Report on Shortcourse and Workshop on Coastal Change

April 26-29th 2004

Sponsored by the Coastal Ocean Institute
Woods Hole Oceanographic Institution.

Chatham Mass, taken in 1985 (top) and 1986 (lower). The barrier breached during a storm, creating a new inlet which remains open today. Photographs by Duncan FitzGerald.

Edited by Rob. L. Evans

Many coastal regions of the world have experienced unprecedented development over the past century. Much of this development is incompatible with the dynamic nature of the shoreline and has led to significant controversy about how to best manage coastal resources. This debate has intensified in the face of recent concerns of projected climate change, sea-level rise and increased storm activity and their potential impacts on coastal areas. Given the drastic increases in coastal population and wealth, coastal environmental issues promise to be of enormous concern in the coming decades.

Although there has been progress in many areas of coastal geology, our fundamental understanding of shoreline change has been limited by a lack of a broad and integrated scientific focus, a lack of resources, and a lack of willingness on the part of policymakers who make crucial decisions about human activity along the coast to support basic research in this area. There are clear, process-based basic science problems that need to be addressed before we can achieve the goal of accurate shoreline change prediction and better assessments of the potential risks to the coastline. Coastal zone managers also require basic research activities to aid in their decision making, but in areas of greater complexity than are currently being studied. Recent advances in technology make this an ideal time to launch such an effort. Our ability to map, monitor, model and understand the fundamental processes shaping the shoreline has never been better.

This report summarizes the proceedings of a shortcourse and workshop on coastal change held at the Woods Hole Oceanographic Institution on April 26-29th 2004. The aim of the shortcourse and workshop was to bring researchers together from different areas of the coastal arena, to learn the state-of-the-art in coastal science and to discuss the major obstacles to obtaining a greater understanding of shoreline change. Participants included representatives from coastal management agencies as well as active researchers. Students from local universities attended and presented posters of their ongoing research. Many of the recommendations in this report echo those in the earlier CoForce report [Anderson et al., 2002] a copy of which is posted on the NSF web-site, as well as those of numerous other articles and meetings on the subject [Fletcher et al., 2000; Goodwin et al., 2000; Leatherman, 2003]. Several contributors to the CoForce report also either attended our meeting, or have contributed to the writing of this document.

Presented in this report are many compelling scientific reasons for increased support for research into coastal change. In addition to these, the obvious societal relevance as well as public familiarity with the shoreline, suggests that enhanced research activity in the coastal environment offers a golden opportunity to educate the public, not only about the critical processes shaping our shorelines, but also about scientific method and the importance of carrying out marine research in general.

This document is organized as follows: Section 1 outlines the motivation for increased support for coastal change research from a societal and science viewpoint; Section 2 summarizes the science presentations made during the shortcourse including the new technological capabilities that make this an ideal time to work in this area; Section 3 details over-arching science problems highlighted at the workshop and then provides examples of specific problems to be solved, with examples of experiments that might fall under the kind of coastal change program we are suggesting; finally, Section 4 outlines the education and outreach possibilities offered by increased coastal research.

1. Motivation

More than 3 trillion dollars are currently invested in dwellings, resorts, infrastructure, and other real estate along the Atlantic and Gulf Coasts of the United States. The acceleration in sea-level rise that has been projected for the next century puts much of this coastal property in jeopardy. The Heinz Center report (THC, 2000) has predicted that in 60 years one house in four within 500 feet of the shoreline will be destroyed. Never before has coastal research been more relevant and more important to our country's future well being. In terms of cost, billions of tax-dollars will be used to restore and protect our wetlands, maintain our beaches and waterways, and rebuild infrastructure after storms. For example, in the State of Louisiana there is a proposal to spend 14 billion dollars over the next 40 years in an effort to restore the coastal barriers along the Mississippi River delta (see: http://www.coast2050.gov/reports.htm). Despite these vast sums of money, very little is being invested in basic research that can improve our ability to predict shoreline change and that can be used by managers in their decision making, or that can be used to provide more accurate risk assessment.

Although we know that the processes involved in coastal change are complex, most scientists agree that rising sea level, coupled with depletion of sediment sources, will result in severe beach erosion and shoreline retreat. We need monitoring programs to examine the rates of shoreline change, the influence of storms, and processes governing large-scale coastal behavior. At present, the state-of-the-art empirical knowledge and modeling techniques cannot even answer simple questions like where the sand eroded from the beaches is going, or what is the role of the offshore geologic framework in determining which areas of the coast will erode and which will accrete.

Backbarrier and estuarine tidal marshes are a critical component to our coastal ecosystem and are particularly vulnerable to accelerated sea-level rise. Tidal marshes are the dominant estuarine habitat along the East Coast of the United States and are ecologically and economically important as they act to filter and absorb terrestrial nutrients and pollutants, buffer coastlines from wave stress and erosion, and provide nursery grounds for fish and invertebrates. Whereas researchers have been studying factors governing biomass production in marshes for many years, scientists have only recently embarked on programs to determine the scales of marsh accretion and erosion. We need to know the threshold rates at which marshes can no longer keep pace with rising sea level. If sea-level rise rates do double (or even quadruple as some more extreme model configurations project) over the next 100 years tidal marshes and indeed coastal ecosystems worldwide will likely experience unprecedented changes. Many such ecosystems may disappear altogether.

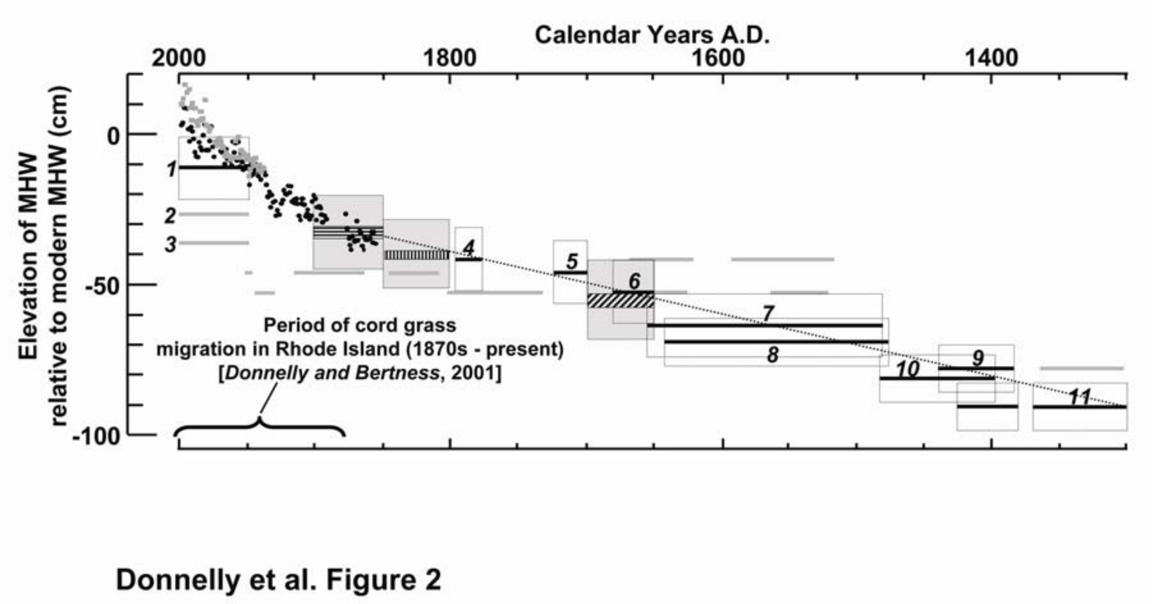


Figure 1. A sealevel history curve for New England from Donnelly et al. (2004). Rates of sealevel rise appear to have almost trebled over the last 150 years or so when compared to the average rate for the previous 500 years.

Previous examples underline the fact that the coast is a complex system that cannot be reduced to the beach only; while beach erosion threatens property near the shoreline, it also profoundly influences marshes located in the backshore and regulates the exchanges of water, nutrients, and waste with the open ocean. Furthermore, changes in the shoreline are inextricably linked to the geospatial framework of the entire coastal zone, from the onshore subaerial and lagoonal components, through the surf zone, and out onto the shelf. Most of this has never been mapped with adequate resolution. The processes that shape our coasts occur on a variety of time and spatial scales. Linking these diverse processes is a challenge, but will almost certainly require a system-wide, multidisciplinary approach tackling basic science questions, identifying the key processes involved in shoreline change, and modeling the interaction of these processes.

Recent advances in technology have greatly improved our ability to monitor coastal evolution. We now have better scientific tools for mapping and monitoring the entire coastal system and to examine changes related to seasonal or individual events. The technologies include dramatic improvements in seafloor mapping and imaging capabilities, laser altimetry systems (LIDAR) for beach and nearshore mapping, improvements in positioning through real-time kinematic (RTK) GPS, high resolution chirp seismic imaging, ground-penetrating radar, marine and terrestrial electrical resistivity, and on and off-shore electromagnetic surveying. We can also gather a more precise record of long-term trends in shoreline motion, which were previously identifiable only through societal records (maps and aerial photographs).

2. Shortcourse on Coastal Change

The two-day shortcourse consisted of fifteen 40 minute talks and subsequent poster sessions (a list of talk and poster titles presented is given in Appendix B). Day 1 began with a series of talks outlining the overall science problems involved in shoreline change, particularly (but not limited to) understanding the role of rising sea level on shaping the coastline. Discussion included the effects of storms, the fragile nature of barrier beaches, and the economic impacts of both long-term and abrupt shoreline change. The afternoon session started to focus in on more specific science issues, running through a variety of topics of both onshore and offshore components of coastal shoreline change. The day finished with a talk discussing the impacts on ecosystems resulting from changes in the nearshore environment. Day 2 started with two talks on modeling studies, both on the long (10-100 year) timescale and shorter sub-tidal timescale processes. Linking the processes that operate on these very different timescales will pose perhaps the greatest research challenge in this area. There then followed a series of presentations focusing on technological advances in onshore and nearshore surveying. The final two talks were more thematic in nature, pointing out opportunities available to the community through the proposed network of coastal observatories and, finally, describing a national assessment of shoreline change program that the USGS has implemented.

Background Motivation

Bill Schwab, who is Team Chief Scientist at the USGS Woods Hole Science Center, set the stage by defining the links between sea-level rise, the framework geology and coastal change. The USGS plays a key role in providing mapping capability that allows assessment of coastal resources and sediment transport processes. The importance of linking the terrestrial and marine components of the coastal system was emphasized, as was the recognition that a system-wide approach is critical to understanding the movement of sediment in the littoral zone. In several places surveyed clear links have been found between the physiography and antecedent geology of the inner shelf that feedback into changes in barrier system evolution. Rob Thieler, also from the USGS, Woods Hole, wrapped up the meeting by describing the National Assessment of Coastal Change program which the USGS has in place to assign vulnerability levels to the entire coastline of the US. The program aims to use the best available technology to improve baseline maps of shorelines and to monitor coastal change.

Duncan FitzGerald from Boston University underscored the impacts of accelerated sea-level rise on barrier islands and backbarrier marsh systems. Sea level is projected to rise anywhere from about 50cm to 90cm over the next 100 years. At the higher end of these estimates (anywhere greater than about 30cm) backbarrier marshes will struggle to keep up with increases in the tidal range. With these increases, many of the barrier systems of the world, which are characterized by mixed energy conditions with segmented barriers punctuated by inlets, will effectively drown. Marshes will disappear, inlets will become more dynamic, with sediment lost to ebb-tidal deltas, causing downdrift shoreline erosion. In Section 3.3.1, we provide more details on this problem and the research strategy that will help us understand the processes in more detail.

Jeff Donnelly from WHOI described the impacts of storms on coastal regions. Faced with expectations of a potentially rapidly changing global climate system, decision makers, scientists and the general public have become increasingly concerned about potential risks to coastal communities and ecosystems related to possible increased storm activity. Gaining understanding of how storm activity may be linked to changes in climate is imperative in order to project future changes and possibly mitigate socio-economic impacts. Coastal areas are often particularly vulnerable as storm surge and wave energy combine to cause significant damage. Given projections of future increases in sea level many coastal resources will likely become more and more at risk in the near future.

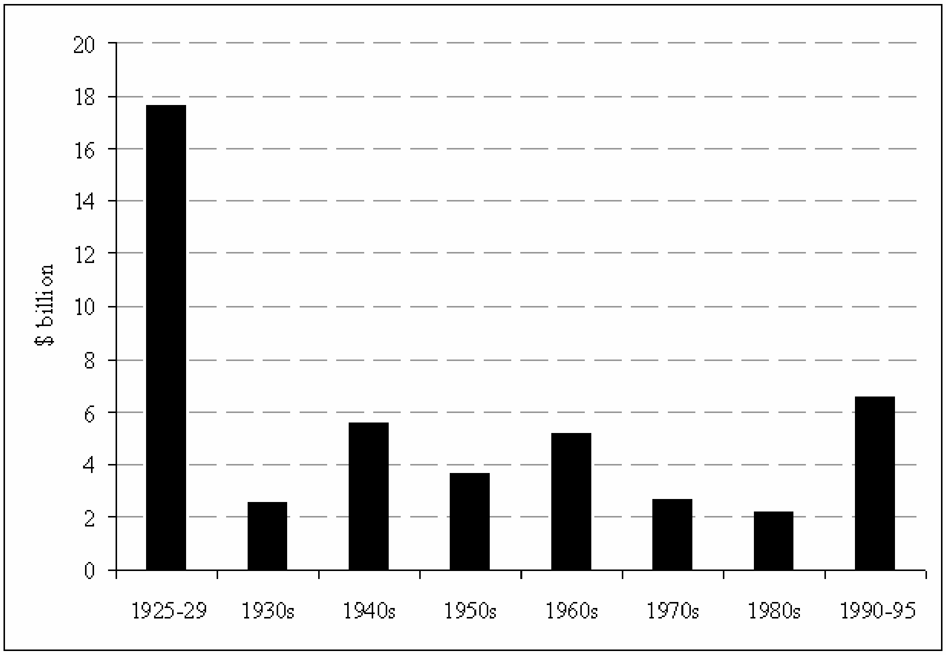


Figure 2. A graph showing the economic impacts of hurricanes. Dollars are normalized to account for inflation and increases in coastal populations and wealth. From Pielke and Landsea (1998).

Anthropogenic impacts on coastlines also feed back into the effects of storms. Many barriers are armored against erosion and as a consequence cannot evolve as they would naturally do. For example, washover events from storms are an important mechanism for moving sediment into the backbarrier, maintaining the health of the system. In many cases the process of overwash has been prevented along heavily armored coastlines. Unravelling the complications of these factors raises the level of complexity in understanding beach erosion during storms, yet the long-term impacts of such armoring are of vital interest to coastal residents and coastal managers.

Economic Impacts

Porter Hoagland, from the Marine Policy Center at WHOI, outlined the overarching economic impacts of coastal change, which highlights the societal need for increased study in this area. The large and rapidly growing human populations in coastal settings are likely to exacerbate the economic consequences of shoreline change. More than 155 million people (53%) of the US population now reside in coastal counties, and this number is expected to grow to 168 million over the next decade. Another 180 million people visit the U.S. coast every year, including substantial numbers of foreign visitors. Between 300 and 350 thousand homes and buildings are located within 500 feet of the ocean, and 85 thousand homes are located within 60-year erosion hazard areas. The Heinz Center (THC, 2000) estimates that as many as 1,500 homes and adjacent land are lost to erosion each year.

Research relating to the economic consequences of shoreline change focuses on the impacts of hurricane damages, the costs of coastal erosion, and predictions of the costs of sea-level rise. Much related research has been concerned with management tools, especially flood insurance. Other studies focus on the localized benefits and costs of specific structural approaches to minimize or prevent shoreline change, such as those associated with beach nourishment projects.

Pielke and Landsea (1998) provide a review of some of the estimates of hurricane damages. The authors estimate “normalized” damages for U.S. East Coast hurricane events over the last 80 years, averaging $5 billion per year. Shoreline change costs, such as flooding and erosion, are only a portion of their annual average estimates, but it is unclear how large that portion is without revisiting the original data. Hurricane damage estimates typically do not include damages to natural landforms or ecosystems or the costs of lost coastal recreation and tourism opportunities. Further, the nature of risks can change over time as demographic patterns shift.

The Heinz Center (THC, 2000) has conducted a recent study of the costs of coastal erosion. Their study finds that the risk of coastal erosion is at least as large as the risks from flooding. There are two main sources of value losses from coastal erosion. One concerns the decrease in the value of coastal properties as a function of the expected number of years away from the shoreline. This is a large loss, amounting to between $3 to $5 billion per year. A second cost concerns the actual loss of property, including structures, due to coastal erosion. This loss may amount to as much as $500 million a year at the national level. The cost estimates are extrapolated to the national level from a select number of local estimates, and they focus only on non-urban environments.

Several studies have examined the cost of sea-level rise as a consequence of global climate change. Early studies focused on the concept of “economic vulnerability,” which refers to the complete loss of coastal property without consideration of adjustments in value or responses to changing risks. Sea level is now expected to rise half a meter on average over the next 100 years. Local changes in sea level may be more or less than this average, depending upon topography and geology. Recent estimates of the cost of sea-level rise by Yohe *et al.* (1999), incorporate assumptions of economically rational adaptation, such as the possibility of allowing structures to depreciate in anticipation of sea-level rise and the option of investing in either permanent or temporary shoreline protection. These new estimates are an order of magnitude lower than the earlier vulnerability estimates, amounting to about $500 million a year by the year 2065. They include estimates of neither the costs of storm damages nor the impacts on natural areas.

Observations

Jeff List (USGS, Woods Hole) discussed the scales of shoreline change and the procedures used to monitor and predict changes. The underlying controls on change are different for the different time scales of interest. Long-term changes are influenced by sediment availability, geologic framework and sea-level trends. Short-term changes are affected by waves and tides and by seasonal climatic factors. Recent results also indicate that even short term changes are influenced by geologic framework. Current predictions of shoreline change are based on extrapolation of past changes into the future and by modeling. There are limitations to both. Extrapolation usually relies on defining a trend from a limited (and hence aliased) set of measurements. The estimated trend is subject to considerable error and, in any event, this approach does not account for future changes in forcing conditions (e.g., storminess, precipitation, wave conditions) that might not be predicted even by an accurate assessment of past trends in change. Modeling also has limitations at present, largely due to oversimplification. Limitations in observations also limit the applicability of models. One critical example is the need for accurate and coeval directional wave measurements that provide accurate assessment of the forcing.

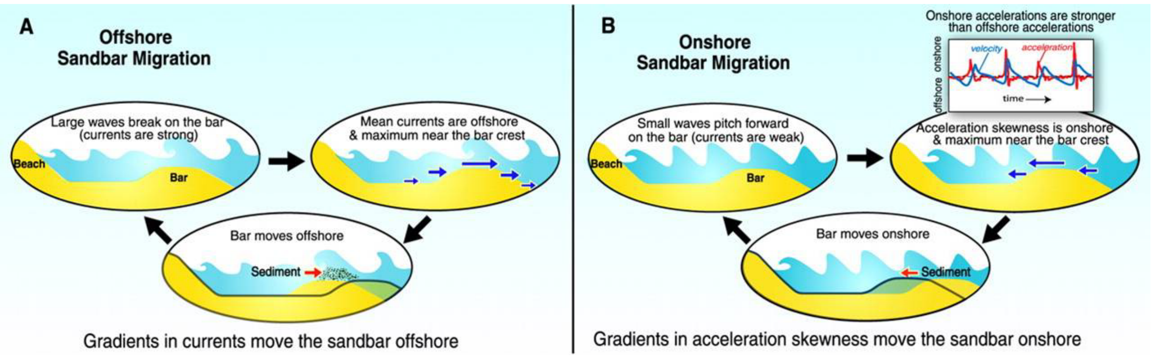


Figure 3. A schematic showing (a) how relatively high energy wave conditions cause strong offshore currents that, in turn, cause sandbars to migrate offshore and (b) that during calmer periods the bars migrate onshore. This behavior is caused by changes in the acceleration skewness that in turn is related to wave shape. A full discussion is in Hoefel & Elgar (2003) from which this figure is taken.

The link between sea-level rise and shoreline change, while undoubtedly present, remains controversial (see for example Leatherman et al., (2000) and comments by Pilkey et al., (2000)). Studies have shown that there is no apparent correlation between sea-level rise rates and shoreline changes at specific locations. Despite this, there is general consensus that rising sea level does pose a threat to the health of most barrier systems and to the back-barrier environments they protect. The key is to understand underlying geologic framework and to recognize that the processes that control coastal change act in concert with longer-term sea-level change. Two example models of coastal transgression were shown with different underlying geologic conditions (seafloor erodability and sediment type) but with identical sea-level histories which produce very different patterns of barrier evolution, shoreline locations and internal stratigraphy. In most barrier settings we have very little idea of the offshore and subaerial geology, and for most areas, no understanding of a quantitative sediment budget.

The surf zone represents the obvious boundary between the beach and continental shelf. Britt Raubenheimer (WHOI) described the key features and processes that shape this dynamic environment. Ripples and sand-bars are important features that migrate and transport sand either from the beach in winter storms or assist in re-building the beach during the calmer summer months. The role of waves in moving sand-bars offshore has been known for a long time and models have done a reasonable job in predicting migration in this direction. However onshore migration of sand-bars has been problematic, although recent breakthroughs based on field observations have taken important steps towards improving predictive capabilities in this area (e.g. Hoefel & Elgar, 2003). As more observations are made it becomes clear that bedload transport is often (at least in sandy settings) the dominant means of moving sediment. Along-shore transport is also important, especially close to sources or sinks of sediment such as rivers or inlets, but this can be difficult to quantify, even after decades of careful observation and study. Research in this field has focused on linking observations to quantitative models of sediment transport and this was evident from this presentation and also that by Tom Hsu (see below).

Much of the recent coastal research has been dedicated to the measurement of waves, sediment transport and morphodynamics of straight and homogenous coastlines, which can be more easily conceptualized for modeling purposes. However, most coastal regions do not match this simplified description. Estuaries and inlets, anthropogenic structures from groynes to harbors, headlands and bays, all depart significantly from two-dimensionality. Furthermore, even the morphodynamics of uniform coasts are not as simple as often assumed. Poorly understood non-linear feedbacks commonly develop between morphology and hydrodynamics leading to self-organized structures such as rip-channels, cuspate features, spits, alongshore sandwaves. There is a critical need to quantify the complex three-dimensional morphodynamic behavior of a diverse range of coastal environments.

Rivers are the primary source of dissolved and particulate materials entering the ocean. Liviu Giosan (WHOI) emphasized that despite their importance, the recent progress in understanding suspended sediment deposition from river plumes has not been duplicated by research on the morphodynamics of river-influenced coasts. Sediment derived from the river plumes impose heterogeneity in the nearshore (e.g., forced accumulation of mud in an otherwise energetic environment), leading to a strong coupling between hydrodynamic and morphodynamic processes in regions far from the river mouth, in contrast to homogenous sandy beaches (Sheremet and Stone, 2003). Near-field sediment deposition contributes to the development of subaqueous deltas; in turn, these deltas modulate the wave and tidal energy reaching the coast and interrupt the longshore sediment transport (Wright, 1977; Giosan et al., in press). It is increasingly becoming clear that river mouth processes exert a primary control on the morphology of adjacent coasts from beaches to entire deltaic lobes (Bhattacharya and Giosan, 2003);

however, our models for river mouth dynamics, and thus the impacts of their modification or response to sea-level rise, remain purely conceptual.

Impacts on Ecology

Both natural and human-induced changes in climate can significantly alter coastal ecosystems worldwide. Mark Bertness of Brown University discussed ecological issues currently affecting back barrier marshes. Increasing temperatures and sea-level rise resulting from climate change, as well as coastal eutrophication, are among the most intense and extensive threats to community structure and function of estuarine ecosystems. Salt marshes are the dominant estuarine habitat along the East Coast of the United States and perform crucial ecosystem services in coastal environments, including filtering and absorbing terrestrial nutrients and pollutants, buffering coastlines from wave stress and erosion, and providing nursery grounds for fish and invertebrates.

Salt marshes are also valuable model systems for experimentally examining the structure and function of natural communities and the causes and consequences of human impacts on ecosystem processes. In addition, salt marshes provide valuable sedimentary archives of past environmental conditions. Given the commercial, scientific, and aesthetic value of salt marshes, and the continuing loss of marshes to shoreline development, other population pressures and to drowning, it is critical to elucidate mechanisms by which climate variability and humans are impacting salt marshes and the important societal services they provide.

Climate warming can directly influence the dynamics of any natural plant community by increasing temperatures. For example, in cooler northern climates where soils often are high in moisture content, temperature increases may lead to increased plant production through increased photosynthetic rates and/or decreased water logging stress on roots as evaporation rates increase. Temperature increases can also drive community changes by shifting the nature of plant interactions, changing species distributions, and fragmenting habitats.

In addition to the direct impacts of increased temperature, climate warming is predicted to indirectly affect coastal ecosystems, including salt marshes, by accelerating sea-level rise. Salt marshes in the eastern United States have developed over the last several thousand years under a regime of relatively slow rates of sea-level rise. Sea-level rise rates in eastern North America have been estimated to have averaged between 0.5 to 1.0 mm/year over the last several thousand years. In response to those relatively modest increases in sea level, marshes grew into expansive systems.

However, recent evidence from southern New England has shown that the rate of sea-level rise accelerated in the late 19th century (e.g., Donnelly et al., 2004), likely as a consequence of climate warming. As a result of this relatively recent increase in the rate of sea-level rise, marshes need to accrete vertically at a faster rate in order to prevent drowning. The documentation of cordgrass invasion of the New England high marsh and marsh drowning in other areas may indicate that marshes are failing to keep up with the increased rate of inundation (Donnelly & Bertness, 2001).

Modeling Capabilities

Numerical modeling of processes on long time and large spatial scales is essential for testing ideas about coastal morphodynamics. Joep Storms, from the Delft group in the Netherlands presented details of the state-of-the-art in modeling these long-term processes. The large number of forcing mechanisms at these scales precludes the understanding of coastal evolution based on simple conceptual models or even physics-based deterministic models. Instead, process-based, simplified and computationally inexpensive, models have been and continue to be developed. Despite significant progress, processes such as delta backstepping, extensive marsh flooding, and rapid barrier retreat and drowning, which are likely to affect the coastal environment if the sea-level increase accelerates further, have few present analogues. The stratigraphic record, although incomplete, is the key to understanding coastal evolution over geological time scales because it provides the only remaining physical evidence of the changes that have shaped the nearshore environment. Acquisition of comprehensive datasets examining the geological record of coastal change during periods when sea level was changing at different rates than today should inevitably be supplemented by development of stratigraphic numerical models that address relevant forcing parameters such as the magnitude and shape of the accommodation space, sea level changes, basin energetics, and sediment budgets.

Many of the processes occurring on short timescales (shorter than a tidal cycle) play a critical role in transporting sediment and, hence, in shaping the shoreline. Yet the links between these short timescale process and decadal shoreline change are not well established. Tom Hsu discussed modeling approaches to understanding sediment transport on the short time scale and how these processes act to move features such as sand-bars. This example shows how short time-scale processes can act to shape large scale features in the nearshore, and hence are an intrinsic component of long term coastal change.

Many of the models that have been traditionally used have, by necessity, made critical simplifying assumptions that limit their applicability. New quasi-3D models include some of the important terms previously omitted, and also make links to regional scale wave forcing. One example given was that of nearshore sediment transport where a coupled wave and circulation model can be used to set up wave forcing conditions from which the bed shear-stress can be calculated. A suite of numerical models have been developed to quantify the response of the seafloor to wave-orbital forcing, and which demonstrate the net sediment transport (e.g., Hsu et al., 2004; Drake & Calantoni, 2001). As discussed above, coupled with field observations these new models have helped improve the predictions of bar migration not only offshore during storms, but also onshore during calmer periods (e.g., Trowbridge & Young, 1989; Thornton et al., 1996; Elgar et al., 2001; Hoefel & Elgar, 2003). Similar advances in terms of coupled observation and modeling have been made for ripple migration (e.g., Traykovski et al., 1999).

Technology for Coastal Zone Studies

There have been dramatic improvements in technology that have greatly improved our capabilities in the coastal zone and which allow us, for the first time, to address some of the over-arching problems involved in shoreline change. Given the active role of geological framework in controlling large-scale coastal behavior and sediment availability, a wide range of critical spatial and temporal scales, as well as inherent heterogeneity of sedimentary systems under investigation, a successful coastal research program will necessarily involve a broad suite of geophysical and oceanographic tools, sampling and dating methods.

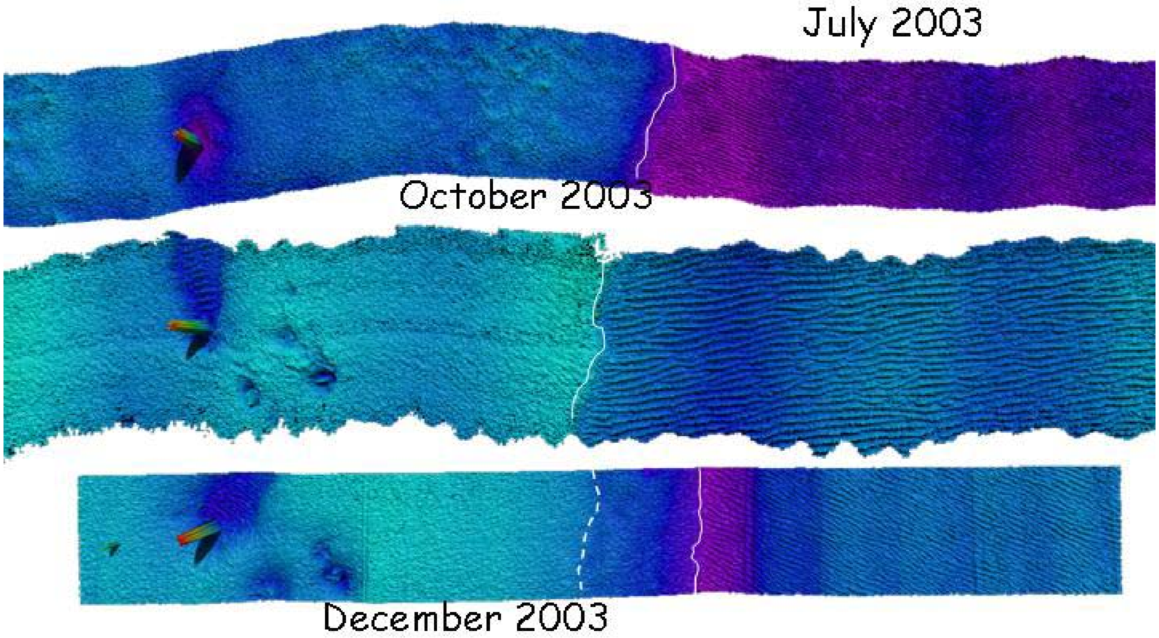


Figure 4. High resolution seafloor bathymetry data from offshore Martha's Vineyard. The data were taken at different dates as noted and show how ripple fields in surficial sands evolve. Bedload transport in ripple fields is an important component of sediment transport in water depths shallow enough to be influenced by wave orbital velocities, but is a process we are only beginning to understand through detailed observations like these and those shown in Figure 2. The large spike in all images is the Martha's Vineyard Coastal Observatory (MVCO), installed and maintained by WHOI (http://www.whoi.edu/mvco). The observatory tower has apparently created a ripple set in its shadow that evolves with time. Seafloor data and image courtesy of Larry Mayer, University of New Hampshire.

There is at present a great deal of activity in observatory science, and we further explain connections between our proposed efforts and developing initiatives in Section 3.3 below. Rocky Geyer (WHOI) gave a presentation arguing for a broader definition of an observatory in the context of coastal change studies and arguing for the kinds of measurements (in terms of scale) that might be needed to improve our ability to predict coastal change. While we tend to think of an observatory as a discrete location, observatory measurements can, and should, be made over a nested series of time and spatial scales ranging from high resolution regional mapping to describe the geologic framework, down to sets of integrated measurements at specific locations that can address process based issues such as sediment transport. Coastal change programs should take advantage of infrastructure to be put in place as a result of the Orion/IOOS initiatives, and also of advances in technology that allow more detailed and rapid mapping of the nearshore environment.

Larry Mayer, from the University of New Hampshire, showed spectacular images of seafloor morphology that were simply not possible to collect until very recently. The now cm level of resolution that is achievable can, with frequent repeat surveys, permit us to understand the large scale behavior of features such as ripple fields (e.g., Goff et al., in press). When these repeat surveys are combined with small scale process based studies (e.g. acoustic sensing experiments such as those described by Geyer below (Traykovski et al., 1999)), we can start to understand the key sediment transport processes on much larger spatial scales. It is also now becoming possible to combine high resolution land topographic data obtained with LIDAR with offshore data, providing a seamless data set from one regime to the other. This is especially important in the context of rising sea level as, in the past, the critical inter-tidal region was poorly defined.

There are a range of morphodynamic processes that occur on the inner shelf, spanning a range of time and spatial scales that are inherently linked with the evolution of the coastline through dispersal of sediments by waves, tides and currents. Gail Kineke, from Boston College, described the roles of the three fundamental mechanisms of suspended-sediment transport: advection, mixing and settling. Examples were given of the technology, much of it new, that is available to measure each transport component. Some of the more recent observations have challenged conventional ideas of sediment transport and delivery to the shelf, and a particular example is the role of fluid muds in shaping muddy coastlines and continental shelves (e.g., Kineke & Sternberg, 1995; Traykovski et al., 2000). Despite the recent breakthroughs, some critical issues persist and these include accurate assessment of fine particle dynamics in the role of settling, and the role of variable bed roughness.

The onshore portion of the coastal zone, including beaches, dunes, lakes, wetlands, and deltas, constitutes an integral part of the coastal zone and contains an archive of oceanographic, climatic, and sea-level changes. Ilya Buynevich (WHOI) described a number of geophysical techniques that can be used to image the shallow subsurface of coastal sedimentary sequences. Ground-penetrating radar (GPR) is a high-resolution geophysical tool that has revolutionized coastal stratigraphic research. Despite its limitations in saltwater-saturated sediments, GPR allows rapid continuous data collection with typical penetration of 8-12 m for a 200 MHz antenna. GPR has been used for imaging the facies boundaries within barrier and deltaic systems, mapping paleo-shorelines and stratigraphy of lake-basin fills, resolving the erosional features in coastal lithosomes (buried storm scarps, unconformities, and breach channels), and for hydrogeological studies in the coastal zone (e.g., Buynevich and FitzGerald., 2003; Buynevich et al., 2003). In many mixed-sediment regions, coring can be difficult, making geophysical tools indispensable in stratigraphic research. Other methods that are being used in terrestrial and lacustrine settings, as well as offshore, include electromagnetic surveying and electrical resistivity imaging (e.g., Evans et al., 1999, 2000; Evans and Lizarralde, 2003; Ruppel et al., 2000), which provide data on the physical properties of sediments in the shallow subsurface.

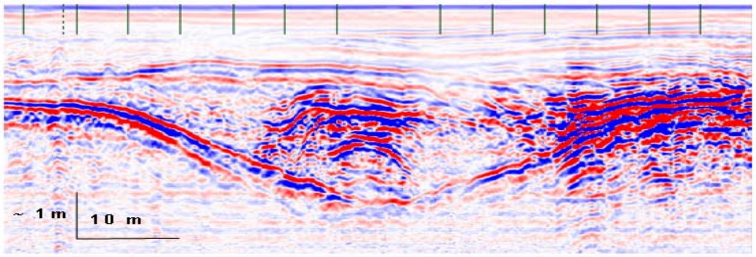


Figure 5. A ground penetrating radar (GPR) images across a coastal barrier system in Falmouth, Mass. The structure of a relict inlet feature can be clearly seen in the subsurface. There is no surface expression of the inlet and its formation pre-dates historical records for the area. GPR has proven to be a valuable tool in barrier settings, providing high resolution stratigraphic information that extends our knowledge of the barrier history back further than societal records.

Sediment sampling and ground-truthing the geophysical data requires a variety of coring techniques, suited for a range of sediment compositions and saturation regimes. Standard vibracores allow preservation of physical sedimentary structures, with penetration depths of 5-6 m in coarse-grained sediments and deeper in muddy sequences. Other systems, such as hand-operated boring apparatus, although disruptive to sedimentary structures, are highly portable and enable penetration of more than 10 m in sandy coastal lithosomes. In areas where deeper sampling is needed commercially available drilling platforms, such as Geoprobe, are being used.

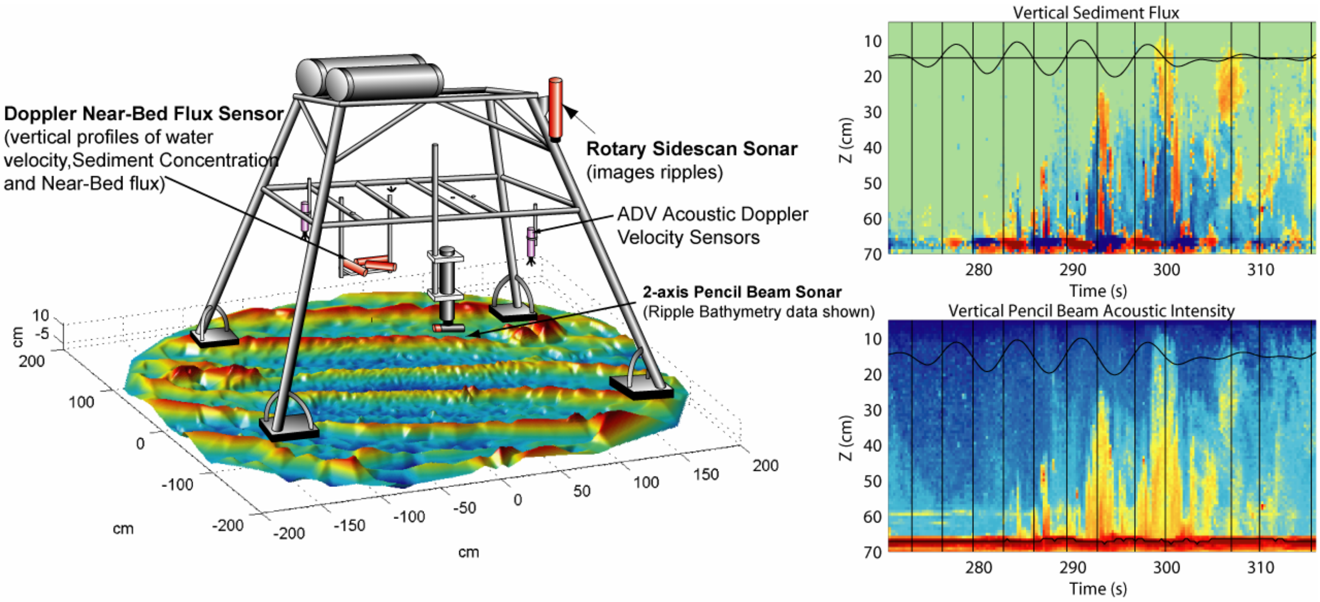


Figure 6. Measuring bedload in all but the most controlled laboratory environments has been a significant challenge for sediment transport research. While mechanical bedload samplers exist for unidirectional flow environments these devices often produce unreliable results and can interfere with the process they are sampling. In the past two decades acoustic backscatter based techniques have been used to measure suspended sediment flux. Some of the advantages of these techniques are that they are remote (i.e., 1 to 2 m range), they have the ability to produce high temporal and spatial resolution vertical profiles of a suspension, and they are robust for long time series measurements in energetic conditions. Recently, scientists have been investigating the use of acoustic Doppler and backscatter to measure near-bed flux, including bedload flux. The conceptual basis for this type of measurement is that the stationary bed will not produce a Doppler shift and grains moving immediately above the bed, while difficult to resolve spatially from the stationary bed, will produce a measurable Doppler shift.

The figure depicts a system that has been recently deployed at the Martha's Vineyard Coastal Observatory (MVCO) to measure the linkages between sediment transport and bedform processes. It has a Doppler profiling system (Near-bed flux sensor) that measures profiles of velocity, sediment concentration and suspended flux and near-bed flux. It also has several systems to measure small a scale changes in ripple topography. Data from this system is revealing how sediment flux on an individual wave time scale controls bedform migration and geometric evolution. Figure courtesy of Peter Traykovski, WHOI.

For chronological control and paleo-environmental reconstruction of the marginal-marine systems, a suite of dating techniques is available. These are being continuously refined due to improvements in sampling and analytical tools. For organic sediments and compounds, AMS radiocarbon dating is a standard technique, complemented by uranium-series age-dating. Isotopic proxies (lead-210, cesium-137, beryllium-7) provide high-resolution chronologies for the most recent events. For the inorganic fraction of Quaternary sediments (quartz, feldspar, zircon), optically-stimulated luminescence has proven to be a successful and accurate dating tool in the range of decades to 300,000 years. With new advances in global positioning system technology, the geological data are being integrated into regional databases of coastal change with potential for 3-D visualization of stratigraphic architecture and onshore-offshore links between multiple databases.

3. Workshop Discussion

The workshop, with a smaller invited participant list (see Appendix A), aimed to identify the outstanding issues in coastal change and devise a strategic plan to address them.

Over the past few decades, applied coastal research has been routinely handicapped by the lack of a dedicated program at NSF. Much of the work in the coastal arena falls between EAR and OCE and as a result often falls through the cracks in each division. Given the obvious societal need and the existing role of federal and state agencies in coastal change (e.g. USGS, Army Corps of Engineers, NOAA), it is likely that the most effective national program will feature a marriage of these agencies each with specific agendas and needs. For example, the USGS already provides mapping capabilities that should be exploited within the framework of a larger program.

The focus of NSF supported science should be on the fundamental processes occurring in the nearshore environment. However, while coastal managers present at the workshop emphasized their need for basic research to be carried out, their needs are often greatest in regions of complexity (mixed-sediment beaches, cobble beaches, near and around inlets) that are typically avoided in hypothesis-driven science presented to NSF. This speaks to the need for a multi-agency program under which work in areas of greater complexity might be supported.

3.1 What are the Over-Arching Science Questions to be Addressed?

The workshop discussion focused on the outstanding science questions that need to be addressed before we have a realistic chance of predicting shoreline change at the time and spatial scales relevant to decision making in the coastal zone. Many science priorities in terms of field experiments, testing key hypotheses of shoreline evolution, as well as the monitoring infrastructure needed to answer them were discussed.

Some of the questions discussed include:

- What is the role of rising sea level on shoreline change and how is the shoreline changing on decadal time-scales?
- How will barrier systems evolve in a regime of rising sea level and what will be the impact on backbarrier ecology?

- What is the impact of modifying sediment and water discharge from land on sediment budgets, coastal stability, and ecology?
- Can we quantify the thresholds controlling major coastal change (i.e. barrier breaching, overwash, storm induced offshore transport)

In the next section we provide more details on these issues and how they might be addressed through specific examples.

3.1.1 Examples of Specific Research Areas:

Along-coast variations in decadal-scale shoreline change.

Many studies of nearshore processes have been conducted on long, straight shorelines, and the mechanisms driving shoreline change along more typical coasts with complicated nearshore and surf zone bathymetry, inlets, and headlands are much less well understood. In particular, the relative importance of alongshore and cross-shore sediment transport to beach erosion and accretion, and the role of inlets as sources or sinks of sediment, must be examined to improve decadal and longer-term models for shoreline change. Future studies focused on wave propagation on complex coastlines, and the corresponding wave-driven nearshore circulation, sediment transport, and morphological change, are needed to develop and test models that coastal planners can use to predict shoreline evolution in response to changing climate, sea level, and storminess. Experiments being considered for the near future include studies of the feedback between waves, circulation, and the evolution of a field of alongshore inhomogeneous sandbars, and an examination of the role of nearshore waves and circulation to the migration of a natural inlet and to the erosion and accretion of the neighboring beaches.

An important goal is to test and improve wave models for prediction of along-coast gradients in wave characteristics, in particular on the East Coast where wave prediction capabilities lag far behind the West Coast. Improved wave modeling capabilities can then be used to test models of large-scale shoreline change variability. The role of the underlying geologic framework in controlling shoreline change at this scale needs to be addressed as an integral part of the modeling.

> *What is Needed?*
> A network of along-coast wave arrays in conjunction with modeling efforts. We need to place these where we expect a significant along-coast variation in wave characteristics, where the coastal response is well-quantified, and where enough information exists to assess the geological constraints.

Regional response to sea-level rise

Our goal is to predict the regionally-averaged shoreline response to a given change in the rate of sea-level rise. Historical records are too short for a meaningful projection of coastal response to sea-level change even for the next few decades; scientists need to turn to detailed geological reconstructions to understand the background against which to examine human-influenced sea-level changes, and to geologically-preserved analogs that record the response of the coast in situations similar to those predicted in the future. There is ample evidence that there is no simple way to do this without knowing a lot about the geologic framework and sediment budget of a region (i.e., sources or sinks related to tidal inlets or coastal bluffs). To date, only a handful of studies (mostly academic thesis research and regional mapping efforts, in particular those by the USGS) have attempted to integrate the regional geological framework that encompasses both onshore and offshore components of the coastal system and addresses land-sea interaction on appropriate temporal and spatial scales.

In order to fully understand and predict the effects of greenhouse-driven eustatic sea-level rise, it is critical to understand, at a high level of detail, the history of sea-level rise, including the nature of vertical crustal movements along the US shorelines. These consist of both isostatic and tectonic movements that operate over relatively long time scales. Since crustal movements can be either positive or negative, and have magnitudes on the order of mm's per year, they can significantly modulate projections of future relative sea-level change. Thus, this information needs to be taken into account to enable successful coastal forecasting.

> *What is Needed*?
> A concentrated application of a variety of coastal evolution models to coastal systems where we have the best information on the geologic framework and where we can evaluate how changes in climate (including the tectonic impacts of ice loading and post-glacial rebound), sea level, and sediment supply may have driven past shoreline change. The models of large-scale coastal evolution should be applied first in a hindcasting mode to test their ability to reconstruct the present coastal morphology and stratigraphy, followed by a forecasting mode to assess the possible impact of climate and future sea-level rise scenarios.
>
> Geophysical models that calculate relative sea-level changes as a sum of eustatic, isostatic, and tectonic components, need to be sufficiently powerful to make meaningful predictions for any stretch of shoreline. In order to validate and fine-tune such geophysical models, a large amount of new, high-resolution Holocene sea-level data is needed, from many of our coastal zones. In addition, Holocene sea-level data should be collected in conjunction with other techniques that focus on quantifying crustal movements, notably the rapidly expanding networks of continuous GPS stations. Associated with such an effort should be the establishment of a national sea-level database.

Modeling the Response of a Barrier Coast in a Regime of Accelerated Sea-Level Rise

In a regime of accelerated sea-level rise the Bruun concept predicts that sand will be transferred from the beach to the nearshore in order to re-establish the equilibrium slope (Bruun, 1988; Pilkey et al., 1993). Added to this loss of sediment from the barrier is the sand that will be removed from the littoral system at tidal inlets. The condition applies to mixed-energy barrier coasts such as those along the East Coast of the United States, East Friesian Islands in the North Sea, and the Copper River Delta barriers in the Gulf of

Alaska. These coasts are characterized by short stubby barrier islands, numerous tidal inlets, well developed ebb-tidal deltas, and a backbarrier consisting of supratidal salt marshes, tidal flats, and/or mangroves incised by tidal creeks. An acceleration in the rate of sea-level rise will gradually, or catastrophically depending upon the rate, change the hypsometry of the backbarrier transforming supratidal areas to open water and intertidal environments. The loss of marshlands will increase tidal exchange between the ocean and backbarrier and ultimately change the hydraulic regime of the tidal inlets. The growth of both ebb and flood-tidal deltas diminishes the supply of sand along the coast leading to a fragmentation of the barrier chain and formation of a transgressive coastal system. It has been shown along mixed-energy coasts that the sand contained in ebb-tidal deltas may be comparable in volume to that of the adjacent barriers (FitzGerald, 1988). The ultimate fate of barriers and their re-establishment onshore is dependent on the trend of sea-level rise.

The latest report of the International Panel on Climate Change (IPCC) predicts that based on global warming and other factors, future sea-level rise during this century could range from 25 to 90 cm (Church et al., 2001). The average Holocene rate of ~55 cm per century may serve as a reasonable estimate on which to base predictions of coastal evolution (although rates have varied greatly through the Holocene and even today vary greatly from region to region as a result of post-glacial rebound). An extensive literature review suggests that low marshes accrete at a rate of 5.6 mm/year through the deposition of inorganic sediment and the accumulation of organic material. Supratidal and high marshes build vertically at a much slower rate (2.2 mm/yr) due to much lower contributions of inorganic sediment and higher elevation compared to low marshes (Fig. 7). Even if we presume that vertical accretion is solely a function of inorganic and organic matter influx and ignore the effects of regional subsidence and tectonic uplift along our coastlines, it is clear that many marshes will not be able to keep up with the projected acceleration in the rate of sea-level rise. This condition will trigger: (1) the wholesale conversion of marshlands to subtidal and intertidal areas; (2) the sequestration of sand on tidal deltas; and (3) the catastrophic loss of sand from barriers. A conceptual model of coastal evolution in a regime of accelerated sea level rise is presented in Figure 8 (FitzGerald et al., 2004). The fact that the East and Gulf coasts of the United States and many other regions of the world are fronted by barrier chains (approximately 15% of world shoreline; Glaser, 1978) suggests that accelerated sea level rise may cause devastation to barrier coasts. For example, the East Coast contains several trillion dollars of infrastructure and property, which would be severely adversely impacted by an acceleration in sea-level rise.

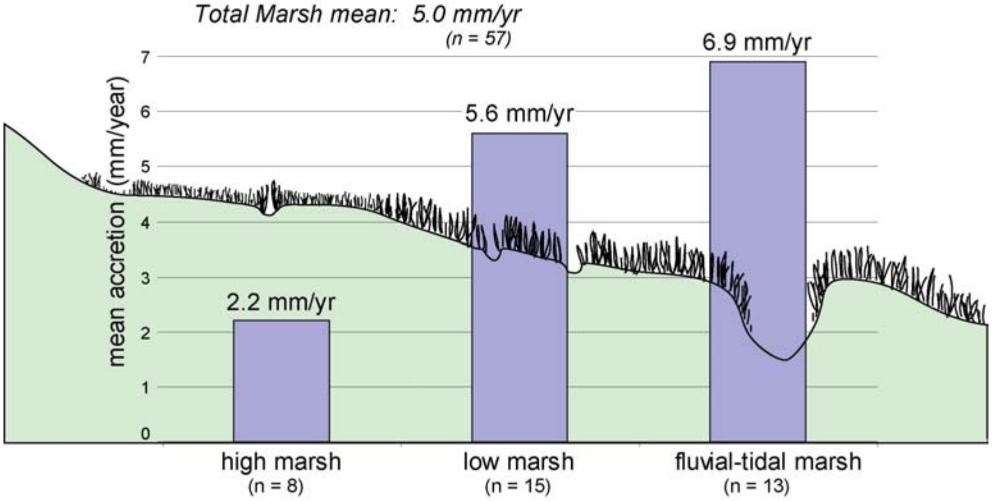


Figure 7. Average yearly rates of vertical accretion for different marsh environments (from FitzGerald et al., 2004).

What is Needed ?

The various stages and coastal processes depicted in the conceptual model in Figure 8 can be demonstrated using historical morphological data for barrier systems throughout the world (FitzGerald et al. 2004). Although the general progression from stage to stage is reasonably predictable, the rate at which the coast evolves given a certain rate of sea-level rise is unknown (Van Goor et al., 2003). For example, it has not been determined at what stage the inlet will be transformed from a channel system that naturally flushes sand by dominant ebb tidal currents to one in which dominant flood tidal currents import sand to the backbarrier. It has been shown by many investigators that the relative strength of the ebb versus flood tidal flow, which controls the net movement of bedload into or out of the inlet is a function of inlet geometry, bay tidal prism, and backbarrier hypsometry (Mota Oliveira, 1970; Boon and Byrne, 1981; Aubrey and Speer, 1985; van de Kreeke, 1998). Focusing on backbarrier hypsometry, it has been shown that large open water bays are conducive to flood dominant inlets, whereas ebb-dominated inlets contain extensive intertidal areas. Looking at the conceptual model (Fig. 8), it is seen that as intertidal areas and supratidal areas are converted to open water (subtidal areas) inlet hydraulics transition from ebb dominance (present condition of most mixed energy barrier coasts) to flood dominance (predicted future conditions).

Mapping and monitoring efforts in these settings, using the techniques described above, will allow us to model how tidal systems will respond in a regime of accelerated sea-level rise to enlarging tidal prisms (the volume of water entering the backbarrier in a tidal cycle) and changes in backbarrier hypsometry. Different bay sizes and configurations of supra-tidal, intertidal, and subtidal areas need to be modeled in order to determine thresholds controlling net directions of sand transport. Ultimately, we wish to quantify a paradigm for barrier coast evolution that is conceptualized in Figure 8. It is expected that this research will have direct relevance to other projects such as Barrier Island Restoration Project presently being undertaken along the coast of Louisiana. The effort in Louisiana requires information concerning how changes in wetland loss will affect tidal inlet stability and sand transport pathways.

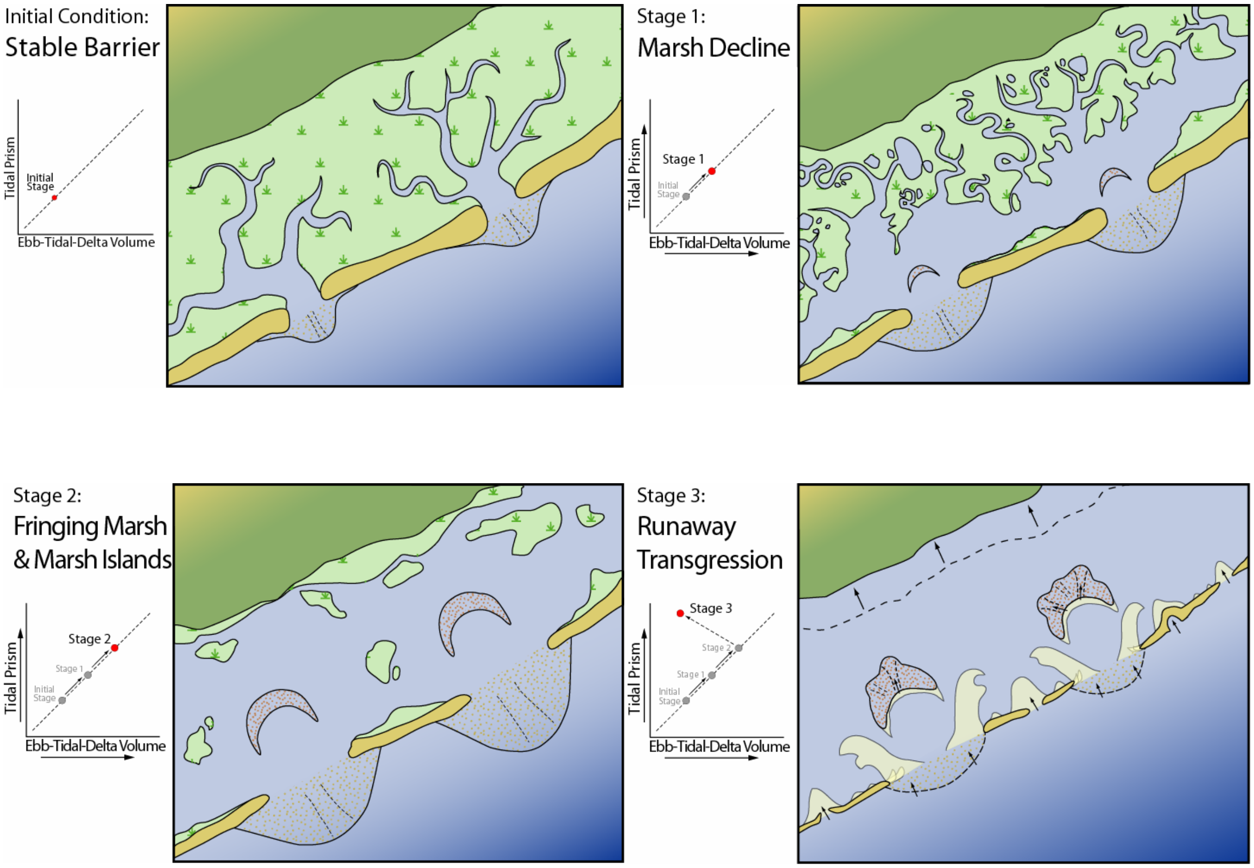


Figure 8. Conceptual model of mixed energy barrier coast evolution in a regime of accelerated sea-level rise (from FitzGerald et al. 2004). Tidal prism is the volume of water entering the backbarrier in a tidal cycle, and increases with rising sea-level.

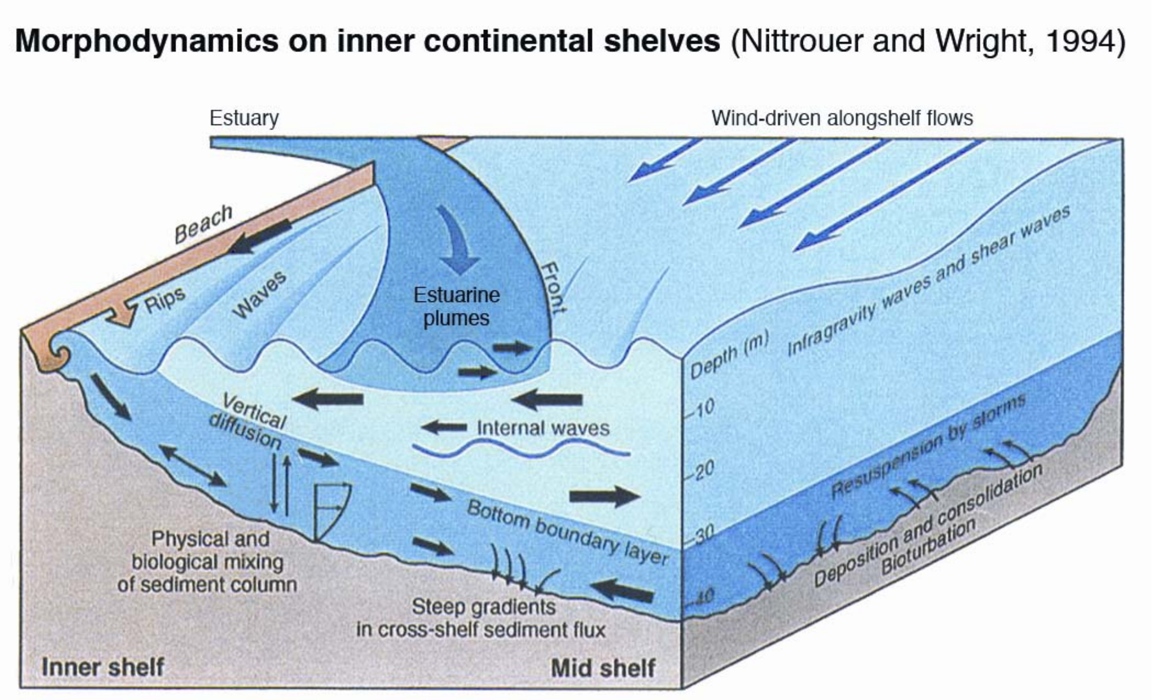
Impacts of storms

Given that intense storms often result in substantial loss of life and resources, we know little about the processes that govern the formation, intensity, and track of severe storms. Due to the relatively short period of reliable instrumental and historic records, little is known about past storm activity in general. For example reliable records for Atlantic tropical cyclone activity, maintained by the National Oceanic and Atmospheric Administration (NOAA), only extend back to the mid 19th century, and an often incomplete historical record of North Atlantic hurricanes dates back several hundred years. For example, the 1635 event recorded in southern New England by early European settlers was apparently more severe than the devastating and more widely known 1938 hurricane (Donnelly et al., 2004). Geological investigations of coastal environments can provide long-term records of environmental change that can be used to address how these systems have responded to changing conditions in the past.

Records of past storms can be found in backbarrier sediments as washover events, many of which can be dated (e.g., Donnelly et al., 2001; Donnelly & Webb, 2004). Mapping out regional occurrences of these overwash deposits can allow past storminess to be estimated and hence probabilities of storm strikes. These kinds of studies provide a framework within which we can begin to predict how coastal areas may respond to future changes in storminess and sea level. Given the current threats to coastal environments, two critical questions arise: 1) How are storminess and sea-level changes related to climate variability on regional to global scales? 2) How have coastal systems responded to past changes in sea level and storm regimes?

Linking the Shore to the Shelf

In the past, beach and surfzone studies and shelf studies have often been separated and studied independently, perhaps due to the logistical barriers presented in combining land-based shallow water work, with shipboard measurements and mooring deployments. However, if we are to fully understand the coastal system, one of the challenges is to eliminate this imaginary barrier. We must seek ways to link the terrestrial and marine realms, and to extend shallow water measurements to deeper water - and the reverse - for spatial continuity and a full understanding of relevant processes and transitions. The region from the 0 to 10 m water depth on an open coast can present some of the most difficult areas to sample. These areas are too shallow for an ocean-going vessel, and too deep or energetic for individuals. However, the zone from 10 m above sea level to 10 m below is perhaps the most dynamic setting and most the vulnerable physically and ecologically. Addressing many of the questions posed above requires use to conduct research within this critical boundary zone.



Morphodynamics on inner continental shelves (Nittrouer and Wright, 1994)

Figure 9. A schematic showing the variety of transport processes operative in the nearshore and continental shelf environments.

Wave Energy Models

Ocean surface waves are the dominant source of energy in the nearshore environment and the principal driving force for sediment transport that causes shoreline change. Accurate estimates of wave energy near the shoreline are of critical importance for predicting shoreline change. Whereas wind, sea and swell conditions in the open ocean vary gradually over typical scales of a few hundred km, waves traveling across the continental shelf are affected by interactions with the underwater topography (refraction and scattering) that enhance the variability of wave conditions along the shore. It has been suggested that “erosional hotspots” observed along the U.S. coast are the result of these local topographic effects. In regions with complex shelf topography (e.g. submarine canyons and shoals) wave heights can vary substantially over distances of only a few hundred meters. Additionally, bottom friction and wave breaking can cause strong decay of waves traveling across wide continental shelves or shallow banks and shoals. The associated divergence or convergence of sediment transport causes bottom erosion or accretion and the resulting change in morphology affects the wave evolution. The coupled dynamics between waves and seafloor evolution are not well understood. Although high-resolution numerical models, capable of resolving small scale topographic effects across the entire continental shelf, are becoming available, the heuristic parameterizations of wave breaking and bottom friction and limited resolution of bathymetry surveys still contribute considerable uncertainty in predictions. On the other hand, shoreline erosion and accretion has been documented on many coastlines but the role of wave variability in these changes remains unclear owing to a lack of coincident wave measurements. Comprehensive experiments are needed to unravel the mechanisms and feedback between waves and shoreline change. We envision a set of experiments at different types of coastlines that include long-term (i.e. numerous storms) and detailed monitoring of both the wave field and changes in the bathymetry and shoreline. The wave measurements need to be used in conjunction with numerical models to obtain an accurate representation of the wave field over the region that can be used to test sediment transport models. These experiments will provide a unique dataset for the future development and testing of coupled wave-sediment transport models.

Modeling Needs

The modeling of processes occurring on the sub-tidal to seasonal time scale requires more field observations of the key processes so that the relative importance of each can be better assessed. These kinds of observations can be made within an observatory framework. More detailed observations of shoreline change, for example of the kind discussed by Jeff List, are important for improving the predictive capabilities of models through comparison and hind-casting.

As a better understanding of the key short-term processes becomes available, along with quantitative parameterizations of their impact on shoreline change, they can be more accurately incorporated into longer time-scale (decadal) coastal models which, at present, deal with such processes in an empirical sense.

Understanding Future Coastal Changes from Past Dynamics

High-resolution records from a variety of sources (e.g., deep sea sediments, ice sheets, corals, speleothems) show that abrupt paleo-environmental changes are a common occurrence; the late Holocene sea level has been in this respect uncharacteristically stable. The modern coastal system has developed in these highstand conditions; however, the remarkable diversity displayed by coastal landforms, even in this stable sea level context, stresses the importance of other parameters in forcing the dynamics of the shoreline. Coasts are complex transitional environments that respond to the variability of both continental and marine processes. Many coastal and shelf settings have high sedimentation rates recording this complex variability, but these archives have yet to be systematically studied. By matching paleo-environmental information from coastal settings to established land and marine proxies, a common chronological and spatial framework can be established and used to understand how the interaction of terrestrial and marine processes controls the dynamics of the coast. Future studies should also address the difficult problem of coastal dynamics in conditions that have no present analog but are expected to occur in the future (e.g., accelerated sea level rise, increased storminess at high latitudes settings, extreme variability in sediment supply).

> *What is Needed?*
>
> Geological and geophysical datasets from a variety of coastal depositional settings that would allow a detailed reconstruction of their stratigraphic architecture, coupled with biological, geochemical, and sedimentological proxy records of

local/regional paleoenvironmental variability that can be correlated/compared to global indices. Numerical models should be developed that will use the detailed information that these focus sites will provide to test ideas about coastal morphodynamics over a range of spatial and temporal scales. We also need to address situations that have no present-day analog by studying coastal deposits preserved in the geological records.

3.2 What are the Science Priorities?

We discussed larger-scale science goals and defined the types of measurements that might be needed to address them. In this section, it is accepted that we have an overarching goal of improving predictions and understanding of shoreline change on all relevant time and spatial scales. Given this, there were clear gaps in our current abilities and these include the need for:

- Improvement in hydrodynamic and morphodynamic modeling (needed for modeling beach processes, estuarine circulation, inlet migration, river mouth processes, estuarine and lowland marsh flooding, etc)
- Quantification of the trends and scales of sealevel change and shoreline recession/progradation (needed to facilitate coastal management, to evaluate long-term models for shoreline change, and to put short-term process studies in regional context)
- Determination of the links between the large scale biological and geological framework and shoreline change.

In addition to focusing on simple coastal settings, there was a consensus that study areas should span a range of sediment and oceanographic conditions (e.g., gravelly, sandy, muddy, and different wave energy conditions, etc.).

To address these priorities, we suggest that experiments should include alongshore arrays of directional wave buoys (needed to improve wave models, to determine trends in storminess, and to drive models for nearshore and estuarine processes), surveys of the beach morphology (for example, bi-annual LIDAR surveys supplemented with monthly waverunner/GPS surveys to determine the shorter-scale fluctuations and aliasing), and mapping of the framework geology and ecology. High resolution imaging of subbottom sedimentary strata involving 2D and 3D seismic, electrical resistivity, and electromagnetic techniques should be employed consistently to understand how modern events are preserved in the sedimentary record which we ultimately use to derive long-term trends in coastal processes. Other suggested instrumentation included CODAR for large scale circulation, alongshore arrays of pressure gauges to measure long wavelength waves, and hard-ground mounted tidal gauges to measure local variations and regional trends in sea-level rise.

From a surf zone/nearshore perspective, scientific priorities include determining the relative importance of along-shore and cross-shore sediment transport in different environments, and evaluating the differences in the transport of mud and sand. Many previous surf zone studies have been conducted on long, straight, sandy beaches where the physics has been assumed to be roughly 1-dimensional. However, we now know that alongshore gradients in transport owing to alongshore inhomogeneous surf zone bathymetry and/or alongshore variations in the incident waves (e.g., caused by alongshore inhomogeneous shelf bathymetry), larger-scale flows (e.g., caused by inlets), and sediment supplies (e.g., caused by river plumes, inlets, etc) can dominate the shoreline evolution. We need to examine these more complicated coastal areas. Additionally, we know that fine sediments (e.g., mud) can behave very differently from sands. Many coastlines are muddy, especially near some of the most ecologically sensitive regions. Furthermore, future increases in precipitation could result in more mud being delivered to the coastal ocean. In many regions, even the coarse-grained bedload contribution by river systems remains in question and is rarely quantified. We need to understand the differences in the response of muddy and sandy coastlines to wave and current forcing. Finally, many areas of high societal interest are heavily reinforced with man-made structures that cause additional alongshore inhomogeneities. The effects of these structures and armoring projects on the evolution and ecology of coastal regions are not well understood.

Many of the research needs expressed by coastal managers at the meeting echo those of the scientists. Some of their basic research needs are summarized as:

- Research that includes applying our knowledge of processes that occur on relatively simple coastlines to more complex, altered shorelines (those with seawalls, bulkheads, jetties, groins etc).
- Littoral cell mapping to define the geologic framework and habitat conditions.
- Accurate sea-level rise data.
- Studies in mixed sediment environments (ranging from sandy mud to sandy gravel)
- Scientific analyses on the effects of removing or modifying engineering structures.
- Studies on impacts of sediment removal on habitat.

This overlap between basic science and applied needs is a compelling argument for increased research and funding in this area and speaks to a potentially large broad impact component to future scientific commitments.

3.3 The Role of Coastal Observatories

Given the rise in observatory-based science, and the fact that our aims include monitoring and understanding shoreline change on a variety of time and spatial scales, we spent time discussing the observatory concept from the viewpoint of coastal change research. It is important to note that by observatory we do not simply mean a fixed node or series of nodes on the seafloor, but an integrated network of nested scientific experiments that span the coastal system we are trying to understand. Thus, for example, an observatory on the outer Cape Cod might include the bluffs, beaches, barriers, tidal inlets, bays and marshes, and inner continental shelf extending to Georges Bank. By integrating observations collected over several years or even decades on hydrodynamics, the currently changing morphology, as well as on the evolution of the Outer Cape, we can start to develop predictive capabilities for coastal changes for that region that might be exported to other coastal settings. A better understanding of the role played by the underlying geologic framework in coastal dynamics has emerged from discussions as an important factor to be considered in defining the scale and scope of an observatory.

Ideally, an observatory would provide the long term, large scale observations that are needed both to understand the trends and fluctuations of coastal processes and to put process-based studies in context for coastal researchers, engineers, managers and the public. Additionally, we mentioned that we would like an observatory to provide a base for shorter, process-based studies. Thus the observatories should be located to optimize the science that will be addressed on both short and long time scales. Finally, it was suggested that the directors of an observatory could benefit the community by organizing local and regional workshops, including updates on results, hypotheses, and priorities from researchers in many different fields (e.g., studying processes affecting the physical, economical, and ecological aspects of shoreline change) to enable links between processes to be examined and to facilitate interdisciplinary research.

> *What is Needed?*
>
> A program which invites proposals for multi-disciplinary integrated experiments at well chosen locales (spanning a range of coastal settings) and which offers sustained funding enabling sufficiently long time series measurements to be collected. The program should encompass the interests of EAR and OCE to the extent that it recognizes the need for both terrestrial and offshore work. Proposals would best be evaluated by a separate and specialist panel with knowledge and expertise in coastal issues. In the discussion above, we suggest that the broad range of needs for research in the coastal zone might best be served by a multi-agency program.
>
> While still to be fully developed, many of these concepts match those planned for the two types of coastal observatories under the NSF-supported Orion program: those that are fixed in location and those which make process based measurements for a period of 5 years or so. We would argue that the scope of the Orion observatories should encompass the barrier, bays and marshes, beach and surf zone. We would also encourage research to be carried out in areas where Orion and IOOS provide relevant data such as wave directional information. In addition to Orion, there are other programs and initiatives which are starting to provide the framework mapping in coastal areas. In response to the Ocean Commission report, the senate has recently proposed a bill which would, within NOAA, integrate mapping efforts in coastal waters.

3.4 Ocean Commission Report

Chapter 12 of the US Commission on Ocean Policy deals with management of sediment in the nation's coastal environment. Within that chapter are a number of comments or recommendations that are of particular relevance to the research goals described in this document.

Within the section describing beach nourishment (page 141) it is noted that in 1997, the National Research Council highlighted “an inadequate understanding of the physical and biological mechanisms of beach and littoral systems.’’ The report notes that achieving the goal of better targeting investment in areas that will reap the highest cost/benefit ratio will “require a better understanding of sediment processes.’’

On Page 142, the section titled “Improving Understanding, Assessment and Treatment’’ opens with a statement that “An enormous stumbling block to improved sediment management is a poor understanding of sediment processes in the marine environment.’’ The report further highlights one of the concerns echoed by workshop participants and colleagues in coastal research that funding in this area is fragmented, uncoordinated and insufficient.

In recommendation 12-4 of the report, the Army Corps of Engineers, NOAA, the US EPA and the USGS are encouraged to develop a strategy for improved assessment, monitoring research and technology development to enhance sediment management. It is unfortunate that the recommendation does not go further and suggest that NSF support basic science research in this area to increase understanding of the fundamental processes of sediment transport deemed so important but so poorly understood earlier in Chapter 12. We must also recognize that the specific missions of the different federal agencies (including NSF) can be better addressed by working cooperatively amongst themselves and in their interactions with academia and the private sector. One means to do this would be the creation of a multi-agency initiative that addresses the mission criteria of the participating agencies, such as has been done for the ECOHAB and GEOHAB programs studying the impacts of harmful algal blooms (Anderson, 1995; GEOHAB, 2001, 2003).

4. Education and Outreach

Increased research activity in the coastal environment offers a golden opportunity to educate the public, not only about the critical processes shaping our shorelines, but also about the importance of carrying out marine research and science in general. The coastal ocean is one aspect of marine science that most of the public can relate to, in many cases through direct contact or experience. Here, we can demonstrate the process of basic science and its application to a problem of obvious and direct relevance. Thus, many proposals for coastal change research offer substantial broader impact and societal relevance. The shoreline is a readily accessible laboratory for a large portion of the US K-12 and undergraduate population, offering great potential for field based education programs tied in with on-going research efforts. Earth Science is already an important component of many K-12 curricula, but typically coastal processes are discussed in a non-quantitative context. An initiative in this area would provide an opportunity to better link coastal processes with other sciences in the curriculum, especially physics, biology and chemistry.

One of the major needs for the future is the training of the next generation of coastal scientists. Given the future coastal problems outlined above, and the current lack of NSF-style funding, the potentially most devastating consequence for coastal science is a severe lack of rigorously trained coastal researchers. This could become a huge problem that has already been noted by others [e.g., Anderson et al., 2002]. Apart from a boost in

NSF-funding that will more likely attract young researchers to the coastal field, we will also need to think about other avenues to make it more likely that these researchers will succeed. This could be done by explicit internship programs for graduate students at oceanographic institutions, and could also be done by further development of coastally oriented curricula at the graduate and undergraduate levels.

It was pointed out, during the workshop discussion, that in many cases there are examples of models and science that could be used by managers but that have not been effectively communicated to that audience. Clearly there is a need for better communication between scientists, coastal managers and engineers on the science that is in place and what its limitations are. The SeaGrant program already supports a significant amount of work in this area, distilling scientific results and making them understandable to a non-technical audience through presentations and workshops. Yet, more clearly needs to be done in this area and support needs to be given to scientists to work with those who are best able to communicate their results.

5. Summary Statement

The shortcourse and workshop held at WHOI identified a number of critical research areas in coastal change that need to be addressed through basic research activities if we are to improve our ability to predict future shoreline change and to better assess risks to coastal communities. This research includes many diverse processes that occur on a wide range of time and spatial scales. The consensus is that the time has never been better to carry out such research, but it needs to be done in an integrated, multi-disciplinary and sustained fashion. The obvious approach to addressing the fragmented and limited nature of research funds in this arena would be the establishment of a multi-agency initiative that satisfies the mission goals of the participating agencies. Clearly one of these goals should be the execution of high-quality process-based basic research of the kind normally supported by NSF. Upcoming observatory initiatives will provide some of the framework infrastructure to facilitate coastal change research. The results of this research needs to be clearly communicated to coastal managers and to the public through outreach, and also offers unique opportunities for K-12 education, linking coastal processes to basic science already within the curriculum.

Appendix A
Speakers and Workshop Participants

Rob. L. Evans – organizer
Ken Brink, COI WHOI
Don Anderson, COI WHOI

Mark Adams, National Park Service
Susan Antenen, The Nature Conservancy
Mark Bertness, Brown University
Ilya Buynevich, G&G WHOI
Mike Carlowitz, Communications WHOI,
Jeff Donnelly, G&G WHOI
Duncan FitzGerald, Boston University
Roger Flood, State University of New York, Stony Brook
Rocky Geyer, AOPE WHOI
Graham Giese, G&G WHOI/Highlands Center
Liviu Giosan, G&G WHOI
Allen Gontz, University of Maine
Rebecca Haney, Massachusetts Coastal Zone Management
Porter Hoagland, MPC WHOI
Tom Hsu, AOPE WHOI
Gail Kineke, Boston College
Jeff List, USGS Woods Hole
Larry Mayer, University of New Hampshire
Jim O'Connell, WHOI SeaGrant
Britt Raubenheimer, AOPE WHOI
Carolyn Ruppel, NSF (Shortcourse only)
Chris Sherwood, USGS Woods Hole
Bill Schwab, USGS Woods Hole
Peter Slovinsky, Maine Geological Survey
Joep Storms, Delft University of Technology, Netherlands
Rob Thieler, USGS Woods Hole
Torbjörn Törnqvist, University of Illinois at Chicago
Peter Traykovski, AOPE WHOI
Chris Weidmann, Waquoit Bay National Estuarine Research Reserve
Jeff Williams, USGS, Woods Hole

Additional contributors to this report:
Tom Herbers, Naval Postgraduate School, Monterey.

Appendix B:

Shortcourse Schedule:

Monday 26, 2004

Time	Title	Speaker/Affilliation
8:30 - 8:45	Introduction	Rob. L. Evans, Dept of Geology and Geophysics, WHOI
8:50-9:30	Setting the Stage: Links between Sealevel Rise, Framework Geology and Coastal Change	Bill Schwab, USGS Woods Hole
9:35-10:15	Accelerated Sea-Level Rise and its Potential Effects on Barrier Coasts of the World	Duncan Fitzgerald, Boston University
10:20-11:00	Storm Events and Other Coastal Hazards	Jeff Donnelly, Dept of Geology and Geophysics, WHOI
11:00 Break		
11:20-12:00	Economic Impact and Policy Issues of Continued Coastal Change	Porter Hoagland, Marine Policy Center, WHOI
12:00 Lunch		
1:30-2:10	Coastal Geomorphology	Liviu Giosan, Dept of Geology and Geophysics, WHOI
2:15-2:55	Shoreline Change: Measurement, Scales, and Processes	Jeff List, USGS, Woods Hole
3:00- 3:40	Surfzone Morphological Change	Britt Raubenheimer, Dept of Applied Ocean Physics and Enginering, WHOI
3:45-4:25	Impacts of Coastal Change on Ecosystems	Mark Bertness, Dept of Ecology and Evolutionary Biology, Brown University
4:30-6:00 Posters and Equipment Demonstrations		

Tuesday 27, 2004

Time	Title	Speaker/Affilliation
9:00-10:20	Modeling Studies and Links to Observations	
	(i) Long Term (Geologic Scale) processes (ii) Nearshore Sub-Tidal Processes	(i) Joep Storms, U. Delft, Netherlands (ii) Tom Hsu, Dept of Applied Ocean Physics and Engineering, WHOI
10:30-11:10	Offshore Mapping Tools	Larry Mayer, University of New Hampshire
11:15 Break		
11:30-12:10	Coastal Ocean Measurements	Gail Kineke, Boston College
12:15 Lunch		
1:45- 2:25	Onshore Surveying and Sampling Tools	Ilya Buynevich, Dept of Geology and Geophysics, WHOI
2:30-3:10	Role of Observatories in understanding coastal change processes.	Rocky Geyer, Dept of Applied Ocean Physics and Engineering, WHOI
3:15-3:50	National Assessment of Coastal Change	Rob Thieler, USGS Woods Hole

Poster presentations.

Name: Jim O'Connell
Affiliation: WHOI Sea Grant & Cape Cod Cooperative Extension
Title: (1) The Art & Science of Mapping Shorelines: Interpreting Shoreline Change- The Massachusetts Experience. (2) Long-term Shoreline Change Susceptibility: Cape Cod, MA

Name: Joe Kelley & Kristen M Lee
Affiliation: University of Maine
Poster Title: Submerged Environments of Saco Bay, Maine

Name: David D. Dow
Affiliation: NOAA/NMFS/NEFSC-Woods Hole Lab.
Poster Title: Waquoit Bay Watershed Ecological Risk Assessment: Using Science to Support Management

Name: Kristen Whiting-Grant
Affiliation: Maine Sea Grant/UMCE
Poster Title: Shoreline Change in Southern Maine

Name: Jeff Williams
Affiliation: USGS
Poster Title: Vulnerability of Cape Cod to Sea Level Rise and Coastal Change

Name: Roger Flood
Affiliation: Marine Sciences Research Center/Stony Brook Univ.
Poster Title: I can describe our studies on nearshore underwater morphology

Name: Allen M Gontz
Affiliation: Dept of Earth Sciences, University of Maine
Poster Title: Paleogeographic Reconstructions of the Black Ledges Pockmark Fields From 13 ka to Present

Name: Richard Raymond
Affiliation: Center for Coastal and Ocean Mapping, UNH
Poster Title: Observed MVCO Geomorphology using high resolution multibeam surveys

Name: Peter Slovinsky
Email: peter.a.slovinsky@maine.gov
Affiliation: Coastal Geologist, Maine Geological Survey
Poster Title: Identifying Future Erosion Hazard Areas in Maine

Name: Tim Cook
Affiliation: University of Delaware
Poster Title: Observations of Sediment Transport in the Delaware Estuary During Spring Runoff Conditions

Name: Elyse Scileppi
Affiliation: Brown University & University of Delaware
Poster Title: Sedimentary evidence of hurricane strikes from Western Long Island, New York

Name: Britt Argow
Affiliation: Boston University
Poster Title: Winter processes on a New England marsh: implications for wetlands survival in a regime of rising sea level

Name: Jo Ann Muramoto, Ph.D.
Affiliation: Falmouth Coastal Resources Working Group / The Horsley Witten Group
Poster Title: Coastal Armoring and the Future of Falmouth's South Shore

Name: Ilya Buynevich
Affiliation: Woods Hole Oceanographic Institution
Poster Title:

1) Multiple Shallow Channel Structures on GPR Profiles Provide Clues to Recent Coastal Drainage Along South Carolina's Grand Strand

2) Shoreface Architecture in a Sediment Starved System: Update from Intertidal Vibracores and Shore Perpendicular Chirp Data.

Name: Rob. L. Evans.
Affiliation: Woods Hole Oceanographic Institution
Poster Title: Marine Electromagnetic Tools for Mapping Offshore Sediments.

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