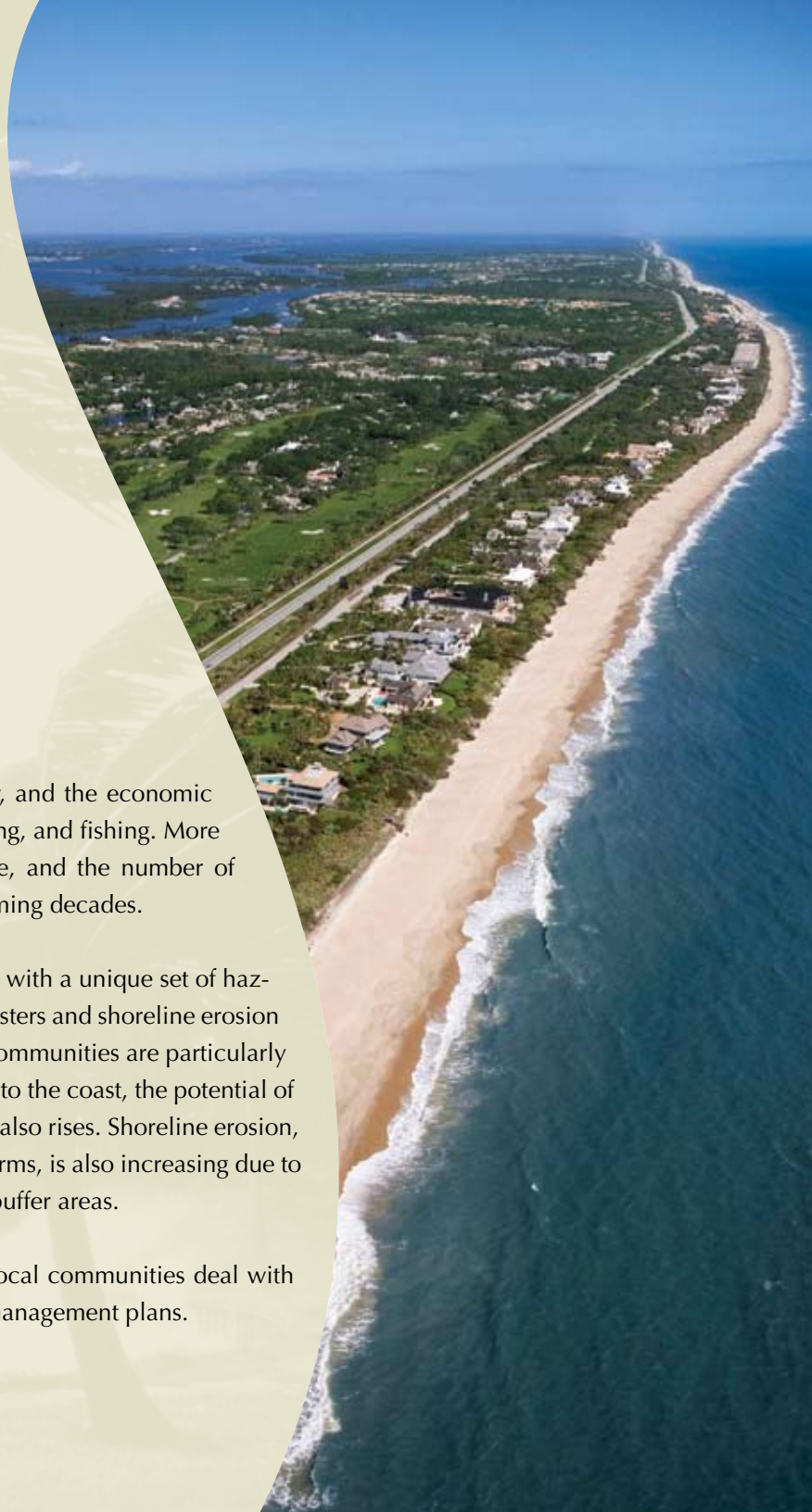
OCEAN SCIENCE SERIES

COASTAL HAZARDS

Highlights of National Academies Reports

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

COASTLINES ARE TREASURED THE WORLD OVER



for their natural beauty, the recreational opportunities they offer, and the economic benefits that result from such coastal industries as tourism, shipping, and fishing. More than half the world's populations have settled along a coastline, and the number of people inhabiting coastal areas is projected to increase in the coming decades.

Although living along a coast has many advantages, it also comes with a unique set of hazards that can threaten lives, property, and economies. Natural disasters and shoreline erosion are two of the main threats that coastal communities face. Such communities are particularly vulnerable to hurricanes and tsunamis, and as more people move to the coast, the potential of such events causing catastrophic loss of life and property damage also rises. Shoreline erosion, a worldwide phenomenon that is often exacerbated by coastal storms, is also increasing due to a number of factors, including sea level rise and loss of wetland buffer areas.

New scientific advances are helping government agencies and local communities deal with coastal hazards more effectively and develop long-term hazard management plans.

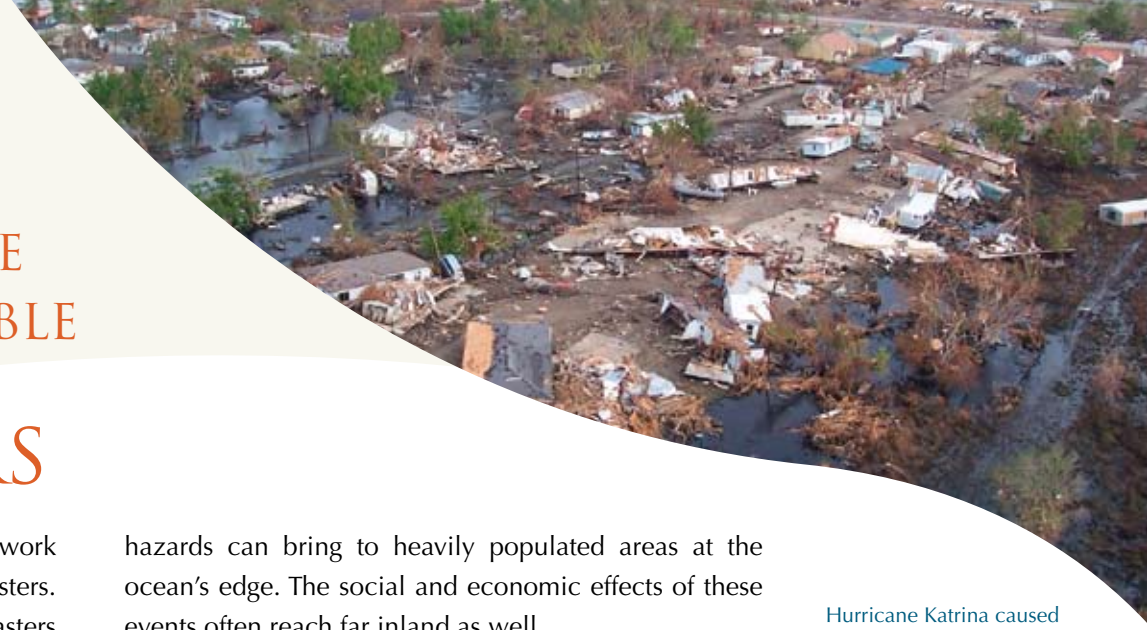
The Miami skyline. Many of the world's large cities are located on a coastline, and coastal populations are expected to continue to grow in the future. (Image © Wolcott Henry 2005/Marine Photobank)

MORE PEOPLE ARE MOVING TO THE COAST

According to the National Oceanic and Atmospheric Administration (NOAA), coastal populations in the United States have grown by more than 33 million since 1980 and are expected to reach 165 million by 2015. More than half the U.S. population now lives in 673 coastal counties. More than 60 percent of homes and buildings within 500 feet of the shoreline are located along the Atlantic and Gulf coasts, the nation's fastest-growing areas.

Coastal populations around the world are also growing at a phenomenal pace. Already, nearly two-thirds of the world's population—almost 3.6 billion people—live on or within 100 miles of a coastline. Estimates are that in three decades, 6 billion people—that is, nearly 75 percent of the world's population—will live along coasts. In much of the developing world, coastal populations are exploding. Two-thirds of Southeast Asian cities with populations of 2.5 million or more are located along coasts, and of the 77 major cities in Latin America, 57 are in coastal areas.

COASTAL COMMUNITIES ARE INCREASINGLY VULNERABLE TO NATURAL DISASTERS



Hurricane Katrina caused devastating personal, social, economic, and cultural losses. This image shows homes destroyed by the storm in Plaquemines Parish, Louisiana. (Image from NOAA; photo by Wayne and Nancy Weikel, FEMA Fisheries Coordinators)

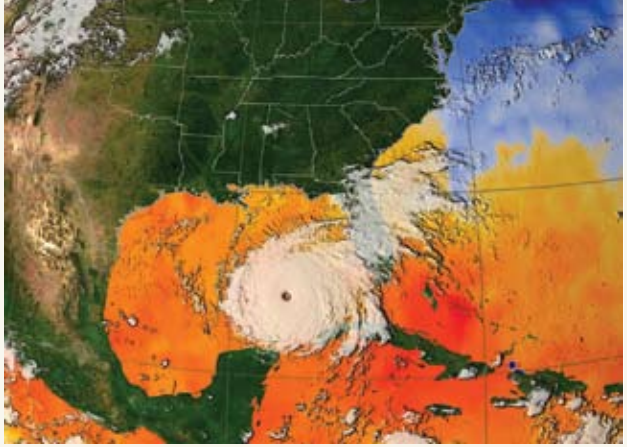
By being close to the ocean, people who live and work in coastal areas face unique risks of natural disasters. And as more people move to the coast, natural disasters have the potential to cause ever more damage. Coastal communities are vulnerable to such catastrophic events as hurricanes, tropical storms, and tsunamis, and even the flooding and high winds associated with smaller, less intense storms can present major dangers to those living along the coast.

The devastations wrought by the Indian Ocean tsunami in 2004 and by hurricanes Katrina and Rita in Louisiana and Mississippi in 2005 are the most recent reminders of the enormous personal, social, economic, and cultural losses that coastal hazards can bring to heavily populated areas at the ocean's edge. The social and economic effects of these events often reach far inland as well.

The National Research Council report *From Monsoons to Microbes: Understanding the Ocean's Role in Human Health* (1999) explains that as more people live and build on the coasts, the damages from natural disasters increase dramatically. For example, the great Miami hurricane of 1926 caused about $76 million in damage. But when Hurricane Andrew, a storm of comparable size, struck southern Florida in 1992, the damages were on the order of $30 billion (dollar values adjusted for inflation), reflecting both the current size and the high value of Miami's buildings and infrastructure.

Hurricane Katrina approaches landfall on the Gulf coast. Very little on land or water was spared by the storm when it struck in 2005. (Image from NOAA)

The Highway 90 bridge from Biloxi, Mississippi to Ocean Springs lies in a twisted mass as result of catastrophic wind and storm surge from Hurricane Katrina. (Image from FEMA, photo by George Armstrong)



Warm-water eddies contribute to the intensity of tropical storms. Hurricane Rita, shown here, gained strength as it passed over warm waters (in orange and red) in the Gulf of Mexico before making landfall shortly after Hurricane Katrina in 2005. (Image from NASA/Goddard Space Flight Center Scientific Visualization Studio)

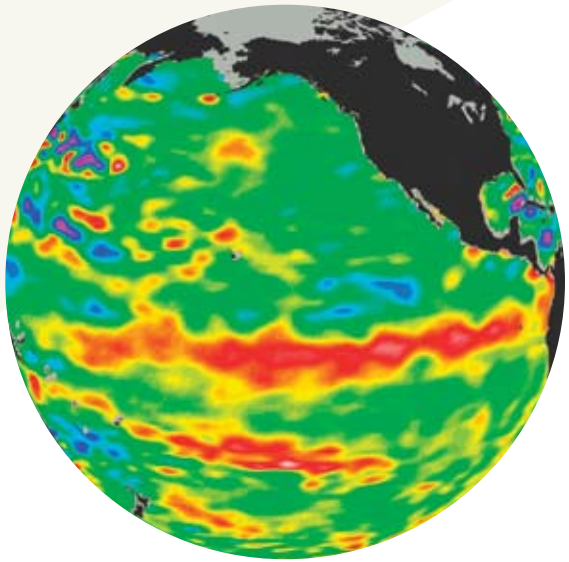
OCEAN CONDITIONS AFFECT THE SIZE AND IMPACT OF MANY NATURAL DISASTERS

Natural disasters and many types of weather patterns—along coastlines and far inland alike—can be influenced by such conditions as changes in ocean temperatures and fluctuations in ocean currents. The ability to anticipate and respond promptly to natural disasters depends on understanding how weather systems develop through interactions of air and land with the sea.

Tropical storms—which include hurricanes, cyclones, typhoons, monsoons, and smaller storms that originate in the tropics—arise through disturbances in the atmosphere that are fed by the transfer of heat and moisture from the surface waters to the atmosphere. Storms can suddenly intensify within 24 to 48 hours of landfall if they pass over warm oceanic features (the Gulf Stream, Florida Current, Loop Current) or warm core rings (transient pockets of warm water spun off by the ocean's major currents) in the western Atlantic Ocean and the Gulf of Mexico. Because of the relationship between storm intensity and warm ocean waters, many experts are concerned that rising ocean temperatures that result from climate change will increase the destructive potential of tropical storms.

Storm surges that cause severe flooding are one of the most destructive forces of tropical storms. A storm surge is created when high winds and low atmospheric pressure beneath the storm cause the sea level to rise. As the storm approaches landfall, surface winds push water onto the coast; the height of the surge is amplified in areas with shallow waters, such as the coastal shelf in the Gulf of Mexico. Hurricane Katrina brought the highest storm surge on record in the United States—up to 30 feet in some locations. This massive volume of water, combined with the waves associated with it, was responsible for most of the loss of life, and it inflicted overwhelming damage to coastal property.

Ocean conditions also influence weather, affecting temperature and rainfall patterns from coastal regions to the



A band of warm water, shown here in red, causes a recurring weather pattern known as El Niño. These warm ocean waters bring unusually warm, wet weather to the west coasts of North and South America and influence climate patterns globally. (Image from NASA)

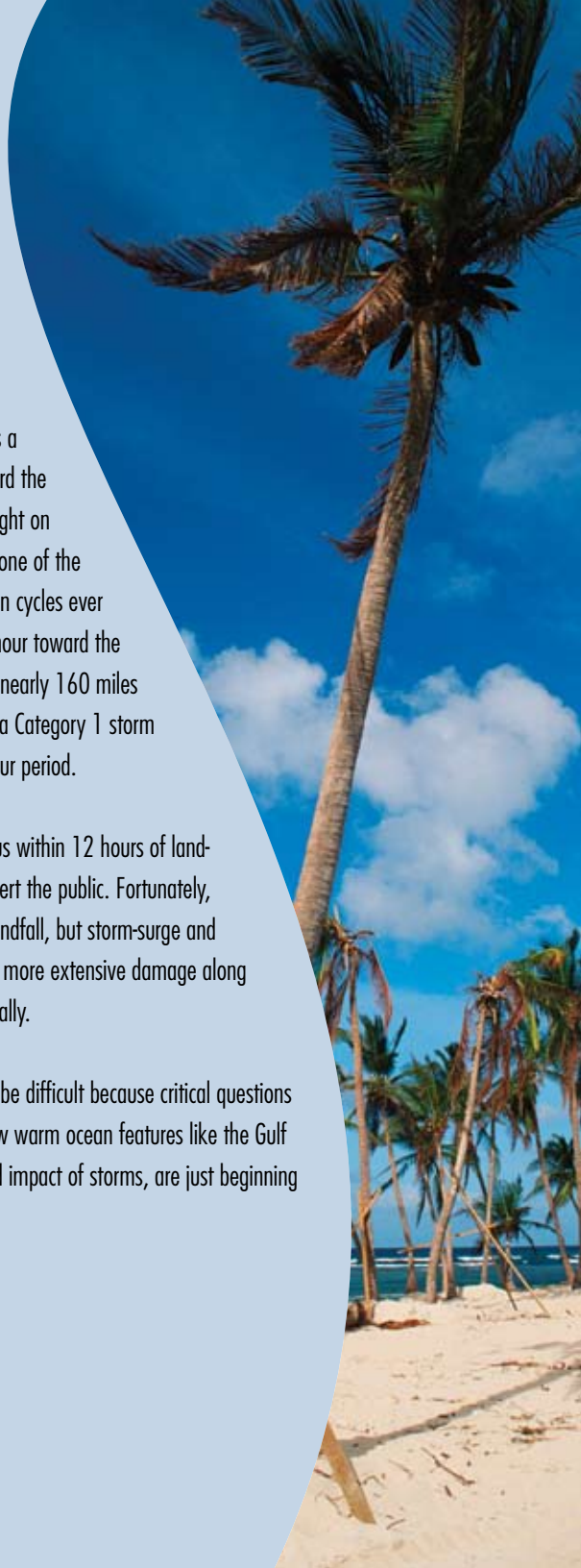
interiors of the continents. An example is the El Niño, a recurring weather pattern that has historically taken place every three to seven years. In an El Niño, the normal upwelling of cold water along the Equator fails, and warm tropical surface water spreads across the eastern Pacific. These warm ocean waters contribute moisture and heat to the atmosphere, bringing unusually warm, wet weather to the west coasts of North and South America and influencing climate patterns globally. Strong El Niño events have been associated with severe weather patterns, from floods to droughts, worldwide and have caused thousands of casualties, mainly from flooding and outbreaks of disease.

DEALING WITH RAPID CHANGES IN STORM INTENSITY

Hurricane Opal is a good example of just how quickly storm intensity can change. When the storm was first observed in early October 1995, it was a slow-moving cell that was drifting toward the Gulf of Mexico. In the middle of the night on October 3, however, the storm started one of the most rapid deepening and intensification cycles ever observed as it moved at 19 miles per hour toward the Gulf coast. Winds quickly increased to nearly 160 miles per hour as the storm progressed from a Category 1 storm to a Category 4 hurricane over a 20-hour period.

The storm approached Category 5 status within 12 hours of landfall—not enough time to effectively alert the public. Fortunately, the storm weakened before reaching landfall, but storm-surge and wave activity caused much greater and more extensive damage along the coast than had been forecast originally.

Forecasting the intensity of storms can be difficult because critical questions about storm intensification, such as how warm ocean features like the Gulf Stream rapidly change the strength and impact of storms, are just beginning to be answered.

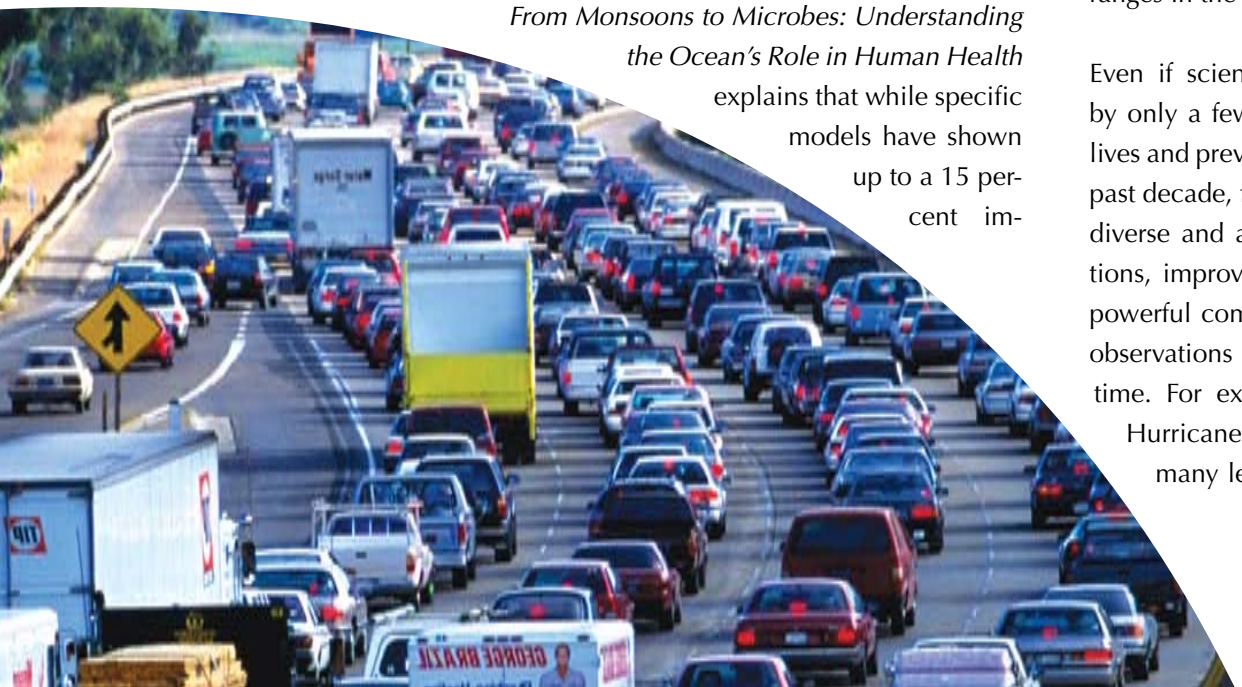


IMPROVED FORECASTING SAVES LIVES

Clearly, the stakes are high for emergency managers and local officials responsible for ensuring public safety and managing resources in coastal zones. Early warning systems for severe storms and tsunamis help people prepare and decide when to evacuate, saving lives and potentially reducing property damage.

It is crucial to provide the most accurate forecasts possible, given that hurricane preparation costs approximately $1 million per mile of coastline. With current forecasting skills, about 125 miles of coastline can be warned (and evacuated, if necessary) 48 hours in advance of a major hurricane making landfall. Inaccurate warnings result both in high costs and in low confidence in the forecasting system, often causing residents to ignore subsequent warnings.

Accurate forecasts of a storm's track and intensity can help people prepare and decide when to evacuate.



From Monsoons to Microbes: Understanding the Ocean's Role in Human Health explains that while specific models have shown up to a 15 percent improvement in predicting a storm's *track*, there has been less improvement in the prediction of a storm's *intensity*. Uncertainties in wind, storm-surge, and rainfall forecasts make it challenging for officials to assess the risk and to identify the most vulnerable regions far enough in advance of the projected landfall. In addition, variations in topography and the built environment contribute to wide ranges in the probable impacts of any given storm.

(Image from FEMA)

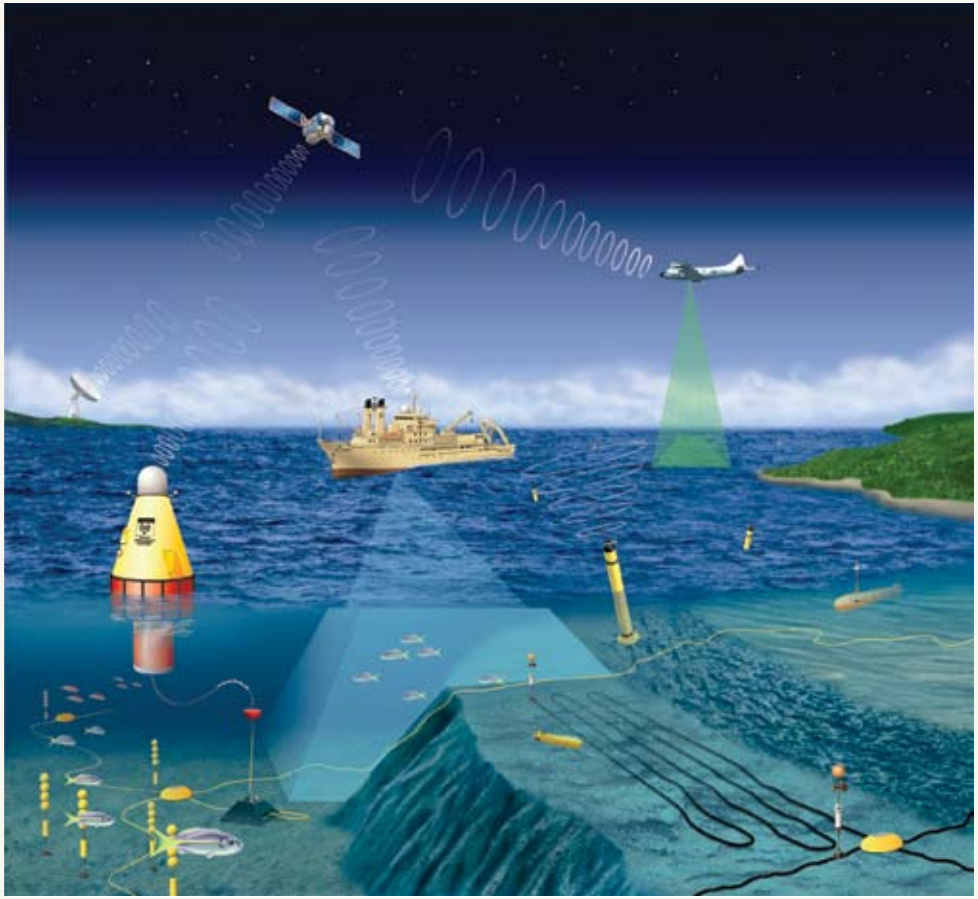
Even if scientists could improve intensity predictions by only a few percent per year, they could save many lives and prevent millions of dollars of damage. Over the past decade, forecasters have had access to increasingly diverse and accurate atmospheric and ocean observations, improved weather prediction models, and more powerful computers that make it possible to assimilate observations into forecast models and run them in real time. For example, although emergency response to Hurricane Katrina was found to be greatly lacking on many levels, accurate forecasting of the storm 60

hours in advance of landfall made it possible for around 80 percent of the population to evacuate safely.

MORE DATA ARE NEEDED FOR ACCRATE FORECASTING

Weather forecasts in the United States are produced through a process that begins with the collection and monitoring of several surface and upper-air observations from around the globe. Data are collected from a diverse network of sources, including automated coastal marine buoys, commercial ships and military vessels, oil and gas platforms, tide and water level installations, the Doppler radar network, automated commercial aircraft, reconnaissance aircraft reports, and satellites. Because storms originate in the tropical ocean regions where few data are available, the scientific community has also pioneered mobile observing strategies in which drifting buoys are released into the ocean during hurricane season to provide critical observations about the location and strength of developing storms. All of these data sources and the data they collect must be assimilated through global and regional weather prediction models.

A network of coastal-marine and offshore moored buoys operated by the National Oceanic and Atmospheric Administration (NOAA) provides one source of real-time data for weather prediction. This buoy system is used along the U.S. coastlines to detect hazardous weather before it strikes the shore. Buoys collect data under conditions of weather too severe for human observers and provide vital real-time information on wind, air and wa-



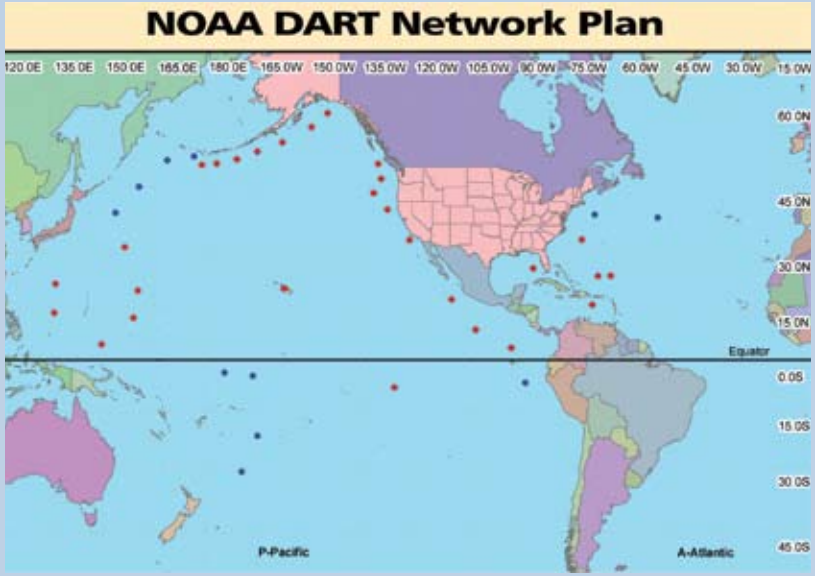
Information on ocean conditions is collected by a diverse network of sources. Observations are then assimilated through weather prediction models to inform forecasts. (Image courtesy of HARRIS Maritime Communications) Sources of weather data include:

- Automated coastal marine buoys
- Commercial ships and military vessels
- Oil and gas platforms
- Tide and water level installations
- The Doppler radar network
- Automated commercial aircraft
- Reconnaissance aircraft reports
- Satellites

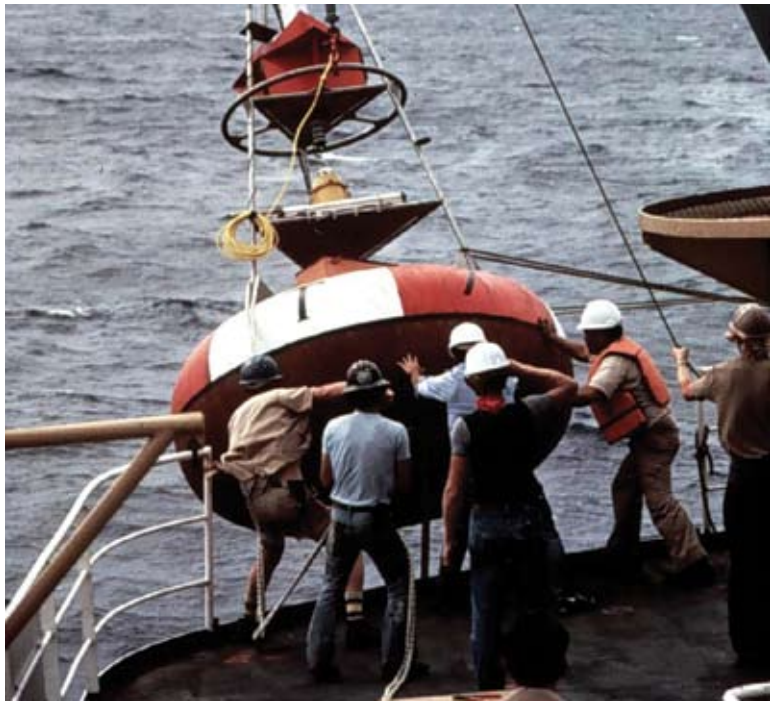
FROM WARNINGS TO FORECASTS: IMPROVING TSUNAMI DETECTION SYSTEMS

Tsunamis occur when ocean waters are rapidly displaced on a massive scale, typically because of an earthquake. During a tsunami event, elevated ocean water forms massive waves that flood coastal areas when they reach the shore. The death and destruction that result from tsunami events can be catastrophic, such as the aftermath of the tsunami that hit Southeast Asia in December 2004 after an earthquake erupted beneath the Indian Ocean. Hundreds of thousands of people died and many more were left homeless. Coastal areas in the United States are also vulnerable to tsunamis, particularly in the Pacific Northwest, Hawaii, and Alaska, but the Caribbean and Atlantic coasts have also experienced tsunamis from both earthquakes and massive offshore landslides.

The National Oceanic and Atmospheric Administration (NOAA) operates a Tsunami Program that addresses many aspects of tsunami preparedness, from hazard assessment to international coordination. In addition to operating several tsunami warning and information centers, NOAA has developed the Deep-ocean Assessment and Reporting of Tsunamis (DART) system, which consists of seafloor pressure sensors that can detect a tsunami as it passes and a communication system to relay information to tsunami warning centers in real time. Science and technology development in tsunami predictability, such as the DART system, is critical to NOAA's Tsunami Program. Increasingly accurate tsunami forecasts can be used to issue watches, warnings, or evacuations and can potentially save many lives.



The locations of active and planned tsunami detection buoys in NOAA's DART system (as of March 2007). (Image from NOAA)



NOAA has deployed new state-of-the-art tsunami detection buoys to bolster tsunami warning and forecasting systems. (Image from NOAA)

ter temperature, air pressure, and waves. Public and private weather forecasters can use the data generated by these buoys to identify possible hazardous wind, sea-state, and water-level conditions and to communicate their findings to public safety officials, shipping companies, fishing and recreational parties, and the general public. Coastal weather forecasters at NOAA's National Weather Service rely extensively on the data provided by the NOAA-operated buoy network.

The National Research Council report *The Meteorological Buoy and Coastal Marine Automated Network for the United States* (1998) recommends that the buoy

coastal-marine observing system add more observing platforms—especially in the storm-prone Atlantic Ocean and Gulf of Mexico regions—to provide better support for weather-forecasting operations. In the years since that report was released, there have been significant improvements in observing platforms and sensors collecting weather and oceanographic data in the ocean. The number of tsunami detection buoys has increased from 6 basic systems to more than 30 state-of-the-art systems, and there have been considerable increases in the number of buoys and sensors collecting information on hurricanes, climate change, and a variety of other changes in the ocean environment, including sea level rise, heavy seas, unusually high tides, and high sea surface temperatures.

ADVANCES IN FORECASTING REQUIRE MORE THAN JUST ADVANCES IN SCIENCE

Marked gains have also been made in obtaining real-time weather and atmospheric observations, especially from satellites. In addition, the National Science Foundation, NOAA, the National Aeronautics and Space Administration (NASA), and other agencies have developed more accurate forecasting models that take advantage of higher computing speed and capabilities to improve our understanding of weather and climate patterns.

Unfortunately, weather and climate forecasting services are under considerable stress just to meet daily demand. The National Research Council report *From Research to Operations in Weather Satellites and Numerical Weath-*

USING RESEARCH DATA IN WEATHER PREDICTION: THE STORY OF TRMM

The Tropical Rainfall Measuring Mission (TRMM) is an example of a satellite designed strictly for research that has turned into a valuable component of many different weather and climate related activities. Launched by NASA and the Japanese space agency in 1997, TRMM's reliable sensors and high-quality measurements provide unique, near real-time data for many different agencies, including the Joint Typhoon Warning Center, the National Center for Environmental Prediction, and the National Hurricane Center. TRMM data have been used in determining hurricane centers and rainfall estimates for flood forecasts and warnings, as well as in routing aircraft across oceans to avoid storm cells.

TRMM was never designed as a long-term mission— it only had enough fuel to power the satellite's operations until 2006 while retaining enough energy for a controlled return to Earth. When NASA announced in 2004 its intention to end the mission, the weather research and operations community strongly objected. At NASA's request, the National Research Council report *Assessment of the Benefits of Extending the Tropical Rainfall Measuring System* (2006) answered an important question: What are the scientific and operational benefits of using the remaining fuel to extend the mission? NASA had to weigh this advice against the safety risks of an uncontrolled reentry. Based on the benefits presented in the report, NASA decided to extend the mission.

TRMM is expected to continue orbiting until about 2012-2013, or earlier if critical systems fail. NASA plans to launch the Global Precipitation Measurement mission (GPM) in 2013 to succeed TRMM.

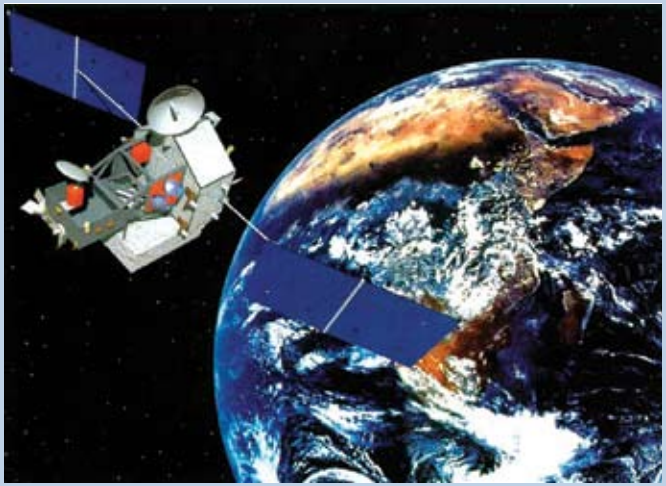
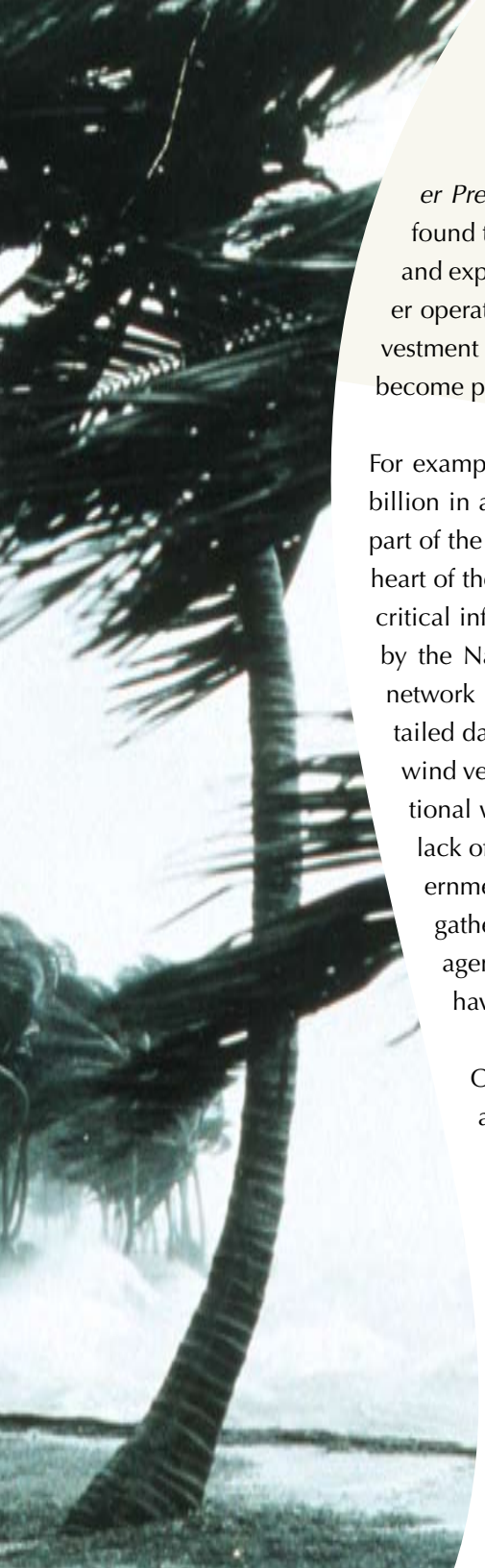


Image from NASA



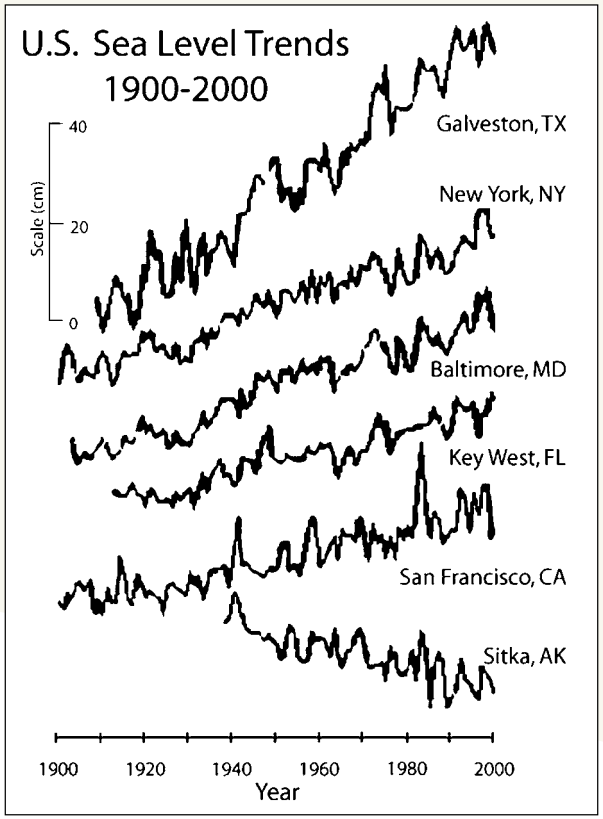
er Prediction: Crossing the Valley of Death (2000) found that there is a lack of resources to incorporate and exploit new research results in day-to-day weather operations. The nation will not benefit from the investment in research until current scientific advances become part of the operational forecasting system.

For example, the United States has invested almost $1 billion in a national Doppler weather radar network as part of the modernization of the weather service. At the heart of the network is the NEXRAD radar that provides critical information for severe weather warnings issued by the National Weather Service. Although the radar network has been working for several years, the detailed data it provides—such as precipitation rate and wind velocity—have not been assimilated into operational weather prediction. Part of the problem is the lack of coordination among the many different government agencies that are involved in researching, gathering data, and issuing forecasts. When these agencies begin to work together, the results will have far-reaching benefits.

Communicating impending risks to potentially affected communities is also an essential part of making the best use of advances in forecasting. Encouraging people to evacuate or take other measures to protect themselves and their property from damage—and actually getting people to heed storm warnings—is critical to the effectiveness of weather-forecasting systems. The National Research Council report *Making Climate Forecasts Matter* (1999) identified some of the social and cultural aspects of effectively disseminating forecast information and concluded that more research would help to improve information dissemination systems.

SHORELINE EROSION PUTS COASTAL POPULATIONS AT RISK

Shoreline erosion is a natural process caused by coastal and ocean dynamics that constantly shape and change the coast as sediment is deposited and lost. This process is exacerbated by rises in the sea level, storms, and other natural events. Shoreline erosion has been on the rise in many areas during the past century. As populations grow and more homes, roads, and businesses are built near the coasts, buffer zones such as coastal forests and wetlands are lost, thus making coastal areas more vulnerable to erosion and flooding. On the Atlantic coast, the average erosion rate is about two to three feet per year. The nation's highest erosion rate—up to six feet per year—occurs along the coasts of the Gulf of Mexico.



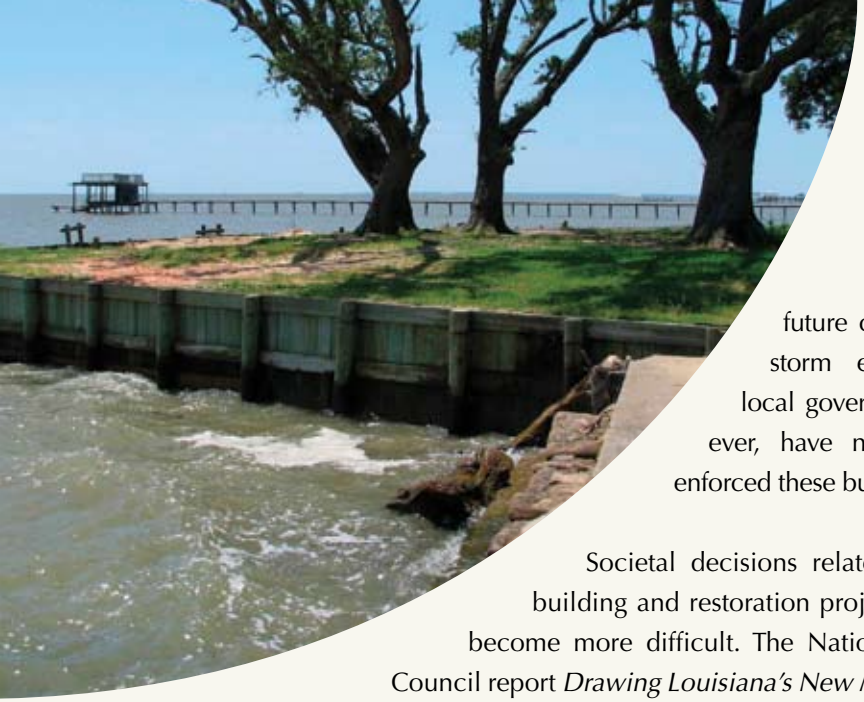
Measured sea level rise, in centimeters, for selected U.S. cities from 1900 to 2000. Rises in sea levels can exacerbate erosion and leave low-lying areas more vulnerable to severe weather. (Data from NOAA, Graph available from the US EPA)

Many experts fear that sea-level rise will further stress low-lying coastal communities and ecosystems already more subject to flooding and loss of land and habitats. As the Earth has continued to warm over the past century, the global sea level has risen by one-half to three-quarters of an inch per decade. A rising sea level can exacerbate erosion and leave low-lying areas more vulnerable to severe weather. In the United States, the Chesapeake Bay region is experiencing a rise in sea level at twice the rate of the world average due to the combination of global sea level rise, local sinking of the land, and wave erosion. The University of Maryland's Laboratory for Coastal Research found that at least 13 islands in the Chesapeake Bay area have disappeared since the region was first mapped by Europeans. Several more islands may be inundated as the sea continues to rise.

REDUCING VULNERABILITY WILL REQUIRE TOUGH SOCIETAL DECISIONS

The Federal Emergency Management Agency (FEMA), the government agency charged with leading the response to natural disasters in the United States, estimates that one-quarter of homes and other structures within 500 feet of the United States' coastlines will fall victim to the effects of erosion over the next several decades. FEMA is part of an ongoing debate on how to best manage coastal erosion and whether or how to use the National Flood Insurance Program to address the problem. This program, which is administered by FEMA, makes flood insurance avaiable in return for local governments taking actions through building codes and planning that are intended to reduce

(Photo courtesy of C. Swinehart, Michigan Sea Grant Extension)



Hard barriers like this bulkhead are often used to protect coastal property from land loss. (Photo courtesy Hugh Shipman)

future costs of major storm events. Those local governments, however, have not vigorously enforced these building codes.

Societal decisions related to coastal building and restoration projects will only become more difficult. The National Research Council report *Drawing Louisiana's New Map: Addressing Land Loss in Coastal Louisiana* (2006), which was written before Hurricane Katrina struck, reviews plans to restore the area's catastrophic wetland loss, which was recorded at 24 square miles per year from 1990 to 2000. The report poses a very important central question: How does Louisiana want its new coast to look? The report recommends that a detailed map of the expected future landscape of the Louisiana area be developed. The map should be based on conscious decisions that consider the distribution of natural and agricultural resources, protection of infrastructure, and future human habitation. For such a map to be meaningful, the commitment of decision makers at all levels of government—local, state, and federal—as well as the public will be needed.

Planting vegetation offers one way to reduce erosion at some sites. Top photo shows a pre-project shoreline on Wye Island in Queen Anne's County, Maryland. Marsh grass was planted on sand fill and short, stone groins were added. Middle photo is three months after installation. Bottom photo is six years after installation. (Image from Virginia Institute of Marine Science)

MITIGATING SHORE EROSION IS COMPLEX AND REQUIRES INTEGRATED MANAGEMENT PLANS

Shore-protection structures, such as levees, seawalls, jetties, and breakwaters, are recent attempts at protecting the coast and preventing flooding. The structures are intended to control the movement of sand and the position of the shoreline. However, as described in the National Research Council report *Mitigating Shore Erosion Along Sheltered Coasts* (2007), what may prove to be a temporary fix in one area could disrupt natural processes and result in more erosion in a different coastal area. Managers and decision makers must balance the trade-offs between the protection of property, on the one hand, and the potential loss of landscapes, public access, recreational opportunities, and natural habitats (with correspondingly reduced populations of fish and other living marine resources that depend on these habitats), on the other.

Mitigating Shore Erosion Along Sheltered Coasts examines the impacts of shoreline management on such sheltered coastal environments as barrier islands along the Atlantic seaboard, bays, and estuaries. These areas experience less intense waves than do open coasts, but they are still greatly affected by erosion and high waters. Typically, landowners adopt a "hold-the-line" strategy that relies on a hard, barrier-type structure to prevent loss of property and to protect buildings. But structures such as seawalls and bulkheads may affect erosion patterns in

CASE STUDY: COASTAL LOUISIANA

Coastal Louisiana provides an example of the complex relationship between natural ocean processes and human development. Long before Hurricane Katrina struck, the area was suffering catastrophic land loss—as much as 39 square miles per year in the in the 1950s, '60s, and '70s due to a combination of natural and human causes.

Coastal Louisiana naturally experiences sinking, which adds to the effects of sea level rise and causes land loss. For thousands of years, however, the natural land degradation was balanced by new land built up by sediment from the Mississippi.

People began to control the Mississippi and its flooding during the 18th and 19th centuries, and in the 20th century the sediment load of the river was reduced, wetlands were drained for urban development, and canals were dredged for navigation and oil and gas extraction. Approximately 2,250 miles of levees were built to prevent flooding of populated and agricultural areas in Louisiana and to maintain navigation channels. However, these activities disrupted the natural dynamics and accelerated land loss in the region as the river levees channeled the Mississippi's sediment load into the deep waters of the Gulf of Mexico.

The vulnerability of New Orleans to storm-surge flooding has increased as the landscape has degraded—ironically, in part, as a result of the attempts to protect the city from river flooding. Approaches to restoring the balance of land building to offset natural land loss in the 21st century must include managing the river for flood protection, navigation, and coastal restoration.

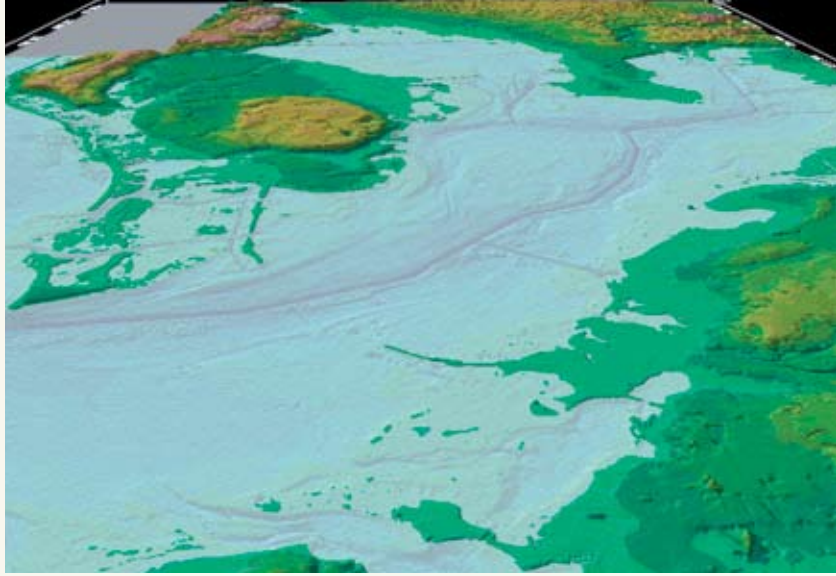
Image from U.S. Army Corps of Engineers

nearby areas through scouring at the edges of structures or by disrupting the transport of sediment downstream. These structures can also damage sensitive marine ecosystems and natural habitats.

The report says that better information is needed in order to develop integrated shoreline management plans that identify the potential effects of structures on ecosystems and erosion. In addition, it recommends that policies encourage methods that reduce habitat loss and enhance natural habitats—such as constructing marsh fringes or using vegetation to stabilize a bluff.

CREATING SEAMLESS LAND-TO-SEA MAPS WILL HELP SCIENTISTS UNDERSTAND COASTAL THREATS

Many tactics have been developed to reduce the risks associated with coastal hazards and erosion. One common approach involves enacting laws that prohibit construction or development activities in particularly vulnerable areas. Other steps, such as elevating oceanfront homes to be above estimated storm-surge levels or burying offshore cables and pipelines, can also reduce the threat of disaster.



Efforts to reduce the impacts of coastal hazards will be successful only if decision makers can accurately assess the nature of the threat. So says the National Research Council report *A Geospatial Framework for the Coastal Zone: National Needs for Mapping and Charting* (2004). Federal, state, and local agencies charged with managing the nation's coasts need information presented on maps and charts to be accurate. For example, in order to understand marine hazards such as tsunamis, high-wave

Bayside homes in Bowleys Quarters, Maryland, were surrounded by water after Hurricane Isabel struck in 2003. In order to understand—and anticipate—marine hazards such as high-wave flooding, coastal inundation, tsunamis, and storm surges, specialists must have precise land-to-shore depth and elevation data. (Image from FEMA, photo by Crystal Payton)

The Tampa Bay Bathy/Topo/Shoreline Demonstration Project—a joint effort of NOAA and the U.S. Geological Survey (USGS)—has developed a suite of tools that ultimately removes the problem of inconsistency between NOAA and USGS maps and charts while also providing a standard framework through which to incorporate other data. This project will allow detailed modeling of the effects of storm-surge or sea-level rise. (Image from the Center for Coastal and Ocean Mapping, University of New Hampshire)

flooding, coastal inundation, and storm surges, specialists must have precise land-to-shore depth and elevation data. Although detailed onshore maps and offshore charts exist, there are no standardized products—either maps or charts—that integrate the two.

For most coastal zone management activities, which include navigation, resource management, beach maintenance, and public safety, the single biggest need is a continuous high-resolution map of the Earth's surface that extends from the land through the shoreline and beneath the water. However, maps and charts of coastal areas have historically been depictions of data collected in either the land or the sea, and differences in scale, resolution, mapping conventions, and reference data (horizontal and vertical frames of reference for mapping) prohibit combining them. The single biggest challenge is to identify a vertical datum—in this case, a fixed point against which to measure land height and sea level, both of which change over time.

A Geospatial Framework for the Coastal Zone: National Needs for Mapping and Charting concludes that vertical datum models must be developed before an integrated onshore-offshore map can be created. To this end, the report recommends creating a series of real-time tidal measuring stations and establishing a national project to develop and apply new models, protocols, and tools. Fortunately, steps are already being made toward this goal: a seamless land-to-sea map of the coastal area is already being developed on a small scale in Tampa Bay, Florida, that ultimately removes the problem of inconsistency between coastal maps from NOAA and land maps from the U.S. Geological Survey (see figure at left).

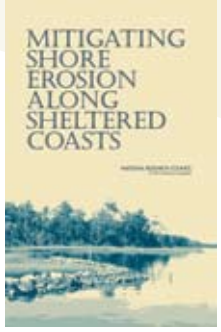
CONCLUSION

As coastal populations continue to grow, so too does the need for better ways to increase the resilience of coastal areas to the effects of severe weather, coastal flooding and inundation, and erosion. Comprehensive, cohesive policies on coastal protection need to be based on the best possible information, from improved coastal mapping to enhanced weather and impact forecasting. Armed with knowledge gleaned from these tools, government officials, coastal managers, property owners, and everyone who enjoys the nation's coastal areas should work toward developing a long-term plan for ensuring that U.S. coastal resources will be sustainable for future generations to enjoy.

About the National Academies

The National Academies—the National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and the National Research Council—provide a public service by working outside the framework of government to ensure independent advice on matters of science, technology, and medicine. They enlist committees of the nation's top scientists, engineers, and other experts—all of whom volunteer their time to study specific concerns. The results of these deliberations are authoritative, peer-reviewed reports that have inspired some of the nation's most significant efforts to improve the health, education, and welfare of the population.

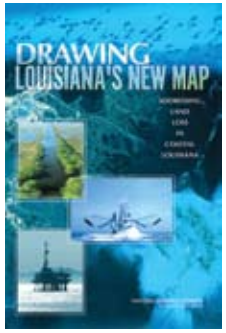
This booklet was prepared by the National Research Council based on the following reports:



Mitigating Shore Erosion Along Sheltered Coasts (2007)
Sponsored by: U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, Cooperative Institute for Coastal and Estuarine Environmental Technology, NOAA Coastal Services Center.

Assessment of the Benefits of Extending the Tropical Rainfall Measuring Mission: A Perspective from the Research and Operations Community: Interim Report (2006)
Sponsored by: National Aeronautics and Space Administration.

Drawing Louisiana's New Map: Addressing Land Loss in Coastal Louisiana (2006)
Sponsored by: State of Louisiana, U.S. Army Corps of Engineers.



A Geospatial Framework for the Coastal Zone: National Needs for Mapping and Charting (2004)
Sponsored by: National Oceanic and Atmospheric Administration, Department of Commerce, U.S. Geological Survey, Department of the Interior, U.S. Environmental Protection Agency.

From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death (2000)
Sponsored by: National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration.

Making Climate Forecasts Matter (1999)
Sponsored by: National Oceanographic and Atmospheric Administration.

From Monsoons to Microbes: Understanding the Ocean's Role in Human Health (1999)
Sponsored by: National Oceanic and Atmospheric Administration, National Institute of Environmental Health Sciences, National Aeronautics and Space Administration.

The Meteorological Buoy and Coastal Marine Automated Network for the United States (1998)
Sponsored by: National Oceanic and Atmospheric Administration.

These and other reports are available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242; http://www.nap.edu. Reports are available online in a fully searchable format.

Cover photo courtesy of Win Henderson/FEMA.

For more information, contact the Ocean Studies Board at 202-334-2714 or visit **http://dels.nas.edu/osb**.

In one way or another, every landform and creature on Earth reflects the presence of the oceans. Understanding the Earth's oceans is essential to our understanding of human history, the origin of life, weather and climate, medicines, the health of the environment, energy sources, and much more. Reports from the National Academies provide in-depth analysis and useful advice for policymakers and the general public on topics ranging from exploring the ocean's incredible biodiversity and resources to reducing threats to human safety from toxic algal blooms, contaminants, and coastal storms. This series is intended to help readers interpret information about the state of our oceans and better understand the role of ocean science.

Other booklets in this series include *Ocean Exploration, Marine Ecosystems and Fisheries, Oceans and Human Health*, and *Pollution in the Ocean*.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The nation turns to the National Academies—National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council—for independent, objective advice on issues that affect people's lives worldwide.

www.national-academies.org