"Climate change, once considered an issue for a distant future, has moved firmly into the present."

- Third U.S. National Climate Assessment

Houston-Galveston, Texas

Observed Trends and Projected Future Conditions for Climate Change Preparedness and Resilience



the setting



The Houston-Galveston area spans the northwest coast of the Gulf of Mexico approximately 146 miles long and stretching inland 150 miles. Elevation ranges from sea level to 1000 feet above sea level. Terrain ranges from flat wetlands to rolling hills to well drained prairies.

Landsat Image of Houston–Galveston Area U.S. Geological Survey

About the Houston-Galveston Area

The metropolitan Houston-Galveston area is home to over 6 million residents,¹ making it the 5th largest in the U.S. by population.² It is a center of economic activity, a major port and cargo hub, hosts numerous universities along with one of the nation's largest medical complexes, and is the location of numerous critical infrastructure sites. The area is crucial to domestic energy production and security with its key industries of energy, transportation, and manufacturing. The U.S. Department of Energy, the National Aeronautics and Space Administration, and the U.S. Coast Guard are just some of the federal agencies that maintain major installations in the area.



Galveston Residential Area Thinkstock



Houston Ship Channel Thinkstoc



Houston-Galveston area residents are vulnerable to disruptions in essential services because the urban and neighboring population depend on aging infrastructure – water and sewage, roads, bridges, medical facilities, utility grids and power plants – that are in need of repair or replacement.

Rising sea levels, storm surges, heat waves, and other extreme weather events can compound problems associated with aging and highly-interconnected infrastructure. As a result, essential services provided to urban populations can be stressed and overwhelmed. For example, a failure in the electrical grid affects water treatment, transportation services, and public health. These infrastructure systems – lifelines to millions – will continue to be affected by climate change.



Tank Farm in Houston Thinkstock



Galveston Bay Oil Rig Thinkstock

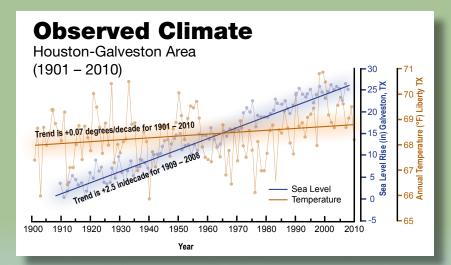


Figure 1. Observed Temperature and Sea Level Rise Increases in the Houston-Galveston Area, 1901-2010. Temperature data are from Liberty, Texas; sea level rise data are from Galveston, Texas. These weather stations were chosen because they have long-term data records. All data are from the National Oceanic and Atmospheric Administration. (Source: Adapting Now to a Changing Climate: Johnson Space Center. National Aeronautics and Space Administration, 2012)

the issue

We know with increasing certainty that climate change is happening now. As the impacts of climate change are becoming more prevalent, Americans face choices. Especially because of past emissions of long-lived heat-trapping gases, some additional climate change and related impacts are now unavoidable. This is due to the long-lived nature of many of these gases, as well as the amount of heat absorbed and retained by the oceans and other responses within the climate system. The amount of future climate change, however, will still largely be determined by choices society makes about emissions. Lower emissions of heat-trapping gases and particles mean less future warming and less-severe impacts; higher emissions mean more warming and more severe impacts.

Observed Climate Trends

Average annual temperature has increased. In the last 20 years, temperature increases across Texas have ranged from 0.5° Fahrenheit in the northeast and 1.5°F in the southwest.³ Local data indicates that the average annual temperature in the Houston-Galveston area has risen approximately 1°F over the past century (see Figure 1).

Precipitation patterns are changing. Extreme rainfall events (non-tropical/hurricane) are common throughout the year, especially those that occur in a one-day period, and can cause flash flooding. Flood events affect transportation infrastructure, making roads impassable and damaging transit systems, while also posing risks to public safety and community health.⁴

Sea level is rising and the land is sinking. Sea level rise and storm surge are pressing issues, since much of the region is exceptionally low-lying and gradually sinking (subsiding), with some areas only a few feet above sea level. Long-term tide gauge data from Galveston over the past century shows that local, relative sea level has risen over 26 inches during this same time period (0.26 inches per year), significantly greater than the global average (see Figure 1).⁵ In addition to global sea level rise

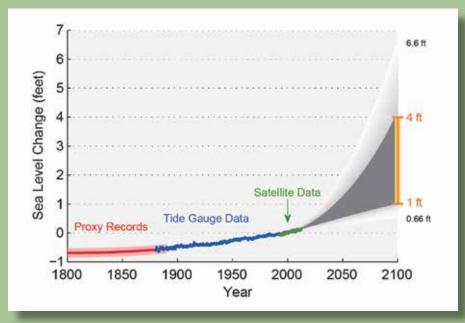
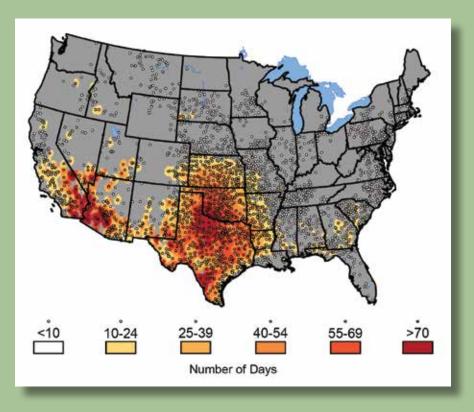
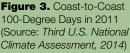


Figure 2. Past and Projected Changes in Sea Level Rise. Estimated, observed, and projected future amounts of global sea level rise from 1800 to 2100, relative to the year 2000. (Source: *Third U.S. National Climate Assessment, 2014*) (see Figure 2), this area has experienced high rates of land subsidence from soil decomposition and compaction, deep fluid extraction of water and petroleum, and the lack of sediment deposition.

Extreme weather events are increasing in frequency and intensity. As a humid, subtropical climate, the Houston-Galveston area typically experiences over 100 days per year of temperatures exceeding 90°F. In August 2011, Houston had the highest number of days reaching temperatures of 100°F or higher in the city's recorded history (see Figure 3). Tropical storms in the region bring extreme rainfall, strong winds, and coastal flooding. The Houston-Galveston area is one of the nation's most hurricane-prone regions⁶ (see Figure 4). In June 2001, Tropical Storm Allison caused





more damage than any tropical storm in U.S. history, with estimates in excess of \$5 billion. Most of the damage, and 22 fatalities, occurred in Houston. Storm rainfall totals peaked at 36.99 inches in the Port of Houston.⁷ In September 2005, Hurricane Rita prompted the evacuation of approximately 2 million Houston-Galveston residents, resulting in massive traffic jams and at least 49 indirect fatalities, mostly due to excessive heat and the transportation of the elderly out of harm's way. Rita, a Category 3 storm by the time it made landfall near the Sabine Pass, did little physical damage to the Houston-Galveston area, but it stressed the region's infrastructure and evacuation systems. ^{8,9} In September 2008, Hurricane Ike resulted in 10–20 foot storm surges and caused an estimated \$29.5 billion in damages to the Houston-Galveston area.¹⁰ In the 12 months following the storm, the estimated economic losses stemming from Hurricane Ike totaled \$142 billion.¹¹

Projected Future Climate Conditions¹²

Average annual temperatures and extreme high temperatures are projected to increase. As climate changes, temperatures in the Gulf Coast region are projected to continue to increase. Extreme high temperatures are also projected to increase – with the number of days above 90°F very likely to increase significantly across the region. The projected hotter summer temperatures will stress many aspects of the built environment, requiring more maintenance to sustain a safe working and living situation.¹³

Droughts will likely become more frequent, last longer, and be more

intense. In addition to hurricanes, the Houston-Galveston area is also vulnerable to droughts: as evident by the extreme drought that affected the region in 2011 (see Figure 3). Rising temperatures and changing precipitation patterns are projected to cause more frequent and intense drought events. Extended periods of drought damage infrastructure, weaken the agricultural economy, endanger Gulf Coast ecosystems, increase the chances of wildfire, and threaten drinking water supplies for Houston-Galveston residents.¹⁴

Extreme weather events are projected to become more powerful.

Storm surge and sea level rise may be the biggest climate-related threats to the Houston-Galveston area. As a region subject to hurricanes and the associated high winds, storm surge, and flooding, rising sea level and land subsidence increases the risk of catastrophic storm surge impacts on regional infrastructure assets, human capital, and natural resources. The Atlantic Ocean and Gulf of Mexico are getting warmer, making hurricanes more powerful. Rising sea level and sinking land will exacerbate exposure to storm surge and flooding. Extreme floods and storms associated with climate change can also lead to increased movement of sediment and changes to the shape and depth of navigation channels.

Sea level is projected to rise. Relative sea level¹⁵ along the Gulf Coast from Houston-Galveston to Mobile, Alabama, is likely to increase by at least 1 foot across the region and possibly by as much as 6–7 feet in some parts of the Gulf Coast area during this century. The analysis of a "middle range" of potential sea level rise of 2–4 feet indicates that a vast portion of the Gulf Coast, from Houston to Mobile, may be inundated over the next 50–100 years. Sea level rise, coupled with storm surge, will continue to increase the risk of major coastal impacts on communities and infrastructure, such as airports, ports and harbors, roads, rail lines, tunnels, and bridges. Increased coastal erosion, saltwater intrusion into aquifers and estuaries, and more frequent flooding from higher storm surges are likely.



Satellite View of Hurricane Ike



Flooding in Galveston from Hurricane Rita



Structural Damage in Galveston from Hurricane Ike



Flooding in Houston from Tropical Storm Allison

what's at stake?

Human health and well-being. As urban areas develop, changes occur in their landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry. These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape.¹⁶ Urban heat islands, combined with an aging population and increased urbanization, are projected to increase the vulnerability of urban populations to heat-related health impacts in the future. Additionally, sea level rise and increased storm surge can contribute to saltwater contamination of freshwater supplies, urban flooding, sewer overflows, and other public health risks in the Houston-Galveston area.

Essential infrastructure and economic activity. The Port of Houston is one of the busiest ports in the Nation and one of the most important in terms of energy supply and security. Current estimates place financial losses of Houston Ship Channel disruption at approximately \$300 million per day. Given the fact that the refining facilities around the Houston Ship Channel is responsible for nearly 12% of U.S. oil refining capacity, a disruption lasting longer than a few days can significantly affect U.S. energy supplies (see Figure 4).¹⁷

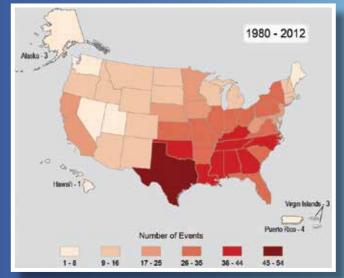


Figure 4. Billion Dollar Weather/Climate Disasters. Map depicting the number of times states have been affected by weather and climate events over the past 30 years, resulting in more than a \$1B dollars in damages. (Source: *Third U.S. National Climate Assessment, 2014*)

Coastal lifelines. The projected rise in sea level will result in the

potential for greater damage from storm surge along the Gulf Coast of Texas. About one-third of the GDP for the state of Texas is generated in coastal counties.¹⁸ According to a recent study co-sponsored by a regional utility, coastal areas in Alabama, Mississippi, Louisiana, and Texas already face losses that annually average \$14 billion from hurricane winds, land subsidence, and sea level rise.¹⁹ According to a recent study, projected sea level rise increases average annual losses from hurricanes and other coastal storms. In Galveston, a typical single-family coastal home worth \$191,000 faces \$4,752 in average annual hurricane losses today that likely grow by \$1,035 to \$1,392 by 2030 and \$2,488 to \$3,303

that likely grow by \$1,035 to \$1,392 by 2030 and \$2,488 to \$3,303 by 2050. $^{\rm 20}$

Fresh water availability. Diminishing water supplies and rapid population growth are critical issues in Texas. On the Texas Gulf Coast, climate change-related saltwater intrusion into aquifers and estuaries poses a serious risk to local populations. In 2011, many locations in Texas experienced more than 100 days over 100°F, with the state setting new high temperature records. Rates of water loss were double the long-term average, depleting water resources and contributing to more than \$10 billion in direct losses to agriculture alone.

Ecosystem services. Ecological impacts to the Texas Gulf Coast are another consequence of climate change in the Houston-Galveston area. Texas coastal marshes and wetlands are fertile breeding grounds for a wide variety of marine life, impede erosion, and help to block some types of inland flooding. Sea level rise threatens to reduce marsh and wetland areas, depriving the Texas Gulf Coast of these benefits. Higher water temperatures and shifting balances between fresh and

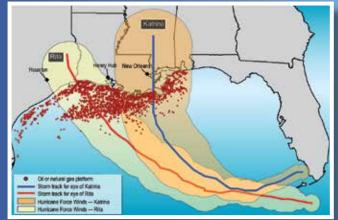


Figure 5. Paths of Hurricanes Katrina and Rita Relative to Oil and Gas Production Facilities. U.S. energy facilities located on the Gulf Coast as well as offshore in the Gulf of Mexico. These facilities are vulnerable to hurricanes and other storms and sea level rise (Source: *Third U.S. National Climate Assessment, 2014*)

salt water can negatively alter marine life habitats, creating problems for this region's large aquaculture economy. The Texas coastal agricultural economy, including livestock, rice, cotton, and citrus cultivation, is threatened by the combination of salt or brackish water from sea level rise and reduced freshwater levels from changes in temperature and precipitation.²¹ Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human interventions creating additional stresses. Climate change will result in further reduction or loss of the services that these ecosystems provide. A March 2014 oil spill in the Houston Ship Channel blocked maritime traffic and required an extensive environmental cleanup, highlighting the economic and ecological dangers posed by storm-surge-induced petrochemical accidents in the Houston-Galveston area.

About the National Exercise Program Climate Change Preparedness and Resilience Regional Workshops

The Climate Change Preparedness and Resilience Regional Workshops are an element of the overarching Climate Change Preparedness and Resilience Exercise Series sponsored by the White House National Security Council Staff, Council on Environmental Quality, and Office of Science and Technology Policy, in collaboration with the National Exercise Division. The workshops are tailored to address issues of particular concern to the host region, such as sea level rise and its impacts on energy and ship channel infrastructure in the Houston-Galveston area. The workshops also feature interactive climate change science panel sessions (at multiple scales) and a facilitated scenario-driven tabletop exercise. The exercise scenario focuses on specific jurisdictional impacts derived from the Third U.S. National Climate Assessment regional scenarios. Ultimately, the regional workshops are intended to help answer the following question: "What can we do now, as a whole community, to collaboratively and sustainably prepare for future projected climate change impacts?" For more information on National Exercise Program Climate Change Preparedness and Resilience Regional Workshops, please contact: NEP@fema.dhs.gov.

The Third U.S. National Climate Assessment

released in May 2014, assesses the science of climate change and its impacts across the United States, now and throughout this century. It integrates findings of the U.S. Global Change Research Program with the results of research and observations from across the U.S. and around the world. The report documents climate change impacts and responses for each region of the country and key sectors of the economy and society, with the goal of better informing public and private decision-making at all levels. For more information, visit: nca2014.globalchange.gov. For questions, contact: engagement@usgcrp.gov

Additional Resources

The U.S. Global Change Research Program was established by a Presidential Initiative in 1989 and mandated by Congress through the Global Change Research Act of 1990 to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." For more information, visit: globalchange.gov.

The White House Council on Environmental Quality coordinates Federal environmental efforts and works closely with agencies and other White House offices in the development of environmental policies and initiatives. For more information, visit: whitehouse.gov/administration/eop/ceq.

The White House Office of Science and Technology Policy was established by Congress in 1976 with a broad mandate to advise the President and others within the Executive Office of the President on the effects of science and technology on domestic and international affairs. For more information, visit: whitehouse.gov/administration/eop/ostp.

The City of Houston Mayor's Office of Sustainability creates policies and innovative programs that protect human health, promote social equity and lead the way toward a sustainable future. The Mayor's Office of Sustainability mobilizes communities and provides the resources needed to safeguard homes, the city and create more livable and vibrant neighborhoods. For more information, visit: greenhoustontx.gov.

The Houston Advanced Research Center is a research hub providing independent analysis on energy, air, and water issues to people seeking scientific answers. It focuses on building a sustainable future that helps people thrive and nature flourish, while works to find sustainability solutions to problems that demand balancing environmental quality, economic health and social equity. The Houston Advanced Research Center supports the implementation of policies and technologies that promote sustainability and are based on scientific principles. For more information, visit: harc.edu.

Considerations with Projecting Future Climate

Climate projections and impacts, like other types of research about possible future conditions, are characterized by uncertainty, to include, but not limited to:

- Human activities and the emissions produced by those activities
- The response of different parts of the planet to human-caused changes in the atmosphere
- Natural variability in climate and weather patterns

Even though quantitative climate projections at the local scale have uncertainties, the information provided here can guide stakeholders as they seek to identify and manage the risks associated with climate variability and climate change.

Unless specified in the endnotes, language in this brochure was adapted or borrowed from the following sources:

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. This source is also referenced throughout this document as the Third U.S. National Climate Assessment.

Adapting Now to a Changing Climate: Johnson Space Center. National Aeronautics and Space Administration, 2012.

Endnotes

Based on 2013 census data of the 13 counties on the Houston-Galveston Area Council. ²Houston now No. 5 in population, overtakes Philadelphia, Houston Business Journal, April 3, 2012.

³ "Climate Change in Texas," The Southern Climate Impacts Planning Program.

4 "Climate Impacts in the Great Plains." U.S. Environmental Protection Agency.

⁵ Impacts of Climate Chance and Variability on Transportation Systems and Infrastructure: Gulf Coast Study. Phase I. U.S. Climate Chance Science Program Synthesis and Assessment Product 4.7. March 2008.

⁶ Top 5 Most Vulnerable U.S. Cities to Hurricanes. Climate Central, June 6, 2012.

7NOAA Service Assessment Report, "Tropical Storm Allison, Heavy Rains and Floods, Texas and Louisiana, June 2001," September 2001

88 years ago, seemingly all of Houston evacuated ahead of Hurricane Rita." Houston Chronicle, September 24, 2013

9"Post-Tropical Cyclone Report: Hurricane Rita." National Weather Service, Houston/Galveston TX, November 30, 2005

¹⁰Hurricane Ike Five Years Later: Photos Show Damage, and Recovery, in Houston and Galveston. The Weather Channel, September 26, 2013. 11 Hurricane Ike Impact Report, Texas Engineering Extension Service, August 15, 2011.

12Some of this content originates from the FACT SHEET: What Climate Change Means for Texas and the Great Plains Region—information derived from the Third U.S. National Climate Assessment. ¹³A Report to the Houston-Galveston Area Council. Adaptation to Climate Change in the Houston-Galveston Area: Perceptions and Prospects. The Bush School. Texas A&M University. 2009.

¹⁴The Impact of the 2011 Drought and Beyond. Texas Comptroller of Public Accounts, February 2012.

1% Relative sea level rise (RSLR) is the combined effect of the projected increase in the volume of the world's oceans (eustatic sea level change), which results from increases in temperature and melting of ice, and the projected changes in land surface elevation at a given location due to subsidence of the land surface.

¹⁶U.S. Environmental Protection Agency. Basic Information – What is an Urban Heat Island? 2013. Online resource.

17"Spill brings concerns of potential economic impact." Houston Chronicle, March 23, 2014.

¹³Houser, T., R. Kopp, S. Hsiang, R. Muir-Wood, K. Larsen, M. Delgado, A. Jina, P. Wilson, S. Mohan, D. J. Rasmussen, M. Mastrandrea, and J. Rising (2014). American Climate Prospectus: Economic Risks in the United States. New York, NY: Rhodium Group. 19 Building a Resilient Energy Gulf Coast: Executive Report, America's Energy Coast, America's Wetlands Foundation, Entergy Corporation, October 2010.

2ºHouser, T., R. Kopp, S. Hsiang, R. Muir-Wood, K. Larsen, M. Delgado, A. Jina, P. Wilson, S. Mohan, D. J. Rasmussen, M. Mastrandrea, and J. Rising (2014). American Climate Prospectus: Economic Risks in the United States. New York, NY: Rhodium Group. ²¹Sea Level Changes and the Texas Coastal Environment. University of Texas Bureau of Economic Geology



