SCIENCE

IMPACTS AND ADAPTATION OPTIONS IN THE GULF COAST

CENTER FOR CLIMATE
AND ENERGY SOLUTIONS

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Prepared for C2ES

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I. INTRODUCTION

The central and western U.S. Gulf Coast is increasingly vulnerable to a range of potential hazards associated with climate change. Hurricanes are high-profile hazards that threaten this region with strong winds, heavy rain, storm surge and high waves. Sea-level rise is a longer-term hazard that threatens to exacerbate storm surges, and increases the rate of coastal erosion and wetland loss. Loss of wetlands threatens to damage the fragile coastal ecosystem and accelerates the rate of coastal erosion.

These hazards threaten to inflict economic and ecological losses in this region, as well as loss of life during destructive hurricanes. In addition, they impact vital economic sectors, such as the energy and fishing industries, which are foundational to the local and regional economy. Impacts to these sectors are also realized on a national scale; Gulf oil and gas is used throughout the country to heat homes, power cars, and generate a variety of products, such as rubber and plastics, while seafood from the region is shipped to restaurants across the country.

This report reviews observed and projected changes for each of these hazards, as well as potential impacts and adaptation options. Information about the scale and relative importance of the energy and fishing industries is also provided, as well as insight into potential vulnerabilities of these industries to climate change. This report also identifies some adaptation options for those industries.

II. THE GULF COAST—A REGION AT RISK

The coastlines of Texas, Louisiana, Mississippi and Alabama combine to cover almost 12,427 miles (National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management). Louisiana's 7,221-mile coastline is longer than the other three states combined, and more than double the coastline of Texas. Louisiana's abundant islands and wetlands, as well as the elongated Mississippi River Delta, are part of a coastline whose vast expanse is not obvious from a quick glance at a national map. Figure 1 shows a map of this coastal region.

The physical geography of this coastline contains several features that make it particularly vulnerable to climate-related hazards. Much of this coastline, particularly in Louisiana, is not protected by barrier islands running parallel to the mainland, sometimes separated by a narrow lagoon of water. Barrier islands are more abundant in the Western and Eastern Gulf of Mexico, as well as the U.S. Atlantic Coast; they often consist of the sandy beaches that millions of Americans visit every year. These islands often contain slightly elevated features, such as sand dunes, which protect the mainland from coastal flooding. Most of the islands along the coast of Louisiana, however, are comprised of saltwater marsh, a mixture of grasses and trees growing in shallow coastal waters. Although marsh reduces the height of hurricane-driven storm surges and waves before they reach the mainland, the absence of barrier islands in this region contributes to the threat of coastal flooding.

It should be noted that barrier islands exist in the four states presented in this report, particularly in Texas and Alabama. However, barrier islands do not protect the vast majority of the Louisiana coastline.

Another unique feature of the central Gulf Coast is the flat topography of this coastline, which extends inland for tens of miles along much of the coast, with very slight rises in elevation. This level landscape enables slight increases of sea level, either from long-term trends or from the effects of hurricanes, to inundate vast areas and impact cities that are well inland.

The combined effects from sea-level rise, wetlands loss, and hurricane activity pose a threat to the human population and the ecosystem along the coast. Sea-level

FIGURE 1: This report reviews climate change impacts on the coastal areas of Texas (TX), Louisiana (LA), Mississippi (MS), and Alabama (AL).

rise makes Gulf Coast communities more susceptible to flooding. Rising sea levels also submerge or wash away vast areas of wetlands, which are important ecosystems that contain abundant varieties of plant and animal life. Because wetlands suppress hurricane-generated storm surges and waves before they reach coastal communities, wetlands loss also increases human vulnerability to hurricanes. In this way, the combined effects of sea-level rise and wetlands loss would threaten human populations even if hurricane intensity did not increase in association with climate change. However, because warm ocean waters feed hurricane development, it is likely that the intensity of hurricanes could increase in the future, as the climate warms. Therefore, the combined impact of these three hazards will increase the vulnerability of coastal communities in this region to climate-related hazards.

These hazards already impact the fishing and energy industries, as well as other economic sectors, such as tourism. The fishing industry suffers losses as hurricanes destroy marinas and other critical infrastructure. Hurricanes also alter the shape of the shoreline, change the water depth and can quickly change the water temperature, creating a stressful environment for fish that live in the coastal zone. The fishing industry is also impacted as sea-level rise increases the salinity of water in estuaries, bayous and coastal wetlands. Changes in salinity levels sometimes force plants and animals to make adaptations, altering the coastal ecosystem. The oil and gas industry suffers economic losses as hurricanes damage infrastructure and cause the evacuation of offshore oil rigs, temporarily reducing production and increasing costs. Hurricanes also delay and reroute the ship traffic that provides a crucial link between the energy industry along the U.S. Gulf Coast and other locations in the country and around the world.

The population explosion in recent decades along the Gulf Coast further exacerbates the vulnerability of this region to climate-related hazards. The total population of all Gulf Coast counties and parishes more than tripled from 1950 to 2000, increasing from 3.8 million to 12.4 million people (Keim and Muller 2009). More recently, however, it should be noted that the New Orleans metro area lost more than 260,000 people, or approximately 54% of its population, between 2000 and 2006, mostly as a result of population displacement due to Hurricane Katrina (U.S. Census Bureau 2009). Nonetheless, the general long-term population trend for the Gulf Coast has been one of steady growth over the past decades. This growing population would place more people at risk of coastal hazards even if the climate were not changing.

SEA-LEVEL RISE

A warming climate causes the sea level to rise through several processes. Warmer temperatures melt land-based ice, causing fresh water to flow into the oceans and increase its total volume. Warmer average global temperatures also increase the ocean volume because water expands as it warms, which also causes the sea level to rise. Finally, an important factor impacting how much it appears that sea level is rising is whether the land itself is sinking (subsiding) or rising (rebounding) (See Observed and Projected Changes below). These first two factors contribute to eustatic, or global, sea-level rise. The third factor combines with this global sea-level rise to result in a local or relative sea-level rise (RSLR).

Sea-level rise is measured in vertical distance. A rise of just several inches can cause salt water to push inland, changing fresh water to brackish water (a mixture of fresh and salt water) in some locations, and changing brackish water to salt water, in a process known as *saltwater intrusion*. This process can raise local water levels, which increases potential for flooding, since the water level is already elevated before a flood event even begins.

Observed and Projected Changes

In 2007, the Intergovernmental Panel on Climate Change (IPCC) estimated that global sea level rose an average 0.07 inches annually from 1961-2003, which means the global average sea level increased just over 3 inches in a 43-year period. If this were to continue at a steady rate, global sea level would increase about 7 inches per century.

The rate of RSLR is also important in the Gulf Coast region, given dramatic subsidence of some land areas along this coast, especially along the Mississippi River Delta in southeast Louisiana. Geologically, this region is mostly comprised of silts and sediment that washed down the Mississippi River and are still settling.

The rate of RSLR along the central and western Gulf Coast is likely the greatest in the nation (See Figure 2). The rate in southern Louisiana is 0.36 inches/year (Doyle et. al., 2010), which means that the relative sea level is rising three feet per century. This is five times greater than the global annual average experienced over the past century (Doyle et. al., 2010). Land subsidence accounts for more than 80% of this rise in Louisiana, but over time as SLR accelerates, this percentage may be lower.

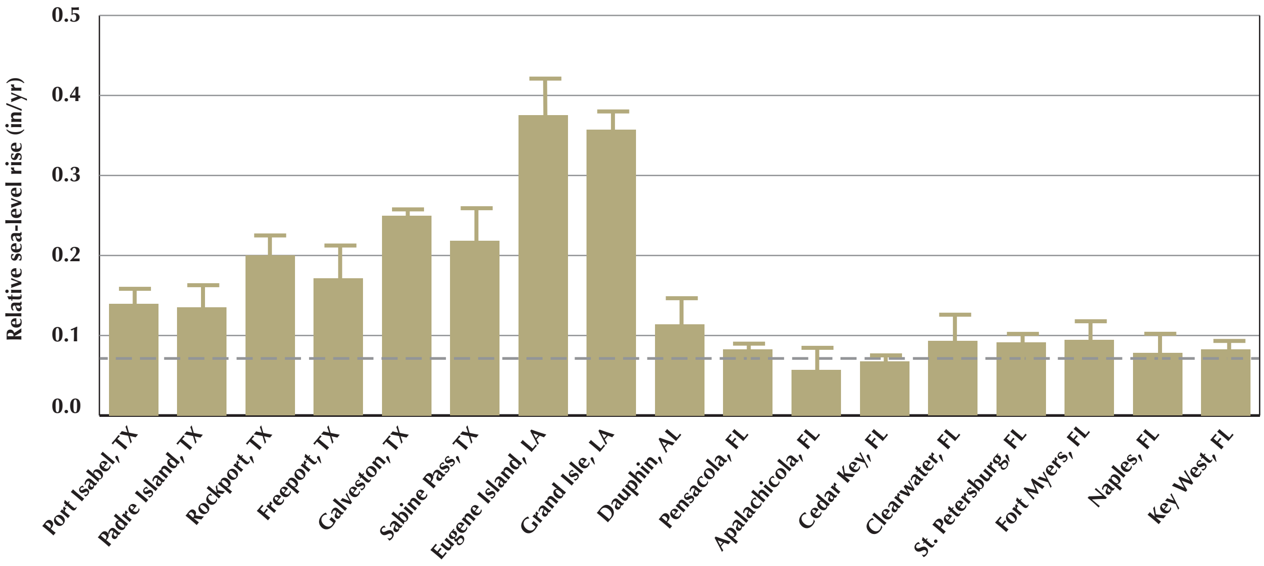
Locations that experienced rapid human-induced land subsidence, as people extracted subterranean fluids such as water, oil or gas, experienced even greater rates of RSLR. The Houston-Galveston area is an extreme example of this phenomenon, as land subsidence rates reached 1.48 inches/year between 1906 and 1987, values that are much greater than natural subsidence rates (Gornitz, 1995). The eastern Gulf of Mexico, on the other hand, experiences slower rates of RSLR, estimated between 0.08 and 0.09 inches/year from National Ocean Survey data (Smith et. al. 2010).

Sea-level rise is projected to accelerate in the future as air and water temperatures increase. The Intergovernmental Panel on Climate Change's 2007 report estimated a global sea-level rise of 18.9 inches by 2100 (Doyle et. al., 2010), more than 2.5 times the rate of sea-level rise from 1961–2003 (Intergovernmental Panel on Climate Change, 2007). This projection does not include accelerated iceberg calving from the Greenland and Antarctic ice sheets (the largest potential source of future sea-level rise) or further enhancement of RSLR in locations with subsiding land. RSLR in southeastern Louisiana is projected between approximately 20 and 40 inches in the next 50 to 100 years, although this estimate is still open for debate (Smith et. al., 2010). Recent projections since the 2007 IPCC report predict that global sea level will rise more rapidly, potentially exceeding three feet (not including local subsidence) in this century (U.S. Global Change Research Program, 2009).

Impacts and Adaptation Options

Rising sea levels could dramatically change the coastal landscape of the central and western Gulf of Mexico. Some coastal marshes would die as they are submerged beneath rising sea levels and destroyed by waves. Inland marshes may also die from increased salinity levels of the water. Beaches could become thinner, as the water edge moves inland, reducing the area of sand. The length of beaches may also be reduced, as higher sea levels enable waves to penetrate further inland, cutting channels into barrier islands. Another impact of rising sea levels will be increased severity of coastal flood events. As sea levels will already be elevated before a coastal flood event even begins, storm surges associated with hurricanes would inundate populated areas much more easily (See Figure 3). The impacts of increased coastal flooding may

FIGURE 2: Relative sea-level rise for NOAA (National Oceanic and Atmospheric Administration) tide stations in the northern Gulf of Mexico, USA.



The dotted line represents the average rate of global relative sea-level rise for the 20th century (Douglas, 1991, 1997; Church and White, 2006). TX: Texas, LA: Louisiana, AL: Alabama, and FL: Florida.

be particularly severe in Louisiana, where approximately 27% of the population resides at an elevation below 9.8 feet (3 meters), the second highest percentage in the nation (Lam et. al., 2009). (See Figure 4)

Saltwater intrusion could also alter the delicate balance of life along the coast. Grasses, shrubs and trees, adapted for specific salinity levels, will either die or migrate inland. As saltwater intrudes, fish and certain land-based animals would likely migrate inland. Wetlands, which serve as valuable habitat for many marine species, are also expected to shrink in size. Saltwater intrusion may also threaten the supply of freshwater needed to sustain human communities, as saltwater moves further up rivers or infiltrates underground aquifers that hold freshwater.

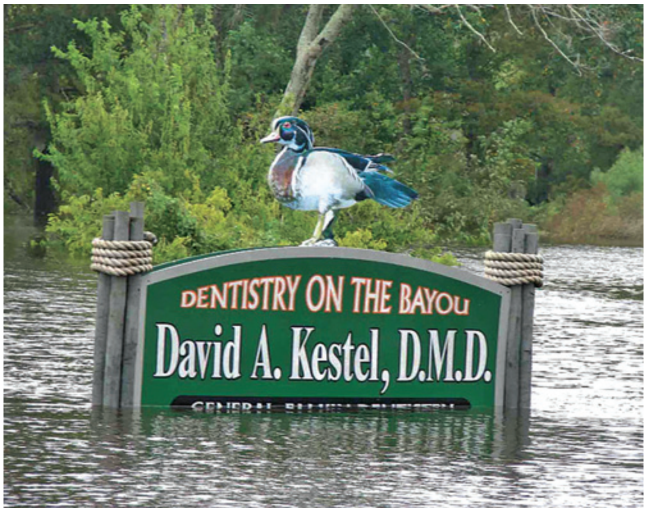
Several adaptation methods have been developed that protect people from the threat of rising sea levels. Elevating infrastructure, such as buildings, roads and bridges, is an adaptation method that enables communities to protect themselves by building "up," hopefully high enough to avoid future flood waters. Building "out," or developing away from the coast, is an adaptation method that is very effective because it removes people from the most vulnerable areas. Another adaptation method is to increase the height of levees, or other flood control devices. Although such improvements protect people from flood impacts, they can also lull people into a false sense of security, and actually attract them to live in a vulnerable location. (See Figure 5)

Careful water management in coastal areas is essential to protect freshwater supplies and minimize saltwater intrusion. If freshwater is not managed properly, saltwater is more likely to infiltrate underground aquifers that supply water to the human population. The development and design of infrastructure, such as canals, pipes, culverts and siphons, which direct freshwater and saltwater flows, may be important for managing the salinity balance in natural areas. The U.S. Fish and Wildlife Service, for example, proposes installing two siphons to reintroduce freshwater supply to McFaddin National Wildlife Refuge on the Texas coast (McFaddin/Texas Point National Wildlife Refuge, 2010). They anticipate this project will restore the natural water salinity in this critical habitat for migrating and wintering fowl.

WETLANDS LOSS

Wetlands are complex ecosystems, comprised of swamp, marsh or coastal woodland. They support wide varieties

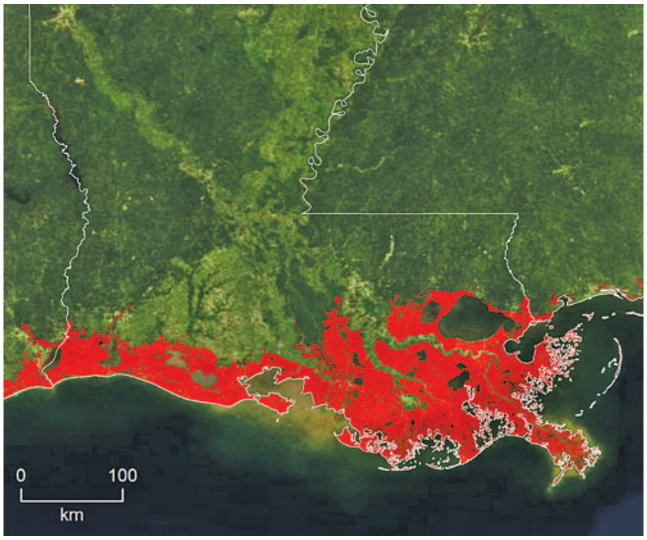
FIGURE 3: Populated coastal areas are at greater risk from storm surges and sea-level rise.



Louisiana is experiencing relative sea-level rise at the rate of nearly .4 inches/year, which is the highest rate in the nation. At this rate, water will rise nearly 3.3 feet relative to the land in the next century.

Photo Credit: Hal Needham

FIGURE 4: Vulnerability in Louisiana to flooding and sea-level rise.



Much of south Louisiana is susceptible to flooding from sea-level rise. The red area on this map depicts locations in Louisiana with elevations at or below 3.28 feet (one meter) and connectivity to the sea.

Source: Weiss and Overpeck, University of Arizona.

FIGURE 5: Raised levee near New Orleans.

This raised levee in the New Orleans area increases protection from storm surges and sea-level rise.

Photo Credit: U.S. Global Change Research Program

of plant and animal life. Wetlands in the United States support nearly 5,000 species of plants, one-third of all bird species, and 190 amphibian species (Natural Resources Conservation Service, 2010). Wetlands also provide important resources for humans. These areas enhance local and regional economies, as they support fishing industries, eco-tourism, and unique cultural and historical heritage.

Wetlands also suppress hurricane-generated storm surges and waves, providing a buffer between coastal communities and the open water of the Gulf of Mexico. This natural protection system saves lives and money in the coastal zone. A recent study calculated the value of wetlands for storm protection by combining historical hurricane data (tracks and intensities) with historical storm damage and gross domestic product within the path of previous hurricanes (Costanza et. al., 2008). This study concluded that the value of wetlands in Mississippi and Texas ranks in the top five nationally, as wetlands in both of these states provide storm protection of greater than $5,000 per acre annually.

Wetlands cover extensive swaths of coastal land in the region. For example, they make up about 7.6 million acres of Texas, or about 4.4 percent of the state (USGS, 1997), and nearly 3.4 million acres of Louisiana (LA Dept. of Natural Resources, 2010). Louisiana contains 40 percent of the coastal and estuarine wetlands, as well as 25 percent of the vegetated wetlands, in the 48 contiguous states (Williams et. al., 1997). A map of the Gulf Coast reveals that Louisiana contains more salt marsh and mangrove areas than any other Gulf Coast state (Doyle et. al., 2010). (See Figure 6)

Observed and Projected Changes

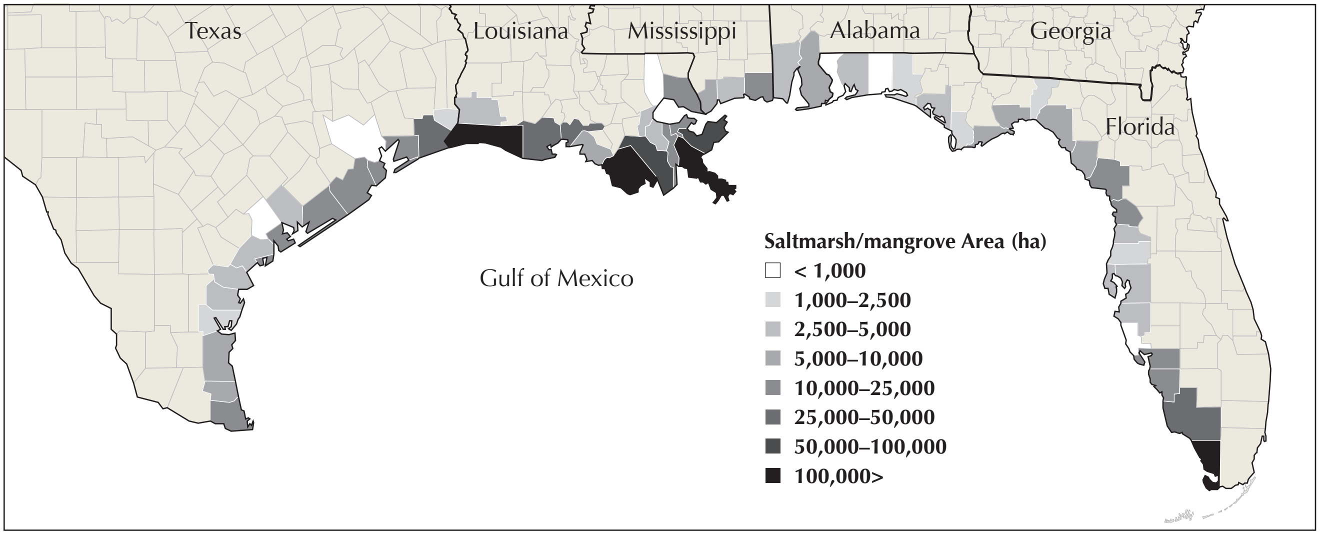
Wetlands in the Gulf Coast region are disappearing due to submersion from sea-level rise, destruction from increasingly intense hurricanes and encroachment from human development. These factors sometimes work together to accelerate the rate of wetlands loss. For example, intense hurricanes in recent years have produced massive storm surges and waves, which have destroyed extensive portions of wetlands. These impacts are exacerbated because the sea level along the coast is already elevated.

Sea-level rise has already inundated extensive wetland areas, changing the landscape from freshwater marsh to brackish marsh, and eventually to open water (Smith et. al., 2010). Tidal freshwater forests are dying or retreating from the coast (Doyle, 2010). In the past 200 years, Texas has lost more than 50 percent of its wetlands (Texas Parks and Wildlife, 2003), Louisiana loses a football field-sized area of wetlands approximately every 38 minutes (LA Dept. of Natural Resources, 2010), and Mississippi lost half of its sea grass area between 1967 and the mid-1990s (Moncreiff, 2006). The western and central Gulf is losing land at a faster rate than the more geologically stable eastern Gulf. For example, the rate of land loss in Louisiana is five times the Gulf of Mexico average (Penland and Ramsey, 1990).

Intense hurricanes produce large storm surges and destructive waves, which submerge or wash away coastal wetlands. The very active 2005 hurricane season provides a recent example of this phenomenon, as Hurricanes Katrina and Rita washed away 217 square miles of land and wetlands, an area almost 10 times the size of Manhattan. These hurricanes eliminated 85 percent of the land mass on the Chandeleur Islands (See Figure 7), a group of islands east of New Orleans (U.S. Global Climate Change Research Program, Pg. 114), with little hope for a full recovery of the island chain.

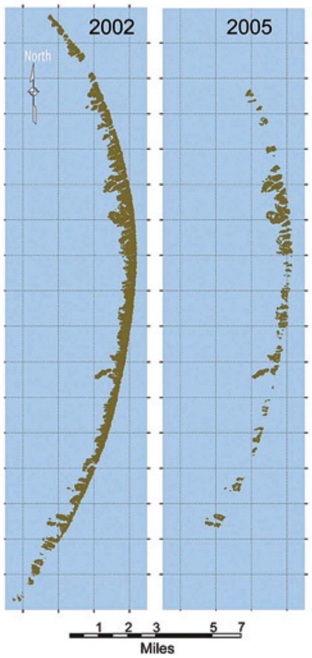
Wetlands will continue to disappear as sea level rises and land continues to sink. Over the next 100 years the western Gulf alone will lose more than 2.5 million acres of freshwater forests (Doyle, 2010). Louisiana will experience 86% of this land loss, as large salt marsh

FIGURE 6: Total salt marsh and mangrove area (ha = hectares) extracted from the National Wetlands Inventory by Field et. al. (1991) for coastal counties of the northern Gulf of Mexico, USA.



Doyle et. al. 2010.

FIGURE 7: Impact of Katrina and Rita on Chandeleur Islands.



The photos and maps show the Chandeleur Islands, east of New Orleans, before and after the 2005 hurricanes; 85 percent of the islands' above-water land mass was eliminated.

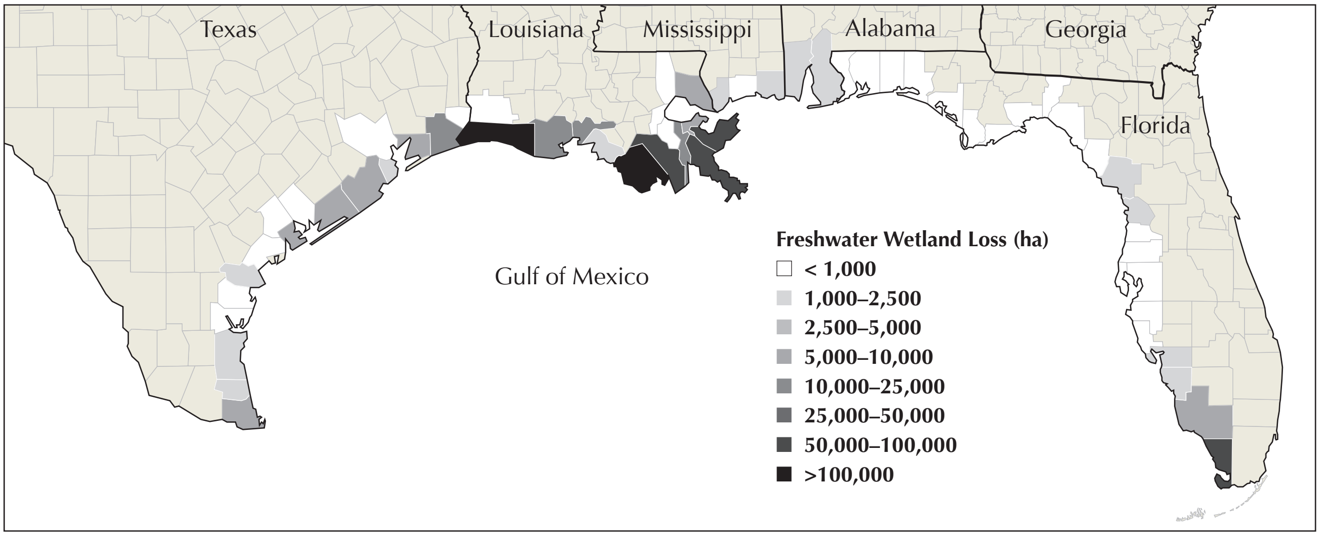
U.S. Global Climate Change Research Program

areas in the state are very close to sea level and have a slope of near zero (Doyle, 2010). The rates of wetland loss will increase even further if the rate of sea-level rise accelerates. A map of projected freshwater forest loss along the U.S. Gulf Coast depicts the highest rates of loss in the western Gulf, particularly in Louisiana (Doyle et. al., 2010). (See Figure 8)

Impacts and Adaptation Options

It is difficult to measure the exact extent by which the loss of wetlands has enhanced coastal flooding in the region during recent years. This is due to the complex nature of waves and storm surges produced by hurricanes, which are difficult to predict and not well understood. Nevertheless, it is reasonable to believe that the loss of wetlands contributed to enhanced storm surge heights, as evidence suggests that storm surge increases one foot for every 2.7 miles of wetlands lost (hearing before the Subcommittee on Water Resources and Environment, 2005). Wetlands loss also reduced critical habitat for migrating and wintering fowl, and unique coastal habitats that support a delicate balance of aquatic life. These impacts affect both the wildlife and people who depend upon these animals for their

FIGURE 8: Projected freshwater forest loss (ha = hectares) over the next 100 years at the present rate of global sea-level rise. Doyle et. al. 2010.



livelihood. The cost of these impacts, in economic terms, is difficult to measure and placing monetary values on wildlife is subjective. Furthermore, annual economic gains of local fishermen depend on a variety of factors, such as market values of fish, overhead expenses, as well as other environmental conditions, such as air and water temperatures, making monetary assessments of the impacts difficult.

Some adaptation methods involve coastal restoration and rebuilding wetlands. One successful method of restoring wetlands involves diverting river water to deteriorating wetlands, enabling sediments to deposit in crucial areas (Day et. al., 2005). Another effective method involves scooping sediments from shallow offshore waters and depositing them in areas that are losing wetlands. For projects like these to succeed, scientists need to develop sediment management plans that ensure such practices are redistributing sediment in the healthiest manner for the environment (Khalil and Finkl, 2009).

Other adaptation methods prepare humans for the impacts of higher storm surges in areas where wetlands loss is inevitable. These adjustments are similar to adaptations to sea-level rise and increased hurricane activity, and include elevating buildings and infrastructure, raising levees and other flood control devices, and placing future development further inland.

INCREASING HURRICANE INTENSITY

Hurricanes require warm ocean waters to develop and sustain strength, generally requiring sea surface temperatures exceeding 78.8 degrees Fahrenheit (Ali, 1996; Holland, 1997; Gray, 1998). Sea surface temperatures warmer than this threshold further enhance hurricane development. For this reason, hurricane activity in the Gulf of Mexico is greatest during the late-summer months of August through October, when surface water temperatures are highest.

As ocean temperatures rise, the maximum potential strength of hurricanes also increases. However, several other variables—such as atmospheric stability and the speed and direction of wind at different elevations in the atmosphere—determine whether an individual storm will form and also whether it will reach its maximum potential strength. This complexity makes it difficult to predict how hurricanes will respond to future climate change, but current evidence suggests that future warming would likely reduce the frequency of weak hurricanes—because fewer storms will form—but increase the frequency of category 4 and 5 hurricanes as well as the amount of precipitation associated with them—because the storms that do form will have the potential to strengthen over warmer water (Knutson et. al. 2010).

The potential impact of such an outcome on the central and western U.S. Gulf Coast is serious, as stronger hurricanes would increase the level of risk for regional residents and threaten to destroy more lives and property along this vulnerable coastline. Sea-level rise and wetlands loss compound this problem by making the coast more vulnerable to hurricane waves and storm surges, while the increasing coastal population puts more people and property in the path of hurricanes. Without efforts to adapt to future climate change, these vulnerabilities are likely to impose substantial costs on the residents of the Gulf Coast.

Observed and Projected Changes

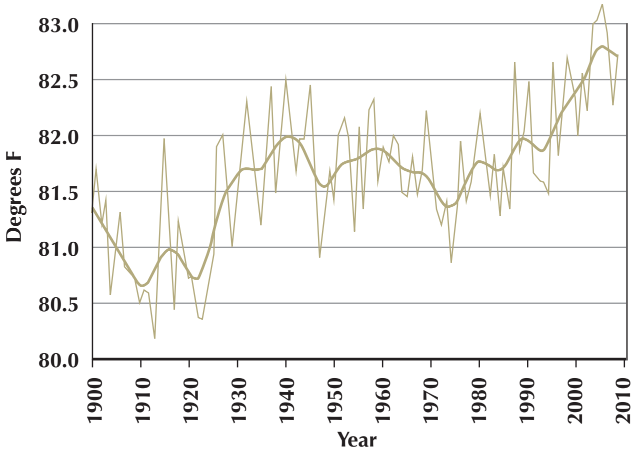
Measurements of ocean temperatures around the world show that temperatures have increased. Figure 9 depicts the increasing trend of the Atlantic Ocean sea surface temperature in the main development region for hurricanes, during the months that comprise the peak hurricane season, August to October.

In recent decades, a higher proportion of hurricanes are developing more intense winds, making them more catastrophic when they interact with ecosystems and human development. A global study found an increase in the number and proportion of hurricanes that reach categories 4 and 5, although the North Atlantic Ocean contributed the smallest increase to this average (Webster et. al., 2005).

Sea surface temperatures in the North Atlantic Ocean generally oscillate between warm and cold water-temperature phases that last between two and four decades. This pattern is called the Atlantic Multidecadal Oscillation. Sea surface temperatures associated with this pattern are depicted in Figure 10. Atlantic sea surface temperatures experienced a cold phase during the early 1900s, followed by a warm phase from the late 1920s to the 1960s, a cold phase from the 1970s to mid-1990s, and a warm phase from 1995 through the present (Landsea et. al., 1999).

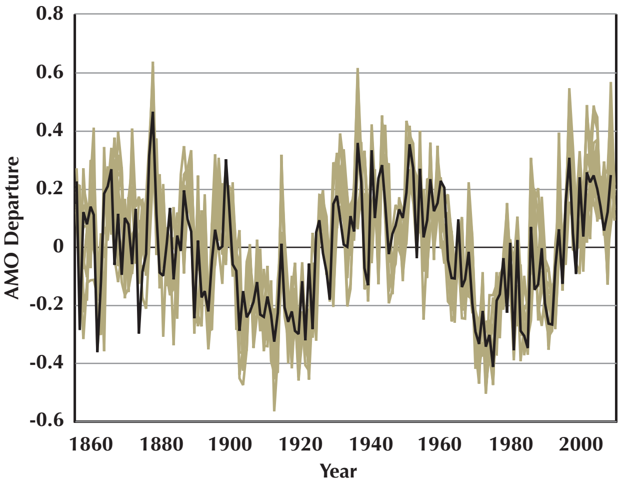
While sea surface temperature variability is well documented in the scientific literature, scientific consensus attributes much of the current oceanic warming to anthropogenic causes (Intergovernmental Panel on Climate Change, 2007). The natural variability

FIGURE 9: U.S. Global Change Research Program.



Ocean surface temperature during the peak hurricane season, August through October, in the main development region for Atlantic hurricanes.

FIGURE 10: Monthly values for the Atlantic Multidecadal Oscillation Index, 1856–2009.



This index indicates the extent to which Atlantic Ocean sea surface temperatures are unusually warm or cold. Orange-shaded areas in the graph represent years in which sea surface temperatures were unusually warm, and blue-shaded areas represent years in which sea surface temperatures were unusually cold.

Data source: http://www.esrl.noaa.gov/psd/data/correlation/amon.us.long.data.

of oceanic temperatures is thought to produce higher amplitude changes that are superimposed upon a smaller, more linear, anthropogenic warming trend. However, the extent to which anthropogenic-induced oceanic warming may increase hurricane activity beyond the limits of natural variability remains unresolved at this time.

Some studies seem to support the notion that anthropogenic warming has not yet pushed hurricane activity beyond natural limitations. Supporting evidence for this viewpoint include studies that reveal no long-term trends in observed hurricane landfalls along the U.S. coastline (Landsea, 2005), and no upward trend in hurricane losses observed along the U.S. coast, if economic losses are adjusted to account for inflation and societal changes (Pielke, 2005). However, such studies may not fully account for the complexities of changes in hurricane activity. While evidence suggests that the frequency of U.S. hurricane landfalls may not increase, it is likely that the average intensity of these hurricanes will increase in the future.

Many climate projections indicate that climate change will cause hurricanes to intensify. Computer model simulations indicate that a 1.8 degree Fahrenheit increase in tropical sea surface temperatures could increase hurricane wind speeds 1 to 8 percent and increase rainfall rates 6 to 18 percent (U.S. Global Change Research Program, 2009). From another perspective, a 1.8 degree Fahrenheit increase in tropical ocean temperature should theoretically increase the wind speed of hurricanes by about 5 percent (Emanuel, 2005).

A study that investigated the effect of doubled CO_2 levels on temperatures and hurricanes found that it is likely hurricane intensity would increase by 10% in such an environment (Anthes et. al., 2006). Such studies warn us to prepare for a future with more intense hurricanes, and also remind us that societal choices we make today, especially regarding the emission of greenhouse gases and what steps we take to adapt to such changes, could impact the costs and environmental damage experienced by future generations.

Impacts and Adaptation Options

Intense hurricanes in recent years have impacted the Gulf Coast region in several ways. Severe hurricane strikes have killed thousands of people, inflicted hundreds of billions of dollars in economic damages, displaced hundreds of thousands of people from their homes and destroyed entire communities. A brief summary of the three most severe hurricane seasons in recent times—2004, 2005 and 2008—describes some of these impacts. Specific impacts to the energy and fishing industries are discussed later in this report.

In September 2004, Hurricane Ivan made landfall along the Alabama coast as a Category 3 hurricane, packing winds of 120 miles per hour at landfall. Although Ivan killed 25 people in the United States, only one fatality was reported from the four-state region that is the focus of this report, a death reported in Mississippi (Stewart, 2004). Ivan destroyed many natural resources in this region, however, such as $610 million of damaged timber reported by the Alabama Forestry Commission (Stewart, 2004).

The 2005 hurricane season was the most active in the modern history of the Atlantic Basin. This season experienced 28 named storms, 15 hurricanes, and four Category 5 hurricanes, all of which were records for the Basin (National Oceanic and Atmospheric Administration, 2006). Also, Hurricane Wilma was the strongest hurricane (lowest central pressure) ever recorded in the North Atlantic Basin (Pasch et. al., 2006). Three hurricanes impacted the region: Dennis (July: Alabama), Katrina (August: Louisiana, Mississippi and Alabama), and Rita (September: Texas and Louisiana). Although Hurricane Dennis made landfall in the western Florida panhandle, it produced hurricane-force winds in southern Alabama. Damage was estimated at over $2 billion (Bevan, 2005). Hurricane Katrina, perhaps the most infamous hurricane in modern American history, exploded into a large, Category 5 storm over the Gulf of Mexico in late August. Katrina made landfall along the Louisiana and Mississippi coasts as a Category 3 storm, burying much of New Orleans under 10 to 15 feet of water, after the surge overwhelmed the levee protection system. This catastrophe was one of the worst in American history; the storm claimed more than 1,800 lives and caused an estimated $134 billion in damage (U.S. Global Change Research Program, 2009). Hurricane Rita followed close on the heels of Katrina, making landfall near the Texas/Louisiana border as a Category 3 hurricane that produced a 15-foot storm surge in Cameron, Louisiana, and inflicted an estimated $10 billion in damage (Knabb et. al., 2006). The coastal evacuation in anticipation of Rita was one of the largest in U.S. history, as the number of evacuees potentially reached 2 million (Knabb et. al., 2006). Unfortunately, many evacuees encountered complete gridlock on the highways; some even ran out of gas as they sat at a standstill for many hours.

Hurricanes Dolly, Gustav and Ike impacted the region in 2008. Dolly made landfall in south Texas in July, producing more than $1 billion in estimated damage (Pasch and Kimberlain, 2009). Gustav made landfall as a Category 2 hurricane along the south Louisiana coast in September, inflicting more than $4 billion in estimated damage (Bevan and Kimberlain, 2009). In September, Ike made landfall on Galveston Island, Texas. Though also only a Category 2 hurricane at landfall, the massive size of this storm generated a storm surge of over 17.5 feet that slammed the Texas coast (Berg, 2008). This surge inundated hundreds of miles of coastline and pushed Gulf waters inland more than 30 miles in some regions, completely inundating many communities (See Figure 11). Although Bridge City, Texas, is located 20 miles from the open water of the Gulf of Mexico, Ike's storm surge flooded all but 14 of the 3,400 homes in this community (FEMA Hurricane Ike Impact Report, 2008). Total damages from Ike were estimated at approximately $25 billion (Berg, 2008).

These catastrophic impacts illuminate the need to make adaptations that prepare communities along the central and western Gulf Coast for more intense hurricane activity. Individuals may need to elevate homes or choose to move inland to avoid storm surge destruction. Communities may need to elevate levees, upgrade flood pumps, or improve drainage systems, to prepare for more frequent floods from storm surge and heavy rainfall. Hurricane Katrina taught city planners, emergency management workers, and law enforcement personnel to prepare for worst-case scenarios that involve the interruption of telecommunications and impassable roadways. These hurricanes also demonstrated the importance of transportation planning. Transportation designers and planners should incorporate improvements into infrastructure design that account for higher probabilities of heavy rain, strong wind, and storm surge (U.S. Global Change Research Program, 2009), while also improving evacuation plans so human-enhanced problems, such as the ineffective evacuation of the Texas coast before Hurricane Rita, can be avoided in the future.

FIGURE 11: Storm surge from Hurricane Ike.

More intense hurricanes will likely generate larger storm surges along the Gulf Coast. Although this gas station in Orange, Texas was more than 60 miles east of Hurricane Ike's (2008) most intense winds, and more than 20 miles inland from the open Gulf of Mexico, Ike's surge inundated it under three feet of water. Some locations in this community reported more than nine feet of surge.

Photo Credit: Hal Needham

III. GULF COAST ENERGY INFRASTRUCTURE

The United States depends upon reliable, affordable energy to meet industrial, commercial, agricultural, and residential demands, as well as to support transportation and communication networks. While some uses are rather apparent, such as jet fuel that powers airplanes, other uses are less obvious, such as oil used to produce rubber and plastics.

As the central and western Gulf Coast is a significant source of the nation's energy, disruptions to energy production in this region impact the national economy and regional economies in various parts of the country. This section takes a closer look at the importance of the Gulf Coast energy industry, as well as potential vulnerabilities of this industry to climate change, and adaptation options that would enable this industry to prepare for a changing climate.

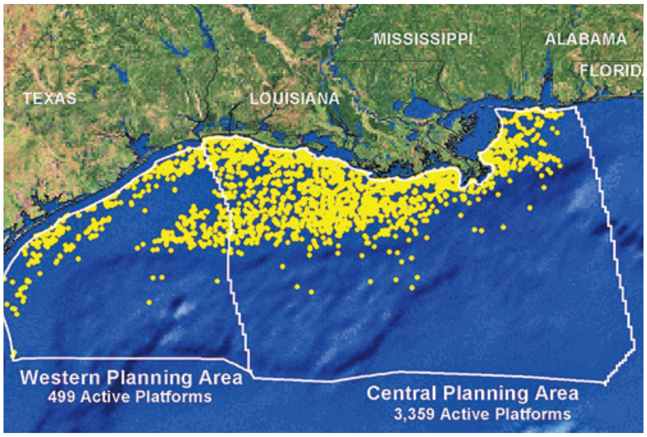
THE SCALE AND RELATIVE IMPORTANCE OF THE ENERGY INDUSTRY

Energy Operations and Infrastructure

The energy industry converts raw materials, such as crude oil and natural gas, into products that are useful for consumption. This process requires a complex network of infrastructure to transport and process materials, which relies on large amounts of industrial development. Energy assets tied to this four-state region total $800 billion (2010 dollars), comprising approximately 90% of industrial assets in the region (Entergy, 2010).

The first step in this process involves extracting raw materials from beneath the Earth's surface. The largest untapped oil and gas deposits in the Gulf Coast region are located beneath the sea floor of the Gulf of Mexico, and many drilling sites are located offshore. Nearly 4,000 drilling platforms dot the Gulf of Mexico, particularly off the coasts of Texas and Louisiana (National Oceanic and Atmospheric Administration, 2006) (See Figure 12). Offshore platforms are classified as either deep-water or shallow-water platforms. Shallow-water platforms are located in water less than 1,000 feet deep, and often stand on metal legs. Deep-water platforms are located in at least

FIGURE 12: Active oil and gas platforms in the central and western Gulf of Mexico.



Nearly 4,000 active oil and gas platforms are located in the central and western Gulf of Mexico. (Source: National Oceanic and Atmospheric Administration, 2006). This map is available on the Web at: http://oceanexplorer.noaa.gov/explorations/06mexico/background/oil/media/platform_600.html

FIGURE 13: The Deepwater Horizon oil spill.

The Deep Water Horizon explosion and oil spill in 2010 was the worst spill in U.S. history. This disaster killed 11 oil workers, dumped 170,000 million gallons of crude oil and 200,000 metric tons of methane gas into the Gulf of Mexico (Natural Resources Defense Council, 2011). This disaster brought much attention to the dangers of deep water oil drilling.

Photo Source: http://www.psp.wa.gov/oilspills.php.

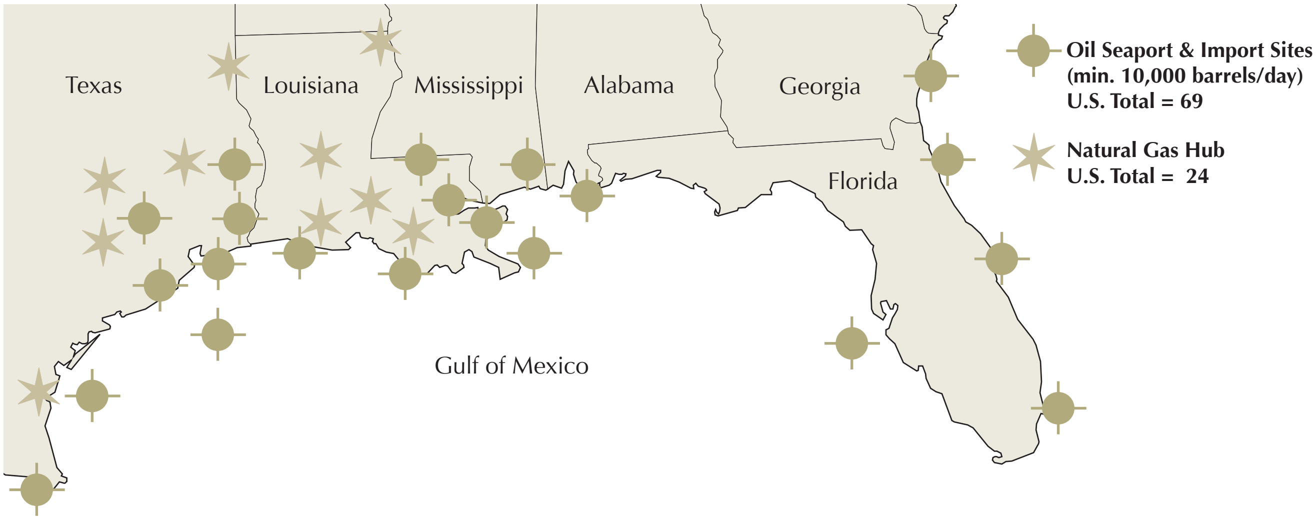
1,000 feet of water (State of Louisiana, 2010), and generally float on the water's surface, only connected to the sea floor through the pipe by which the drilled oil flows. Deep-water platforms are especially important to this industry, as they produce 80 percent of the Gulf of Mexico's oil and 45 percent of its natural gas (State of Louisiana, 2010).

Following extraction at the platform, oil is then distributed via the vast pipeline network covering the region (Minerals Management Service, 2006). Some pipelines connect directly to offshore platforms, while others provide openings for large ships, called oil tankers, to unload oil and gas into the network. Some tankers carry oil from as far away as Russia or Saudi Arabia, while others simply transport oil from platforms in the Gulf of Mexico to the pipeline network, a distance of less than 100 miles in some cases. Figure 14 depicts the distribution of energy infrastructure, including oil seaport and import sites, natural gas pipelines, and natural gas hubs (U.S. Energy Information Administration, 2010). The largest concentration of oil seaport and import sites is located along the western and central Gulf Coast, where 17 sites are located.

Once the oil and gas enters the pipeline network, it is pumped to a refinery, which removes pollutants and separates raw materials into useful products, such as heating oil, asphalt, jet fuel or gasoline (McCrossin et. al., 2002). The central Gulf Coast is home to the largest concentration of refineries in the United States, and Texas and Louisiana have more refineries than any other states in the nation. The 27 refineries in Texas and 17 in Louisiana account for approximately 30% of the nation's 147 refineries (U.S. Energy Information Administration, 2010). Most refineries are located near coasts to provide access to shipping and transportation routes (McCrossin et. al., 2002). Figure 15 depicts the location of oil refineries in the United States (U.S. Energy Information Administration, 2010).

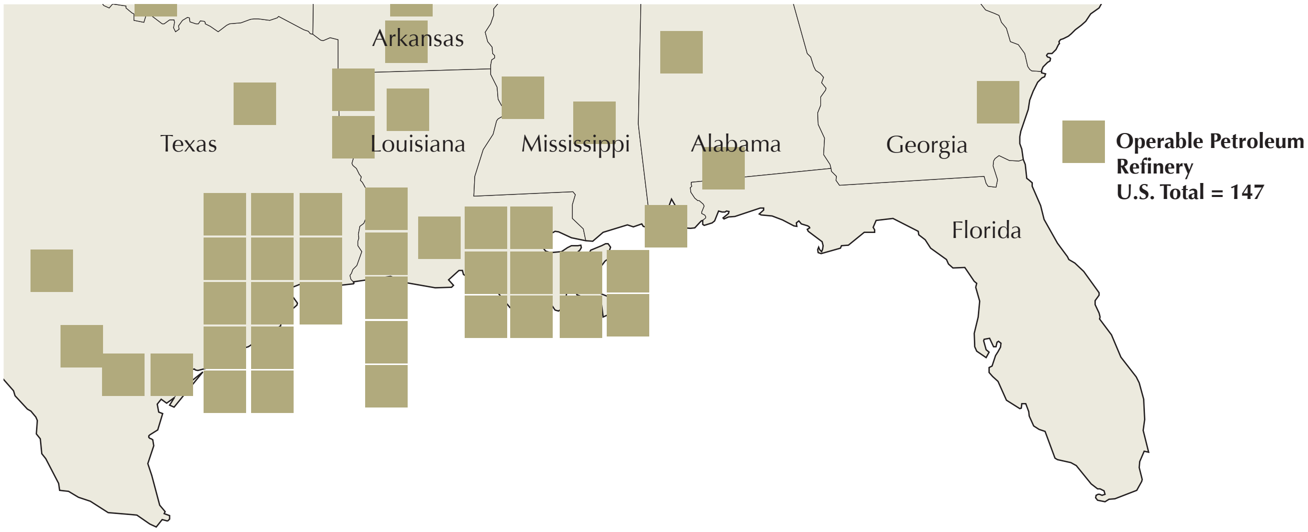
After the oil and gas is processed at the refinery, the finished products are shipped to regional, national and global consumers, who use these products to make rubber and plastics, fuel cars and heat homes. A pipeline network transports these products throughout much of the East Coast, Great Lakes and Central Plains states, and trucks transport supply to locations west of the Rocky Mountains and the Pacific Coast. Ships transport these products to locations where pipelines and roads do not easily reach, such as international destinations, Alaska, Hawaii, and U.S. territories.

FIGURE 14: Oil and gas industry infrastructure along the Gulf Coast.



This oil and gas industry infrastructure map depicts high concentrations of infrastructure along the central and western Gulf Coast. The 17 oil seaport and import sites in this region provide locations for ships to unload crude oil into the pipeline network, which transports these resources to refineries. U.S. Energy Information Administration, 2010. This map is available on the Web at: http://www.eia.doe.gov/state/.

FIGURE 15: Petroleum refineries along the Gulf Coast.



This petroleum refinery map depicts the highest concentration of refineries along the central and western Gulf Coast. Texas leads the Nation with 27 refineries, followed by Louisiana's 17 refineries. U.S. Energy Information Administration, 2010. This map is available on the Web at: http://www.eia.doe.gov/state/.

Electric power plants may use this energy (for example, in the form of natural gas) to create electricity. Natural gas is the most popular fuel source in the Gulf Coast region for generating electricity, although some plants use coal, hydroelectric or nuclear power. The electricity industry has invested heavily in infrastructure, such as transmission lines, which transport power from the plant to consumers.

Economic Benefits and State-By-State Production

TEXAS

Texas produces approximately 16 percent of the energy in the United States. It is the leading producer of natural gas, producing approximately 30 percent of the nation's supply. Texas is also the leading producer and consumer of electricity nationally. Its abundant supply of natural gas provides an accessible fuel for electricity production; natural gas fuels approximately 50 percent of Texas' electric power plants (U.S. Energy Information Administration, 2010).

Texas also leads the nation in refining capacity. Its 27 refineries can process 4.7 million barrels of crude oil daily, accounting for 27.2 percent of the nation's refining capacity. Most of these refineries are located along the Gulf Coast, from near Beaumont and Port Arthur, through the metropolitan Houston area, south to near Corpus Christi. The nation's largest refinery, operated by Exxon Mobil, is located in Baytown, Texas, near Houston (U.S. Energy Information Administration, 2010).

These vast industrial operations greatly benefit Texas' economy. Texas employs 1.8 million people in the oil and gas industry, the highest number nationally. These jobs account for 13.1% of jobs in the state. The industry produces $141 billion in labor income in Texas, more than double the amount of any other state, accounting for 19.5 percent of the state's income (Price Waterhouse Coopers, 2010).

LOUISIANA

Much of Louisiana's oil and gas resources are found in the federally-administered Outer Continental Shelf (OCS) region of the Gulf of Mexico. This is the largest oil-producing region in the United States. Ninety percent of the crude oil reserves found in the OCS are located in the section assigned to Louisiana. Including these offshore reserves, Louisiana contains nearly 20 percent of the nation's crude oil and 10 percent of the nation's natural gas reserves (U.S. Energy Information Administration, 2010).

Louisiana is the top crude oil producer in the nation if production from the OCS is included. The state is the second leading producer of natural gas and produces more petroleum products than any state but Texas. Louisiana's 16 refineries can process 3 million barrels of crude oil per day, accounting for 17 percent of the United States' refining capacity.

Louisiana also contains specialized infrastructure that is essential to the regional and national energy industry. The Louisiana Offshore Oil Port (LOOP) is the only U.S. port that accommodates deepwater oil tankers, enabling Louisiana to import approximately 20 percent of the nation's foreign oil supply (U.S. Energy Information Administration, 2010). The port, which is located offshore, connects to approximately 50 percent of the U.S. refining capacity. Louisiana also contains the Henry Hub, the nation's largest centralized point for natural gas spot and futures trading. Activity at this hub generally sets the primary price for the North American natural gas market. The Henry Hub connects 13 natural gas pipelines to markets in the Midwest, Great Lakes, Northeast, Southeast and along the Gulf Coast (U.S. Energy Information Administration (b), 2010). Although infrastructure such as the LOOP and Henry Hub are located in Louisiana, they impact oil and gas operations throughout much of the country.

The oil and gas industry contributes greatly to Louisiana's economy. Louisiana is more dependent on the energy sector than any state except Alaska, in part because the state's economy is not very diversified (State of Louisiana, 2010). The oil and gas industry provides 330,000 jobs in Louisiana, which account for 13.4% of the state's total labor. These jobs generate $18 billion, which accounts for 16.6% of state labor income (Price Waterhouse Coopers, 2009). The industry also contributes significantly to state taxes, providing $1.4 billion in 2006, or 14 percent of the state's revenue (State of Louisiana, 2010).

MISSISSIPPI

Although the energy industry plays an important role in Mississippi's economy, the state does not produce as much energy as its regional neighbors, Texas and Louisiana. The oil and gas industry provides nearly 84,000 jobs in the state, accounting for 5.5% of its jobs, the eleventh-highest share in the nation. These jobs create $3.6 billion in labor income, which provides 6.5% of Mississippi's revenue (Price Waterhouse Coopers, 2010).

The three refineries in the state account for approximately 2% of the United States' refinery capacity. The Pascagoula refinery, Chevron's largest U.S. refinery, and the largest refinery in Mississippi, is well-suited to process heavier, sour crude oil (Chevron, 2010). This type of oil is often less expensive and readily available on the foreign market, from places such as Saudi Arabia. Such processing capabilities are important to diversify the refining capacity within the region and the nation.

ALABAMA

Alabama's economy depends less upon the energy sector than the other states in this region. As a result, Alabama imports some of its oil and gas through pipelines from Louisiana and Texas, to meet the state's demands, which are mostly for industrial operations and electric power generation. Alabama contains important infrastructure to transport energy to highly-populated markets along the East Coast. The state also produces more than 1% of the natural gas produced in the nation (U.S. Energy Information Administration, 2010).

The oil and gas industry produces nearly 95,000 jobs in the state, which is 3.7% of the state's total employment. These jobs generate more than $4 billion in annual revenues, or almost 4% of the labor income (Price Waterhouse Coopers, 2010).

It should also be noted that Alabama produces more hydroelectric power than the other states in this region. Alabama produces more than 5% of the nation's hydroelectric power, whereas Texas and Louisiana produce less than 1% (U.S. Energy Information Administration, 2010).

POTENTIAL VULNERABILITIES OF THE ENERGY INDUSTRY TO CLIMATE CHANGE

The energy industry along the central and western Gulf Coast faces vulnerability to several aspects of climate change. The increasing intensity of hurricanes threatens to damage oil and gas drilling platforms, pipelines, refineries and electricity transmission lines. The threat of hurricanes causes sizable delays in the production and shipping of oil and natural gas. Rising sea levels increase the threat of flood damage to coastal infrastructure. Warmer temperatures may strain the electric grid, as the demand for air conditioning increases. Also, more frequent droughts may reduce water availability to generate hydroelectric power and regulate the temperature of industrial operations.

Recent damage and economic losses inflicted by these environmental threats are discussed in this section. Perhaps most dramatic are the recent impacts of severe hurricanes in this region. It should be noted, however, that although hurricanes produce sudden, catastrophic impacts, longer-term processes, such as sea-level rise, will also substantially affect the energy industry. The combination of multiple hazards will likely carry a large price tag in future decades; it is estimated that losses to the energy industry will reach $21.5 billion by 2030 and $34.6 billion by 2050, given an average climate change scenario that includes modest estimates of future carbon dioxide emissions and temperature rise (Entergy, 2010).

Increasing Intensity of Hurricanes

The increasing intensity of hurricanes creates potential vulnerabilities for the energy industry along the central and western Gulf Coast. High winds and waves damage offshore oil and gas platforms, as well as coastal infrastructure, such as pipelines and refineries. Electric transmission lines, usually elevated high above the ground, often experience stronger winds than those at ground-level. This section discusses the economic losses and damage inflicted by hurricanes in the Gulf of Mexico during three recently active hurricane seasons: 2004, 2005 and 2008.

2004

Hurricane Ivan slammed the Central Gulf Coast in September 2004. The storm traversed the offshore drilling area as a Category 4 hurricane, packing winds of nearly 140 miles per hour (Unisys Corporation, 2010), before making landfall as a Category 3 hurricane on the border of Alabama and Florida (Stewart, 2005). Perhaps the most extraordinary feature of this storm was the enormous waves it generated, some of which reached as high as 89 feet as they damaged offshore oil and gas platforms (Stone et. al., 2005).

Ivan destroyed seven platforms and caused significant damage to 24 others (Kaiser et. al., 2009). Additionally, at the Nakika Oil Export Line, Ivan triggered a major offshore oil spill, close to a wildlife refuge (Coyne and Dollar, 2005). Most of Ivan's damage was offshore, enabling most onshore facilities to be operational for post-storm recovery (Cruz and Krausmann, 2009).

Hurricane Ivan caused considerable economic losses to the oil and gas industry. Although the infrastructure damage was costly, approximately two-thirds of the economic losses were attributed to the interruption of operations (Kaiser et. al., 2009). Ivan caused an estimated $2.5 to $3 billion in economic losses (Kaiser et. al., 2009).

2005

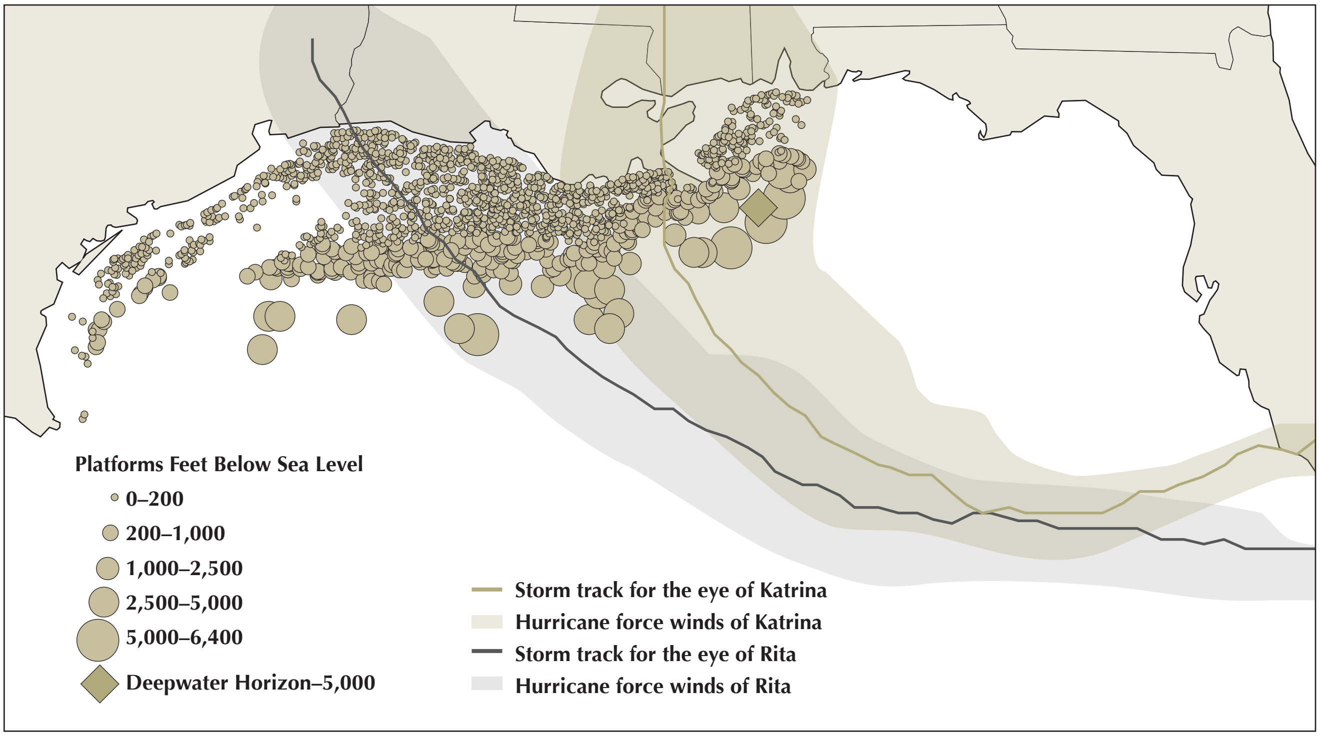
Hurricane Katrina inflicted severe damage on the central Gulf Coast in late August 2005. Katrina was a Category 5 hurricane when it entered the Outer Continental Shelf (OCS) (Minerals Management Service, 2006), an offshore region clustered with oil and gas platforms. Katrina destroyed and damaged offshore oil and gas platforms, as well as offshore pipelines. The storm also caused widespread damage to onshore infrastructure, as it made landfall as a Category 3 hurricane in Louisiana and Mississippi, producing a 28-foot storm surge (Knabb et. al., 2005).

Several weeks later, Hurricane Rita traversed the Gulf of Mexico, entering the OCS as a Category 4 storm (Minerals Management Service, 2006), before making landfall as a Category 3 hurricane on the Texas and Louisiana border (Knabb et. al., 2006). More than 3,000 of the 4,000 offshore platforms, as well as 22,000 of the 33,000 miles of pipeline, were in the direct path of at least one of these storms (Minerals Management Service, 2006). (See Figure 16).

Katrina destroyed 46 offshore platforms and damaged 20 others, while Rita destroyed 69 platforms and damaged 32 others (Minerals Management Service, 2006). The two storms damaged a combined total of 457 pipelines (Cruz and Krausmann, 2008). Unfortunately, Katrina and Rita caused severe damage onshore as well as offshore, which slowed the recovery process, as damaged onshore facilities, infrastructure, communication systems, transportation routes, food and water supplies reduced the speed at which recovery workers could repair damage (Cruz and Krausmann, 2009).

Katrina and Rita also triggered pollution incidents, including hazardous-materials releases. More than 400 minor pollution incidents on the OCS were reported to the Minerals Management Service by January 2006 (Minerals Management Service, 2006). These storms also triggered more than 600 hazardous-materials releases at offshore platforms and pipelines, which included pollutants such as crude oil and other oils (such as fuel,

FIGURE 16: Hurricanes Rita and Katrina, August–September 2005



Hurricanes Katrina and Rita destroyed a combined total of 115 offshore oil and gas platforms (Minerals Management Service, 2006). Most platforms off the central and western Gulf Coast experienced hurricane force winds in at least one of these storms. The areas in which Katrina and Rita produced hurricane-force winds are shaded in light orange and pink, respectively. Black dots depict the location of offshore platforms. Minerals Management Service, 2006. This image is available on the Web at: http://www.mms.gov/ooc/Assets/KatrinaAndRita/Rita1.jpg.

lubricating or hydraulic oils) natural gas, nitrogen oxide and nitrogen dioxide (Cruz and Krausmann, 2009). Although hazardous materials were released from both platforms and pipelines, more than 80 percent of the reported incidents occurred at platforms, presumably because platforms are more exposed to hurricane winds and waves (Cruz and Krausmann, 2009). The most significant incidents, however, occurred onshore or in the coastal areas, in association with Hurricane Katrina. The Murphy Oil Spill released approximately 820,000 gallons of oil into a densely populated area of St. Bernard Parish, Louisiana, while 10,500 gallons of the Shell Oil Spill reached the shoreline, including coastal marshes (Pine, 2006).

Katrina and Rita also caused significant financial losses. They were responsible for a record-breaking $15 billion loss to energy markets (Kaiser et. al., 2009). Two-thirds of these losses were associated with physical damage to energy infrastructure (Kaiser et. al., 2009). In addition to infrastructure damage, Katrina and Rita reduced production as they suspended oil and gas operations for much of the offshore drilling area. For example, Katrina took more than 90% of the oil production and more than 83% of the natural gas production offline, as more than 700 platforms and rigs were evacuated (Cruz and Krausmann, 2008).

Katrina also severely damaged the electric grid in Louisiana and Mississippi. The storm damaged or destroyed nearly two-thirds of the transmission and distribution system in Mississippi's affected area. Nearly 700,000 Louisiana customers were without power five days after the storm. Six weeks after Katrina hit the area,

FIGURE 17: Hurricane damage to the Thunder Horse platform.

Hurricane Dennis (2005) damaged the Thunder Horse platform 150 miles southeast of New Orleans, causing it to list into the water. Minerals Management Service. This image is available on the Web at: http://www.mms.gov/ooc/Assets/Photos/ThunderHorseDamage/600CG1.jpg

nearly 75% of people in a half-mile wide strip along the Mississippi Coast, 70% of St. Bernard Parish, Louisiana, and 50% of New Orleans were still without power (Kwasinski et. al., 2009).

Although Katrina and Rita produced the greatest destruction to the energy system during 2005, the season was very active, and other storms also impacted the Gulf of Mexico. In July, Hurricane Dennis severely damaged BP's Thunder Horse Platform, 150 miles southeast of New Orleans. The storm caused the platform to list into the water, requiring assistance from the Coast Guard, and delaying oil production (Energy Information Administration, 2006). Figure 17 shows images of the listing platform.

2008

Hurricane Gustav tracked across the offshore drilling area of the central Gulf Coast as a Category 3 hurricane, before making landfall in southern Louisiana on September 1, as a Category 2 hurricane. The storm exposed 677 platforms to hurricane-force winds (Kaiser and Yu, 2010). Hurricane Ike followed about two weeks later, crossing the offshore drilling area of the central and western Gulf Coast as a Category 2 hurricane, before making landfall on Galveston Island at the same intensity. Ike exposed 1,450 platforms to hurricane-force winds, more than twice the number of Gustav. Ike's large size and more westward storm track enabled the storm to impact a larger portion of the offshore oil and gas infrastructure to strong winds and high waves.

These storms destroyed 60 platforms and damaged 31 others (Kaiser and Yu, 2010). The destroyed platforms accounted for about 2.5% of the gas and 1.6% of the oil produced daily in the Gulf of Mexico, and represented reserves valued at between $4.6 and $10.9 billion (Kaiser and Yu, 2010). Although energy prices increased after these storms, the spike in prices was not as severe as it could have been. Fortunately, the cost of energy was generally decreasing during the summer and fall of 2008, which moderated the impact of these storms (Darr et. al., 2010).

Sea-Level Rise

Sea-level rise threatens to inundate refineries, port facilities and other critical energy infrastructure in the coastal zone. Also at risk are low-lying roads that provide access to these facilities. For example, multiple studies have concluded that Louisiana Highway 1, between Golden Meadow and Leeville, will be inundated more than 300 days per year by 2050 (Armand, 2011). This road provides the only land access to Port Fourchon, a critical location for the U.S. energy industry. Port Fourchon is the land base for the Louisiana Offshore Oil Port (LOOP), which is the only deep-water oil import facility in the nation.

Sea-level rise also increases the vulnerability of oil and gas pipelines, refineries, and chemical storage containers in the coastal zone during hurricanes. Elevated sea levels enable storm surges and powerful waves to hit buildings and infrastructure at a higher level than before, causing more damage. Sea-level rise also enables hurricanes to inundate a larger area, immersing more buildings in water.

Hurricane Katrina's flood damage to coastal infrastructure provides a snapshot of problems incurred during such events. Katrina's surge and powerful waves damaged many industrial and harbor facilities, as well as refineries, chemical plants and pipelines (Harris and Wilson, 2008). Storm surge accompanied by wave action caused the Murphy Oil Spill, which released approximately 820,000 gallons of oil into a densely populated area of St. Bernard Parish (Pine, 2009). Hurricanes

Katrina and Rita also suspended oil and gas operations in the coastal region, causing eight refineries to shut down (Cruz and Krausmann, 2008).

It is difficult to calculate the economic damage inflicted by rising sea levels, partly because coastal flooding associated with hurricanes destroys coastal infrastructure even if sea levels are not rising. Also, it is difficult to categorize the exact amount of hurricane damage caused by coastal flooding versus strong winds. However, it is obvious that rising sea levels will exacerbate the damage inflicted by hurricane storm surges, and increase the economic losses to the energy industry along the central and western Gulf Coast.

Increasing Temperatures

Temperatures across the southeastern United States will likely warm in all seasons in future decades. Projected temperature increases range from 4.5 degrees Fahrenheit to 9 degrees Fahrenheit in a higher emissions scenario by the 2080s (U.S. Global Change Research Program, 2009). More importantly, the number of high-heat days will likely increase in the region. The number of days per year exceeding 90 degrees in the coastal regions of Louisiana, Mississippi and Alabama is expected to increase from approximately 75 days in the recent past (1961-1979) to approximately 120 days in lower-emissions scenarios, or 150 days in higher-emissions scenarios, by the end of the 21st century (U.S. Global Change Research Program, 2009).

The increase in the number of high-heat days in the region will likely increase the demand for electricity, as the demand for air conditioning rises. Increasing demand for electricity may also result in higher energy costs for consumers, as supply struggles to keep up with demand. Warmer winters would not likely offset this demand, because air conditioning demands more electricity than heating, as sources other than electricity, such as natural gas, oil and wood, can heat buildings. For every 1.8 degree Fahrenheit increase in temperature, demand for cooling energy increases between 5 and 20 percent (Scott and Huang, 2007; U.S. Global Change Research Program, 2009).

Such increases in electricity use can overwhelm power grids, causing system failure. Several heat-related blackouts in major metropolitan areas during the past decade reveal this vulnerability in the energy system. The largest blackout in U.S. history occurred during a heat wave in the summer of 2003, leaving as many as 50 million people in the northeastern U.S., including a large portion of New York City, without power (Miller, 2008). Regional electricity use reached a single-day record during the 2006 California heat wave, causing rolling blackouts and brownouts that left millions without power for days (Miller, 2008). Although such widespread power outages have not yet struck the central or western Gulf Coast region, increased electricity use during warmer summers may strain the electrical power infrastructure in the future.

Drought

The U.S. Southeast is likely to face water shortages in the future as increased societal demand, longer time periods between rainfall events, and increased rates of evapotranspiration combine to decrease water availability (U.S. Global Change Research Program, 2009). These conditions will reduce stream flow rates, which on average decrease 2-3% for every 1% reduction in precipitation (National Assessment Synthesis Team, 2001; U.S. Global Change Research Program, 2009). Water shortages will likely constrain electricity production in Texas, Louisiana and Alabama by 2025 (Bull et. al., 2007; U.S. Global Change Research Program, 2009). Cooling for electrical power production represents most of the water used in Alabama; this source used about 83% of the state's water during 2005, most of which was surface water used for cooling and then returned to the surface water source (Hutson et. al., 2009).

Lack of water could also impact industrial facilities, such as refineries and power plants throughout the region, as many plants rely on water as a cooling agent. Insufficient water supply could lead to a reduction in industrial productivity, which could then lead to reduced demand for energy, such as electricity.

ADAPTATION OPTIONS FOR GULF COAST ENERGY INFRASTRUCTURE

Increasing Hurricane Intensity

The energy sector must prepare for increased damage to offshore oil and gas platforms as hurricanes may intensify in the future. Generally, hurricane-force winds destroy 2-4% of platforms and damage another 3-6% (Kaiser et. al., 2009), which means an increased number of platforms could be destroyed and damaged as hurricanes intensify. The industry may adapt to this problem by building stronger and sturdier platforms, or budgeting for increased offshore infrastructure loss. The next couple of decades will likely be very active with hurricanes, as long as the sea surface temperatures of the Atlantic Ocean remain warmer than normal.

Energy planners must also re-evaluate the probability of strong winds and large waves at offshore sites. Offshore platforms currently follow the design requirements established by the American Petroleum Institute, which recommends platforms withstand one-hour average wind speeds of 93 miles per hour, one-minute average wind speeds of 112 miles per hour, and wave heights of 72 feet (Ghonheim and Colby, 2005; Ward et. al., 2005; Kramek, 2006; Cruz and Krausmann, 2008). These values are recommended as 100-year criteria, meaning a given site should expect to experience conditions this severe once every 100 years, on average. However, it is likely that these figures underestimate 100-year wind and wave levels. For example, Hurricane Ivan generated waves as high as 89 feet at offshore platforms, well beyond the 100-year wave height of 72 feet. According to the present statistical estimates, such waves should only occur every 2500 years (Cruz and Krausmann, 2008). It is likely that once these statistics are re-evaluated, scientists will increase the 100-year wind and wave estimates, enabling designers to better prepare offshore infrastructure for hurricanes in the Gulf of Mexico.

It is also necessary to improve the durability of pipelines. The pipeline network was identified as the weakest link during the 2005 hurricane season, causing long delays in oil and gas operations (Mouawad, 2005; Cruz and Krausmann, 2008). Design experts need to better understand the causes of these failures, update design standards and regulations, and improve the process by which workers conduct post-storm assessments (Ward et. al., 2005; Cruz and Krausmann, 2008).

Finally, the energy industry should improve risk-management strategies that incorporate a wide range of scenarios, including hurricane strikes that destroy offshore platforms, offshore and onshore pipelines, and onshore infrastructure, such as refineries and pipelines. The industry must also prepare for disabled communications and transportation, and offshore and onshore hazardous chemical spills. Disaster preparedness planning will also improve recovery after a hurricane strikes.

Sea-Level Rise

The energy industry along the central and western Gulf Coast will reap long-term benefits from adapting to hazards associated with sea-level rise. Hurricane storm surges are very costly and will likely become more severe as the intensity of hurricanes increases. As the oil and gas industry is still an important economic contributor to the region, it may make sense for the industry to develop adaptation strategies that incorporate more frequent and severe flood events.

Elevating infrastructure is a strategy that would lessen the probability that critical facilities and transportation routes would flood in the future. The plan to elevate Louisiana Highway 1, between Golden Meadow and Leeville, is an example of this type of adaptation (Armand, 2011). This highway will be less susceptible to flooding once it is elevated, providing more consistent land access to Port Fourchon.

Improving levees is another adaptation strategy that protects facilities, such as petro-chemical plants and refineries. Such improvements may involve making levees higher or changing the design to plan for waves that will approach the plant from the direction of the sea. In some particularly vulnerable areas, the best adaptation strategies may involve relocating infrastructure farther inland, where it is less susceptible to damage in coastal flooding events.

DuPont's DeLisle Plant in Pass Christian, Mississippi, has pursued several of these options to better prepare itself for future storm surges (Harris and Wilson, 2008). The plant conducted several analyses to better define the extent of storm surge hazard in the region. In addition, the facility incorporated several physical improvements, such as improving levee designs to protect the plant and associated infrastructure. Although such investments may be costly in the short term, they are likely to reap long-term benefits, as they protect the facility from hurricane storm surges and waves in the future.

Increasing Temperatures

As temperatures rise, the energy production sector in the Gulf Coast region may upgrade its infrastructure to prepare for increased electricity demand related to greater air conditioning use. This may involve building more power plants and transmission lines, or upgrading existing infrastructure to generate and transport more power.

Another adaptation strategy involves increasing energy reserves in preparation for spikes in energy demand. Utility companies may then tap into reserves of fuels, such as natural gas, to accommodate short-term energy demands that are above normal. Such management strategies could keep power grids from failing during extreme heat waves.

Increasing the proportion of energy produced by alternative energy sources, such as solar and wind power, is an adaptation strategy that could increase available power in the future, without substantially increasing emissions from fossil fuel combustion. This region has the potential to develop solar energy, as it receives more solar radiation than most of the country, due to its relatively low-latitude. Wind power also has potential in this region, as coastal regions often experience persistent winds due to the temperature differential between land and sea. Also, offshore locations near the central and western Gulf Coast may be ideal places for turbines, as they may be less visible and interfere less with human activities, while potentially having access to offshore infrastructure developed for the oil and gas industry, such as vessels, helicopters and float planes.

Finally, improved energy conservation may reduce the overall demand for energy, or keep demand relatively constant, even as the climate warms. Improved insulation and ventilation in buildings, as well as more widespread use of lighter building materials and reflective roofing are concepts that would likely conserve energy in a warming climate. Green spaces in urban landscapes, such as trees and grasses planted on the rooftops of skyscrapers, would likely reduce warming in cities, because vegetation generally absorbs less heat than buildings and roads.

Drought

Hydroelectric power generation and industrial operations that rely upon water as a cooling agent may benefit from future drought-adaptation methods in the region. An important adaptation strategy involves developing comprehensive water-management plans. Such plans would be useful in Alabama, as the signs of drought often develop months before the most severe drought conditions develop. Although droughts in Alabama generally are most severe during summer, droughts in the state often begin with decreased precipitation during the winter and spring months, when soil moisture should normally recharge (Jeffcoat et. al., 2010). Water-management plans could help the state respond effectively to drought warning signs months before droughts become severe.

IV. GULF COAST FISHING INDUSTRY

The Gulf of Mexico contains fertile fishing grounds that provide a large portion of local and regional seafood. This region is the leading domestic producer of shrimp and oysters, and an important source for other shellfish and finfish, including tuna, red snapper, mullet, menhaden, grouper, crawfish, blue crab and stone crab (National Oceanic and Atmospheric Administration, Fisheries, 2008). Shrimp provide the largest revenue share of fishing in the Gulf Region, contributing $424 million, 58% of the total commercial fishing revenue, over the 10-year period from 1999 to 2008 (National Oceanic and Atmospheric Administration, Fisheries, 2008).

This section takes a closer look at the operations and infrastructure involved in the fishing industry, as well as the economic importance of this industry along the central and western Gulf Coasts. Potential vulnerabilities of this industry to climate change are then discussed, including the possible impacts of increasing hurricane intensity, warming water temperatures, and changes in water chemistry. This section concludes with a discussion of possible adaptation strategies of this industry to these potential changes in climate.

While this region is an important producer of these products on national and regional levels, the fishing industry also shapes the local economy and culture along the Gulf Coast. Because many workers in this industry comprise the third or fourth consecutive generation to engage in this occupation, fishing plays a large role in the culture in this region. Annual seafood and marine festivals attest to this fact. *Blessing of the Fleet* ceremonies are an important marine tradition in locations such as Bayou la Batre, Alabama; Grand Isle, Louisiana; and Brownsville, Texas. Seafood festivals, such as the Shrimporee, in Aransas Pass, Texas; the Shrimp and Petroleum Festival, in Morgan City, Louisiana; and the Shrimp Festival, in Gulf Shores, Alabama, are annual traditions that shape the culture of these communities (National Oceanic and Atmospheric Administration, Fisheries, 2006).

THE SCALE AND RELATIVE IMPORTANCE OF THE FISHING INDUSTRY

Fishing Operations and Infrastructure

The process by which seafood is caught, processed and sent to market involves several steps, which require specialized infrastructure. Marinas contain docks equipped with moorings, as well as gas stations, bait and tackle shops, hardware stores customized for the fishing industry, restaurants where workers can eat, drink and share information, and sometimes local or federal regulatory offices, where the latest information about fishing regulations and permitting can be obtained. Boats are designed with specialized equipment for the local fishing industry. Processing plants often contain tables and conveyor belts, forklifts, refrigerators, freezers, preservation chemicals, loading ramps, and sometimes a fleet of trucks used for delivery. Of course, processing plants usually depend upon the reliability of local utilities to provide consistent power for operating machinery and chilling the catch. Infrastructure outside processing plants, such as roads leading away from the plants, must also be reliable so trucks can make quick deliveries to markets.

Fishing operations do not merely consist of workers catching fish, but also specialized networks of people working in facilities and, creating and maintaining infrastructure. When viewed in this way, fishing is a specialized sectoral economy of catching, processing, transporting and selling seafood. This network essentially comprises the foundation of fishing communities.
The Magnuson-Stevens Fishery Conservation and Management Act (which governs U.S. marine fisheries) defines a “fishing community” as “substantially dependent on or substantially engaged in the harvest or processing of fishery resources to meet social and economic needs” (Clay and Olson, 2008, pg. 144). National Marine Fisheries Service social scientists have identified 211 fishing communities in the Gulf Coast region, including 99 communities in Louisiana, 68 in Texas, 30 in Alabama and 14 in Mississippi (National Oceanic and Atmospheric

Administration, Fisheries, 2008). Ten of these communities made the Unites States' list of top 50 ports by fishing revenues, including Bayou La Batre, Alabama; Dulac-Chauvin, Empire-Venice, Golden Meadow-Leeville, Intracoastal City, and Laffitte-Barataria, Louisiana; and Brownsville-Port Isabel, Port Arthur, Galveston, and Palacios, Texas (National Oceanic and Atmospheric Administration, Fisheries, 2006).

The fishing industry provides an important pillar of support to many coastal communities by providing extensive capital, infrastructure, and small businesses that generate many jobs in the region. In 2006, the Gulf Coast region, including the west coast of Florida, contained 174 fish-processing plants and 255 wholesale businesses, together hiring 10,841 workers. Louisiana contained the most wholesale plants, 126, which employed 661 workers, followed by Texas, which contained 77 wholesale plants, which employed 825 workers (National Oceanic and Atmospheric Administration, Fisheries, 2006). Mississippi and Alabama also contained important fish-processing infrastructure, particularly near Biloxi, Mississippi, and Bayou la Batre, Alabama (National Oceanic and Atmospheric Administration, Fisheries, 2006).

Transport, support and marine operations provide another category of operations and infrastructure that are quite extensive. It is difficult to calculate the contribution provided by the transportation industry, as trucks, planes and ships that haul seafood to market often transport other merchandise as well. However, it is easier to count marinas; the Gulf Region, including the western coast of Florida, contained 755 marinas in 2007, which provided locations to dock, repair and fuel fishing boats (National Oceanic and Atmospheric Administration, Fisheries, 2008).

Regional Production and Economic Benefits

Commercial fishermen in the Gulf of Mexico, including western Florida, caught 1.27 billion pounds of shellfish and finfish in 2008. This harvest produced $659 million in landings revenue, or the total harvest value. Shellfish produced the majority of this revenue, as the $513 million in shellfish production accounted for 78% of total-fishing revenue. Shrimp harvest provided the largest contribution of any seafood type, providing $366 million for 188 million pounds harvested (National Oceanic and Atmospheric Administration, Fisheries, 2008).

In 2008, Louisiana generated $273 million in landings revenue, the highest amount along the central and western Gulf Coast (not including western Florida). Texas produced $176 million, followed by Alabama and Mississippi, which each produced approximately $44 million. The sales impact of these landings produces even more revenue, because of business profit from processing, transporting and selling seafood. Louisiana and Texas led the region in revenue generated by these landings, as each of these states generated around $2 billion in total sales. Alabama generated approximately $445 million in sales, while Mississippi generated approximately $391 million. The commercial seafood industry—including the commercial harvest sector, seafood processors and dealers, seafood wholesalers and distributors, and seafood retailers—generated approximately 44,000 jobs in Louisiana, 42,500 in Texas, 9,800 in Alabama and 8,600 in Mississippi (National Oceanic and Atmospheric Administration, Fisheries, 2008).

POTENTIAL VULNERABILITIES OF THE FISHING INDUSTRY TO CLIMATE CHANGE

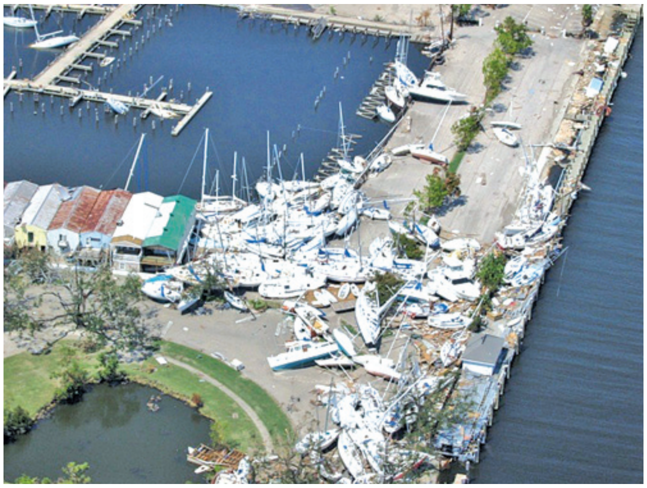
Increasing Intensity of Hurricanes

While the fishing industry has always been vulnerable to extreme weather events, the increasing intensity of hurricanes threatens fishing stocks in the waters of the central and western Gulf of Mexico, as well as the lives of workers and the infrastructure required for this industry.

Hurricane Katrina's strong winds, high waves, and record-setting storm surge illustrate the damage that hurricanes can inflict on this industry. Katrina damaged or destroyed 1,816 federally-permitted fishing vessels, 177 seafood-processing facilities and 15 major fishing ports. Losses to the seafood industry were initially estimated at $1.1 billion in Louisiana and may have exceeded $200 million in Alabama and Mississippi. (Buck, 2005). Katrina also destroyed infrastructure, expensive fish-processing machinery, as well as utility and communications networks, hindering the ability of the industry to process and transport seafood (National Oceanic and Atmospheric Administration, Fisheries, 2008).

In addition to inflicting immediate damage and destruction to the Gulf Coast's fishing industry, Hurricane Katrina also caused long-term impacts. Katrina destroyed or damaged entire ecosystems that are sensitive to severe environmental conditions. This caused fish populations to decrease, either from direct storm

FIGURE 18: A marina damaged by Hurricane Katrina.



Hurricane Katrina's storm surge tossed boats around like toys in Louisiana and Mississippi. This pile of boats indicates the extent of damage to this marina in New Orleans, Louisiana, on September 11, 2005, almost two weeks after Katrina struck the city. Photo Credit: The National Oceanic and Atmospheric Administration's National Weather Service (NWS) Photo Collection. Contributing Photographer: Lieut. Commander Mark Moran, NOAA Corps, NMAO/AOC. This photo is available on the Web at: http://www.photolib.noaa.gov/htmls/wea02900.htm.

impacts, such as fish washing up on land, or indirect impacts, such as fish dying because Katrina destroyed the plants or animals on which they feed. Katrina also destroyed many oil and gas platforms, as well as chemical facilities, which produced hazardous-materials spills along the coast. Although Hurricane Katrina was just one storm, it is possible that the Gulf Coast fishing industry may experience more catastrophic events like this if hurricanes continue to intensify.

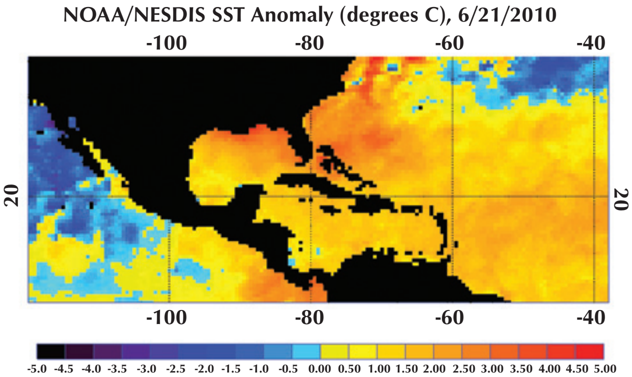
Warming Temperatures

Air and water interact near the surface of large water bodies, a process called air-sea interaction. Water and air share moisture, temperature and chemicals with each other near this boundary. This interaction enables water temperatures to warm in conjunction with the warming of air temperatures just above the water surface. For this reason, surface water temperatures are rising and are likely to continue to do so, by as much as 4 to 8 degrees Fahrenheit this century (U.S. Global Change Research Program, 2009).

Scientists study temperature anomaly maps to understand the rate at which water temperatures are rising. These maps show that water temperatures have been unusually warm in much of the Atlantic Ocean, including the Gulf of Mexico. For example, a sea-surface temperature anomaly map for the western Atlantic Ocean, Caribbean Sea and Gulf of Mexico, on June 21, 2010, depicts above-normal water temperatures for most of the Gulf of Mexico, U.S. Atlantic Seaboard, and the Caribbean (National Oceanic and Atmospheric Administration, Satellite and Information Service, 2010, see Figure 19). Yellow on this map depicts areas in which water temperatures are above normal, orange depicts areas in which water temperatures are at least 3.6 degrees Fahrenheit above normal, and red indicates areas that are at least 8 degrees Fahrenheit above normal. This image reveals that waters off the central and western Gulf Coast were approximately 3 to 4 degrees Fahrenheit above normal on this date.

Because marine life is adapted to survive at specific temperatures, plants and animals that form marine ecosystems must often migrate to cooler waters if water temperatures exceed survivable ranges for specific species. In some cases, a particular marine species is able to adapt

FIGURE 19: June 2010: Abnormally warm water in the Gulf of Mexico, Caribbean and Atlantic Coast.



This water temperature anomaly map from June 21, 2010, reveals that water temperatures throughout most of the Gulf of Mexico, western North Atlantic Ocean and the Caribbean Sea, are unusually warm. National Oceanic and Atmospheric Administration, Satellite and Information Service (2010).

to warmer waters, but the change in water temperatures enables new species to move in and compete for food and habitat (Peterson et. al., 2008; U.S. Global Change Research Program, 2009). These ecosystem shifts may result in ecological changes within marine communities, such as changes in the dominant fish species of a given ecosystem (Yanez-Arancibia and Day, 2004). These shifts in marine life have already been observed (Janetos et. al., 2008; U.S. Global Change Research Program, 2009), and are likely to continue.

Warming water temperatures also enable what are considered invasive species, species that are not native to a location, to survive and establish communities. In some cases, invasive species grow very rapidly, harming the ecosystem in which they are introduced. Invasive species may be introduced to an ecosystem intentionally or unintentionally. The release of tropical pet fish into the wild is an example of an intentional introduction, whereas the release of ballast water, which is used to provide stability to a ship and which may contain non-native organisms, may be unintentional. Warmer water temperatures enable some warm-water marine species to gain a foothold in their new environment (Stachowicz et. al., 2002; U.S. Global Change Research Program, 2009).

Changing Water Chemistry

Changing climate produces changes in water chemistry. These changes alter the ecosystem as they impact the health of plants and marine creatures. Examples of these chemical changes include increases and decreases in water salinity and oxygen levels, as well as increases in acidity. These changes place stress on certain plants and animals, forcing them to adapt to the new conditions, migrate to other locations, or die.

Hypoxia, a condition characterized by low oxygen content in water, threatens marine ecosystems along the northern Gulf Coast. Hypoxic waters are defined as those with oxygen contents less than 2 parts per million (United States Geologic Survey, 2010). Because marine plants and animals rely on oxygen to survive, such oxygen-starved waters can be deadly.

Increased nutrient concentrations in Gulf waters, caused at least in part by elevated levels of fertilizer runoff into the Mississippi River and Gulf of Mexico, increase nitrogen levels in the water, contributing to the extent of hypoxia in the region. These nutrients feed microscopic plant life, such as algae and zooplankton, which form vast blooms, or areas in which dense concentrations of this plant material is suspended in the water column. Figure 20 shows the extent of algae blooms in the northern Gulf of Mexico, as seen by a satellite. The plant material in these blooms eventually dies and settles to the seafloor, where the decomposition process removes oxygen from the deepest waters. Figure 20 illustrates the extent of algal blooms along the northern Gulf Coast.

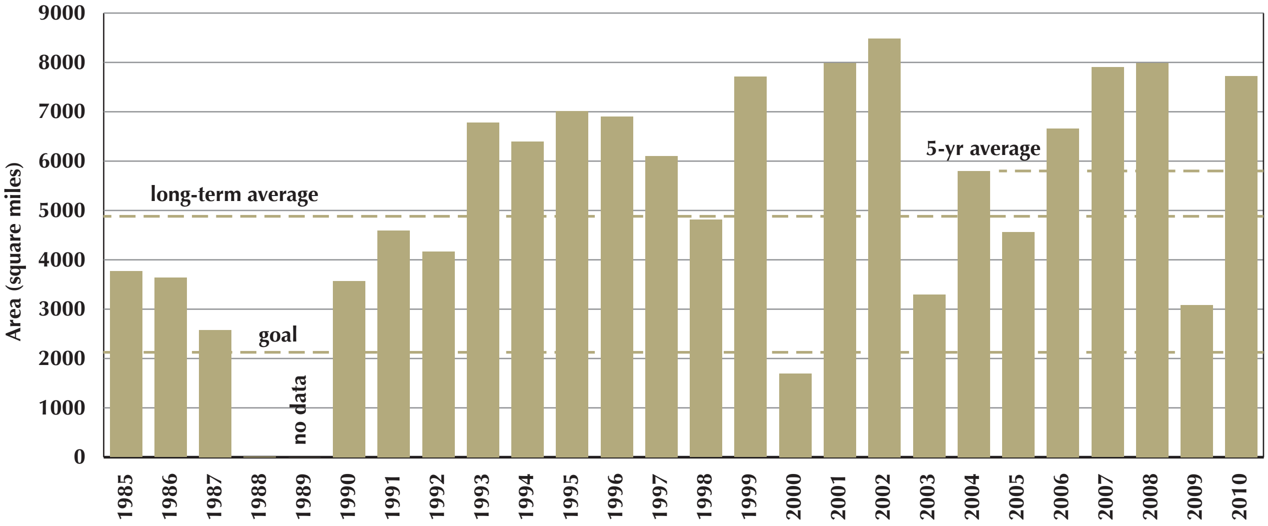
In recent years, scientists have observed increases in the area of mid-summer hypoxia near the Gulf of Mexico seafloor. Figure 21 indicates that the 5-year average area of hypoxic waters in the Gulf of Mexico covered nearly 6,000 square miles, for the period 2005-2009. This is larger than the long-term average, which covered an average of less than 5,000 square miles annually (United States Geologic Survey, 2010).

Global climate change may influence the extent of hypoxia because the amount of rainfall observed over inland regions affects the quantity of nutrients washed into the Gulf of Mexico. In fact, research indicates that increased river discharge, or the amount of fresh

FIGURE 20: **Algae blooms near the Mississippi River Delta.**

This NASA image shows the extent of algae blooms (shaded green) growing in the nutrient-rich waters near the Mississippi River Delta, in the northern Gulf of Mexico. The algae blooms expand in coverage as the Mississippi River dumps increased nutrient loads into the Gulf, eventually creating hypoxic zones with reduced oxygen, once the algae settles to the seafloor and decomposes. NASA. This image is available on the Web at: http://plantandsoil.unl.edu/croptechnology2005/pagesincludes/printModule.jsp?informationModuleId=1086025423.

FIGURE 21: **Area of Mid-Summer Bottom Water Hypoxia (Dissolved Oxygen <2.0 mg/L).**



The area of mid-summer hypoxia near the seafloor of the Gulf of Mexico is increasing. The 5-year average extent of the hypoxic zone is nearly 6,000 square miles, whereas the long-term average area is less than 5,000 square miles. This image is available on the Web at: http://toxics.usgs.gov/hypoxia/hypoxic_zone.html.

Data source: N.N. Rabalais, Louisiana Universities Marine Consortium, R.E. Turner, Louisiana State University

Funded by: NOAA, Center for Sponsored Coastal Research

water rivers release into salt-water bodies, is the leading factor stimulating hypoxia (Stow et. al., 2005; Eldridge and Roelkea, 2010). As scientists anticipate that the midwestern United States should observe more winter and spring precipitation, as well as heavier downpours in the future (U.S. Global Change Research Program, 2009), fertilizer runoff into the Mississippi River should increase, which would likely elevate the extent of hypoxia in the Gulf of Mexico (Jusic et. al., 2003).

Climate change will likely also impact salinity levels along the Gulf Coast. Water salinity increases or decreases when changes occur in the balance between the amount of fresh water flowing toward the sea and the amount of salt water flowing toward land. Locations that experience the greatest rates of relative sea-level rise often observe the greatest salinity increases because sea water pushes inland more rapidly in these places. Locations near river mouths also tend to observe rapid salinity changes, as changing precipitation patterns inland alter the rate at which freshwater from rivers is discharged into saltwater basins. Heavy inland rainfall patterns produce higher freshwater discharge levels, lowering salinity levels near the coast. Conversely, salinity levels rise during droughts, because during these periods rivers provide less freshwater to the coastal environment.

It is difficult to determine how climate change will impact salinity levels. Similar to what happens with hypoxia levels, anticipated increases in Midwest winter and spring precipitation, as well as increased frequencies of heavy downpours in that region, may increase the discharge rate of the Mississippi River, which could decrease salinity levels in the northern Gulf of Mexico. However, scientists also expect longer time periods between rainfall events in the southeastern United States (U.S. Global Change Research Program, 2009), which may decrease the runoff of other rivers, and increase salinity levels in those regions. Much of the central and western Gulf Coast will also observe increased salinity levels in association with sea-level rise and the resulting saltwater intrusion along the coast.

Increases in atmospheric carbon dioxide concentrations, the primary greenhouse gas, have increased ocean acidity levels, which may adversely impact fisheries. As oceans absorb carbon dioxide from the atmosphere, chemical reactions increase the acidity of the ocean water (Caldeira and Wickett, 2003; Kurihara, 2008). Ocean surface waters have absorbed approximately one-third of the carbon dioxide that has entered the atmosphere over the past 100 years (Denman et. al., 2007; Kurihara, 2008).

Increased ocean acidity could impact mollusks and crustaceans in several ways. If increases in acidity levels are not uniform throughout the central and western Gulf Coast, these creatures may adjust distribution patterns, as they migrate to areas with lower acidity levels. Also, as increased acidity levels hinder the ability of these creatures to build shells and skeletons, it is also possible that they will be less healthy, decline in numbers, and possibly face extinction (Kurihara, 2008). These negative impacts could affect mollusks, such as clams, scallops, oysters and mussels, as well as crustaceans, like crabs, lobsters, crawfish and shrimp. This could also affect the development of marine plankton, an important food source for many aquatic organisms (Hays et. al., 2005).

These changes in water chemistry, including increasing and decreasing levels of oxygen and salinity, as well as increases in acidity levels, will likely impact the commercial fishing industry. Marine ecosystems are clearly sensitive to such changes. Harvested seafood, as well as the fauna and flora upon which those species depend, may migrate or die as precipitation patterns, air and water temperatures, and ocean-acidity levels change in the future.

ADAPTATION OPTIONS

The commercial fishing industry of the central and western Gulf of Mexico will face substantial challenges in adapting to potential climate changes because this industry is intimately connected to the environment. Complex marine ecosystems have limited ability to adapt to climate change (Yanez-Arancibia and Day, 2004), which means that workers in this industry must prepare for the impacts of a changing climate. Some of these changes may involve new fishing strategies that take advantage of environmental changes, such as fish migration or replacement of species. Other adaptations may protect infrastructure, such as fishing vessels, processing plants and marinas.

Increasing Hurricane Intensity

Hurricane Katrina demonstrated the grave impacts that increasing hurricane intensity could have upon the fishing industry. The industry will likely benefit by preparing for future storms with similar wind intensities, wave heights, and storm-surge levels.

Preparing marinas and boathouses for hurricanes is an adaptation that could save the industry millions of dollars in one large storm. Increasing the strength of building materials and providing equipment that elevates small boats above the water level are strategies that may protect boats from wind and waves. Figure 22 depicts a docking facility in Hopedale, Louisiana, that elevates docked boats approximately four feet above the water level. Providing machinery, ramps, tow dollies, and multiple marina access points are strategies that could enable fishermen to quickly remove boats from the water, and perhaps transport them inland.

Another strategy involves locating processing plants, warehouses and other facilities farther inland. Although

FIGURE 22: Docking facility, Hopedale, Louisiana.

This small docking facility in Hopedale, Louisiana, elevates boats that are not in use. Strong straps hold these boats four feet above the water level. While such facilities protect boats from waves, they also may be useful in the future as sea levels rise.

Photo Credit: Hal Needham

this arrangement may increase the time and cost required to transport catches from docks to processing plants, this system could pay large dividends in the event of a hurricane. Because hurricane wind, waves and surges are usually the most severe at the coast, relocating facilities inland as little as several miles could protect important aspects of this industry in the future.

Finally, the fishing industry could support research on the response of coastal ecosystems to hurricanes. Such research could reveal the processes through which marine life responds to catastrophic events. As knowledge on this subject increases, the fishing industry could make better decisions regarding the extent of ecosystem damage from hurricanes, and the length of time required for marine ecosystems to recover from such disasters.

Warming Temperatures

As water temperatures rise, it is possible that some marine life will migrate to cooler waters, while other plant and animal species may die out. The time periods of important life cycles, such as mating, reproduction, nesting, and migrating seasons may also change. The fishing industry could monitor such changes and adapt fishing operations in a manner that benefits the long-term health of fishing stocks and the entire ecosystem. For example, the industry may need to adjust periods of fishing restrictions to accommodate earlier or later mating seasons.

Research into new fishing practices that harvest different species could also be considered. Although this may mean the industry must develop different fishing and processing procedures, it may be a better alternative than over-fishing depleted fish stocks, or traveling excessive distances to find sufficient fish to make a trip profitable. However, it should be noted that marketing different fish species may take additional effort and planning, as consumers adjust their diets as well.

Changing Water Chemistry

Changing water chemistry has the potential to profoundly impact the fishing industry because marine ecosystems are very sensitive to slight chemical changes, such as subtle variations in salinity or oxygen content of water. Adaptations undertaken regionally and even by others outside the region will benefit the fishing industry.

Systems that monitor and limit fertilizer use may help reduce the amount of nutrients that wash into the Gulf of Mexico, thereby reducing the extent of hypoxia. Such systems may include educational programs, monitoring programs, or legislation that limits fertilizer use. These adaptation methods address harmful human activity that contributes to the development of hypoxic water. Plans to reduce nutrient loading in the Mississippi River watershed by as much as 40% have been considered as a method to reduce Gulf of Mexico hypoxia (Savia et. al., 2003; Rabalais et. al., 2007; Eldridge and Roelke, 2010).

The industry might also consider ways to adapt to changes in water chemistry. Although water-monitoring programs cannot change the salinity or oxygen levels of water, they can indicate the chemical composition, enabling the industry to change fishing practices accordingly. The industry might also prepare to relocate fishing practices in accordance with changes in the water composition, such as moving fishing operations away from hypoxic zones.

Decreasing global carbon dioxide emissions is the best widespread solution to lessen the rate of ocean acidification; however, this would require restructuring global energy and transportation infrastructure (Cooley and Doney, 2009), which is costly and will take time to implement. In the meantime, the local and regional fishing industry could prepare for changes caused by acidification. Including the effects of acidification in updated fishery management plans along the central and western Gulf Coast could help fishermen in this region adapt to these changes (Cooley and Doney, 2009).

V. SUMMARY AND CONCLUSION

Hurricanes, sea-level rise and wetlands loss are three hazards that threaten the central and western U.S. Gulf Coast. These hazards threaten humans by destroying coastal buildings and infrastructure, and, in some cases, particularly during strong hurricanes, inflicting casualties. They also threaten the development and sustainability of the energy and fishing industries, two economic sectors that are vital to the prosperity of this region. Ecologically, these hazards threaten the delicate balance of plant and animal life in this region.

Rising sea levels increase the rate of coastal erosion, exacerbate the impacts of coastal flood events, and raise the salinity levels of water near the coast. The rate of relative sea-level rise (RSLR), or the combination of land subsidence and sea-level rise, is higher in this region than anywhere in the nation, particularly in coastal Louisiana, where rates of RSLR reach three feet per century. Adaptation options include "building up," or increasing the elevation of coastal buildings and infrastructure, "building out," which refers to placing future development farther from the coast, and constructing higher flood control devices, such as levees.

This region also experiences high rates of wetlands loss due to submersion from sea-level rise, destruction from hurricanes and encroachment from human development. This trend is especially pronounced in Louisiana, which loses a football field-sized area of wetlands approximately every 38 minutes (LA Dept. of Natural Resources, 2010) and will account for 86% of the total freshwater forest loss in the region (Doyle 2010). The impacts of wetlands loss include ecological consequences associated with the loss of critical habitat that supports a delicate balance of life, as well as the potential of increased storm surge and wave heights in coastal communities, due to the loss of the wetlands barrier that protects many communities from the open water of the Gulf of Mexico. Adaptation involves coastal restoration methods, such as diverting river water to deteriorating wetlands.

Warming sea-surface temperatures in the Atlantic Basin may intensify hurricanes, which could lead to increased damage from strong winds, heavy rains and storm surge. While sea-surface temperature variability is well documented in the scientific literature, scientific consensus attributes much of the current oceanic warming to anthropogenic causes. The staggering number of casualties and economic losses recently inflicted in the region by Hurricanes Ivan (2004), Katrina (2005), Rita (2005), Gustav (2008), and Ike (2008) remind us that we need to adapt quickly to the possibility of more intense hurricanes in the future. Adaptations that may benefit coastal communities include elevating homes, infrastructure and levees to avoid storm surge damage, as well as upgrading flood pumps and improving drainage systems. Improved building designs could better protect structures from wind damage, while building farther inland will protect structures from both high winds and storm surge associated with intense hurricanes.

The energy industry is vital to the economy along the Gulf Coast, while providing fuel that is essential to run industries, power transportation and heat homes. Much of the oil and gas in this region is extracted at offshore oil and gas platforms, and then transported through a network of pipelines to refineries located near the coast, which transform raw materials into marketable products. Increasing temperatures, sea-level rise, drought, and the increasing intensity of hurricanes are climate-related hazards that impact this region. Recent hurricanes have inflicted billions of dollars of losses to the energy industry by destroying infrastructure and suspending operations during and after these storms. Adaptations that may help this industry cope with climate change include increasing the capacity of electric grids in preparation for rising demand for air conditioning, monitoring drought conditions, particularly for hydroelectric power generation, incorporating projections for higher sea levels into the design of coastal infrastructure, and preparing for stronger winds and higher storm surges in hurricanes both offshore and along the coast.

In addition to providing revenue in many coastal communities, the Gulf Coast fishing industry also provides an important link to the heritage of this region, while supplying seafood restaurants throughout the nation with shellfish and finfish, such as shrimp, oyster, tuna, red snapper, crawfish, and crab. Warming water temperatures threaten this industry by changing the coastal ecosystem, changing water chemistry, and making hurricanes more intense, which results in more plant and animal losses. Sea-level rise and increasingly intense hurricanes also threaten fishing infrastructure, such as marinas. Adaptation options include elevating docks and wharfs, as well as improving access for mariners to remove boats quickly. Efforts to monitor water chemistry, temperature and levels may help the industry stay informed of environmental changes that may negatively impact the industry. Also, widespread efforts to limit fertilizer use may reduce the negative impacts of hypoxia, which would likely benefit the fishing industry.

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This report examines climate change impacts, risks and adaptation options for the Gulf Coast region of the United States. The Center for Climate and Energy Solutions (C2ES) is an independent non-profit, non-partisan organization promoting strong policy and action to address the twin challenges of energy and climate change. Launched in 2011, C2ES is the successor to the Pew Center on Global Climate Change.

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