirkpatrick
Mote Marine Laboratory
1600 Ken Thompson Pkwy
Sarasota, FL 34236
(941) 388-4441 x389
gkirkpat@mote.org

Dave Kohler
Florida Environmental Research Institute
4807 Bayshore Blvd., Suite 101
Tampa, FL 33611
(813) 837-3374
dkohler@flenvironmental.org

Keith Laakkonen
Florida Dept. of Environmental Protection
3266 N. Sailboat Pt.
Crystal River, FL 34428
(352) 563-0450
Keith.Laakkonen@dep.state.fl.us

Remy Luerssen
USF College of Marine Science
140 7th Ave. S
St. Petersburg, FL 33701-5095
(727) 533-1186
luerssen@seas.marine.usf.edu

Mark Luther
USF College of Marine Science
140 7th Ave. S
St. Petersburg, FL 33701-5095
(727) 553-1528
mluther@marine.usf.edu

Hugh MacIntyre
Dauphin Island Sea Lab
101 Bienville Blvd.
Dauphin Island, AL 36528
(251) 861-7535
hmacintyre@cobalt.disl.org

Tom Malone*
Ocean.US
2300 Clarendon Blvd., Suite 1350
Arlington, VA 22201-3667
(703) 588-0849
t.malone@ocean.us

Alex Mansfield
Battelle
397 Washington St.
Duxbury, MA 02332
(781) 952-5329
mansfielda@battelle.org

Sharon Mesick
NOAA National Coastal Data
Development Center
Building 1100, Room 101
Stennis Space Center, MS 39529
(228) 688-2256
Sharon.Mesick@noaa.gov

Cynthia Moncreiff
Gulf Coast Research Laboratory
University of Southern Mississippi
P. O. Box 7000
Ocean Springs, MS 39566-7000
(228) 872-4260
Cynthia.Moncreiff@usm.edu

Worth Nowlin*
Texas A&M University
3146 TAMU
College Station, TX 77843-3146
(979) 845-3900
wnowlin@tamu.edu

Tim Orsi
NOAA National Coastal Data
Development Center
Building 1100, Room 101
Stennis Space Center, MS 39529
(228) 688-3908
Tim.Orsi@noaa.gov

Jennifer Patch-Cannizarro
USF College of Marine Science
140 7th Ave. S
St. Petersburg, FL 33701
(727) 553-3954
jpatch@monty.marine.usf.edu

Ruth Preller
Naval Research Laboratory
Ocean Dynamics and Prediction Code 7320
Building 1100, Room 101
Stennis Space Center, MS 39529-5004
preller@nrlssc.navy.mil

Andy Reich
Florida Dept. of Health
4052 Bald Cypress Way, Bin #C-22
Tallahassee, FL 32399-1742
(850) 245-4444
Andy.Reich@doh.state.fl.us

Kevin Sellner**
Chesapeake Research Consortium
645 Contees Wharf Rd
Edgewater, MD 21037
(410) 798-1283
sellnerk@si.edu

Jim Simons
Texas Parks and Wildlife, Coastal Studies Program
NRC Bldg, Suite 2501
6300 Ocean Dr.
Corpus Christi, TX 78412
(361) 825-3241
James.Simons@tpwd.state.tx.us

Karen Steidinger*
Florida Institute of Oceanography
100 Eighth Ave. SE
St. Petersburg, FL 33701-5095
(727) 896-8626
Karen.Steidinger@fwc.state.fl.us

Rick Stumpf
NOAA National Centers for Coastal Ocean Science
SSMC4 Room 9109, 1305 East-West Hwy.
Silver Spring, MD 20910-3282
(301) 713-3028 x-173
Richard.Stumpf@noaa.gov

Bill Teague
Naval Research Lab
Code 7332
Stennis Space Center, MS 39529-5004
(228) 688-4734
teague@nrlssc.navy.mil

Larinda Tervelt
EPA Gulf of Mexico Program Office
Stennis Space Center, MS 39529-6000
(228) 688-1033
Tervelt.Larinda@epa.gov

Mark Vincent
NOAA Center for Operational Oceanographic Products and Services
SSMC4 Room 7307, 1305 East-West Hwy.
Silver Spring, MD 20910-3282
(301) 713-2890 x151
Mark.Vincent@noaa.gov

Bob Weisberg
USF College of Marine Science
140 7th Ave. S
St. Petersburg, FL 33701
(727) 553-1568
rweisberg@marine.usf.edu

Dana Woodruff
Pacific Northwest National Laboratory
1529 West Sequim Bay Rd.
Sequim, WA 98382
(360) 683-4151 x-13608
Dana.Woodruff@pnl.gov

**Workshop Co-chair
*Steering Committee member

Appendix C – Summary of Raw Data Collections for HABSOS Case Study

1996	Florida	Alabama		Mississippi	Louisiana	Texas	
	FMRI	ADPH	DISL	USM	LUMCON	TPWD	UTMSI
Data Types							
DO	X						X
Salinity	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X
Chlorophyll							X
Cell counts	X	X	X	X	X	X	X
Data Formats							
Excel			X	X	X	X	X
Access	X	X					
Metadata	X	X					

1997	Florida	Alabama		Mississippi	Louisiana	Texas	
	FMRI	ADPH	DISL	USM	LUMCON	TPWD	UTMSI
Data Types							
DO	X						
Salinity	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X
Chlorophyll							
Cell counts	X	X	X		X	X	X
Data Formats							
Excel			X	X	X	X	X
Access	X	X					
Metadata	X	X					

2000	Florida	Alabama		Mississippi	Louisiana	Texas	
	FMRI	ADPH	DISL	USM	LUMCON	TPWD	UTMSI
Data Types							
DO	X						
Salinity	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X
Chlorophyll							
Cell counts	X	X	X		X	X	X
Data Formats							
Excel			X	X	X	X	X
Access	X	X					
Metadata	X	X					

Appendix D – GCOOS Priorities

TEXAS A&M UNIVERSITY
DEPARTMENT OF OCEANOGRAPHY
3146 TAMU
COLLEGE STATION, TEXAS 77843-3146

WORTH D. NOWLIN, JR.
DISTINGUISHED PROFESSOR

wnowlin@tamu.edu

TELEPHONE: (979) 845-3900
FAX: (979) 847-8879

May 17, 2004

TO: Dr. Thomas Malone, Director, Ocean.US Office

FROM: W. D. Nowlin, Jr., on behalf of GCOOS developers

SUBJECT: GCOOS observing system priorities and GCOOS administrative cost estimated for FY 2005 and FY2006

As requested by your office, this memorandum provides our cost estimates for establishing and supporting a GCOOS Regional Association, for the Gulf of Mexico, and initial priorities for both enhancements to the national backbone in the Gulf of Mexico and for enhancements and additions to regional observing system elements of GCOOS.

The assembly of this information has been a difficult but interesting task. I must caution that providing priorities before a Regional Association is in place means that these priorities are indeed tentative. Nevertheless, they are based on results of three previous workshops in our region, inputs solicited over the past month, and a meeting last week of key organizers to sort out the inputs. Therefore, I believe that they provide a reasonable starting place.

As a zero-order priority for the national backbone is the continuation and expansion of a healthy satellite remote-sensing program. We have not included this in our list of Gulf priorities because it clearly is a very high priority for the entire Global Ocean Observing System.

The projected costs for developing and administering the GCOOS Regional Association in FY2005 and FY2006 represent refinements to the budget initially proposed to the Coastal Services Center of NOAA. We anticipate holding a full Gulf organizational meeting about September 2004, and that, based on advance preparations, we can at that time adopt interim governance and fiscal structures for our Regional Association. It may require an additional 18 months to decide on a final governance state.

Our proposed administrative cost budget for the next two fiscal years include some funding to begin activities in the areas of education and outreach. We propose to establish a Sea Grant GCOOS Stakeholder Outreach Advisory Council for GCOOS. Also, we have been asked by the Gulf HABSOS program to provide outreach assistance to train individuals in Gulf States (both U.S. and Mexican) in measuring and reporting HABs. We are considering the establishment of an educational council for our region, but will await development at the national level. It is important to note that the amount received from NOAA CSC for a three-year organizing effort ($106K of which we still have $103K) is much too small to do the job given the level of complexity now required in developing and administering Regional Associations.

Activity	FY05	FY06	Notes
GCOOS RA Coordinator	$75K	$155K	Half time FY05; full time thereafter
IT assistance	$25K	$25K	1/3 time each year
Data Mgmt. Coordinator	$22K	$44K	1/4 time in FY05; 1/2 time in FY06
Travel for RA Coordinator and Data Management Coordinator	$7K	$10K	
Meetings to organize the GCOOS RA and for governance bodies	$26K	$30K	
Workshops to identify and develop user base and requirements	$35K	$35K	
Other outreach activities, including expanding relations with Mexico	$20K	$40K	
Totals	$210K	$339K	

Our top priorities for both enhancements and expansions to IOOS in the Gulf of Mexico are given below. All activities are important, but in accordance with instructions from the Ocean.US Office, the first five in each list should be considered out highest priorities.

GCOOS Priorities for Enhancements to the National Backbone in the Gulf of Mexico

1. Efforts to improve DMAC compliance in the Gulf region
   - NDBC is working with several Regional Observing Systems and providing a QA/QC and real-time data distribution service using a product called the "MODEM Kit". In the Gulf of Mexico NDBC is working with TABS, COMPS, TCOON, and LUMCON. We will expand this activity to include other data providers so as to achieve complete integration of real-time measurements in the region.
   - NDBC also places these data sets on a DODS server once a month. They will expand this to real-time on an OPENDAP server, using a Live Access Server as a user interface to keep current with the DMAC guidance.
   - Transition the NDBC Real-Time OPENDAP server to operational status

2. Enhancement of NDBC buoy and C-MAN networks
   - Add wave directionality to wave height—useful for rip current forecasting and sediment transport estimation
   - Add visibility measurements—needed off Mississippi River and other areas for biological productivity estimation and for river-ocean connection
   - Add ADCPs—constraints for models and for HF radar network
   - Add ecosystem measurements, as feasible
   - Add water level measurements
   - Increase the number of stations in these networks by a factor of five, including additional meteorological stations in the near coastal zone for use in forecasting surface currents for HABSOS as well as improved regional models
   - Develop a deep-ocean, advanced capability sentinel station. Envisioned is a station with a measurement suite capable of characterizing the environment form the sea floor to the troposphere (-3000 m to +3000 m). It would serve both as a sentinel station in the U.S. EEZ but also as a test bed for advanced technology.

3. Improve and enhance monitoring of inputs to the coastal ocean from the continent
   - Monitoring in additional streams
   - Monitoring to include nutrients and other ecosystem indicators, as well as flow rates—uses include monitoring coastal eutrophication

4. Establish long-range HF radar monitoring of surface currents
   This should be as a part of the national surface current monitoring initiative being planned by Ocean.US.

5. Integration and assessment of numerical circulation models for the region.
   One or more numerical circulation models for the Gulf of Mexico should be added to the national backbone. The benefits of having both high density model data (compared to measured data density) and the capability to forecast currents, will greatly increase the usefulness of GCOOS.
   - Create a portal to outputs from all accessible full Gulf models
   - Ensemble and assess the skill of these models
   - Provide boundary conditions for smaller-scale coastal and estuarine models

6. Integrate water level network for Gulf of Mexico
   - Adjust all water level measurements to a common datum
   - Analyze all extant water level records for regional trends and assess new requirements
   - Expand NWLON (NOS National Water Level Network) as needed based on foregoing activities

Priorities for New or Enhanced Regional Observing System Elements of GCOOS

These priorities are predicated on the assumption that the priority enhancements to the national backbone will be forthcoming. A high priority is provision of funds for regional education and outreach, which will be budgeted as a part of the administrative costs of the GCOOS Regional Association. High priority outreach areas are the identification of system users and capacity building between Gulf states (U.S. and Mexican) for HABs measurements.

1. Enhance and expand the real-time networks of COMPS, LUMCON, TABS, TCOON, WAVCIS, and other extant observing system elements. [COMPS costs will be budgeted via SERA-COOS.] This will include:
   - Expand LUMCON observing system by one offshore station per year beginning in 2007
   - Strengthen TCOON platforms against hurricanes
   - Upgrade TCOON with improved data communication capability to reduce data delay.
   - New sensors on COMPS, TABS, LUMCON, and other elements serving data in real-time via MODEM Kit to OPENDAP server.
   - Expand COMPS buoy and HF radar sites, expand types of measurements, and provide adequate spares.
   - Enhancement and expansion of TABS to improve near shore coverage in southwest region and include meteorological packages on all platforms.
   - Expand buoy measurements of surface currents and other parameters to cover the region off Louisiana, Mississippi and Alabama.

2. Technology development for ecological monitoring, particularly for use in HABSOS, and hypoxia study.
   Moored sites will be used to test and evaluate new technology, and proven instrumentation will be added. This will be carried out at sites of TABS, COMPS (budgeted as part of SERA-COOS) and perhaps other elements.

3. Project to develop and improve products and services
   This must be joint public-private venture from the beginning. Some new products may be envisioned as being produced and sold by the private sector. Other new products may be envisioned to be produced for the common good, and those might be handed off to NOAA's Coastal Services Center for routine production and distribution.

4. Ground support for non-real-time activities, including:
   - Evaluation of developing technology
   - Calibration/validation of satellite remotely sensed measures
   - Transects for HABs monitoring

5. Expansion of surface current measurement near coasts and in estuaries using short-range HF radar systems.

6. Pilot project demonstrating the use of fiber optic cable for data retrieval and instrument control in the IOOS.

7. Pilot project to retrieve deep current data being collected by oil industry and MMS and to begin selected use of these data
   - Systematic monitoring of deep currents
   - Model improvements

8. Monitoring of effects of Mississippi River on the region.
   This is of very high priority, but design will require time and effort. Sought is the ability to trac outflow, spreading and effects of river water and constituents. This likely will include:
   - Major densification of present levels of measurements, both spatially and in type
   - A concerted modeling effort
   - Coordinated data integration
   - Development of products and reporting

Action Plan for Harmful Algal Blooms and the Gulf of Mexico Coastal Ocean Observing System:

Results from a Regional Workshop

For additional copies or information, please contact
NOAA Coastal Services Center
2234 S. Hobson Ave.
Charleston, SC 29405-2413
Telephone: (843) 740-1200
Fax: (843) 740-1224

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