Potential Impacts of Climate Change and Variability on Transportation in the Gulf Coast/Mississippi Delta Region

By **Virginia R. Burkett**

If the Earth's atmosphere warms within the range projected by the Intergovernmental Panel on Climate Change (IPCC, 2001) during the 21st century, the climate of the northern Gulf of Mexico coastline (hereafter, Gulf Coast) and the Mississippi River Deltaic Plain will likely become warmer, with more frequent or prolonged periods of heavy rainfall and drought. These climatic changes would have significant impacts on water quality, flooding, soil moisture, runoff, and many other environmental factors that affect the transportation sector, either directly or indirectly. Changes in interannual climate variability will also have practical significance to the Gulf Coast transportation sector. Seasonal rainfall and hurricane frequency in the Gulf Coast region have been linked with El Niño and La Niña events, which may become more intense as the Earth's atmosphere warms. The anticipated increase in global average temperature will accelerate sea-level rise, which can lead to increased vulnerability of transportation infrastructure to storm damage and flooding in low-lying coastal zones.

20th Century Climate and Sea Level Trends

Temperature and Precipitation Trends

In the southeastern region, 20th century temperature trends varied between decades, with a warm period during the 1920s-1940s followed by a downward trend through the 1960s. Since the 1970s, however, southeastern temperatures have been increasingly warmer, with 1990s temperatures the highest on record. The average temperature in the Southeast has increased approximately 1 °F since 1970, which was the average annual temperature increase for the entire United States between 1901 and 1998 (Burkett and others, 2001).

The southeastern region of the United States receives more rainfall than any other region, and the region as a whole grew wetter during the 20th century. Average annual precipitation has increased 20-30% over the past 100 years across Mississippi, Alabama, the Florida panhandle, and parts of Louisiana (Figure 1). The southern tip of Texas and several other areas have slightly decreasing trends in annual precipitation. Much of the increase in precipitation in the Southeast was associated with more intense events (rainfall greater than 2 inches or 5 cm per day). A small percentage of the increased precipitation was associated with moderate rainfall events, which are generally beneficial to agriculture and water supply (Burkett and others, 2001). Analysis of stream flow trends during 1944-93 for the southeastern region of the U.S. showed little change in annual maximum daily discharge but significant increases in annual median and minimum flows in the lower Mississippi Valley (Linns and Slack, 1999).

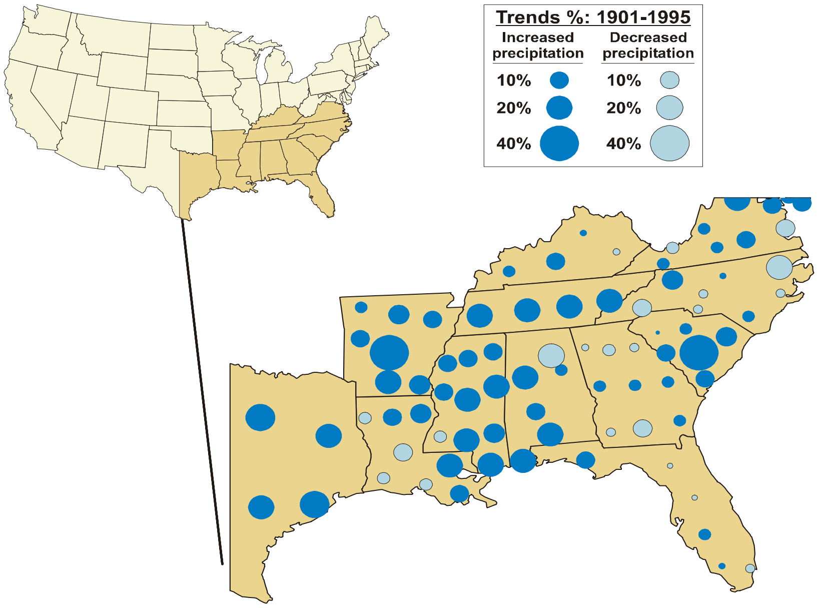

Figure 1. *Map of trends in average precipitation in the Southeast (percent change), 1901 - 1995. Source: National Atmospheric and Oceanic Administration, National Climatic Data Center, Asheville, North Carolina, 2000.*

Trends in wet and dry spells during the 20th century, as indicated by the Palmer Drought Severity Index (PDSI), are spatially consistent with the Gulf Coast region's increased precipitation trends, showing a strong tendency to more wet spells. The percentage of the southeastern landscape experiencing "severe wetness" (periods in which the PDSI averages more than +3) increased approximately 10% between 1910 and 1997 (Burkett and others, 2001). Average annual summer precipitation decreased and average annual winter precipitation increased in the Gulf Coast region during that period (Melillo et al., 2000).

El Niño/Southern Oscillation Effects on Gulf Coast Climate

The El Niño/Southern Oscillation (ENSO) phenomenon contributes to variations in temperature and precipitation that can affect transportation in the northern Gulf of Mexico coastal zone. ENSO is an oscillation between warm and cold phases of sea-surface-temperature (SST) in the eastern tropical Pacific Ocean with a cycle period of 3 to 7 years. El Niño events (the warm phase of the ENSO phenomenon) are characterized by 2 to 4 °F (about 1 - 2 ºC) cooler average wintertime air temperatures in the Gulf region. During the spring and early summer months, the region returns to near normal temperatures. Gulf Coast states encounter wetter than normal winters (by about 1 - 2 inches per month) during El Niño events. By the spring, the entire eastern seaboard typically shows increased precipitation. In summer, climate impacts of warm events are more localized; for example, drier conditions are typically found in eastern coastal regions, and from north Texas to northern Alabama. El Niño events also create upper atmospheric conditions that tend to inhibit Atlantic tropical storm development, resulting in fewer Gulf Coast hurricanes, while La Niña events have the opposite effect, resulting in more hurricanes (Bove and others, 1998a; Muller and others, 2001). Figure 2 depicts U.S. Gulf of Mexico hurricane landfall trends and the probability of hurricane landfall during El Niño and La Niña years.

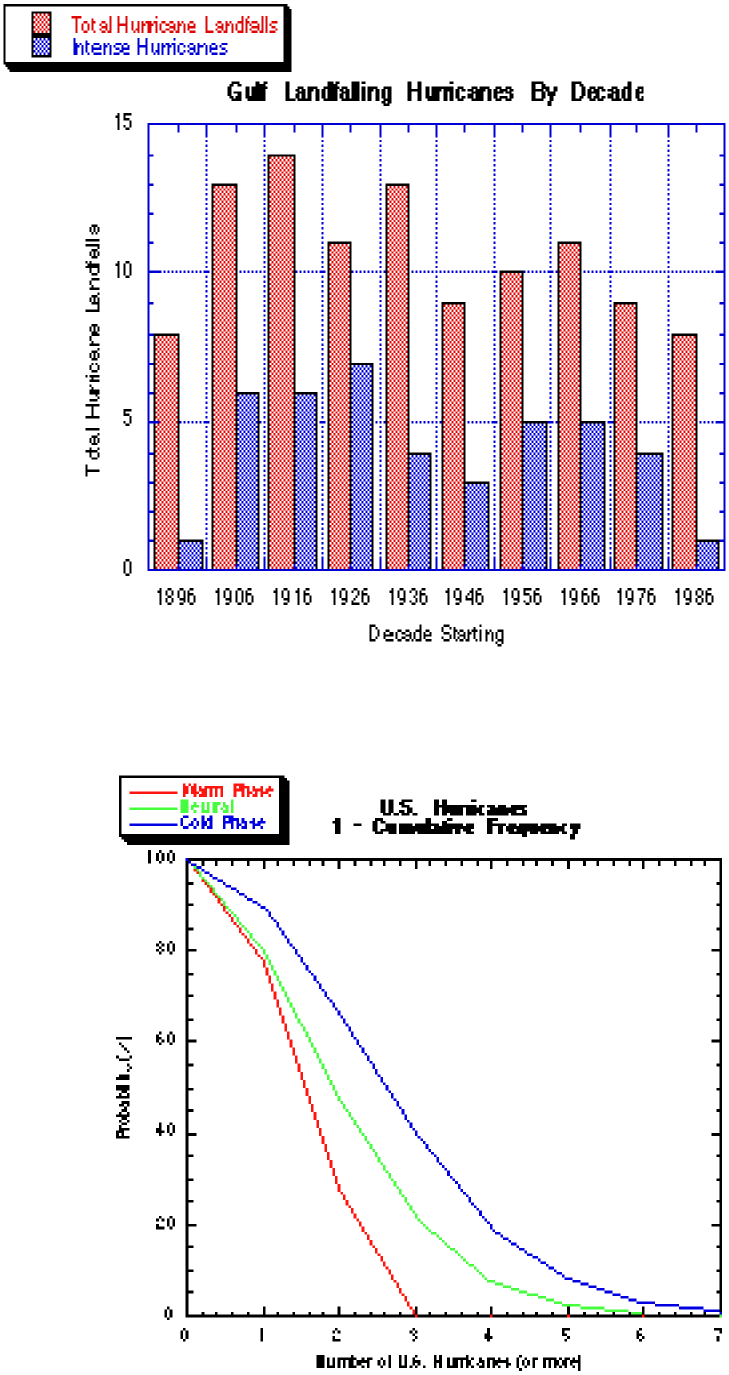

__Figure 2.__ U.S. hurricane landfall trends in the Gulf of Mexico. These charts show the number of U.S. hurricanes making landfall in the Gulf of Mexico by decade for the past 100 years and the probability of the number of hurricane landfalls on the U.S. in a given hurricane season and ENSO phase: warm phase (El Niño), neutral, and cool phase (La Niña) (modified from Bove et al, 1998 a and b).

During La Niña events (the cold phase of ENSO), the anomalies are sometimes reversed from those associated with warm events, but not everywhere. Wintertime precipitation patterns associated with cold events show increases (1-2 inches or 2.5-5 cm per month) in the band stretching from northern Mississippi to southwestern Pennsylvania. In the spring of a La Niña event, Gulf Coast areas typically have increased precipitation. In summer, the extreme southern U.S. is colder than normal and greater precipitation is evident in the Southeast. Dry to very dry conditions are typically found in parts of Texas and Louisiana during La Niña events (Burkett and others, 2001).

Sea-Level Rise

Global sea level has risen about 400 ft (120 m) as a result of melting of large ice sheets since the last glacial maximum about 20,000 years ago (Fairbanks, 1989). The most rapid rise occurred during the late and post-glacial periods followed by a period of relatively stable sea level during the past 6,000 years (Mimura and Harasawa, 2000). During the past 3000 years, reconstructions of sea level indicate that it rose at an average rate of about 0.004 - 0.008 in/yr (0.1-0.2 mm/yr), but during the 20th century the rate had increased to approximately 0.04-0.08 in/yr (1.0-2.0 mm/yr) or 10-20 centimeters per century (4-8 inches) (Gornitz, 1995; IPCC 1996).

Relative or observed sea level at the ocean/land interface is influenced by local and regional vertical movements of the land surface associated with isostasy (e.g., rebound of the surface after the retreat of ice sheets), tectonic processes (e.g., earthquakes, geosynclinal downwarping, and uplift) and sediment accretion or erosion at the land surface. Although they are mostly natural, these vertical movements can be influenced by human activities such as the extraction of groundwater and hydrocarbons or by the removal and/or redirection of river-borne sediments through the construction of dams and levees. Hence, the local rate of sea-level rise is more important than the global average when evaluating the vulnerability of transportation infrastructure in a coastal region.

Sea-level rise observed along the U.S. coastline varied between and within coastal regions during the 1900s. However, in general, the U.S. Gulf and South Atlantic coasts (with the exception of Florida) experienced rates of sea-level rise that were significantly greater than those observed on the U.S. Pacific Coast. Relative sea-level rise is greatest along the Louisiana coastline where the land surface of the Mississippi River Deltaic Plain is subsiding (sinking with respect to sea level) as much as 0.25 in/yr (10 mm/yr) due to a combination of natural and human-induced processes. The average rate of sea-level rise in Texas and several segments of the Atlantic shoreline is also double or more the global average. Wetland loss and shoreline erosion are typically higher in regions where relative sea-level rise exceeds the global average.

Projected 21st Century Changes in CO_2, Climate, and Sea-level Rise

Atmospheric CO_2 is higher now than it has been in at least 400,000 years, and the likely scenario over the next 100 years is that it will double or triple over preindustrial levels, and that this increase in CO_2 will be accompanied by an increase in the rate of global warming (IPCC, 1996, 2001). Computer-based general circulation models (GCMs) of the atmosphere and oceans help us understand how elevated CO_2 and other changes in greenhouse gas composition will ultimately affect ecosystems and society. GCMs indicate accelerated warming of the United States over the next hundred years.

Climate change scenarios selected for the United States' "National Assessment" (Melillo and others, 2001) were based on GCM experiments conducted at the United Kingdom's Hadley Centre for Climate Prediction (HadCM2) and the Canadian Climate Centre (CGCM1), hereinafter referred to as the Hadley and the Canadian models, respectively. For the emissions scenario used, these two models are representative of the higher and lower ends of the range of temperature sensitivity among the "transient" GCMs available at the beginning of the "National Assessment." Both of these models do a good job of hindcasting 20th century change; they also use a consistent set of realistic, mid-range assumptions about the rate of increase in greenhouse gas emissions during the next 100 years, assuming emissions controls are not implemented. Output from these models should be viewed as a range of two plausible climate futures rather than predictions of what will happen at any particular location. It should also be noted that the current spatial resolution of GCMs is not sufficient to simulate changes in the geographical distribution of storms.

Temperature and Precipitation Scenarios, 2000-2100

Climate models used in the "National Assessment" indicate that the average temperature of the Gulf Coast could increase by 4 to 10 °F during the 21st century. The Hadley model simulates less warming than the Canadian model for the Gulf Coast, and the models do not agree about the direction of future precipitation change. The Hadley model simulates increased rainfall for the Gulf Coast region while the Canadian model simulates declining annual rainfall in this region during the next 100 years. Differences in projections of precipitation change are due mainly to differences in the location of storm tracks simulated by the two models. Both GCMs, however, indicate that the July average heat index increase is very likely to be greatest in the southern states, increasing by 8 to 20 °F above present levels. Both models also simulate declining summer soil moisture in most Gulf Coast counties during the 21st century.

Changes in the Frequency and Intensity of ENSO Events, Tropical Storms, and Hurricanes

Some climate models indicate that the mean climate in the tropical Pacific region will shift toward a state corresponding to present-day El Niño conditions (Timmermann and others, 1999), which could influence seasonal rainfall and decrease hurricane activity in the Gulf region as described previously. Several ocean-coupled GCMs indicate that the intensity of hurricane rainfall and wave height may increase as the climate warms during the next 100 years (Knutson and others, 1998). However, an analysis by Bove and others (1998) of hurricane intensity in the Gulf Coast region between 1886 and 1995 did not show an increase in hurricane intensity during this historical period. While it is widely acknowledged that El Niño seasons are associated with fewer Gulf of Mexico hurricanes than La Niña seasons, an analysis of less intense tropical storms over the Gulf of Mexico between 1951 and 2000 showed very little difference in the frequency of minor tropical storms during El Niño and La Niña events (Muller and others, 2001).

A recent analysis of Atlantic basin hurricane activity by Goldenberg and others (2001) indicated a five-fold increase in hurricanes affecting the Caribbean when comparing 1995-2000 to the previous 24 years (1971-94). Conversely, Gulf of Mexico hurricane activity decreased from the first half to the second half of the 20th century (Figure 2) (Bove and others, 1998b). It is important to note that hurricanes exhibit multidecadal patterns that appear to be associated with variations in tropical sea-surface temperature patterns and vertical wind shear, and we may be entering a period of high-level hurricane activity in the Atlantic Basin that could persist for 10 - 40 years (Goldenberg and others, 2001).

Acceleration of Sea-level Rise

Sea-level rise is regarded as one of the more certain consequences of increased global temperature, and sea level has been rising gradually over the past 15,000 years. The current average rate of global sea-level rise (1-2 mm/yr) is projected to accelerate two to four-fold over the next one hundred years (IPCC, 2001). The mid-range estimate of global sea-level rise that will occur during the 21st century is 0.48 m (IPCC, 2001).

The Hadley Model simulates a slower rate of sea-level rise than the Canadian model (Figure 3). The relative or apparent rate of sea-level rise during the 21st century in areas will be greater in regions where the land surface is sinking or subsiding. Parts of the city of New Orleans that are presently 7 feet below mean sea level may be 10 or more feet below sea level by 2100, due to a combination of rising sea level and subsidence of the land surface (Figure 4).

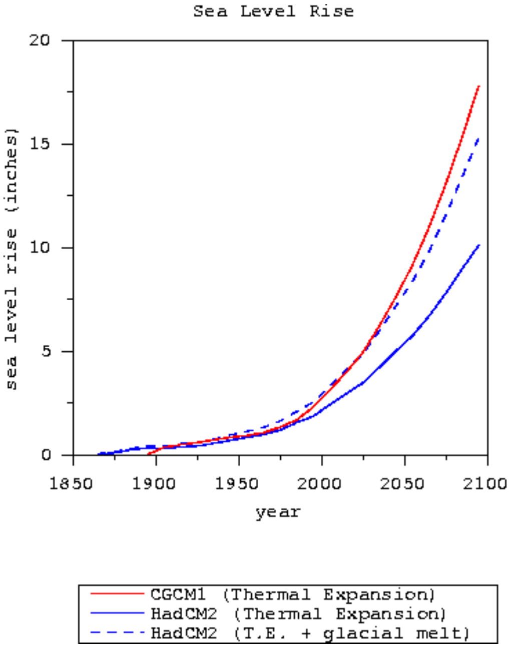

Figure 3. *Reconstruction (over the past 100 years) and projections (over the next 100 years) of global sea-level rise from the Hadley Climate Center Model (HadCM2) and the Canadian Center Climate Model (Boesch et al., 2000). This graph illustrates the acceleration of sea level rise in the 21st century as compared to previous periods. Note that the Canadian model (red) does not include sea level rise associated with glacial melt.*

Even if storms do not increase in severity, storm surge and its effects will be intensified as sea level rises and natural coastal defenses deteriorate. As sea level rises, islands will tend to "roll over" or move toward the mainland if human activities and changes in storm patterns do not impact this natural landward migration (Scavia and others, 2002; Twilley and others, 2001).

Louisiana, Florida, and Texas are the top three states in the Nation in terms of annual losses due to hurricanes and floods. Flood damages in Gulf Coast states will increase if sea-level rise accelerates, due to two factors: increased storm surge, and loss of coastal wetlands and barrier islands. Large areas of the Gulf Coastal plain will experience shoreline retreat and coastal land loss if mean sea level increases. Since 1980, losses of coastal forests in parts of Florida, South Carolina, and Louisiana have been attributed to salt water intrusion and/or subsidence. Low-lying Gulf Coast marshes and barrier are considered particularly vulnerable to sea-level rise, but they are all not equally vulnerable. Marshes that are subsiding or have little sediment supply are more vulnerable than those that are accreting material vertically at rates that equal or exceed the rate of sea-level rise. Under the IPCC's mid-range estimate of average global sea-level rise over the next 100 years, the Big Bend area of the Florida Gulf coast will likely undergo extensive losses of salt marsh and coastal forest (Burkett and others, 2001).

Submergence of coastal marshes is expected to be most severe along the shorelines dominated by unconsolidated sediments along the U.S. Gulf and Atlantic coasts. Some coastal marshes and mangrove systems along these coasts are presently accumulating sufficient mineral and/or organic sediment at rates that will compensate for the projected increase in the rate of sea-level rise. In south Louisiana, however, roughly 1 million acres of coastal marsh have been converted to open water since 1940. Natural subsidence and a variety of human activities (drainage projects, dredge and fill, groundwater withdrawals, levee construction on the Mississippi River) have contributed to these losses. If the rate of sea-level rise accelerates, additional marshes and baldcypress swamps are likely to be inundated as the shoreline advances inland (Burkett, 2002) (Figure 5).

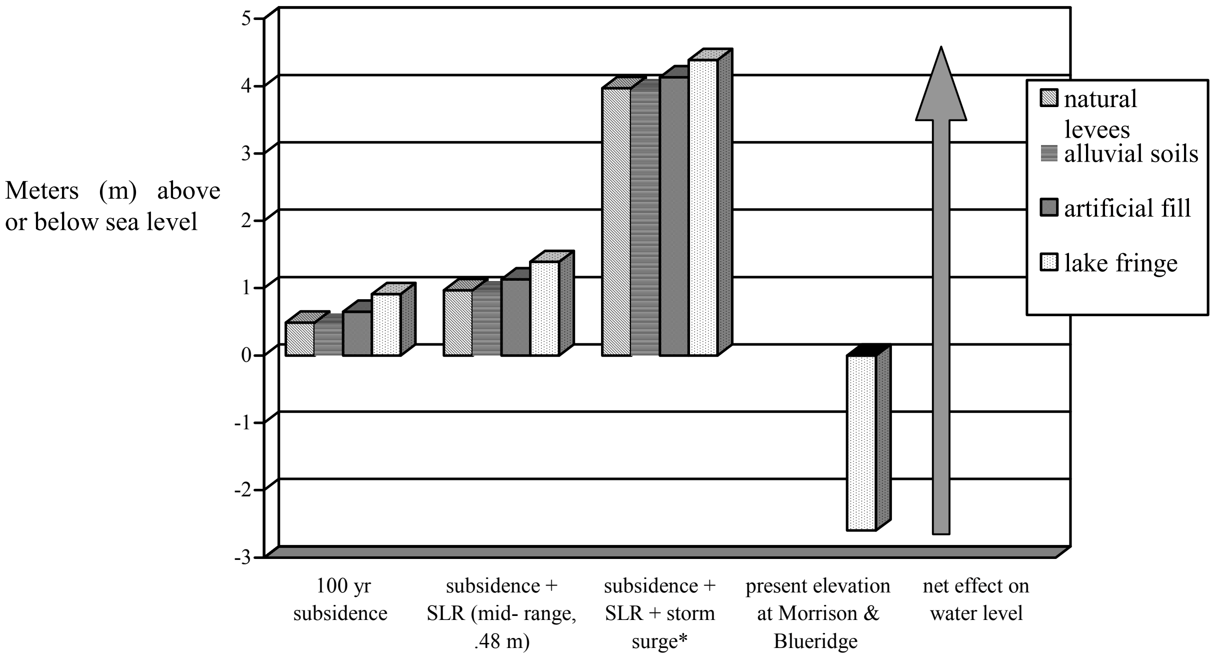

*__Figure 4.__ Subsidence and sea level projections for major geologic units in New Orleans and vicinity through 2100. When global sea-level rise, local subsidence, and the present elevation of the land surface are all considered, parts of the city could lie 7 meters below water level during a category 3 hurricane in the year 2100. The arrow on right illustrates this effect for the Morrison Road/Blueridge Court intersection, which is presently about 2.6 m below mean sea level. The arrow represents the cumulative influence of land surface elevation change and sea-level rise on storm surge level (*category 3 hurricane) at this location (from Burkett et al., In Press).*

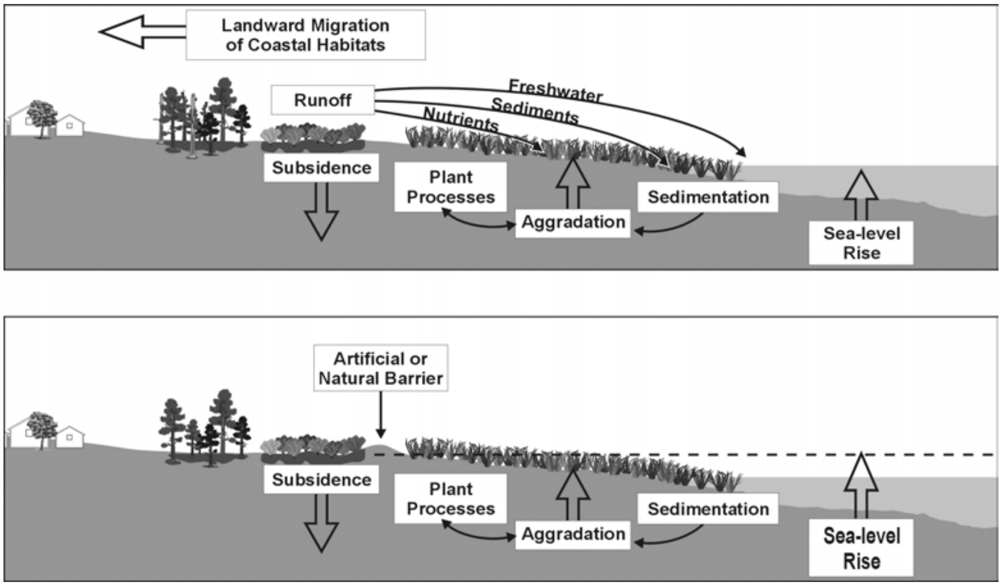

__Figure 5.__ Depiction of processes that affect shoreline retreat as sea level rises (from Burkett, 2002). (a) Due to sea level rise, coastal barriers, shorelines, and wetlands will recede inland. Not all coastal landforms are equally vulnerable to sea level rise. Sedimentation rates, subsidence rates, and the presence of natural or artificial barriers can influence the potential for submergence. (b) Barriers will curtail natural processes such as sedimentation from runoff that maintained the elevation of the land surface. However, they may delay or prevent the submergence of areas landward of the barrier.

Implications for the Gulf Coast Transportation Sector

The changes in temperature, precipitation and sea level that are projected during the 21st century are likely to have numerous implications for the Gulf Coast transportation sector. The six potential impacts on transportation presented below are not intended to be exhaustive, but rather to provide examples that can stimulate ideas and discussion about adaptations within this sector.

Construction Activities

Highway and airport construction activities may be adversely affected by the heat index increase that is anticipated in this region. Effects will vary among age groups. The scheduling of construction and maintenance work, equipment and shelter design, and other modifications for reducing heat stroke could mitigate some effects.

Understanding how El Niño and La Niña events affect rainfall could prove to be very valuable in planning construction work, just as farmers have benefited from using El Niño and La Niña predictions to plan seasonal agricultural activities.

Bridge construction over Gulf Coast streams should consider the fact that the 100-year flood is likely to occur more than once every 100 years, and that flood heights are likely to increase in some watersheds. Bridges and roads can act as dams that increase the potential for flooding if streamflow and/or rainfall increase. Several people have drowned in their vehicles in elevated highway underpasses in Louisiana and Texas Interstate during the past 15 years. Bridge design in virtually all of the Gulf Coast states should consider the fact that rainfall patterns are changing and that peak flows may increase in streams and tidal channels, thereby requiring more erosion prevention and clearance than during the past century.

Soil moisture decline, runoff trends, and increased maximum summer temperature may be a consideration in materials selection and standards. For example, thermal expansion of materials used in the construction of bridges and roads may become a more important factor in materials testing.

Design for highway construction in coastal counties should consider relative sea-level rise, subsidence, and rainfall trends. For example, culverts should be designed so that increases in tidal levels and peak runoff will not flood property adjacent to highways. Some nations and some states (Maine, Massachusetts, Rhode Island, South Carolina) have passed laws that require development setbacks lines for highways, airports and buildings constructed near shorelines and on barrier islands to accommodate sea-level rise (McLean and others, 2001). The “shelf life” of a coastal highway will generally be shorter than that of an inland highway, and higher costs should be planned to maintain vehicular transportation in the coastal zone.

Port facilities are another class of transportation infrastructure that may be affected by climate change and sea-level rise. Higher sea level will decrease the effectiveness of breakwaters against wave forces, and wharves may need to be raised to avoid inundation. When such effects are anticipated, countermeasures can be implemented to maintain function and stability (McLean and others, 2001).

Freight and Passenger Transport

If the intensity of rainfall continues to increase, runoff and flooding of highways are likely to increase. In low-lying coastal areas and along coastal shorelines, increased storm surge is likely to affect highway access and use. Intense rainfall events in Houston (June 2001) and New Orleans (May 1995) were two of the region’s most costly weather disasters, and in each case major highways were impassable for several days. Elevation of highways and improved drainage of highways, railways, and other transportation facilities may be needed.

Impacts of climate change and sea-level rise on Gulf Coast ports and waterways could be significant, but little work has been conducted to reveal vulnerabilities. Increased dredging may be required to maintain coastal waterways because siltation in waterways will increase in some areas as natural coastal landforms and man-made levee systems erode. Shipping activity along the Lower Mississippi River could be affected by lowered river stage during a continued drought or by the loss of shipping in other waterways that are affected by climate change (such as the Great Lakes).

Loss of Wetlands

Coastal and interior wetlands in the Gulf Coast states will likely deteriorate as a result of increasing disturbance (fire, storm surge, drought), declining summer soil moisture, and gradual submergence or saltwater intrusion associated with sea-level rise. Wetland loss has two important implications for the transportation sector: (1) mitigation of wetland loss for highway construction may become more difficult and (2) vulnerability of transportation facilities to storm damages will increase as natural coastal defenses deteriorate.

Hurricane Preparedness and Evacuation

Many important hurricane evacuation routes along the Gulf coastal plain are vulnerable to storm surge flooding. Tides were elevated 22.6 feet in one area of Mississippi when Hurricane Camille made landfall in 1969. Sections of Highway 90 and several other evacuation routes were flooded. New Orleans is particularly vulnerable to the loss of life and property during hurricanes since much of the city lies below sea level and there are only two elevated northbound evacuation corridors.

Current evacuation routes are inadequate to evacuate over 1 million people that will need to leave the region in the event of a direct strike of a category 4 or 5 hurricane. Many other Gulf coast cities and small towns are highly vulnerable to loss of life if evacuation capacity is not increased. Design of highways used as major evacuation corridors could be improved to accommodate the reliance on them as evacuation routes (e.g., wider shoulder to accommodate accidents, crossovers on parallel elevated highways).

Oil and Gas Transportation

Storm surge damage and flooding could have important impacts on oil and gas production, transportation, and processing facilities in the Gulf Coast. There are roughly 4,000 production platforms located off the Louisiana/Texas shoreline, accounting for roughly 25% of domestic oil and gas supplies. Storm damage to the network of Gulf Coast pipelines, bulk terminals, and processing plants could be a serious threat to domestic product transportation as well as that of oil imports. Roughly two-thirds of the Nation’s imported oil is transported onshore into Texas and Louisiana facilities. Emergency preparedness could decrease the potential impacts of storms and other weather-related disasters on oil and gas transportation. Construction design for these facilities should consider the climate model projections of increased sea level, wave heights, and rainfall.

Water Quality

If summer soil moisture continues to decline in the Gulf Coast region, runoff could be reduced. Summer low flows occur when water quality (particularly dissolved oxygen) of many Southeastern streams and rivers is at its lowest (Meyer, 1992). Reduced dissolved oxygen during summer months can result in fish kills and harmful algal blooms in both coastal and inland waters. Water quality conditions may become critical during more frequent periods of extreme low flow. Water quality problems are most acute in areas of intensive agricultural activity, in coastal areas, and near coastal streams (Burkett and others, 2001). Consideration of these water quality problems in transportation project planning may reduce project obstacles, environmental impacts, and costs.

References

Boesch, D.F., Scavia, D., Buddemeier, R.W., Burkett, V., Cayan, D.R., Field, J.C., Fogarty, M., Harwell, M.A., Howarth, R.W., Mason, C., Park, R., Piefrafesa, L., Reed, D.J., Royer, C.T., Sallenger, A.H., Spranger, M. and Titus, J.G., 2000, The potential consequences of climate variability and change on coastal areas and marine resources. NOAA Coastal Ocean Program Decision Analysis Series No. 21: Silver Spring, MD, NOAA Coastal Ocean Program, 163 pp.

Bove, M.C., Elsner, J.B., Landsea, C.W., Niu, X., and O'Brien, J.J., 1998a, Effect of El Niño on U.S. landfalling hurricanes, revisited. Bulletin of American Meteorological Society,v.79, no.11, p.2477-2482.

Bove, M.C., Zierden, D.F., and O'Brien. J.J., 1998b, Are Gulf landfalling hurricanes getting stronger? Bulletin of American Meteorological Society, v.79 no.7, p. 1327-1328.

Burkett, V, Ritschard, R., McNulty, S., O'Brien, J.J., Abt, R., Jones, J., Hatch, U., Murray, B., Jagtap, S., and Cruise, J., 2001, Potential consequences of climate variability and change for the Southeastern United States, *in* National Assessment Team, U.S. Global Research Program, eds., Climate change impacts in the United States: potential consequences of climate variability and change, Foundation document: Cambridge, United Kingdom, Cambridge University Press, pp. 137-164.

Burkett, V. 2002. Intertidal zones, *in* H.A. Mooney and J.G. Canadell, eds., The Earth system: biological and ecological dimensions of global environmental change, Encyclopedia of Global Environmental Change: Chichester, John Wiley and Sons, Ltd., v. 2, p. 365-369.

Burkett, V.R., Zilkoski, D.B., and Hart, D.A., in press, Sea-level rise and subsidence: implications for flooding in New Orleans. U.S. Geological Survey Subsidence Interest Group, Proceedings of the Technical Meeting, Nov. 27-29, 2001, Galveston, Texas, USGS Water Resources Division Open File Report Series.

Fairbanks, R.G., 1989, A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep ocean circulation: Nature, v. 342 no.7, p.637-642.

Goldenberg, S.B., Landsea, C.W., Mestas-Nuñez, A.M., and Gray, W.M., 2001, The recent increase in Atlantic hurricane activity: Causes and implications: Science, v. 293, p.474-479.

Intergovernmental Panel on Climate Change (IPCC), 1996, Climate change 1995, impacts, adaptations and mitigation of climate change: scientific-technical analyses: New York. Cambridge University Press, 872 pp.

Intergovernmental Panel on Climate Change (IPCC), Working Group I., 2001, Climate change 2001, the scientific basis, contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change: Cambridge, United Kingdom, Cambridge University Press, 881 p.

Gornitz, V., 1995, Sea-level rise: a review of recent past and near-future trends: Earth Surface Processes and Landforms, v. 20, p.7-20.

Knutson, T.R., Tuleya, R.E. and Kurihara, Y., 1998, Simulated increase of hurricane intensities in a CO_2-warmed climate: Science, v. 279, p.1018-1020.

Linns, H. F. and Slack, J.R., 1999, Streamflow trends in the United States: Geophysical Res. Letters, v. 26, no.2, p.227-230.

McLean, R.F., Tsyban, A., Burkett, V., Codignotto, J., Forbes, D., Ittekkot, V., Mimura, N., and Beamish, R.J, 2001, Coastal zones and marine ecosystems. IN: *Climate Change: Impacts, Adaptation, and Vulnerability.* Third Assessment Report, Working Group II report of the Intergovernmental Panel on Climate Change (IPCC). IPCC Secretariat, Geneva, Switzerland, pp. 343-379.

Melillo, J.M., Janetos, A.C., Karl, T.R., Corell, R.C., Barron, E.J., Burkett, V., Cecich, T.F., Jacobs, K., Joyce, L., Miller, B., Morgan, M.G., Parson, E.A., Richels, R.G. and Schimel, D.S., 2000, Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, Overview: Cambridge, UK, Cambridge University Press, 154 pp.

Meyer, J. L., 1992, Seasonal patterns of water quality in blackwater rivers of the coastal plain, southeastern United States, *in* C.D. Becker and D.A. Neitzel, eds., Water Quality in North American River Systems: Columbus, Batelle Press, pp. 249-276.

Mimura, N. and Harasawa, H., 2000, Data Book of Sea-level Rise. Center for Global Environmental Research, National Institute for Environmental Studies, Environment Agency of Japan, 128 pp.

Muller, R.A. and Stone, G.W., 2001, A climatology of tropical storm and hurricane strikes to enhance vulnerability prediction for the Southeast U.S. Coast: Journal of Coastal Research*,* v.17, no. 40, p.949-956.

National Atmospheric and Oceanic Administration, National Climatic Data Center, Asheville, North Carolina, 2000.

Scavia, D, Field, J. C., Boesch, D.F., Buddemeier, R. W., Cayan, D.R., Burkett, V., Fogarty, M., Harwell, M., and Howarth, R., Mason, C., Reed, D.J., Royer, T.C., Sallenger, A.H., and Titus, J.G., 2002, Climate change impacts on U.S. coastal and marine ecosystems: Estuaries, v. 25, p.149-164.

Timmermann, A., Oberhuber, J., Bacher, A., Esch, M., Latif, M., and Roeckner, E., 1999, Increased El Niño frequency in a climate model forced by future greenhouse warming: Nature, v. 398, p.694-697.

Twilley, R.R., E.J. Barron, H.L. Gholz, M.A. Harwell, R.L. Miller, D.J. Reed, J.B. Rose, E.H. Siemann, R.G. Wetzel and R.J. Zimmerman (2001). *Confronting Climate Change in the Gulf Coast Region: Prospects for Sustaining Our Ecological Heritage.* Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C.

Virginia R. Burkett is Chief of the Forest Ecology Branch of the U.S. Geological Survey's National Wetlands Research Center at Lafayette Louisiana. Before joining the USGS, she was Director of the Louisiana Department of Wildlife and Fisheries. She formerly served as Assistant Director of the Louisiana Geological Survey and as Director of the Louisiana Coastal Zone Management Program. From 1998 to 2001, Dr. Burkett served on climate change assessment teams for both the U.S. government and the United Nations' Intergovernmental Panel on Climate Change. She received her B.S. and M.S. from Northwestern State University of Louisiana and her doctorate degree in Forestry from Stephen F. Austin University in Nacogdoches, Texas.