Coastal Ocean Processes and Observatories: Advancing Coastal Research

Report on the CoOP Observatory Science Workshop
May 7-9, 2002
Savannah, Georgia US

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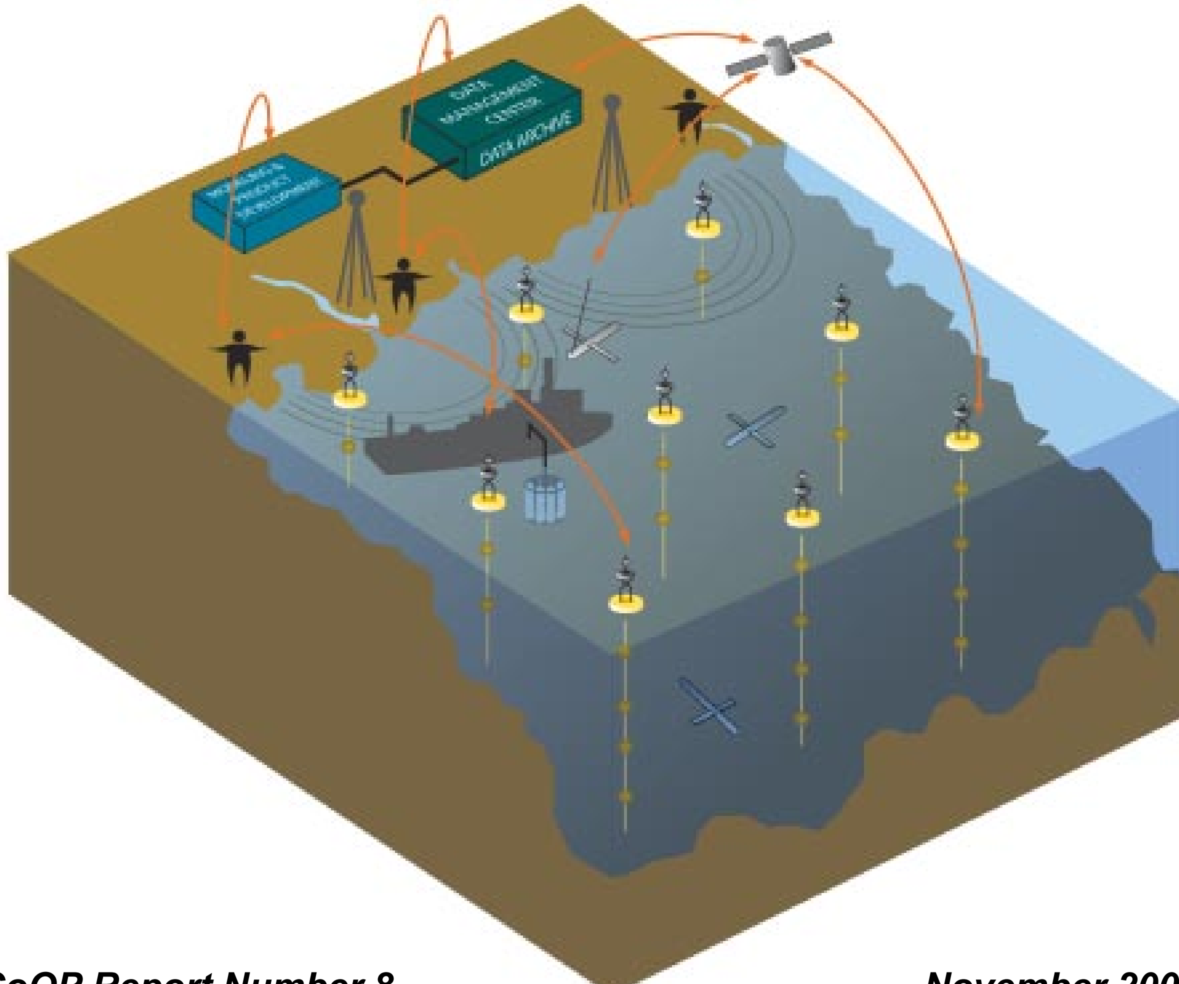

CoOP Report Number 8 ***November 2002***

SkIO TR-02-01

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Coastal Ocean Processes (CoOP) Report Number 8

November 2002

Technical Report

Funding was provided by the National Science Foundation under Grant No. OCE-0000039 and by the Office of Naval Research under Grant No. N00014-00-1-0129.

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Executive Summary

Currently, there is much activity in the Federal government related to the establishment of a network of ocean observing systems that will suit both research and operational needs. On the research side, NSF has developed the Ocean Observatories Initiative (OOI), which will utilize cabled and moored buoy technologies to investigate both the open ocean and coastal zone. The coastal component of the OOI will interact with that of the Integrated Ocean Observing System (IOOS) whose mission is to serve operational oceanographic needs. The system is envisioned as a federation of regional observing systems nested in a federally-supported national infrastructure with a backbone of core measurements and shared communications and data management. In addition to the common backbone, the regional observing systems would be augmented in part through NSF's OOI to focus on measurements and processes of special interest to each region.

Previous workshops have described the substantial new benefits an observing system will provide to society. In many instances, attaining the benefits for society will require major improvements in our fundamental understanding of coastal processes and phenomena which, in many cases, may only be achieved through observatory-based measurements.

To provide focus and direction for the development of observatory research science, a workshop was held (Savannah GA, 7 - 9 May 2002) to articulate the advancements in coastal research that could be achieved through the use of coastal observing systems. Specifically, participants were asked to: 1) identify research topics that can best be studied through coastal observatories and observing systems; 2) identify current capabilities that are critical to those research topics; and 3) identify observatory development areas that would provide the greatest benefit to future coastal research.

Coastal observatories represent an exceptional enabling technology that will greatly advance future research efforts by expanding the space and time scales over which coastal processes are observed. The four-dimensional complexity of ocean systems must be challenged. Observatories will provide fundamental new opportunities for research and development and, as such, represent a unique resource for augmenting coastal research. Observatories will permit researchers to resolve the mean and variance of annual and seasonal signals, as well as individual events. Examples of research areas that will significantly benefit from the development of observatories include the study of the variability in the large scale circulation fields, material mass balances such as nutrient and carbon budgets, ecosystem studies, and shoreline morphology and beach erosion.

Of particular importance is the study of episodic and extreme events. Coastal observatory technologies can potentially provide the high resolution, long time-series measurements necessary to capture rare but important events and the in situ information to direct targeted and remotely controlled sampling campaigns to examine specific phenomena. While at present direct sensor measurements are dominated by physical parameters, numerous research opportunities have been identified for coastal biological and chemical systems by providing the physical context, by deployment of emerging biological and chemical sensors and by directing targeted sampling programs.

Coastal observatories must be configured to maximize the space and time scales over which observations can be made. It is envisioned that coastal observatories will be comprised of three basic observing components. A widely-spaced distributed set of operational backbone moorings will span and link all regions. Within each region, additional operational observatories will be positioned to maximize observations of specific features and processes most important to the region.

Finally, relocatable research arrays (Pioneer Arrays) are proposed that would serve to provide detailed information about targeted processes and for the development of new observatory technologies. Each Pioneer Array would be comprised of 30-40 sensor moorings positioned at a range of scales and supplemented by mobile (eg., ship-, glider- and AUV-deployed) and remote (eg., HF radar- and hyperspectral satellite-) sensors. By expanding our intellectual understanding and technical capabilities, Pioneer Arrays will fuel the advancement of the operational system. These arrays would be dedicated to a particular study and deployed for appropriate periods (3-5 years) after which they would be recovered and reassigned.

I. Introduction

For more than a century, oceanographers have operated largely in exploratory mapping and sampling modes using ships as primary observational platforms. More recently, satellite observing systems have provided a quasi-synoptic, global view of surface ocean characteristics, and extended moorings have been deployed in key places to yield more localized measurements. These measurements have led to a growing recognition of the wide range of space and time scales over which the fundamental processes that control the characteristics and dynamics of ocean systems occur. These observations have also resulted in a growing belief that traditional ship-based and data-recording mooring-based observations are, by themselves, inadequate for the challenge of studying the myriad of ocean processes that are now recognized as critical to the understanding of the marine environment.

The ocean sciences are currently poised to exploit revolutionary new technology now available or in development. These technologies will greatly expand the range of scales over which ocean phenomena can be observed and will allow us to identify and study processes previously not recognized. In addition, the envisioned systems offer the opportunity of in situ, real-time, interactive observations that cross conventional disciplinary boundaries and provide useful information to many marine-related user groups. Processes whose interrelationships need improved understanding include (but are not limited to) weather systems, ocean currents, air-sea exchange, primary and secondary production, ocean mixing, carbon sequestration, tectonic and earthquake cycles, seafloor volcanism, chemosynthetic systems, and marine mammal migration. In each case, the relevant ocean processes occur over a range of scales and are often episodic, interlinked, and driven by dynamic forces which are, in many cases, poorly understood. Further insight requires the proactive approach of maintaining a continuous presence within the ocean so that events can be observed when and where they occur. This will allow scientists to move beyond our current reactive approach of responding to changes in the oceans.

II. Purpose of Workshop

Previous workshops devoted to the topic of ocean observatories and observing systems have described coastal observing system capabilities which would be required by end users within such areas as public health and safety, fisheries and other marine resources, transportation, and national security but have not to date addressed the justifications for basic scientific research per se. **However, in many cases, observatory system-based products that would be useful to applied end-user groups require advancements in our level of understanding of coastal phenomena.** The development of such ocean observing systems also gives research oceanographers a new suite of tools with which to better understand coastal ocean processes.

The purpose of this Coastal Observatory Science workshop, therefore, was to determine what critical research questions could best be answered using coastal observing systems and to identify the current and emerging technologies that would be most useful and would jump-start the development of a coastal observing system (COS). COS refers to observing assets in the coastal zone whether they are part of OOI or IOOS.

The workshop organizing committee (OC) consisted of the Chair and four members of the CoOP Scientific Steering Committee, a representative for Ocean.US, and four additional scientists selected for disciplinary expertise and regional representation. Participation in the workshop was solicited by advertisements placed in EOS and on Oceansp@ce, Ocean.US and other electronic bulletin boards. In addition, the OC invited 35 participants directly in order to ensure disciplinary representation and to provide a mix of scientists conversant with observatory research and scientists with no observatory experience. The OC invited no more than four scientists from any institution to balance regional representation. An additional approximately 30 scientists submitted applications to attend the workshop. Attendees are listed in Appendix A. In advance of the meeting, all participants were asked to submit a list ofthree processes or science questions that they believed could be best addressed using observatories. The compiled list (Appendix B) was provided to the participants as a starting point for discussions.

The workshop was held in Savannah GA (Agenda included as Appendix C) and was hosted by the Coastal Ocean Processes (CoOP) Program of the National Science Foundation. Sixty-four people participated from 20 states and Washington DC, as well as from Canada and Great Britain. A total of 35 universities, government agencies and other institutions were represented. Invited participants who had field-program timing conflicts and were unable to attend the workshop but contributed significantly to the content are so indicated in Appendix A.

III. Workshop Structure and Narrative

The concept of ocean observatories can be envisioned in different ways, depending on goals. We are dealing with several systems (acronyms are defined in Appendix D):

Existing national systems (NDBC, NWLON, CMAN, NWS)

Existing research observatories (such as LEO, SABSOON, COMPS, CBOS, GoMOOS, CalCOOS, Caro-COOPS, FRONT, MVCO, MOOS)

Development of cabled and moored observatories currently being considered within NSF's OOI MREFC

Proposed Integrated Ocean Observing System (IOOS) consisting of a national backbone linking a federation of regional systems

The workshop participants were therefore asked to envision science questions that could be addressed using observatory systems, many of which do not yet exist and to a large extent are not yet well described. While the lack of a firm system description caused some inconsistencies, consensus on a wide range of topics was achieved.

The workshop began with plenary presentations on the NSF MREFC (A. Isern), IOOS (L. Atkinson) and existing observing systems (O. Schofield, East Coast US and F. Chavez, West Coast US), as well as an overview of the potential role of the CoOP Program in observatory science (R. Jahnke). During the workshop additional plenary presentations were presented by John Howarth on the Proudman Oceanographic Laboratory's planned observatory (Appendix F) and by Charles Ericksen on glider technology (Appendix G).

Participants were given a working charge in plenary and met in four working groups to develop consensus statements about each charge. The working groups were established semi-randomly across disciplines and all four groups addressed the same set of questions. Each working group included two organizing committee members. Two working group members were assigned as co-chairs to facilitate each day's discussions and are indicated in the working group reports as CC1 for day 1 and CC2 for day 2.

The first day's working groups were asked to develop critical research questions. There was an initial challenge to think of research questions that require an integrated ocean observing system, which to a large extent does not now exist. At day's end, the products of the working groups were reviewed. Based on the results, the groups were asked to continue their discussions of the science questions. For each question, the groups were asked to:

Provide specific examples:

Describe the components and characteristics of a coastal observing system that would provide the information required to address the question.

Indicate:

Which components already exist?

Which components must be developed?

Which will be ready soon?

Which will take a few years?

Which will take a decade?

The second morning in opening plenary this plan was discussed and was followed by a very productive plenary discussion. We asked for examples of critical research questions and the complementary observing systems required to answer these questions. Examples given included the eastern Pacific anchovy regime (Chavez), the west Florida shelf harmful algal blooms (Schofield), air-sea interactions at high wind velocities (Edson), and offshore boundary current - shelf current interactions (Jahnke). A more complete discussion of these examples is given in Section IV. Following these discussions, the working groups returned to their deliberations. At the end of the final morning of the workshop, participants met in plenary. The working groups presented their reports (summarized in Sections IV and V) and established a set of consensus statements from their deliberations. For convenience, the consensus statements have been grouped into four general topic areas (Section VI), although it must be recognized that most statements are cross-disciplinary and fit into more than one such artificially-established category.

IV. Critical Research Questions

Ocean observatories represent a fundamentally new enabling technology that will permit future research efforts to examine processes on space and time scales that were not previously achievable. This includes sustained measurements at multiple locations to develop synoptic time-series observations of large-scale phenomena and sustained high frequency measurements to examine short-duration and rare events. Real-time data reporting also greatly expands research opportunities by supporting remotely-controlled and targeted sampling efforts. The technological capabilities afforded by coastal observatories such as high-bandwidth, two-way communication and substantial power for measurement systems will provide unprecedented access to the sea and enhance scientific inquiry by providing continuous, long-term measurements of oceanographic and atmospheric properties. The development of critical technologies in communications, power, robotics, and ocean engineering will facilitate infrastructural changes that will gradually rival and in some instances displace ships as the main observational platforms for studying ocean processes. Additionally, the data management framework, which is envisioned to unite a national observatory backbone (Fig.1), will greatly facilitate and expand coastal research efforts.

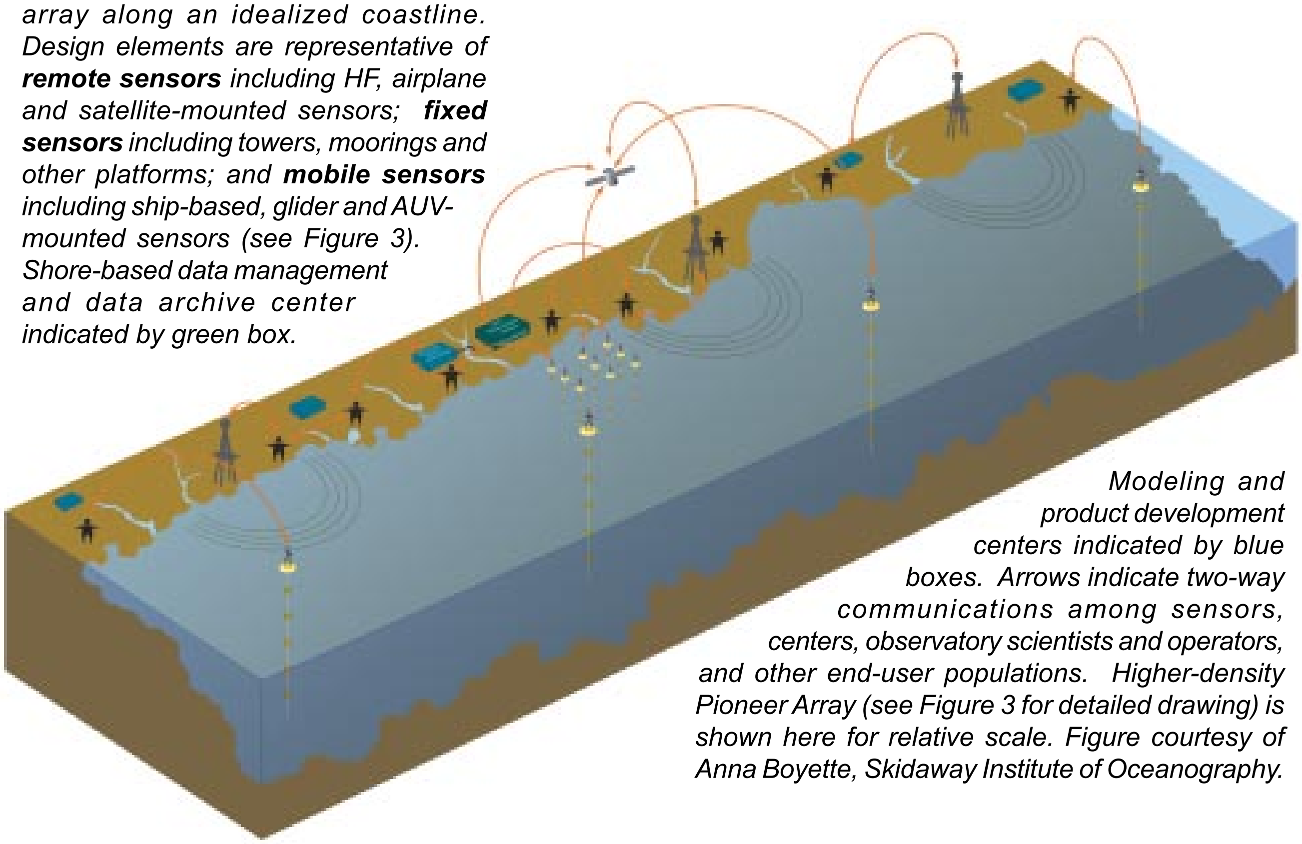

*Figure 1. Artist's rendition of a backbone array along an idealized coastline. Design elements are representative of **remote sensors** including HF, airplane and satellite-mounted sensors; **fixed sensors** including towers, moorings and other platforms; and **mobile sensors** including ship-based, glider and AUV-mounted sensors (see Figure 3). Shore-based data management and data archive center indicated by green box. Modeling and product development centers indicated by blue boxes. Arrows indicate two-way communications among sensors, centers, observatory scientists and operators, and other end-user populations. Higher-density Pioneer Array (see Figure 3 for detailed drawing) is shown here for relative scale. Figure courtesy of Anna Boyette, Skidaway Institute of Oceanography.*

While not all marine research activities will directly benefit from a coastal observatory, the above-listed attributes will uniquely advance the study of a wide variety of marine phenomena. Critical research questions that can best be addressed by observatories were identified by each working group. The original reports of each group are provided in the appendices. Below are examples of research topics that demonstrate the potential contribution of a coastal observatory. Questions have been sorted into three broad categories. Since the research questions are cross-disciplinary, placement in these categories is almost arbitrary in many instances and is primarily for presentation purposes. However, the recurring themes across working groups demonstrate community consensus on unique opportunities afforded by observatories that are necessary to advance specific areas of science. These themes are the need to focus on the spatial and temporal scales over which coastal processes occur; the episodic and/or extreme nature of specific processes; and the effects of these processes on ecosystem structure and function.

A. Expanded Time and Space Scales of Observation

Coastal oceanographic processes are inherently complex and multidisciplinary. It is consequently inaccurate to define time and space scales of any disciplinary research in the absence of the interaction of other controlling factors. For clarity and organization more than for accuracy, the following section is divided into disciplinary fields where one field dominates. Biological processes are the most difficult to consider to the exclusion of the other disciplines, and where appropriate, those sections are presented as a discussion of coupled processes.

1. Marine meteorology: Marine meteorological studies will greatly benefit from an integrated ocean-atmosphere coastal observing system that combines measurements across the air-sea interface. This is particularly true in coastal ocean regions where the weather is strongly influenced by, e.g., coastal upwelling and fog formation, orographic effects set up by coastal topography, and modification of air-sea exchange due to the influence of limited fetch, bottom friction, and bottom topography on both the wave and current fields. Process studies that investigate these effects would benefit from coincident high quality measurements in both the ocean and atmosphere. This will improve our parameterizations of air-sea exchange that will be required for coupled atmosphere-ocean models to provide forecasts of marine weather, ocean currents, and waves. In addition, the sustained observations of atmosphere-ocean interaction made possible with a coastal ocean observatory are crucial for climate studies and to improve climate models.

Large-scale regime shifts in marine communities and trophic structure co-occurring with large-scale changes in climate have been well documented in coastal ecosystems. However, the underlying mechanisms are poorly understood. It is now believed that ecosystems may shift between different states as a result of environmental forcing. Numerous other large scale fluctuations in forcing characteristics as indicated by variations in Pacific Decadal Index, North Atlantic Oscillation Index or El Niño/La Niña conditions are also widely reported. Often changes in large scale indices are accompanied by alterations in local processes such as rainfall/runoff. Continuous, synoptic measurements in the coastal zone will quantify how these signals and factors propagate through the coastal ocean and the temporal scales upon which the coastal ecosystem responds to these factors.

The large-scale, synoptic assessment of coastal meteorological conditions provided by a coastal observatory system will advance our understanding of the relationships among large-scale forcing, local forcing and ecosystem structure and productivity, how these forcing processes may change temporally, and how and to what extent ecosystem structure may respond to these changes. Examples of research questions that could be addressed include: How do changes in freshwater discharge along the coast of Alaska affect zooplankton and salmon populations? How are zooplankton and fish populations in oceanographic transition zones, such as the Gulf of Maine, influenced by basin-scale forcing associated with the North Atlantic Oscillation? What is the nature of non-linear processes that result in regime shifts and are there top-down as well as bottom-up components? Do density-dependent feedbacks influence persistence and stability of marine populations?

2. Geology/geochemistry/biogeochemistry: Understanding the mass fluxes of particulate material in the coastal ocean is key to a number of applied and basic research questions ranging from the movement of sand resources and the fate of anthropogenic materials, to the dispersal of important biogeochemical constituents and the geological significance of sediment transport and accumulation. The dispersal of particulate material in the coastal ocean is often episodic, reflecting the importance of wind/storm events and periodic flooding of the adjacent landscape. Furthermore, much of the material transport occurs within the near-bottom boundary layer (a meter or so above the seabed), rendering traditional satellite or upper water column measurements ineffectual. Therefore, long-term synoptic measurements of boundary-layer and seabed parameters are necessary to understand the conditions under which such transport occurs, and to quantify the magnitude of near-bed material fluxes.

Instrumentation developed for benthic boundary-layer measurements, and routinely deployed from bottom tripods, is presently limited by battery power and data logging capacity and thus will immediately benefit from inclusion on observatory platforms. Acoustic transducers designed for bottom boundary-layer studies are particularly resilient to long-term calibration drift in the presence of biofouling. New, commercially-available acoustic profiling and scanning technology allows resolution of suspended particle concentration, measurement of mean and turbulent velocity on multiple scales, and imaging of time-dependent deposition, erosion and bed roughness. Although such measurements are critical to better understanding of resuspension, sediment transport and strata formation, they also quantify key properties of macrobenthos and plankton.

Microbial, microplankton, and zooplankton rate processes must be integrated into biogeochemical studies. Ship-based experiments will continue to be necessary to measure many biological rates. Recent advances in modeling provide novel approaches to incorporating experimental and observatory level data in order to understand biogeochemical cycles as a function of food web interactions. Specific ancillary research questions include: Is the coastal ocean a net source or sink for atmospheric carbon? Are there anthropogenic impacts (human pathogens, eutrophication, climate change, hypoxia/anoxia and land use) on coastal biogeochemical cycles? What is the role of the benthic boundary layer on coastal ocean biogeochemistry? How do sub-mesoscale (fronts, internal waves, eddies) physical processes determine the fate and transport of natural and anthropogenic substances? To what extent does food web structure and dynamics control elemental fluxes versus other physical/chemical processes?

Other promising technologies for documenting both geological and biological processes include laser particle sizing and velocimetry, fiberoptic backscattering and digital video imaging. Observations of surface wave fields using radar and video can be used to monitor movement of sand resources in the nearshore by tracking the distribution of sandbars. Specific questions include: What processes control the spatial and temporal distribution of sand resources in the coastal ocean? What is the frequency, direction and magnitude of episodic transport of biogeochemically important materials? How do the various transport processes affect the burial and off-shelf transport of carbon, contaminants and sediment?

3. Physical processes: In general, long-term, synoptic, large-scale measurements of critical physical parameters such as T, S, sea level and velocity are not available in the coastal zone. While there are a few selected studies which may incorporate large-scale, synoptic measurements of individual components, such as the analysis of sea level measurements along the West Coast, or time-series measurements at a single location (e.g., sea surface temperature record at the Scripps pier), an integrated set of observations does not exist. Such observations would significantly advance our understanding of how signals and phenomena are transmitted throughout the coastal ocean and which factors control the temporal and spatial variability of coastal circulation. Examples of specific large-scale research questions that could be addressed include: How would changes in annual and decadal time scales in the freshwater flux from the Arctic influence the Mid-Atlantic Bight? How does ENSO propagate through the California Current system? How does the inter-annual variability in the Mississippi River discharge and the inter-annual variability in the Loop Current influence the circulation in the Gulf of Mexico?

Observatory system observations also open new research opportunities on shorter temporal scales. For example, variability within western boundary currents, such as the Gulf Stream, is exhibited on many time scales, with nearly equal variance at weekly and monthly time scales as occurs at seasonal and interannual time scales. Approximately 90% of the nutrient input to the South Atlantic Bight continental shelf region is from upwelling associated with eddies along the Gulf Stream thermal front. Additionally, zooplankton assemblages that develop in shelf waters depend on the seed populations of both phytoplankton and zooplankton delivered in Gulf Stream-derived waters. Furthermore, the extent and pathways of boundary current - shelf water exchange depend critically on wind-controlled shelf currents and stratification from the input of low salinity near-shore waters. Assessing the variability of boundary current - coastal water interactions is critical to furthering our understanding of the ecology and biogeochemistry of the SAB coastal system and will require high resolution, large-scale measurements of boundary and shelf currents and atmospheric forcing. Real-time observations can be used to direct biological and chemical sampling.

4. Biological/physical coupling: Biological signals are often enhanced in coastal regions in the vicinity of physical discontinuities, such as fronts and eddies. Over broader regions, physical forcing by wind leads to coastal upwelling in some regions, enriching ecosystems and sustaining important fisheries. Recurring elevated abundances of phytoplankton, zooplankton, and/or fishes over that of mean background have been observed in these 'hot spots' (Fig. 2). Associated rate processes also may be elevated inferring that many of these areas are not only sites of aggregation. These 'hot spots' occur over a variety of spatial and temporal scales in coastal and estuarine systems, and may be associated with episodic physical features. Recent advances in technology have allowed researchers to detect thin layers (10's of

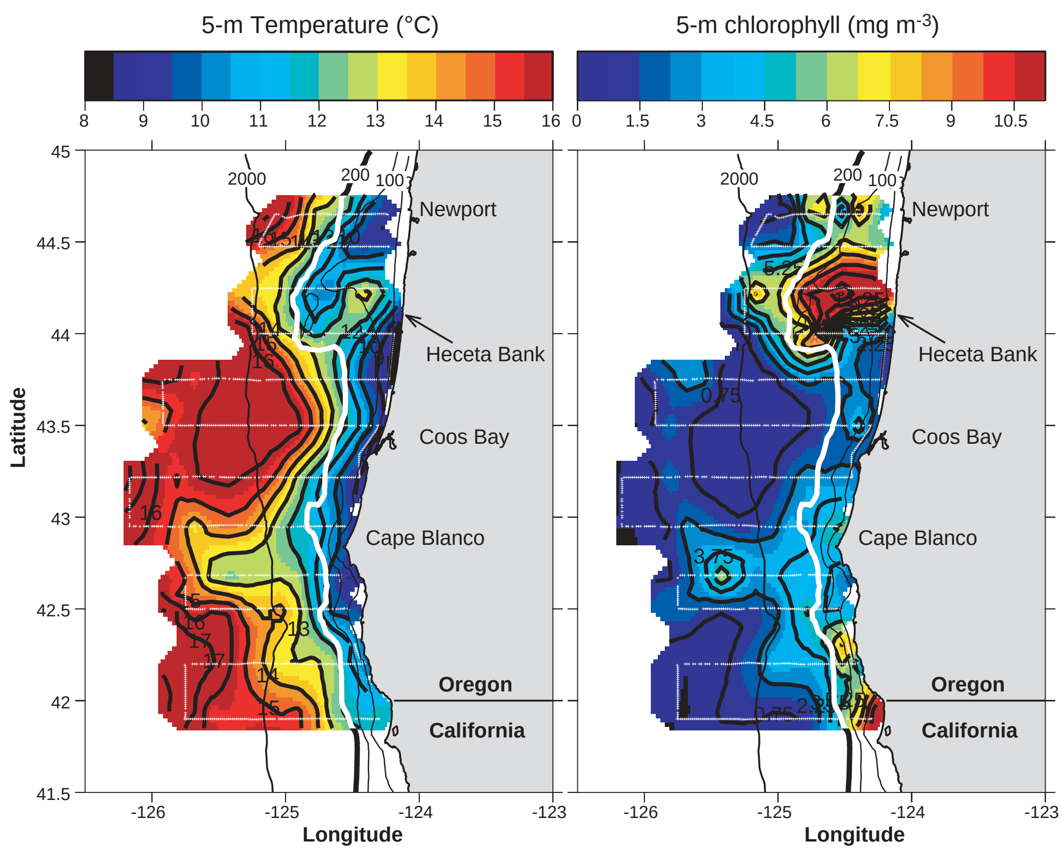

Figure 2. Near-surface temperature (^{o}C) and chlorophyll ($mg\ m^{-3}$) during coastal upwelling off central Oregon and northern California. Data are from 30 July to 4 August 2000, taken along 12 E-W lines; bottom contours in meters with the thick 200-m isobath indicating the continental shelf break. Note the strong correspondence between mesoscale physical and biological structure, and the high productivity associated with Heceta Bank. Courtesy of John Barth (Oregon State University).

cm to a few m in thickness) of plankton extending for more than several km and persisting for more than 24 h. The ecological consequences of these hot spots and thin layers remain poorly understood.

In addition, coastal physical transport processes influence the distribution and settlement of invertebrate and fish larvae, including many commercially important species. Many larvae develop offshore and then must migrate back to the shore to continue their development. Nearshore topographically generated circulation affects the cross-shelf dispersal of larvae, whereby changing flow patterns may prevent or aid this shoreward migration. Coastal eutrophication and changes in freshwater flux may influence these patterns. Specific research questions include: How do key ocean habitats, such as fronts and eddies, enhance biological productivity as 'hot spots'? Do sites of estuarine turbidity maxima promote fish recruitment? Do changing patterns in freshwater input into bays and estuaries disrupt the migration of invertebrate and fish larvae?

The development of long-term, synoptic measurements and visualization of the temporal evolution of the physical environment is critical to future coastal ecological and biogeochemical studies. The abundance and distribution of zooplankton, fish, marine mammals, and other higher trophic level organisms such as sea turtles are poorly known, as are the physical and biological factors controlling those distributions. Strategically placed moorings/and or AUVs having acoustic and imaging sensors could detect short-term and seasonal patterns of zooplankton and fish distribution. Ship-based sampling will be necessary to validate the acoustic targets at appropriate intervals. Whale migration patterns may be followed using passive acoustic sonabuoys, while tagged turtles, manatees, or sharks could be detected using acoustic devices. Movement near or within marine sanctuaries would provide critically needed information to manage protected and endangered species and commercial fisheries.

Within this framework, an observatory would allow researchers to focus on a single species to understand all underlying processes, from molecular to environmental and population affects, that influence population dynamics over a wide range of spatial and temporal scales. The motivation would be to obtain a mechanistic understanding at an organismal level to improve our predictive modeling capability. Specific research questions include: How does the species composition and distribution of zooplankton and fishes change between ENSO/La Niña events in the California Current? What is the seasonal pattern of grey whale migration along the West Coast of North America? Are marine sanctuaries sufficiently large and in appropriate locations to support endangered species and sustain fisheries?

5. Biogeochemical/physical coupling: Coastal studies of biogeochemical processes must also be conducted and interpreted within the context of physical processes and include long-term measurements to quantify often subtle temporal changes. Temporal variations in the location of coastal fronts, the magnitude and timing of events such as storms and peaks in river discharge can profoundly alter the interpretation of location-specific biogeochemical studies and net mass balances within a specified region. Long-term, synoptic measurements of the physical environment, in tandem with chemical and biological measurements, are critical to understanding the influence of climate variability and large-scale physical forcing on biogeochemical processes. Chemical and biological sensors currently under development, such as high sensitivity ammonium and DNA sensors, will, over time, be added to the observational infrastructure, providing important continuous biological and chemical measurements. Near real-time visualization of the physical environment will permit ship-based sampling to be targeted at appropriate locations to maximize the utility of temporal comparisons for assessing biogeochemical changes. Thus the implementation of a coastal observatory system will likely provide unique and necessary observations and context to assess the fate (sequestration versus transport versus air-sea flux) of carbon and nutrients in the coastal ocean over inter-annual scales.

B. Episodic Events/Extreme Events

Episodic events, such as storms or large river discharge events, can be forced on local or distant scales, can rapidly change on short time-scales and can influence regions ranging from several to hundreds of kilometers. As such, episodic events are a subset of the temporal and spatial scale issues presented in Section IV A. We highlight episodic events separately here because many processes are thought to be greatly accelerated during these periods and may significantly influence coastal conditions. Importantly, however, it is the influence of short, extreme events relative to mean conditions that determines the importance of episodic events. Episodic events may perturb marine communities or change conditions, thereby favoring the establishment of a new community.

The movement of particulate material in the coastal ocean is heavily biased by low-frequency high-magnitude events. Thus, in order to understand the mass fluxes and transformation/burial of biogeochemically important particulates, we must be able to make key measurements during such extreme events to quantify the fluxes. Furthermore, the morphology and stratigraphy of the seabed is likewise strongly controlled by episodic events, and it is during such events that significant coastal erosion occurs. The ability to monitor the erosion/transport of material during extreme events and subsequent deposition is important for understanding the long-term evolution of the margin and the various biological and mineral resources. Such events also exert a profound influence on the coastline erosion and nearshore sand resources, and we need to be able to predict the effects of such events, and subsequent recovery, in order to address coastal management issues. Thus, the long-term monitoring of boundary-layer parameters and seabed characteristics is a critical component of coastal observatories.

While catastrophic transport events, such as hurricanes, are readily noted and recorded, gradual processes occurring between specific events are also important to the understanding of the overall controls of coastal morphology. Readjustment to mean wave conditions, changing non-storm wave characteristics, sea level rise and other factors that may change temporally impact the susceptibility of coastlines to such consequences as catastrophic failure, barrier island migration and island breaching. An observing system that permits long-term, large scale records of wave direction and energy, water level, current speed and other influential factors along with morphologic surveys would significantly advance our understanding of the interactions between mean and episodic conditions.

In many coastal environments (e.g., the northern Gulf of Mexico) large phytoplankton blooms are associated with riverine inputs (e.g., the Mississippi River). However, there is no clear correlation between production, consumption and sinking. Moreover, consumption is variable and sinking losses are highly episodic. We do not as yet understand the factors controlling variability in these episodic losses. Continuous observations within the coastal zone will permit an examination of the role of episodic events on the fate of organic matter and nutrients in coastal systems and the relative roles of consumption, sinking and lateral export.

What is perhaps less obvious is the need for these types of observations to improve our understanding of air-sea interactions during episodic and/or extreme events. For example, substantial progress has been made in our ability to make direct covariance measurements of momentum, mass, and heat from research ships. These efforts have focused on quantification and removal of motion contamination and flow distortion effects to reduce the uncertainty in the flux measurements. These fluxes have been used to develop the latest generation of flux parameterizations such as the TOGA COARE 2.6 algorithm, which works well for wind speeds between 5 and 18 m s^{-1}. However, decades of expeditionary measurements from research vessels have done little to advance our understanding of heat, mass, and momentum fluxes at wind speeds above 20 m s^{-1}. This is due to the harsh conditions encountered at sea under these conditions, and also because research vessels are reluctant to enter into these regions to ensure the safety of the crew and passengers. Therefore, it is unlikely that our understanding of air-sea exchange at very high winds (U greater than 20 m s^{-1}) can be significantly improved from ship-based measurements. Additionally, the high sea states, low visibility, and dangerous winds also restrict aircraft operations to heights that are well above the region directly influenced by air-sea interactions.

One obvious solution to this problem is to make long-term, continuous measurements of air-sea interaction from fixed platforms, e.g., at coastal observatories where the flux footprint is over the ocean for at least some wind directions. We expect the latest generation of sonic anemometers to provide accurate estimates of momentum and buoyancy flux to wind speeds of 30 m s^{-1}. However, rugged hygrometers and thermometers must be developed to handle the high winds and spray. Additionally, rugged fast response anemometers must be developed to survive even greater extreme wind conditions that may be encountered in hurricanes and typhoons.

C. Ecosystem Dynamics

Continuous measurements of coastal conditions may also be key to advancing our understanding of changes in living resources, the onset of planktonic blooms, including harmful algal blooms, and the increase in invasions of exotic species. While blooms can now be monitored from space-borne sensors, conditions leading to the initiation of a bloom are not so readily observed. A coastal observatory continuously provides information on physical, biological and chemical conditions prior to regime shifts or blooms. In addition, it is clear that there are numerous potential connections between physical and chemical processes and biological systems.

In general, coastal observatories will provide insight into basic questions including how temporal and spatial variability in coastal circulation influences primary, secondary, and higher trophic level productivity of coastal ecosystems. Within this broad category, detailed questions can be posed: What is the connection between eddy variability and sardine recruitment? Are red tides in the Gulf of Mexico driven by Loop Current intrusions, river discharge, iron dust influx, competitive interactions with other plankton, or some combination of these events? What is the impact of inter-annual variation in river discharge on the production of commercially important species (like shrimp, crab and oyster populations)? What are the anthropogenic impacts on fish and shellfish populations? How is larval fish recruitment driven by Gulf Stream frontal eddies or estuarine processes? What controls recruitment success of menhaden on the East Coast of the US?

In addition, the development of a coastal observatory provides the basis for assessing temporal variations in the myriad of factors that may control coastal biological systems. For example, coastal hypoxia, which is increasing in certain locations, may be enhanced by increased deep water and benthic respiration (fueled by increases in surface production); increased stratification of the water column, inhibiting ventilation of deep waters; or increased turbidity, which decreases deep photosynthesis and accompanying oxygen production. Additionally, the occurrence of harmful algal blooms is increasing along the coasts of the United States. Numerous phytoplankton species can discolor sea water leading to so-called 'red tides', most of which aren't harmful. However, about 40 phytoplankton species produce toxins, which may be transferred through the food web and kill zooplankton, fish, marine mammals and birds, and humans. Some examples are the dinoflagellates *Alexandrium* spp. in the Gulf of Maine, *Gymnodinium breve* in the Gulf of Mexico, and the diatom, *Pseudonitzschia australis*, along the West Coast of the United States. These blooms may potentially be the result of anthropogenic increases in nutrient loads from rivers, from the atmosphere or from benthic pools that are periodically resuspended and released to the water column.

Gelatinous zooplankton blooms also appear to have increased in recent years, leading to significant changes in local or regional ecosystems, in addition to occasionally being highly visible to the public as a nuisance to swimmers. At this time it is uncertain whether these blooms are increasing, and, if so, what factors influence their populations. Another organism that has received considerable attention in recent years is *Pfiesteria piscicida*. This unicellular organism has a complex life cycle and is potentially a significant health hazard in many estuaries along the East Coast. The health risks and an assessment of underlying factors controlling outbreaks may be better understood within the context of observatories. Other examples of invasions by exotic species that have altered local ecosystems include the European green crab, *Carcinus maenas*, a voracious predator. The Smithsonian Environmental Research Center database lists at least 160 non-indigenous species in Chesapeake Bay alone. Our ability to predict community interactions and dispersion of exotic species is limited by our knowledge of the extent and ecological consequences of invasions, as well many other factors including transport processes. The long-term, integrated nature of a coastal observatory will permit the simultaneous assessment of the different potential factors to examine individual impacts and feedbacks.

V. Design Criteria for a Coastal Observatory

The general consensus of working group discussions is that the exceptional opportunity offered by an observing system is that it expands the time and space scales over which studies can be conducted. To maximize the increase in the scales of observation, measurements at a variety of scales and configurations will be required. The overall configuration will depend on the coastal settings and processes of interest. In general, three types of in-water sensor systems were envisioned.

1) Relocatable (Pioneer) research arrays (Fig. 3) can be used to focus research on specified aspects of the coastal ocean to provide the basic scientific understanding for the interpretation of observatory measurements. Such arrays can also provide the foundation for the development and testing of new observing system components.

2) Selected dedicated moorings will be required at uniquely important locations within each region. Examples would include the mouths of major estuaries or rivers and cross-shelf arrays of current meter moorings at selected locations to study the large-scale response of the coastal ocean to external forcing and to determine fluxes along the coast.

3) A widely distributed set of backbone moorings that span all regions will be required to link all regions with a set of common, comparable measurements.

A. Existing Capabilities and Sensors

It is envisioned that development will proceed by building upon the existing operational observatory networks and research observatories. Existing networks include the NDBC buoy system, CMAN network and NWLON Program. Existing research observatories are dispersed throughout the coastal zone and include such observing sites and programs as: LEO-15, Cal-COOS, TABS, COMPS, SABSOON, CBOS, Caro-COOPS, FRONT, MOOS, MVCO, and GoMOOS. In general these systems include a combination of fixed platform, buoy and space-borne sensors. On a more limited basis, glider-based sensors are being deployed at coastal sites (see Appendix G). In general, present-day observatories are dominated by physical sensors, although a limited number of chemical and biological sensors are now transitioning to routine use.

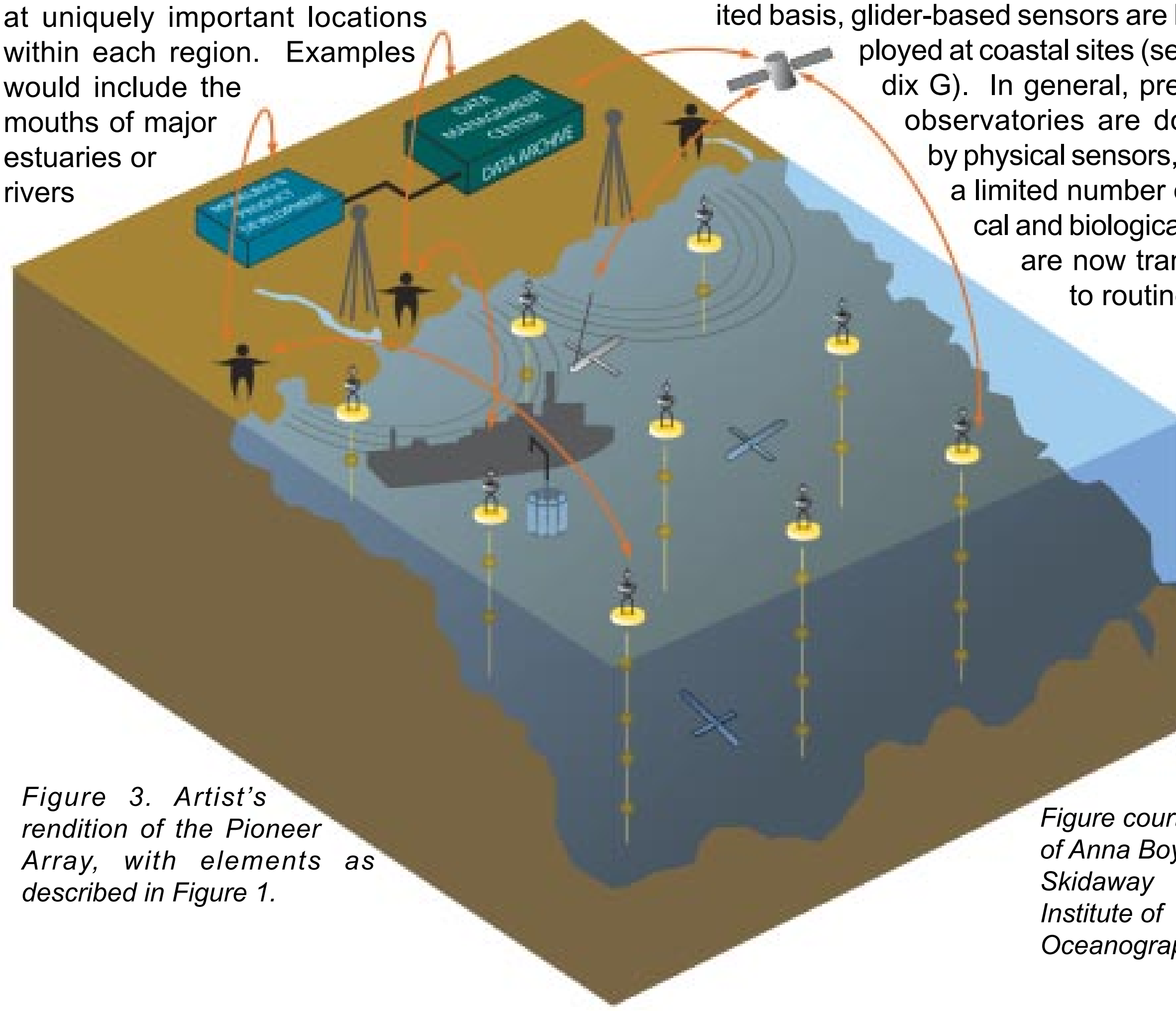

Figure 3. Artist's rendition of the Pioneer Array, with elements as described in Figure 1.

Figure courtesy of Anna Boyette, Skidaway Institute of Oceanography

Examples of existing measurements and sensor systems that are currently available for widespread deployment are listed in Table 1.

Table 1. Examples of oceanographic parameters that can be measured by sensors or routine shipboard surveys.

- Temperature[b]
- Conductivity (salinity[b])
- Irradiance[a,b]
- Sea Level[b]
- Waves (spectrum/direction)[b]
- Current velocity and direction[b], zooplankton distribution profiles (ADCP)
- Meteorological parameters (e.g., temperature, humidity, wind velocity/direction[b], precipitation[b], barometric pressure)
- pH
- pCO_2
- Optical properties[a,b]
- Nutrients[a]
- Fluorescence[a,b]
- Zooplankton and larval fish distribution [e.g., OPC (Optical Plankton Counter), VPR (Video Plankton Recorder), SIPPER (Shadowed Image Particle Profiling and Evaluation Recorder), CPR (Continuous Plankton Recorder), hydroacoustics]
- Fish distribution (hydroacoustics)
- Marine mammal distribution (passive hydroacoustics)
- Seafloor bathymetry (multibeam sonar)[b]
- Boundary layer parameters (profiles of mean currents, turbulence, shear stress, particle size and concentration)
- Surface gravity wave distribution[b] (radar, video)
- Seabed morphology and dynamics (rotating sidescan sonar, bedform-profiling altimetry)

[a] *routine measurement may require additional development to overcome biofouling problems, although antibiofouling technology is improving rapidly (Fig. 4)*

[b] *parameters which can be remotely sensed: remote indicates satellite, airborne or ground-based platform*

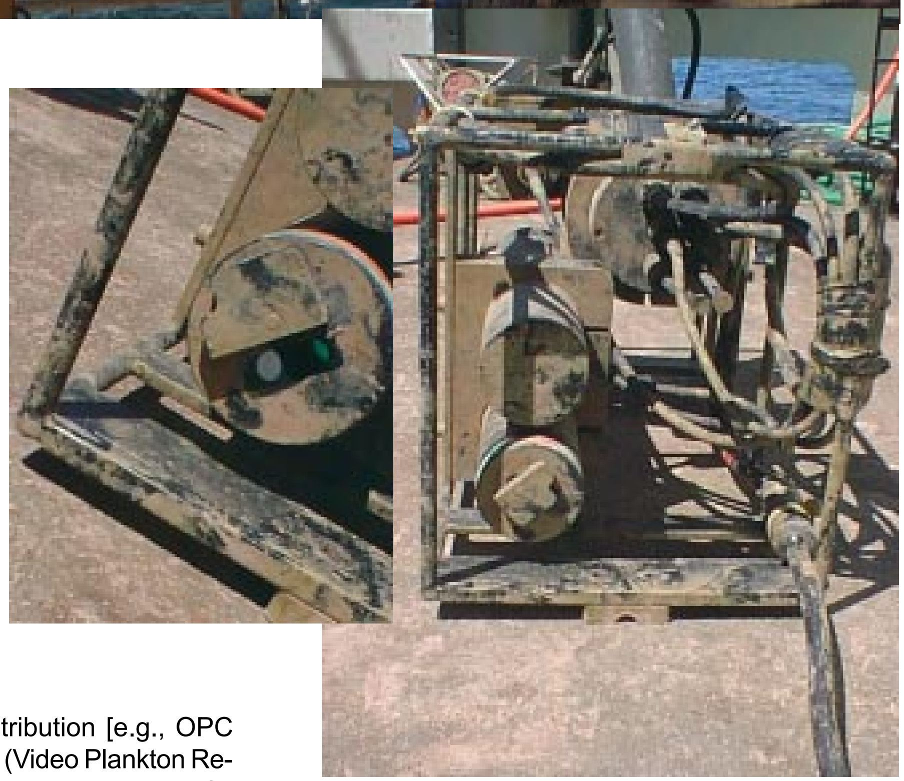

Figure 4. Before (upper left) and after (upper right) deployment of in-water sensor packages at a 27-m water depth station in the South Atlantic Bight (SABSOON tower). Instruments shown in upper right panel were deployed at 3-5 m below the water surface. Lengths of copper tubing were used inline with Tygon tubing to inhibit growth inside the fluorometer. Growth occurred over a 21-day period. Courtesy of Trent Moore, Skidaway Institute of Oceanography. Lower panels show the effectiveness of copper shutters used to keep optical sensors clean during a 3-month deployment at 18 m in the Gulf of Maine. Lower left panel shows shutter rotated open, while shutter is closed in lower right panel. Courtesy of GoMOOS, Collin Roesler and Andrew Barnard, Bigelow Laboratory for Ocean Science.

The development of coastal observatories will require parallel development efforts on a range of issues including in situ sensors, deployment platforms, data management, and assimilative modeling and data products. We recommend that initial activities focus on establishing a list of core measurements and then installing a common set of sensors at existing observatory locations. As the system expands, new observatory sites need to be established to fill in the gaps and additional sensors deployed at each new location.

B. Research and Development Needs

A diverse set of research and development activities were identified that would improve observing capabilities. These include the development of specific in-water sensors, improvement of sensor packaging to expand deployment opportunities, improvement of deployment platforms and profiling moorings, and improved techniques for the interpretation of specific data streams.

1. Remote and in situ sensor development: Advancement in our understanding of the physical and biogeochemical characteristics and dynamics of regional coastal systems requires the (continued) development of a number of remote sensing (satellite, airborne, and ground-based) and in situ instruments. In particular, existing space-based capabilities generally reflect open ocean sampling requirements, with spatial and temporal resolutions inadequate for detecting and quantifying the small-scale and/or episodic variability that is characteristic of coastal regions. Improved coordination and cooperation between agencies is required to ensure strategic development and sustained operation of these new or improved technologies, as is the need for open dialogue with the coastal science community during the planning and development of new satellite missions to ensure that user information needs are satisfied.

Satellite imagery has been a workhorse for assessing mesoscale structure of surface ocean properties over the last decade, but advances in remote sensing of physical coastal processes and phenomena are still necessary. Many processes and features within the coastal ocean require higher resolution than present-day instruments provide. Observations of coastal sea level can be improved through the development and deployment of a Wide Swath altimeter, delayed Doppler altimeters, and ground-based GPS altimetry systems. Improvement of ground-based, high-frequency radar systems will provide high-resolution, near real-time mapping of the surface current field, as can Synthetic Aperture Radar Along-Track Interferometry (SAR-ATI) from both airborne (existing) and satellite (proposed) platforms. Remote sensing of surface salinity is an emerging capability, with accurate airborne retrievals for coastal waters demonstrated and a satellite mission planned. In terms of other relevant physical properties, multi-platform scatterometer observations could provide synoptic, high-resolution coastal winds, although improved access to existing data streams from space-based synthetic aperture radar (SAR) sensors could also serve this purpose to some extent.

Advances in remote sensing of coastal biogeochemical processes and phenomena are also required. Existing polar-orbiting ocean color sensors provide useful information, but their utility for coastal studies is reduced by moderate spatial resolutions (typically 1 km at best), frequent cloud cover and the potential for tidal-aliasing. Furthermore, coastal waters are optically complex, and the spectral resolution of existing satellite sensors is insufficient to adequately discriminate the various in-water constituents (e.g., pigments, particulate and dissolved organic materials). A hyperspectral, geostationary coastal satellite imager(s) with sub-km ground resolution (preferably < 300 m) would address all of these concerns.

Airborne sensor systems, such as LIDAR, SAR, and imaging spectrometers, may be especially useful for coastal applications because they can focus on specific events and features, achieving much greater resolution (spatial, temporal and/or spectral) than can be realized from space-borne sensors at present (Fig. 5). In particular, pump and probe LIDAR systems can be used to characterize regional phytoplankton photosynthetic activity, biomass, and diversity (e.g., algal bloom events); airborne SAR can be used effectively for water quality applications (e.g., fate and transport of storm water and waste water).

Development of chemical and biological sensors is urgently needed. Some chemical sensors and sensing techniques, such as automated chemical analyzers, mass spectrometers, Raman spectrometers, gamma detectors, and optical analyzers, are now possible candidates for deployment in the ocean. Others, such as O_2 sensors, need continued development. We recommend that priority be given to developing sensors for biochemically active solutes, such as nutrients, trace gases, particulate and dissolved organic matter, and element speciation of selected trace metals. Such sensor systems would complement the development of other biological sensors such as the fast repetition rate fluorometer for estimating primary production, DNA microchip sensors which can be used to identify particular species, and acoustical sensors for assessing populations of organisms ranging in size from zooplankton to fish.

There currently are no sensors available to detect microzooplankton or to assess any vital rates of zooplankton in situ. In developing sensors, particular attention needs to be paid to hardware and software compatibility (i.e., Plug-N-Play issues). In addition, many sensors already in use require further validation and precision and calibration issues must be standardized. The accuracy, precision, and interpretation of sensor data also need to be improved. Furthermore, biofouling issues must be resolved (Fig. 4). Two websites with more comprehensive lists of currently available sensors can be found at the end if this document.

2. Platform development/packaging: In addition to improvements to specific sensors, significant advances in our ability to observe coastal processes and phenomena will be made possible by developments to deployment platforms and sensor package design. Improvements to sensor platforms may include relatively simple alterations such as modifying the NDBC buoys to provide vertical profiles of subsurface distributions of particular parameters, use of profiling moorings, or to more sophisticated developments such as modifying existing autonomous underwater vehicles (AUVs) to accept variable payloads. An ancillary task would be to capitalize on new nanotechnology advances and develop sensor packages that are lighter and require less power. This would again increase the number of sensors that could be deployed on a single AUV and therefore increase the value of these types of observations. Standardized power and communication among sensors on AUVs and other deployment platforms need to be considered.

Additionally, creative means for deploying sensor packages can greatly expand the types of coverage of observations available. For example, air-deployed autonomous vehicles can be rapidly deployed to capture specific events. Autonomous packages could be dropped within the predicted path of hurricanes to obtain unique and valuable information on air-sea interactions within the storm. Plug-N-Play instrument packages can also be developed which would permit installation of sensors on a wide range of platforms of opportunity such as ferries, greatly expanding our measurement coverage in certain areas.

Sensor data streams can also be augmented by direct sampling and subsequent analysis. Two-way communications within an observing system provide the opportunity to implement remotely controlled sampling systems that can be triggered to capture specific events or conditions. These 'smart sensors' could be used to acquire samples for analyses for which a real-time sensor is not yet available. Such direct sampling can also be used to verify sensor calibration and to assess variations that are beyond the sensitivity of existing sensors. Finally, further development of anti-fouling techniques and strategies hold the promise of extending deployment periods and thereby lowering costs of sensor deployments.

There is also a need for intelligent, integrated coastal sensor networks such that linked in situ platforms can communicate with a high-resolution, space-based coastal imager, or a constellation of such imagers, sharing environmental information in real-time and triggering adaptive, event-based acquisitions by either the remote or field assets. This type of system architecture would also enable robust satellite calibration and validation in dynamic, optically complex coastal waters, and provide a responsive, four-dimensional data stream for researchers, managers and policy makers.

3. Models: It is envisioned that a coastal observing system will ultimately yield numerous operational products supported by assimilative models. The usefulness and accuracy of these products will depend on the level of understanding of the fundamental processes and interactions among

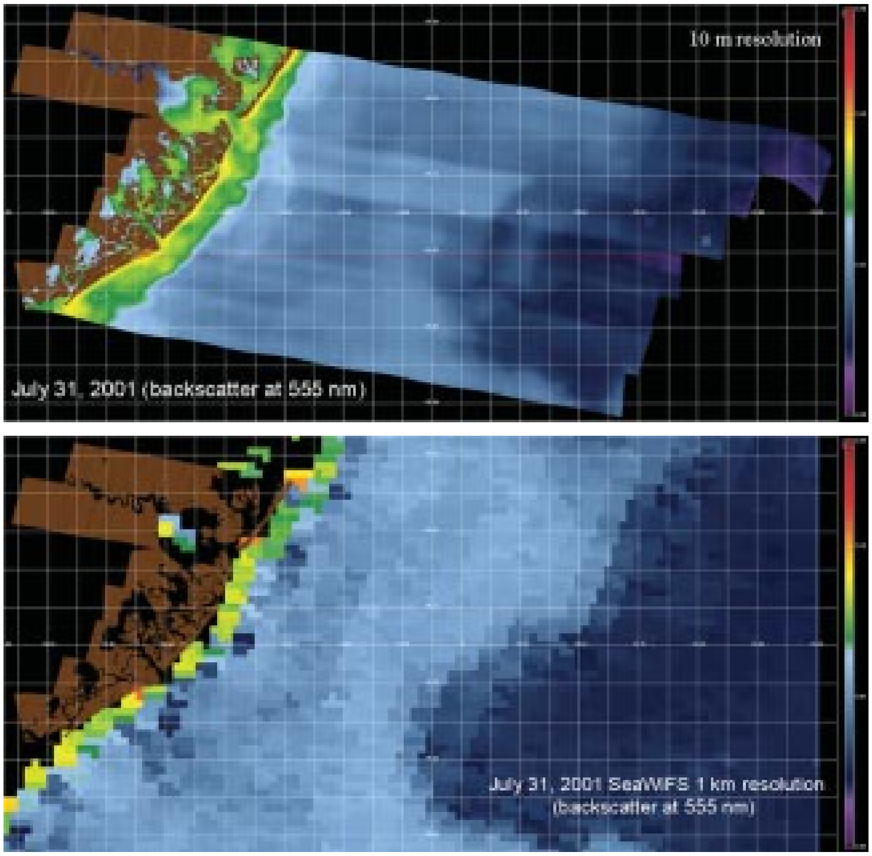

Figure 5. Comparison of hyperspectral high resolution imagery collected via aircraft and by the American SeaWiFS system (brown color indicates land). Upper: High resolution (10 m) estimates of optical backscatter collected from an aircraft carrying a sensor that is proposed for future hyperspectral satellites. The resolution of the aircraft is 10 m, the proposed resolution of some of the new satellites is 30 m. Clearly evident are flow patterns in the estuaries and the variable distribution of material in the estuary is clearly visible. Spatial resolution such as this should be available in the coming years, and offers remote sensing data on ecologically relevant scales for the coastal ocean. Lower: The current spatial resolution of the SeaWiFS system which does not even effectively define the estuary. Thanks to Paul Bissett (FERI) and Robert Arnone (NRL) for providing the image.

the physical, chemical and biological systems. To quantitatively explore the linkages in interactions, numerous model types will be required including operational coupled ocean-atmosphere forecast/nowcast models, and coupled physical-biogeochemical assimilative models. Additionally, models of special processes and concerns, such as surge and wave models, will be required as the foundation for anticipated observatory products.

C. Relocatable Research Arrays: The Pioneer Array

Many significant events in the coastal ocean, for example flow-topography interactions, phytoplankton or harmful algal blooms, and sediment deposition or resuspension occur at short time and space scales. Events might last from a few days to a few weeks and occur on scales of a few to tens of kilometers. They can be episodic, but are also often associated with geographic features (coastline and/or bottom topographic irregularities, rivers). Since these events are important to coastal ocean physics, biology, chemistry and geology, we need to have the capability to observe them on these short time and space scales. At the same time, it is clear that we cannot instrument the entire US coastal ocean with a dense array of year-round measurement platforms. Lastly, through experimentation, careful data analysis and array design, we can use results from a well-sampled region to choose a minimal set of observations that, when coupled with validated numerical ocean circulation and ecosystem models (and this is critical!), can serve as a reliable coastal ocean observation system.

With the above background, workshop participants concluded that there is a need for dedicated research arrays (Pioneer Arrays, Fig. 3), which would be comprised of a dense array of instruments that would be used to establish the foundation for a longer term coastal observation system. This array would be installed and kept in place for a length of time dependent on the local temporal scales of interest, but most likely for a few years. The information from this dense array would then be used to select a minimal set of observations that could be left in place to provide, when coupled with verified numerical ocean circulation and ecosystem models, a reliable ocean observation system. The Pioneer Array resources would then be relocated to another coastal region of interest and the process would repeat. The minimal set of observations left behind could become part of the national coastal ocean observatory backbone. In a sense, the array is transient, moving from place to place, but it leaves fundamental advances in understanding and observing the coastal ocean in its wake. Furthermore, since in many locations, it will constitute the initial observing system, this system can be thought of as a 'pioneer' array - leading the advancement of the C-IOOS.

The Pioneer Array region might be 100 km alongshore and the appropriate length offshore to bound the coastal ocean and important continental slope processes. It might be centered on a geographic feature, for example an estuary, river mouth, cape, submarine bank or sewage outfall, chosen by the compelling science questions for each coastal region. It might include a dense set of moorings (15-20) with physical, biological, chemical and geological sensors nested in a larger array of moorings. Gliders and other remote sensors might provide a larger scale context or measure properties within the intensive study region. More details of the Pioneer Array concept are contained in Working Group 4's report in Appendix E.

The Pioneer Array would serve as a test bed for new instrumentation before installation on the longer term, coarse spatial resolution coastal ocean observatory backbone. Investigators supported by a variety of sources (federal, state, private) would stage their experiments within the array to make use of the excellent spatial and temporal context. Elements of the Pioneer Array could be supported by individual institutions or by state or private contributions. Perhaps more importantly, if a particular locality wants the dense array to remain in place for a longer time, interested parties in that region (institutions, states, private foundations) could provide the financial support as the Pioneer Array moved on to a new location.

An early prototype of this type of array, although almost purely physical oceanographic, was the one used during the Coastal Ocean Dynamics Experiment conducted off northern California in the early 1980s. The CODE array consisted of up to a dozen heavily instrumented moorings extending from the shore to the continental slope and about 100 km alongshore. Hydrographic surveys, drifter deployments and aircraft measurements were made around and in the moored array. The proposed Pioneer Array would extend this almost purely physical oceanography array to include biogeochemical measurement capabilities. The list of modern instrumentation that could be brought to bear is impressive and includes, for example, surface current measurements from land-based radar, gliders, bio-optical and bioacoustics instruments, and moored chemical sensors. Real-time data reporting and visualization will focus targeted sampling programs. The key concept here is that the Pioneer system could effectively serve as a transportable ocean observatory maximizing flexibility for intensive process studies while also entraining the wider ocean community by not locking the infrastructure to a single geographic position. Granting infrastructure access to the entire coastal science community is considered a key goal as it will allow the system to be viewed as a community resource analogous to the UNOLS fleet.

It is proposed that more than one Pioneer Array be active at one time around the nation's coastline. Because of their spatial scale, it will take a single array moved multiple times to fill in important regions of each coast. A Pioneer Array on each coast (west, east, Gulf of Mexico and Alaska) is one possibility. The scale of the Pioneer Array effort is such that it would take many investigators from multiple institutions to carry out. It would succeed only as a coastal ocean community effort. One powerful lesson from the early coastal observatories is that they take a considerable amount of people power to maintain and operate. The sheer size of the undertaking moves this beyond a parochial effort to one that the coastal ocean community should embrace and in which their participation is critical.

VI. Consensus Statements

A. Research

• Important oceanographic processes occur on a wide range of temporal and spatial scales. Sustained measurements, obtained at a reasonable frequency, are necessary to detect and quantify processes and to develop and test predictive models. Observing system technologies that extend the temporal and spatial scales at which measurements can be made synoptically offer exceptional new opportunities to greatly expand the types of processes that can be studied and modeled.

• We envision that research programs will be required to develop and enhance the intellectual foundation upon which observatory products are based and to promote technological developments which will expand the capabilities of the operational coastal observatory system. One possible mechanism is to establish Pioneer Arrays that are deployed for periods of 3-5 years to examine specific processes and coastal environments and to develop new technologies.

• Development of coastal observatory systems will require considerable international collaboration, especially with Canada and Mexico, in addition to regional cooperation. We recommend that there be periodic international meetings of coastal scientists engaged in the development and use of coastal observatory systems.

• There is a critical need for operational coupled ocean-atmosphere assimilation models with improved predictive capability. These models must continually evolve and be updated to include biogeochemical and ecosystem aspects.

B. Logistics/Funding

• Operations management and data/information management are critical. Data are a community resource and should be made available to the ocean community in a timely fashion. This requires researcher involvement to maintain data integrity, usefulness and quality. **The research community needs to be involved in the design of the observatory backbone from the beginning to ensure a strong link between research and operations.**

• The OOI MREFC is an important critical step to develop the research focus of the C-IOOS. Example applications would be the development of relocatable research (e.g. Pioneer) array technology, and/or HF coastal radar arrays. The Coastal Ocean Processes Program is a logical conduit to provide the science support for these research arrays.

• Longer duration of research grants will be necessary to support individual research projects for appropriate time periods in the field to observe system dynamics, as well as supporting data synthesis after the field component is completed. **Long-term, sustained operational and engineering activities will require separate support as needed by the observatories and data management networks.** Dual funding modes, perhaps using those developed to support the Ocean Drilling Program or UNOLS shiptime as an analogy, must be established.

• Effective partnerships amongst agencies must be established to utilize the expertise within agencies to conduct hypothesis-driven research and operational data collection and product distribution simultaneously. It is envisioned that new partnerships will be established with user groups in related fields, such as Atmospheric Sciences, Environmental Sciences, Fisheries Biology, Engineering, and Computer Sciences. Much of this could be coordinated through the OCEAN.US office.

C. Technology

• **Instrument development and validation and improvements to technology must be implemented as soon as possible so that promising new technology will be available to make the transition from research/development to operational status when needed.** This effort should include the development of both the platforms (moorings, AUVs, drifters, and fixed platforms) and the sensor packages.

• Space-based remote sensing is critical to present and future coastal ocean research. Existing systems must be made operational and new systems with higher resolution must be developed as the standard 1-kilometer resolution is often not sufficient for studying coastal processes. Greater satellite availability might also be achieved if the coastal science community, in conjunction with the appropriate agencies, negotiated access to many of the international satellite systems. Data management systems must be designed to permit researcher access to both derived products as well as raw data.

• Existing buoy, tide gauge, fixed platform and other existing systems should be enhanced or equipped to a common level as quickly as possible as an initial step in the implementation of a national system.

D. Technical Support/Education

• **Planned ocean observatories will require people to operate them. Observatory operators are as critical to the success of an observatory program as dedicated shipboard personnel are to current and previous decades of expeditionary research.** Ocean-going scientists are not expected to run ships or maintain them. Observatories should be similarly supported at the national level. Educational institutions must develop the curriculum that will provide the workforce necessary to operate a national coastal observatory system.

• Post-baccalaureate training will be required for technical support staff, likely at the Master's level. Career paths should therefore be developed for observatory operators. This need is critical and should be advanced as rapidly as possible given the lead-time required to develop a community capable of maintaining the proposed observatories. Training and long-term support for modelers & data assimilators is also necessary to ensure the existence of reliable models for dynamical interpolation and prediction.

Acknowledgements: *In addition to the contributions of the organizing committee and workshop participants, several people provided text and figures during the preparation of the report to balance the content. In particular, CoOP Scientific Steering Committee (SSC) members Steve Kuehl, Chris Sherwood and Carl Friedrichs provided information for the geology/geochemistry sections, and SSC member Jim Wilczak contributed signicantly to the meteorological sections. Workshop participant Paul DiGiacomo provided additional text for remote sensing. The CoOP SSC reviewed and improved an earlier draft of the report. Anna Boyette provided original artistic renditions of the backbone array and the Pioneer Array.*

Websites of interest:

link to current coastal observatories:

NOAA Coastal Services Center's Coastal Ocean Observing System website -

http://www.csc.noaa.gov/coos

links to currently-available sensors:

NOAA CSC Coastal Technology Services -

http://www.csc.noaa.gov/cts/instrument_table.htm

University of South Florida College of Marine Science - Ocean Sensor Gateway -

http://sensors.marine.usf.edu

links to other useful websites:

CoOP website -

http:www.skio.peachnet.edu/coop/

National Science Foundation -

http://www.nsf.gov

Office of Naval Research -

http://www.onr.navy.mil

Ocean.US -

http://www.ocean.us.net

Consortium for Oceanographic Research and Education (CORE) -

http://www.coreocean.org

CORE link to Dynamics of Earth and Ocean Systems (DEOS) -

http://www.coreocean.org/DEOS

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