Anderson and others, 2001 EOS, 10/30/01

Researchers Focus Attention on Coastal Response to Climate Change

The world's population has been steadily migrating toward coastal cities, resulting in severe stress on coastal environments. But the most severe human impact on coastal regions may lie ahead as the rate of global sea-level rise accelerates and the impacts of global warming on coastal climates and oceanographic dynamics increase [*Varekamp and Thomas*, 1998; *Hinrichsen*, 1999; *Goodwin et al.*, 2000]. Little is currently being done to forecast the impact of global climate change on coasts during the next century and beyond. Indeed, there are still many politicians, and even some scientists, who doubt that global change is a real threat to society.

Coastal change occurs in response to natural processes that operate across a wide range of spatial and temporal scales. Long-term, century-scale impacts of climate change that will affect coastal environments include decimeter-scale sea-level rise; shifts in sea-surface temperatures, which will likely influence tropical storm tracks, as well as storm frequency and magnitude; and precipitation variations that may impact sediment flux to coastal areas. Other effects may include changes in coastal and ocean currents and wave regime.

Coastal scientists participating in the International Geosphere-Biosphere Program (IGBP) core projects on Past Global Changes (PAGES) and the Land-Ocean Interactions in the Coastal Zone program (LOICZ) generally agree that our ability to forecast coastal environmental change needs to be improved [*Goodwin et al.*, 2000]. A report from the Subcommittee on U.S. Coastal Ocean Science (SUSCOS) concludes that these predictive capabilities should encompass both the short term and long term, and that research should focus on developing methods for assessing the impacts of natural changes on coastal environments [*Scavia et al.*, 1995]. Until scientists are able to forecast coastal change with some level of confidence, there is little hope that serious long-term coastal planning and management will occur.

Many aspects of coastal change are poorly understood, largely because fundamental knowledge of many of the coastal change-forcing mechanisms is limited to sparse observations of modern variability gained through coastal monitoring. The best way to examine coastal response to long-term forcing agents is to study how different coastal systems have responded to these forcing agents in the past. The questions that must be addressed are: what has the nature of coastal change been during the last few thousand years, and how do we apply this information to coastal planning and management scenarios?

Future Impact of Rising Sea Level

One of the key issues raised in the Intergovernmental Panel on Climate Change (IPCC) Report concerns the potential impact of global warming on sea level; specifically, the magnitude and rate of sea-level rise that will occur over the next century [*Warrick et al.*, 1996]. Although future changes in global temperature and sea level are difficult to predict and subject to debate, long-term tide gauge records and radiocarbon dating of salt marsh deposits indicate that the rate of sea-level rise has increased during the past century. It is clear that an increased rate of sea-level rise will have a number of adverse impacts on world coasts, such as wetlands loss and accelerated coastal erosion, but the magnitude of these changes remains unpredictable.

Modern coasts and estuaries of the U.S. East Coast and Gulf Coast evolved during an interval of relatively slow sea-level rise (15–25 cm/century) that spanned the past 4,000 years.

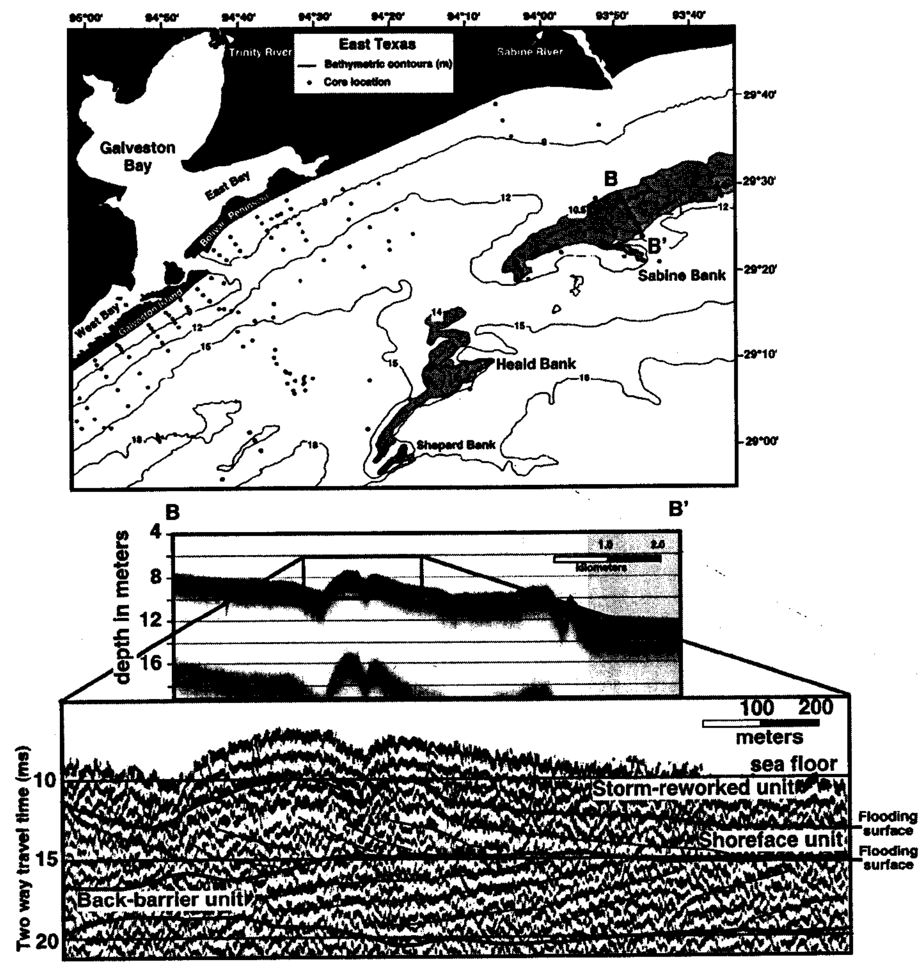

Fig. 1. Banks located off the east Texas coast represent former barrier shorelines that have been drowned in place by rising sea level. Section B-B' is a bathymetric profile across Sabine Bank with a segment of a high-resolution seismic profile collected along with a transect of sediment cores through the bank. The seismic profile shows a landward-dipping unit, which cores reveal contains backshore fossils (back-barrier unit). This unit is separated from a seaward-dipping unit that contains offshore, shallow marine faunas (shoreface unit) by a prominent flooding surface [Rodriguez et al., *1999]. Another flooding surface near the top of the bank marks the final episode of barrier submergence.*

Prior to this time, sea level was rising at a faster rate (average 100 cm/century) in response to ice sheet melting in both hemispheres. During the past 10,000 years, the east Texas coast has retreated landward approximately 50 km at an average rate of 5 m/yr. This is five times the current rate of coastal retreat.

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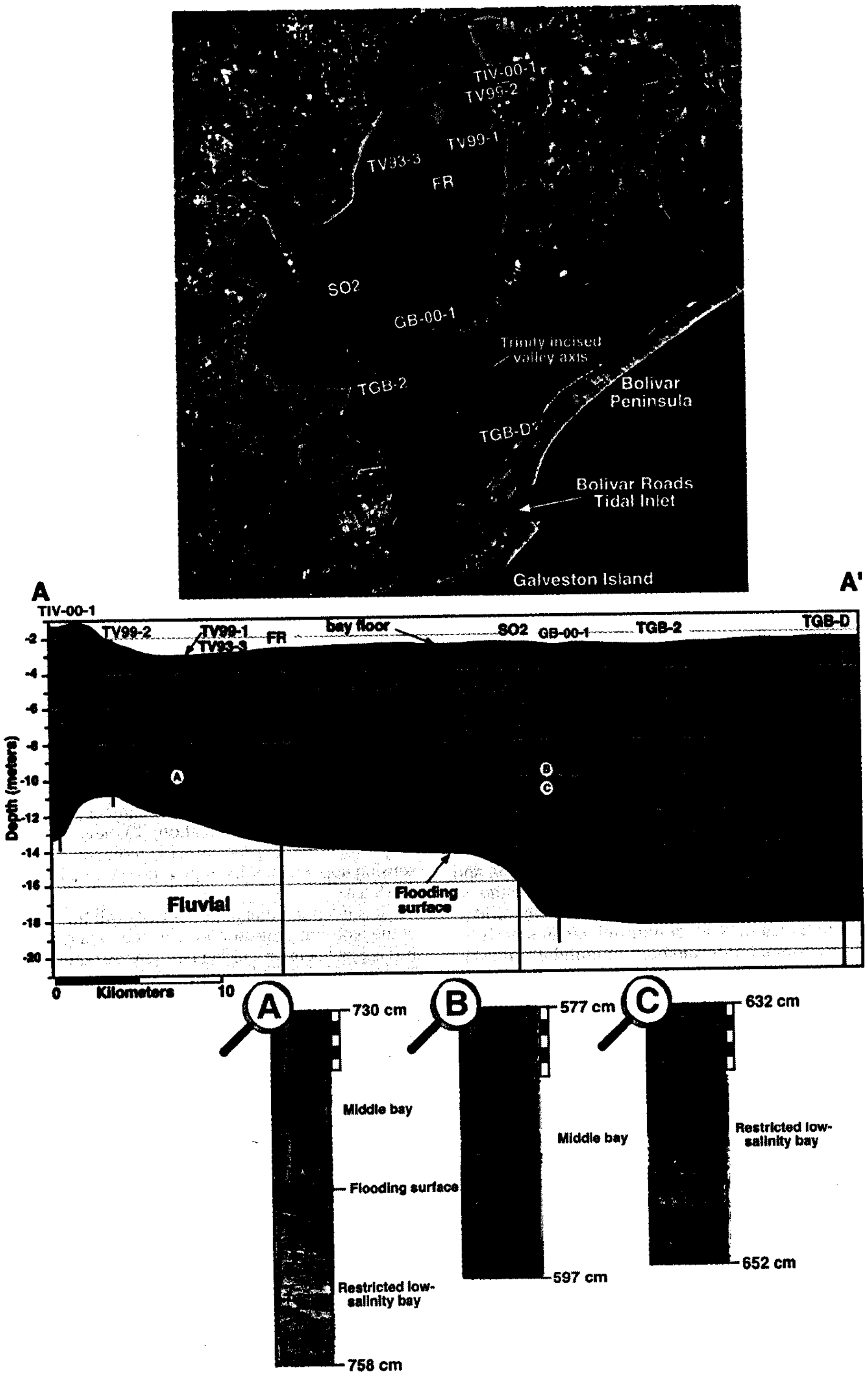

Fig. 2. An aerial photo of Galveston Bay shows the locations of a seismic profile and sediment cores acquired along the axis of the bay. The cross section (A-A') was constructed from these combined data and shows flooding surfaces that separate deposits and faunas of different bay environments, including a restricted low-salinity bay that does not exist today. The flooding surfaces represent landward shifts in coastal environments of several tens of kilometers. Radiocarbon dates indicate that the change from low-salinity bay to the modern bay setting occurred in less than two centuries.

The predicted rates of sea-level rise from global warming by the year 2,100 range from 20–23 cm/century to 86–96 cm/century [*Warrick et al.*, 1996], with the main uncertainty in this prediction being the contribution from polar ice sheets. A more conservative estimate of 49–55 cm/century is close to the average rate of sea-level rise during the Holocene, the last 10,000 years. This being the case, we should be able to better predict coastal response to accelerated sea-level rise by examining the geological record of coastal change during the Holocene.

How did coastal environments respond to rapid sea-level rise during the Holocene? Preliminary results from research on the low-gradient east Texas coast indicate that the coastal barriers, bays, and wetlands of this region have experienced dramatic changes. These changes include in-place drowning of coastal barriers (Figure 1) and landward shifts in bay environments and wetlands (Figure 2). Over a few centuries, these landward shifts occurred on the order of tens of kilometers and possibly even faster. These changes occurred when sea level was rising at an average rate of 50 cm/century. This begs the question, is there a threshold of sea-level rise at which low-gradient coastal systems are no longer able to combat the rising sea?

It is important to recognize that even the fastest predicted sea-level increases occur more slowly than the rates at which many coasts are subsiding. For example, subsidence rates along the Texas and Louisiana coasts are locally in excess of a meter per century, while subsidence rates along the East Coast are much less, and portions of the West Coast are stable or slightly emerging. These differences are due to regional subsidence, neo-tectonic activity, and variations in sediment compaction. The latter can vary on a local (tens of kilometers) scale. Further complicating the issue is the fact that the magnitude of future sea-level rise will not be the same everywhere on Earth. Geoidal and hydroisostatic influences will govern the position of relative sea level on a global scale.

Thus, the impact of rising sea level will impact the coasts differently. That is why research aimed at forecasting coastal change must be regional in nature. Indeed, precise sea-level histories will be needed for each region of study. Participants in a recent PAGES-LOICZ workshop in Honolulu, Hawaii, concluded that existing sea-level records are inadequate as control data for the numerical prediction of future centennial sea-level trends forced by global warming [*Goodwin et al.*, 2000]. They suggested that research should focus on the last few thousand years, which is when the modern coastal systems evolved, and that researchers should strive to achieve accuracy in the range of 0.5–1.0 m. This is the range of sea-level variability expected over the next few centuries.

Future research should focus on the following questions. What has been the response of coastal systems to more rapid sea-level rise during the Holocene? Were past episodes of marked coastal change caused by rapid relative sea-level rise, or is there a threshold at which coastal systems suddenly respond to some continuous rate of relative sea-level rise? What rate of relative sea-level rise, or threshold, is necessary to shift coastal environments landward and to submerge barrier shorelines? What length of time is required for coastal environments to re-establish themselves? Given current sediment supply and subsidence rates, how will coastal environments respond to future sea-level rise predictions?

Increased Tropical Storm Impact

Another potential impact of global warming is a potential change in tropical storm

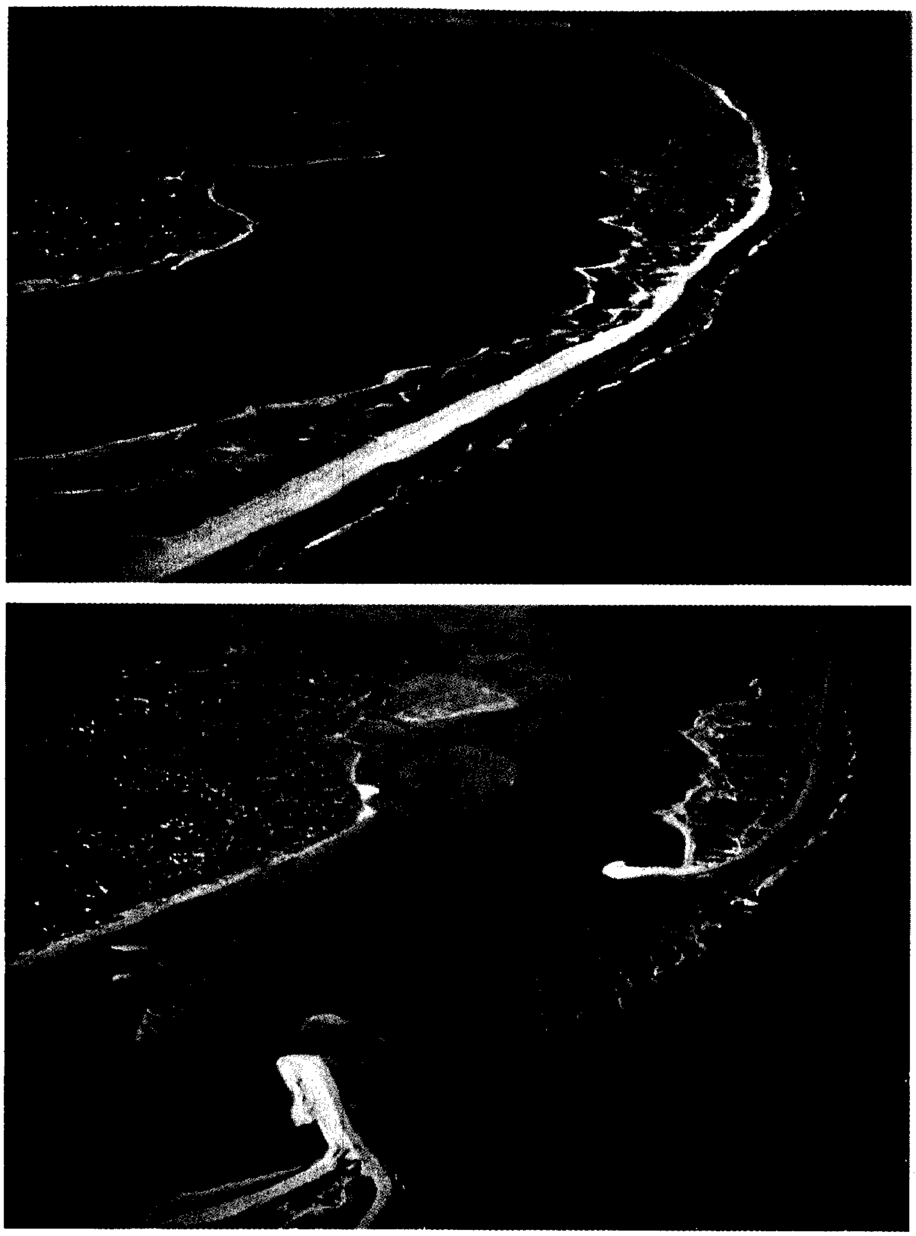

Fig. 3. Aerial photographs of Nauset Spit taken before (top) and after (bottom) along the outer coast of Cape Cod, Massachusetts. These changes in the coast occurred after a January storm breached the barrier. The coast never fully recovered from this event.

landfall distribution, frequency, and magnitude. Intense hurricanes have caused more loss of life and damage to coastal ecosystems than any other natural disaster in the United States. Most devastating was the Galveston storm of 1900, which resulted in the loss of at least 6,000 lives. Recent tropical storm landings along the eastern seaboard have resulted in historically unprecedented changes in that coast (Figure 3). For this reason, accurate predictive models that yield hurricane landfall probabilities for any given coastal area are of great socioeconomic value. These predictive models are created largely from the historical record of U.S. hurricane landfalls, which is complete only from about 1900.

Historical records provide only a limited sample of the most intense hurricanes. To increase the validity of predictive models, a prehistoric record of intense hurricanes must be obtained. This can be accomplished using the stratigraphic and geomorphic records of past storm activity. Recent studies of these geological records indicate times when storms were more frequent and possibly of greater magnitude, both along the Gulf Coast and East Coast. These records exist in the form of storm beds preserved in bays and coastal lakes [*Liu and Fearn*, 1993] and large storm washovers on the backsides of barrier islands and storm surge channels that cut through barriers.

Questions that need to be addressed include the following. How did tropical storm frequency and magnitude vary regionally in the past? Was there an associated climatic change? If the frequency and magnitude of tropical storms increases in the future, how would this change impact coasts that are already stressed by rising sea level?

Community Model Needed for Forecasting Coastal Response to Climate Change

Our ability to forecast coastal response to climate change is imprecise and desperately needs to be improved. If the scientific community is to succeed at forecasting coastal change during the 21st century and beyond, quantitative models that relate coastal response to various forcing mechanisms must be developed. Much of the information needed to create these types of models is lacking. Not knowing how, why, and when coastal systems took on their present-day morphology greatly limits our ability to develop predictive models of morphodynamic variability through time.

It is essential to assess how different coastal systems respond through change in height-to-width ratios, landward retreat rates, submergence rates, and sediment budget variations to quantifiable forcing mechanisms such as changes in relative sea-level rise and climate and associated biogeochemical, hydrogeophysical, and anthropogenic processes. This information is needed for the development of numerical models that can unify and integrate observational data bases, as well as improve prediction of natural phenomena with magnitudes greater than those that have occurred in historical time. Model uncertainty must be quantified to determine applicability at various time scales to ensure the results are suitable for predicting future impacts on ecosystems and society. Coastal forecasting should be carried out at decadal to centennial time scales emphasizing geomorphic and environmental changes. For example, these models should predict future locations of shorelines, reef growth, wetlands, bay margins, tidal inlets, etc., as well as anthropogenic impacts.

To truly understand how different coastal systems respond to long-term forcing mechanisms, a variety of coastal environments need to be examined and compared. Research efforts need to be focused in mainland beaches and barrier coasts, carbonate shorelines, estuaries, wetlands, river-dominated coasts, and glaciated coasts.

Investigating the geologic framework of coastal systems—tectonic setting, antecedent topography, coastal substrates, sediment sources, and geomorphology—yields important information about how these systems evolved in the past, including rates of change. An important strategic tool should be the integration of multidisciplinary teams of investigators working in specific coastal environments. Data extracted from each type of coastal system should be integrated into coastal forecasting models.

Coastal forecasting models also need to be tested for accuracy. The best method of testing a forward-looking model is through hindcasting. This work will make a significant contribution toward quantifying coastal change, and it will also create data sets appropriate for testing coastal forecasting models.

Is the Coastal Science Community Ready to Meet the Challenge?

Coastal scientists are making progress toward improving our understanding of the dynamics

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of sedimentation within the littoral zone and defining future research needs [*Thornton et al.*, 2000]. Likewise, the international Quaternary geology community has taken steps to coordinate research projects aimed at examining the stratigraphic record of coastal change through the International Geological Correlation Program (IGCP Projects 367 and 437). The U.S. coastal sedimentology community, in particular, has been slow in organizing itself and adopting a specific research plan for the future [*Fletcher et al.*, 2000].

Although a number of federal and state agencies currently fund coastal research, a significant amount of this work focuses on environmental quality, coastal habitat conservation, use of living and non-living resources, national defense, and coastal erosion. These programs represent a first line of defense against changes that are already occurring within the coastal zone. But relatively little money or effort is being spent to prepare for changes that will affect coasts by the year 2100. The National Science Foundation (NSF) is the most likely agency to fund multidisciplinary studies aimed at long-range prediction of coastal change. However, interdisciplinary research is not easily funded within the current NSF-Earth Sciences (NSF-EAR) Program [*Fletcher et al.*, 2000]. NSF programmatic areas typically stop at the shoreline. The marine aspects are funded through NSF-Ocean Sciences, and coastal projects must compete for funding from NSF-EAR.

In addition, there is concern that the number of young scientists who are being trained in the multidisciplinary fields of coastal research may be declining. Indeed, the number of universities with coastal research programs focusing on basic science problems has declined. So, as various governmental panels and agencies appeal for more coastal research, there is a declining number of young scientists to respond to the challenge. The only way to remedy the problem is through improved coordination of the coastal research community and a sustained funding program.

Acknowledgments

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