



SIMPLE PLANNING TOOL

FOR TEXAS CLIMATE HAZARDS

VERSION 1.1 (DECEMBER 2022)



Suggested Citation: SCIPP, 2022: *Simple Planning Tool for Texas Climate Hazards v 1.1*, A. Wanless, D. Bertrand, R. E. Riley, and M. Shafer, eds., Southern Climate Impacts Planning Program, 53 pp, <https://www.southernclimate.org/wp-content/uploads/SPTTX.pdf>.

Front Cover Photo: NOAA Office of Satellite and Product Operations, 2017: Hurricane Harvey approaches the Texas Coastline before it makes its landfall between Port Aransas and Port O'Connor. GOES-East satellite RGB composite image from August 25th, <https://www.ospo.noaa.gov/Organization/History/imagery/Harvey/index.html>.

Back Cover Photo: Keim, B., 2018: Buffalo Bayou, Houston, TX.

Copyright 2022 Board of Regents of the University of Oklahoma

TABLE OF CONTENTS (Subtopics below are clickable)

Introduction

i. About the <i>Simple Planning Tool for Texas Climate Hazards</i>	1
ii. User Instructions	2
iii. A Note About Climate Data Availability.....	3
iv. A Note About Climate Change	4
v. A Note About Impact Data	4
vi. A Note About Climate Divisions	4

Climate Hazards

1. Coastal Erosion	5
2. Cold Extremes.....	7
3. Drought.....	9
4. Hail.....	11
5. Heat Extremes	12
6. Heavy Rainfall and Flooding	15
7. High Tide Flooding	18
8. Hurricane/Tropical Storm/Storm Surge.....	21
9. Lightning	24
10. Sea Level Rise	26
11. Severe Thunderstorm Wind.....	28
12. Tornado	29
13. Wildfire	30
14. Winter Storm (Ice, Sleet, Snow)	32

Other Hazards

1. Dam or Levee Failure.....	33
2. Earthquake.....	34
3. Poor Air Quality (Dust, Pollutants, Smoke).....	35

Supporting Materials

i. Acknowledgements 36

ii. References 37

iii. Appendix A: Hazard Definitions and Descriptions..... 40

iv. Appendix B: Historical FEMA/Presidential Disaster Declarations..... 48

v. Appendix C: Climate Change Science and Projection Resources..... 49

vi. Appendix D: Incentive and Action Programs for Hazard Risk Reduction 51

vii. Appendix E: Other Miscellaneous Resources 53

About the Simple Planning Tool

This tool is a compilation of relatively easy-to-use online interactive tools, maps, and graphs to assist planners and emergency managers in the state of Texas who are assessing their long-term climate risks, both historically and in the future. It is primarily designed for decision-makers who serve small- to medium-sized communities but may also be of interest to those who serve larger areas. This tool was developed with input from local and state emergency managers and planners. While it may not answer every question one has about hazard climatologies and future trends, it aims to cut through the internet clutter and point to relatively simple data tools that can be used during planning processes and in plans. The *Simple Planning Tool for Texas Climate Hazards* was produced by the Southern Climate Impacts Planning Program (SCIPP, www.southernclimate.org).

The tool may be accessed online at <https://www.southernclimate.org/wp-content/uploads/SPTTX.pdf>.

For tool assistance or questions, please contact scipp@southernclimate.org.

About SCIPP

The Southern Climate Impacts Planning Program (SCIPP) is one of 12 National Oceanic and Atmospheric Administration (NOAA) Climate Adaptation Partnerships (CAP) teams, formerly Regional Integrated Sciences and Assessments (RISA). SCIPP assists organizations with making decisions that build resilience by producing research, tools, and knowledge that reduce weather and climate impacts. The area SCIPP serves includes the 4-state region of Oklahoma, Texas, Arkansas, and Louisiana.

Contributors

Anna Wanless, SCIPP Graduate Research Assistant, University of Oklahoma (2019-2021)

Darrian Bertrand, SCIPP Climate Assessment Specialist, University of Oklahoma

Rachel Riley: SCIPP Director, University of Oklahoma

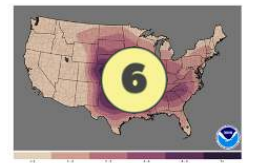
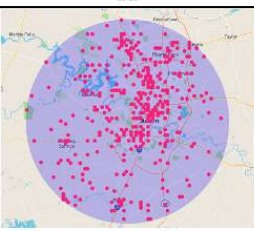
Mark Shafer: SCIPP Deputy Director, University of Oklahoma

User Instructions

This document is alphabetically organized by climate hazard (p. 5-32) and three other hazards (p. 33-35). A table is included for each hazard and describes the data limitations, historical climatology tools, and projected future trends. See the example table below and corresponding descriptions to the left for more details on how each table is organized.

Table Components

1. This section describes known data limitations for the hazard. Knowing limitations can help one interpret data results more accurately.
2. The historical data rows show several tools that provide freely-available historical data relevant to each hazard.
3. For each individual tool, this column provides its name, period of record of the data used (some tools use multiple periods), and the source.
4. This column provides the information that can be obtained from the tool and instructions on how it can be found.
5. This row provides the website link to access the tool. (Note: In the event of a URL change, search the web using the accompanying information.)
6. This column shows an image of the tool's final product (i.e., map, graph, table).
7. This section shows tools that include climate projections and future trends of the hazard (if available). It also includes a concise summary of the state-of-the-science on whether the hazard is projected to be influenced by climate change, and if so, how.

Hail																																																																																			
Data Limitations: Hail data are not of sufficient quality to robustly determine historical trends and are of poorer quality than even the tornado dataset. This can be attributed to the increases in non-meteorological factors such as population and storm spotter coverage over time, as well as the uncertainty in reported hail size. However, the recent decision to assess the number of hail days instead of individual hail reports has mitigated some of the biases. Also note that the criteria for severe hail changed from 0.75" to 1" in 2009.																																																																																			
Historical Data	2	3 Severe Hail Days Per Year (1986-2015) NOAA/National Weather Service Storm Prediction Center	4 The map provides a sense of the approximate number of days each year that you can expect to see severe (0.75- and 1-inch) or significant (greater than 1-inch) hail in your area. Note: Severe hail size changed from 0.75" to 1" in 2009, so both sizes are included on the webpage.	5 1. Click on the link below to go to the website 2. Scroll to the last three maps and select the map of interest to see the full-size image. Tool Link: https://www.spc.noaa.gov/wcm/#30yrclimo	6 																																																																														
		Severe Hail Reports Hail: (1955-present) Southern Regional Climate Center	This interactive tool displays the historical record for individual severe hail reports in your area. It can be used to determine hail events that have impacted your area. 1. On the left side of the screen, click on <i>Search within Radius</i> . 2. Choose the diameter of the area of which you want to investigate (25 or 50 miles). 3. Under <i>Filter by Storm Types</i> select <i>Hail</i> (or select Tornado and Wind). 4. Pan, zoom, and then click on the map area of interest. Reports will be displayed on the map and in two tables below the map. Map: Mouse over individual storm reports for details. Tables: There are two tables, <i>Recent Storm Data</i> and <i>Historical Storm Data</i> . Click on a column header to sort by column of interest. For example, to view the dates in which the largest hail occurred, click on the <i>Scale</i> column headers to sort by the largest hail value. Tool Link: https://www.srrc.tamu.edu/storm_reports/																																																																																
		Storm Events Database Hail: (1955-present) NOAA National Centers for Environmental Information	This interactive tool displays a historical record for individual severe hail reports by county. It can be used to determine events that have impacted your area or close to your area. 1. On the bottom left, under <i>Select State or Area</i> , choose <i>Texas</i> → then <i>Search</i> . 2. From top to bottom, select <i>Specific Begin and End Date</i> , as well as <i>County</i> of interest. 3. Under <i>Event Type(s)</i> , select <i>Hail</i> . 4. Expand <i>Advanced Search and Filter Options</i> → <i>Hail Filter</i> , select hail size of interest. 5. Press <i>Search</i> . Summary results are presented in a table. Note: This tool can be used to analyze a variety of additional hazards with various time periods, and hail data goes as far back as 1955. This database is likely incomplete and does not account for all hail events. Tool Link: https://www.ncdc.noaa.gov/stormevents/	<table><thead><tr><th>Location</th><th>County/Zone</th><th>St.</th><th>Date</th><th>Size</th></tr></thead><tbody><tr><td colspan="5">Totals: (for 500 results below)</td></tr><tr><td>LOCKPORT</td><td>WILMINGTON CO.</td><td>TX</td><td>10/08/1989</td><td>17.0</td></tr><tr><td>WINDREEDS AFB TX</td><td>DALLAS CO.</td><td>TX</td><td>11/22/1989</td><td>18.4</td></tr><tr><td>DALLAS</td><td>DALLAS CO.</td><td>TX</td><td>11/22/1989</td><td>18.5</td></tr><tr><td>VERNON</td><td>WILMINGTON CO.</td><td>TX</td><td>12/02/1989</td><td>18.1</td></tr><tr><td>CLAY CO.</td><td>CLAY CO.</td><td>TX</td><td>12/02/1989</td><td>18.3</td></tr><tr><td>PERDUE</td><td>JACK CO.</td><td>TX</td><td>12/02/1989</td><td>20.4</td></tr><tr><td>MYRA</td><td>COOKE CO.</td><td>TX</td><td>12/02/1989</td><td>21.0</td></tr><tr><td>LAKE BRIDGEPORT</td><td>WISE CO.</td><td>TX</td><td>12/02/1989</td><td>21.3</td></tr><tr><td>LAKE BRIDGEPORT</td><td>WISE CO.</td><td>TX</td><td>12/02/1989</td><td>21.5</td></tr><tr><td>BOVSE</td><td>MONTAGUE CO.</td><td>TX</td><td>12/02/1989</td><td>21.5</td></tr><tr><td>DECATUR</td><td>WISE CO.</td><td>TX</td><td>12/02/1989</td><td>22.1</td></tr><tr><td>DECATUR</td><td>WISE CO.</td><td>TX</td><td>12/02/1989</td><td>22.2</td></tr><tr><td>DECATUR</td><td>WISE CO.</td><td>TX</td><td>12/02/1989</td><td>22.3</td></tr><tr><td>DECATUR</td><td>WISE CO.</td><td>TX</td><td>12/02/1989</td><td>22.4</td></tr></tbody></table>	Location	County/Zone	St.	Date	Size	Totals: (for 500 results below)					LOCKPORT	WILMINGTON CO.	TX	10/08/1989	17.0	WINDREEDS AFB TX	DALLAS CO.	TX	11/22/1989	18.4	DALLAS	DALLAS CO.	TX	11/22/1989	18.5	VERNON	WILMINGTON CO.	TX	12/02/1989	18.1	CLAY CO.	CLAY CO.	TX	12/02/1989	18.3	PERDUE	JACK CO.	TX	12/02/1989	20.4	MYRA	COOKE CO.	TX	12/02/1989	21.0	LAKE BRIDGEPORT	WISE CO.	TX	12/02/1989	21.3	LAKE BRIDGEPORT	WISE CO.	TX	12/02/1989	21.5	BOVSE	MONTAGUE CO.	TX	12/02/1989	21.5	DECATUR	WISE CO.	TX	12/02/1989	22.1	DECATUR	WISE CO.	TX	12/02/1989	22.2	DECATUR	WISE CO.	TX	12/02/1989	22.3	DECATUR	WISE CO.	TX	12/02/1989
Location	County/Zone	St.	Date	Size																																																																															
Totals: (for 500 results below)																																																																																			
LOCKPORT	WILMINGTON CO.	TX	10/08/1989	17.0																																																																															
WINDREEDS AFB TX	DALLAS CO.	TX	11/22/1989	18.4																																																																															
DALLAS	DALLAS CO.	TX	11/22/1989	18.5																																																																															
VERNON	WILMINGTON CO.	TX	12/02/1989	18.1																																																																															
CLAY CO.	CLAY CO.	TX	12/02/1989	18.3																																																																															
PERDUE	JACK CO.	TX	12/02/1989	20.4																																																																															
MYRA	COOKE CO.	TX	12/02/1989	21.0																																																																															
LAKE BRIDGEPORT	WISE CO.	TX	12/02/1989	21.3																																																																															
LAKE BRIDGEPORT	WISE CO.	TX	12/02/1989	21.5																																																																															
BOVSE	MONTAGUE CO.	TX	12/02/1989	21.5																																																																															
DECATUR	WISE CO.	TX	12/02/1989	22.1																																																																															
DECATUR	WISE CO.	TX	12/02/1989	22.2																																																																															
DECATUR	WISE CO.	TX	12/02/1989	22.3																																																																															
DECATUR	WISE CO.	TX	12/02/1989	22.4																																																																															
Future Trends	7	Hail is commonly associated with severe thunderstorms, and northern Texas had the highest frequency of large hail from 1986-2015 (SPC 2016). Climate models project an increase in the atmospheric conditions that tend to favor severe thunderstorms, especially favoring events capable of producing large hail (Kossin et al. 2017). This increase in large hail will likely occur in the springtime, but an increase in temperature will lead to less hail overall, especially in summer (Nielsen-Gammon et al. 2017). Confidence in the projections is currently low, however, due to the isolated and sporadic nature of hail events and limited comprehensive datasets which make it difficult to track long-term trends (Wuebbles et al. 2017a).																																																																																	

A Note About Climate Data Availability

Data availability differs among weather variables. Some variables are easier and less costly to observe than others. For example, temperature and liquid precipitation have longer and more complete periods of record than tornadoes and freezing rain. In addition, it is not scientifically appropriate to analyze long-term trends for some hazards due to reporting differences over time. For example, the long-term trends of tornadoes, severe wind, and hail reports are biased due to population increases and advances in the ability to detect and communicate information. **Refer to the data limitations portion of each hazard section for more details.**

In an ideal world, every city or county in Texas would have detailed, long-term climate records. However, even though modern science and technology have greatly advanced data collection, there are limitations which are noted above. Data products such as tables, graphs, and maps are commonly produced from single point observations, analyses that interpolate between data points (for those locations that do not have individual records), or by averaging (such as across climate divisions). **Users should be aware that this document references tools that show observational points, some that show interpolation analyses, and some that show averages.**

Although individual stations are often favored as they provide local data, it might not be the best choice to use a single station's data for long-term risk analysis if it is of poor quality (i.e., has data gaps or has not been calibrated) or has a short period of record. For example, some stations have long-term temperature records that begin in the eighteenth century. Other stations, such as those operated by the Texas Mesonet, for example, have only existed since 2016. Also, the system doesn't cover the entire state but has a relatively high spatial density where it does exist. **Depending on user needs, it may be more appropriate to look at data from a station that is relatively close to the desired location (i.e., not in the exact city or county) if it has a longer period of record.** In other words, if a user is looking to assess a location's long-term risk, a nearby station with 60 or 100 years' worth of data may be more valuable than a local station that only contains 15 years of data or has long periods of missing data. Furthermore, if a nearby station does not have a long-term record, it may be more valuable to focus on the tools with interpolated analyses or averages. These tools are acknowledged by atmospheric science professionals, including climatologists, to represent accurate and relevant data when locations are under-represented.

Using point data may also miss important events that pose a risk to the city. For example, if a strong tornado passed close to a city, using only historical tracks from within city limits would not include the event and therefore underestimate risk. **It is wise to consider nearby areas along with the particular location of interest when assessing hazard risk.**

For more information on data limitations or questions regarding suspect data, contact the Texas State Climatologist, Dr. John Nielsen-Gammon, at n-g@tamu.edu or 979-862-2248.

A Note About Climate Change

The future trend portion accompanying each hazard section in this document provides concise summaries of the most up-to-date scientific knowledge regarding how climate change currently is or is expected to impact each hazard. The science is clear that our global climate is changing at a rate at which we have not experienced before in modern times, and humans are a primary influence behind this rate of change. However, the changes we are experiencing and can expect to experience in Texas are nuanced. In many cases, only descriptive information about likely changes can be given, as climate models are currently not capable of providing skillful magnitudes of the changes. For example, models may be able to examine changes in environmental conditions favorable to storms but lack the resolution to determine likely storm severity. When appropriate, the future trends are broken into regions because of Texas's large geographic range and diverse climate. These regions include western, central, and eastern Texas (see map below). For climate change information that is more in-depth than that which accompanies each hazard section in this tool, please visit the resources listed in Appendix C.

A Note About Impact Data

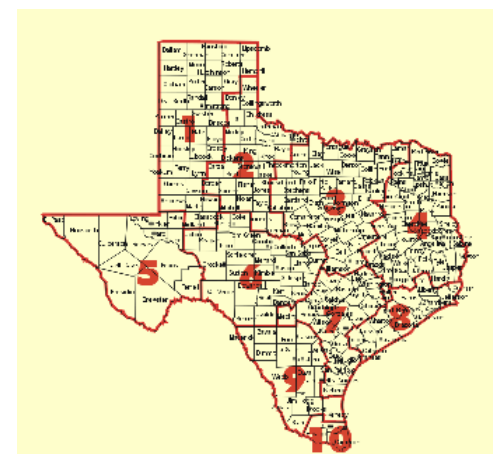
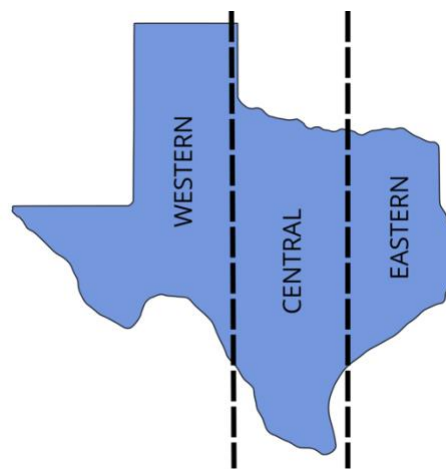
Understanding the detailed impacts of weather and climate on cities, counties, and tribes is an important and necessary step to be able to reduce risks and costs. Impacts of events are dependent upon characteristics of the location such as low-lying areas susceptible to flooding, soil types, housing construction, and resources available to respond and rebuild. Given disparate data sources, however, gathering comprehensive impact data and including it in the *Simple Planning Tool* was not possible due to resource constraints. If future resources support further research, additional versions of the *Simple Planning Tool for Texas Climate Hazards* may include impact data.

A Note About Climate Divisions

Due to its size and geography, Texas has a diverse climate. Southeastern Texas is very different from the Panhandle. This variation makes it difficult to generalize the current state or future climate trends for the entire state. If the future trend of a hazard is not uniform across the state, the trend is broken down by three regions: western, central, and eastern Texas (see map to the right) within the Future Trend section. Climate divisions were not used for this breakdown because there are 10 climate divisions, and it was more efficient and appropriate to describe trends over a larger area. The climate divisions (CD) were established by the US Weather Bureau in the 1960s (far right map). These divisions split states into sectors by climatic characteristics (Guttman 1996).

Texas Climate Divisions map: From

https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/CLIM_DIVS/texas.gif



Coastal Erosion

Data Limitations: Coastal erosion is complex because of the many factors that affect the changing coastline, including sea level rise, coastal flooding, subsidence, winds, and wave action. Therefore, measuring changes from erosion can be difficult. Coastal gauges are also sparse, so there is limited historical data at many locations. Satellites have greatly improved observations of eroding coasts but do not yet provide a long-term record. Long-term changes are found through a combination of archived aerial images, surveys, coastal gauge data, and satellite observations.

Historical Data

Coastal Change Hazards Portal

(Historical: ~150 years; short-term change: ~30 years, long-term change: ~78+ years)

U.S. Geological Survey

Access this tool to view historical shorelines and short- and long-term shoreline change rates due to hurricanes, coastal erosion, and sea level rise.

1. To view coastal erosion changes, zoom into the area of interest **2.** Select *Shoreline Change* from the righthand menu. **3.** Choose to view long-term or short-term shoreline change rates or historical shoreline positions. **4.** Click *Gulf of Mexico shorelines*, then choose *Texas*. The map will show your selection along the Texas coast.

Tool Link: <https://marine.usgs.gov/coastalchangehazardsportal/>



Gulf Tree

(Period of record varies by product)

Northern Gulf of Mexico Sentinel Site Cooperative, Gulf of Mexico Climate Resilience Community of Practice, & Gulf of Mexico Alliance Resilience Team

This decision support site guides users to the coastal erosion tools and resources they need along the Gulf Coast through several filters of information, including how much time and effort they're willing to spend on the tool.

1. Choose a *Filtered Search* to look through all filter categories on one page or choose *Guide My Search* to walk through questions step by step to achieve what you're looking for. **2a.** If you chose the *Filtered Search*, first navigate to *Geographic Scope*. Click the *Texas* drop-down menu and choose *Shoreline* to select all coastal counties or choose specific one(s). **2b.** Under *Tool Function*, select what you'd like to use coastal erosion information for. **2c.** Under *Cost*, choose *Free*. **2d.** Under *Level of Effort*, choose from low, moderate, or high (will determine how advanced the tool is). **2e.** Under *Climate Change Themes*, check the box for *Sea Level Rise*. **2f.** Under *Climate Change Topics*, select the drop-down for *Coastal Processes*, then check the box for *Erosion*. **2g.** Click *View Tool Matches* on the top right to go to the results page. Click any of the tools or resources to go to that site.

3a. If you chose *Guide My Search*, Gulf Tree will walk you through the same filters by asking 6 questions. For step 1 (*Tool Function*), check the box for why you need a coastal erosion tool, then click *Submit*. If you're not sure which option to use, you can *Skip* this step. **3b.** Step 2 (*Topic Area*) includes a filter for what aspect of the topic you're interested in. Click the drop-down menu for *Coastal Processes* and check the box for *Erosion*, then click *Submit*. **3c.** On Step 3 (*Location*), click the *Texas* drop-down menu, then choose *Shoreline* to select all coastal counties or choose specific one(s). Then, click *Submit*. **3d.** For Step 4 (*Level of Effort*), choose how much effort you'd like to put into the tool, which will determine how advanced the tool is. Then, click *Submit*. **3e.** For Step 5 (*Tool Cost*), choose *Free*, then click *Submit*. **3f.** Click *Leave Guided Search and View Matches* to go to the results page or go back to a previous page on the left menu to change your selected options. Click any of the tools or resources to go to that site. **4.** To create a new search, click *Reset All Filters* at the top right of the results page.

Tool Link: <http://gulftree.org/>



Coastal Erosion (Continued)

Future Trends

Sea level rise increases coastal erosion, so we can expect erosion to increase over time (USGCRP 2019). On the Texas coast, beach erosion is 10 feet per year, on average (Kloesel et al. 2018). According to the USGS Coastal Change Hazards Portal data, some areas of the Texas coast have eroded more than 15 feet per year over the last ~30 years. The erosion of 56% of freshwater wetlands is expected in the middle coast of Texas by 2100, removing protective coastal barriers (Pathak and Fuller 2021). Read more about future coastal erosion in the resources found in Appendix C.

Cold Extremes

Data Limitations: Texas generally has good quality long-term data records for cold temperature values, however, the consistency of cumulative years on record varies by station. The majority of stations consist of a large data record (Nielsen-Gammon 2011); however, some station locations include gaps in records that could be subject to technical issues or changes in monitoring location.

Historical Data

Temperature Trends Dashboard

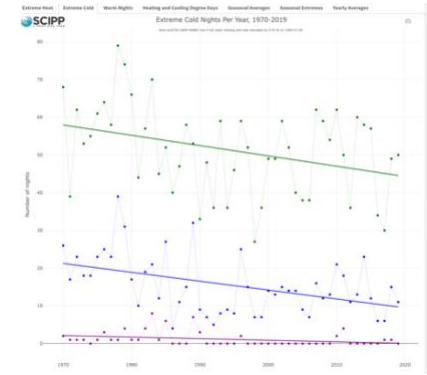
(1970-2022)

Southern Climate Impacts Planning Program

This tool shows temperature trends at individual stations across Texas, including trends in extremely cold nights, seasonal extreme and average high/low temperatures, and heating degree days, since 1970.

1. At the top of the tool, click the *Extreme Cold*, *Heating and Cooling Degree Days*, *Seasonal Averages*, or *Seasonal Extremes* tab. 2. The default station is in Abilene, TX. To choose a station nearest to you, use the map on the right. Zoom in and click any of the blue dots to change stations. You can also select a station under the *Station* drop-down menu on the left of the page 3. Use the graph to determine the trend (if any) for your selection. Solid lines represent significant trends. 4. Mouse over individual data points to view more information. 5. For seasonal selections, make sure *Winter* is selected in the *Season* drop-down menu on the left of the screen.

Tool Link: https://scipprisa.shinyapps.io/SCIPP_temp_dash/



Record Low Temperatures

(Period of record varies by station; up to ~125 years)

Southern Regional Climate Center

This tool displays the lowest temperature ever recorded at individual stations.

1. Under *Select a Product*, select *All-Time Records*. 2. Under *Select an Element*, select *Low Min Temperature*. 3. Click *Submit*. 4. Temperature records are displayed on the map (pan, zoom in or out if needed). Mouse over a station to view its period of record and day on which the record occurred.

Tool Link: <https://www.srcc.tamu.edu/extremes/>



Wind Chill Days and Hours

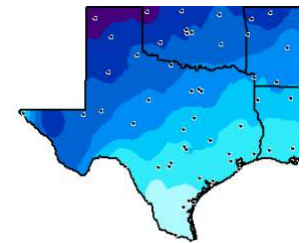
(1973-2019)

Midwest Regional Climate Center

This set of maps depicts the average number of days, days with 3 or more hours, and average number of hours per year with wind chill values at or below a variety of thresholds (e.g., 15°F, 0°F, -10°F).

1. Near the top of the page, click on the map link of interest out of the three options: *Average Number of Days*, *Days with 3 or More Hours*, or *Average Number of Hours*. 2. Right above the map, mouse over the wind chill temperature value of interest to view the corresponding data on the map. 3. To interpret the colors, see the legend on the upper right side of the map.

Tool Link: <https://mrcc.purdue.edu/clim/windChill/index.jsp>



Cold Extremes (Continued)

Historical Data

Freeze Maps

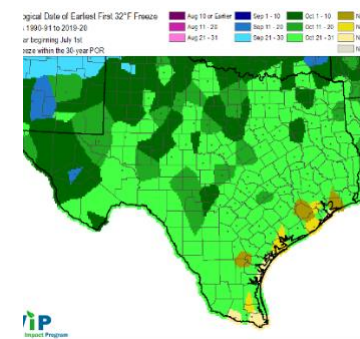
(1990-2020)

Midwest Regional
Climate Center

This tool shows the average dates of the earliest fall freeze and latest spring freeze. Maps can be used to understand the times of the year in which you might experience temperatures below freezing for your area.

1. Click *28°F (or 32°F) FREEZE CLIMATOLOGIES* on the left-hand side of the page to view the average dates of first/last freezes. Click any of the subcategories to view earliest, first, median, late, or latest freeze information. 2. Click on your area of interest on the map to zoom in to a county-level view. **Note:** *To only view station points on the map and remove the shaded regions, click Show Only Points (no shading) at the top of the page.* 3. To view an interactive map with station information, click *All Frost/Freeze Products* at the top right of the page, then choose *GIS Freeze Maps Interface*.

Tool Link: https://mrcc.purdue.edu/VIP/frz_maps/freeze_maps.html#



Future Trends

Climate Explorer – Climate Maps and Graphs Tools

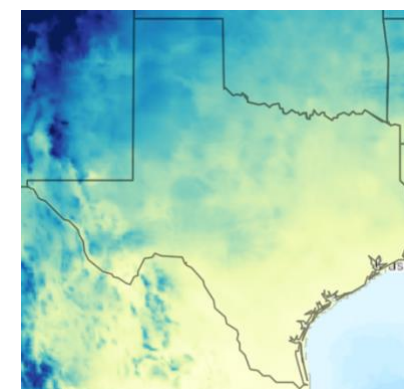
(1950-2099)

NOAA Climate Program
Office and National
Environmental
Modeling and Analysis
Center

The Climate Explorer is an interactive tool that allows you to view and compare the annual heating degree days and the average number of days per year with a maximum or minimum temperature below 32°F for the historical period and in the future under both higher and lower emissions scenarios.

1. Type in the city or county you are interested in. 2. Click *Climate Maps*. 3. Using the drop-down menu in the upper-left corner, select the variable of interest (*Days w/ max temp <32°F*, *Days w/ min temp <32°F*, or *Heating Degree Days*). 4. Next to the drop-down menu, select *Map*. 5. Use the middle slider on the map to compare averages between the historical period (1961-1990) and future decades (2020s-2090s) under lower and higher emissions scenarios. (Use the bottom drop-down menus to choose variables and the slider on the bottom right to choose a decade to compare with.) On the map, zoom in to the county level and click a county to view the associated values. 6. To view this information over time (1950-2099) for a single location, click the *Graph* tab at the top of the map and type a location at the top.

Tool Link: <https://crt-climate-explorer.nemac.org/>



In recent decades, the number of days below freezing has declined across Texas, and the number of extremely cold days is expected to decrease (Runkle et al. 2022; Kloesel et al. 2018). Extreme cold events will continue to impact Texas; however, they will occur less frequently and with less intensity (Nielsen-Gammon et al. 2021). Warmer winters signify that temperatures will remain warm for a longer amount of time, shortening the cold season which will subsequently lead to a longer frost-free period and growing season. Also, by mid-century, the coldest day of the year is projected to be 5°F warmer and the most intense cold wave is projected to be 10°F warmer in the Southern Great Plains (Vose et al. 2017). Read more about future cold extremes in the resources found in Appendix C.

Western TX: By mid-century, models project that Texas will experience decreases in the number of days below 32°F, with as many as 30 fewer days per year (~20-50% decrease) in the Panhandle and northwest part of the state under a higher emissions scenario and 10-20 fewer days under a lower emissions scenario (Vose et al. 2017; U.S. Fed. Gov. 2021). By the end of the century, western Texas could experience 40-50 fewer days below 32°F (~40-80% decrease) under a higher emissions scenario and 10-30 fewer days under a lower emissions scenario according to the Climate Explorer tool (U.S. Fed. Gov. 2021). There is not much change expected in number of days below 32°F in south Texas because of the already low frequency in these events.

Central TX: By mid-century, central Texas is projected to experience 10-20 fewer days per year with temperatures below 32°F (~30-60% decrease) under a higher emissions scenario and 5-15 fewer days under a lower emissions scenario (Vose et al. 2017; U.S. Fed. Gov. 2021). While the number of days below 32°F is not expected to change much in south central Texas, the percent decrease is greatest in this area as there are already fewer days below 32°F historically. By the end of the century, north central Texas could receive 30 fewer days with temperatures below 32°F (~55% decrease) under a higher emissions scenario and up to 20 fewer days under a lower emissions scenario (U.S. Fed. Gov. 2021). There is not much change expected in number of days below 32°F in south central Texas because of the already low frequency in these events.

Eastern TX: By mid-century, eastern Texas is projected to experience up to 20 fewer days with temperatures below 32°F under a higher or lower emissions scenario, with coastal areas experiencing less change in frequency (Vose et al. 2017). There is a ~60-75% decrease in days below 32°F (U.S. Fed. Gov. 2021) in this area because there is already a low frequency in these days historically. By the end of the century, eastern Texas could receive up to 35 fewer days below freezing under a higher emissions scenario and up to 20 fewer days under a lower emissions scenario.

Drought

Data Limitations: Drought cannot be assessed by a single indicator. Unlike many other hazards where impacts are immediate and apparent, drought has a slow onset, sometimes goes undetected, and affects different sectors on different timescales. Consequently, it is important to assess drought using a variety of indicators, some which respond better to short-term conditions, such as for agriculture, and others that respond to longer-term conditions, such as water resources. Many indicators are combined into the weekly U.S. Drought Monitor, however, this only dates back to 2000.

Historical Data

U.S. Drought Risk Atlas

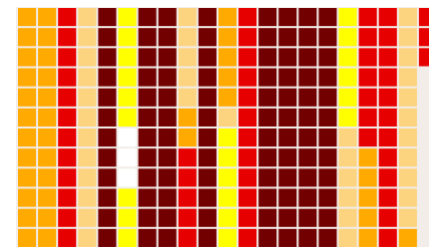
(Period of record varies by station; up to ~80 years)

National Drought Mitigation Center

This interactive tool provides historical drought indices at a local level and can identify drought periods at different levels of severity, duration, and frequency.

1. On the left side, select *Texas* to search by state or zoom in on the map, then search by location. **2.** Scroll down to select a station from the *Station List* on the right or choose a station from the map. Then, click *Update Selection*. **3.** Below, there are a variety of drought indicator tabs to explore. Choose which indicator you would like to view. **3a.** The *Precip & Temp* tab provides weekly, monthly, or annual averages of total precipitation and minimum and maximum temperature, shown in graphs. Select a date range or select a decade or the period of record from the drop-down menu. Select weekly, monthly, or annual information from the *Aggregate* drop-down menu. **3b.** The *Drought Monitor* tab shows values from the U.S. Drought Monitor, which began in 2000. Select a date range and a *Boundary* (state, county, etc.). There are three ways to view the information. Select *Time Series* to view a graph of U.S. Drought Monitor values over time, averaged over the boundary you selected, *Table* to view a table of weekly drought monitor values, or *Heat Map* to view weekly values by year (use the slider to scroll through the weeks). **3c.** The *Trends* tab shows various trends in several drought indicators and how statistically significant those trends are. Under the *Index* drop-down menu, select precipitation or a drought indicator. For any indicator, select a *Start Year* and *Significance* level. Some indicators require you to also select a *Season*, and the *Precipitation* indicator requires a *Precipitation Threshold* in inches. After you make the selections, click *Trends Chart* on the right. A graph will display with the trend in the selected indicator over time. A blue dashed trendline represents an increasing trend in that indicator, a red dashed trendline represents a decreasing trend, and a black dashed trendline represents no trend. The trend value per decade is shown in text underneath the graph.

Tool Link: <https://droughtatlas.unl.edu/Data/Climate.aspx>



Historical Climate Trends Tool

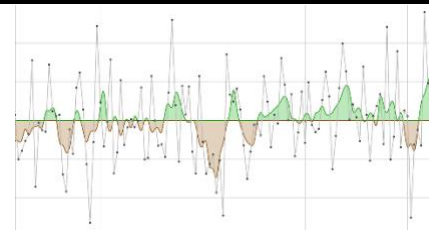
(1895-present)

Southern Climate Impacts Planning Program

This interactive graphing tool shows precipitation trends, of which very dry periods are a drought indicator.

1. In the left column, moving from top to bottom, select *Texas* → *Climate Division of Interest* → *Season of Interest* → *Precipitation*. **2.** Hovering the cursor over a point will display the year and total rainfall for the selected season. **3.** For more information on how to interpret the chart, click on *Chart Info*.

Tool Link: <http://charts.climate.lsu.edu/trends/>



U.S. Drought Monitor Time Series

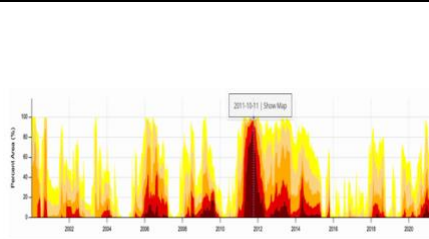
(2000-present)

Texas Water Development Board and Office of the Texas State Climatologist

This tool shows the frequency of drought conditions since 2000, along with each drought's maximum intensity and duration (shown by color scale).

1. This page first shows a large map of current U.S. Drought Monitor categories across Texas. Select a county you're interested in from the map or leave the map as the default for statewide information. **2.** A graph will be displayed under the map, showing the weekly U.S. Drought Monitor categories from 2000 to present day for your selected county or the state. On the graph, hover over the time period of interest to get information on percentages of area in the different levels of drought across the county/state.

Tool Link: <https://waterdatafortexas.org/drought>



Drought (Continued)

Historical Data

Reservoir Storage Tool

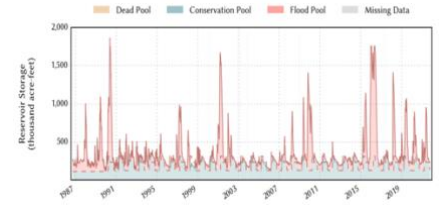
(Period of record varies by station; up to ~80 years)

Texas Water Development Board

This interactive tool provides recent and historical reservoir storage data across Texas. You can view graphs of recent and historical reservoir storage for the dead pool, conservation pool, and flood pool, as well as statistics of monthly averages for percent full for the most recent 30 years.

1. Select a reservoir by clicking on the map then clicking the link in the pop-up box OR select a regional area from one of the drop-down menus above (By Planning Area, By River Basin, etc.). **2.** Recent data is shown on the graph by default. Select the *Historical* tab below the graph to view the data for the period of record. **3.** To view monthly percent full statistics, click the *Statistics* tab. **4.** The tables below the graph show statistics up to one year in the past, and additional reservoir information is located further down the page.

Tool Link: <https://waterdatafortexas.org/reservoirs/statewide>



Future Trends

Precipitation Projections

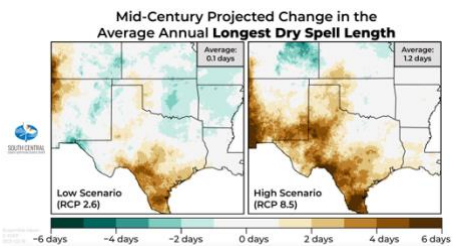
(2036-2099)

South Central Climate Adaptation Science Center

This webpage includes several precipitation projections, including the projected average annual number of days with rain and longest dry spell length, for the south-central U.S. during the mid-century (2036-2065) and end-of-century (2070-2099) time frames under low and high emissions scenarios.

1. The projections are grouped by mid-century and end-of-century. Scroll down to *Projected Change in the Average Annual Number of Days with Rain* or *Projected Change in the Average Annual Longest Dry Spell Length* for the time frame you're interested in. These two variables relate to drought from a precipitation perspective. **2.** The maps in the middle of the page show the projections under a low emissions scenario on the left and high emissions scenario on the right. The average value in the top right of each map represents the average for the entire region, so use the legend below the map to estimate the value for your area. **Note:** Click the map to view a larger version. **3.** On either side of the page is a text summary of the projections for both emissions scenarios. **Note:** You can use these maps to view the range of projected values, as the future value will likely fall somewhere in between the low and high emissions scenarios.

Tool Link: <https://southcentralclimate.org/resources/climate-projections/precipitation-projections/>



Drought has always been part of Texas' climate because of highly variable precipitation patterns. Because Texas is large and diverse, it is hard to make a statewide summary or projection of drought (Nielsen-Gammon et al. 2020). However, droughts will likely increase in severity and frequency. Even in areas where there is little change in annual precipitation expected, higher temperatures will increase evaporation from soils in all areas of the state, intensifying naturally occurring droughts (Runkle et al. 2022; Wehner et al. 2017). An increase in drought conditions would strain natural resources, resulting in economic and societal consequences as it will affect agriculture and drive up costs of commodities and utilities (Kloesel et al. 2018). Read more about future drought in the resources found in Appendix C.

Western TX: In western Texas, annual rainfall has changed little over time since 1895 (Nielsen-Gammon et al. 2021). Models project a decrease in rainfall by the end of the century, especially in winter and spring in far western Texas (Hayhoe et al. 2018). With the addition of increased evapotranspiration and decreased soil moisture from higher temperatures, drought conditions are expected to increase (Runkle et al. 2022; Wehner et al. 2017).

Central TX: In central Texas, the most prominent decrease in rainfall is projected in the winter and spring by the end of the century. However, the changes in rainfall are small and not significant except in south central Texas (Easterling et al. 2017). Even with small changes in precipitation, increased temperatures will increase evapotranspiration from soils and increase risk of drought. Furthermore, it is estimated that there will be more time in between rain events for dry conditions to occur.

Eastern TX: Precipitation has increased since 1895 in eastern Texas, and little overall precipitation changes are expected by the end of the century (Nielsen-Gammon et al. 2021; Hayhoe et al. 2018). However, soil moisture is projected to be much drier by the end of the century from increased evapotranspiration from rising temperatures (Runkle et al. 2022). More time between rain events is also expected, which can lead to periods of dry conditions.

Hail

Data Limitations: Hail data are not of sufficient quality to robustly determine historical trends and are of poorer quality than even the tornado dataset. This can be attributed to the increases in non-meteorological factors such as population and storm spotter coverage over time, as well as the uncertainty in reported hail size. However, the recent decision to assess the number of hail days instead of individual hail reports has mitigated some of the biases. Also note that the criteria for severe hail changed from 0.75" to 1" in 2009.

Historical Data

Severe Hail Days Per Year

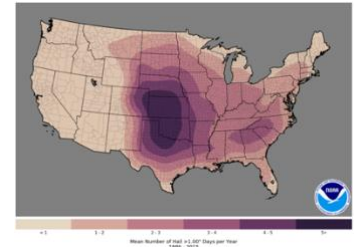
(1986-2015)

NOAA/National Weather Service Storm Prediction Center

The map provides a sense of the approximate number of days each year that you can expect to see severe (0.75- and 1-inch) or significant (greater than 2-inch) hail in your area. **Note:** Severe hail size changed from 0.75" to 1" in 2009, so both sizes are included on the webpage.

1. Click on the link below to go to the website 2. Scroll to the last three maps and select the map of interest to see the full-size image.

Tool Link: <https://www.spc.noaa.gov/wcm/#30yrclimo>



Severe Hail Reports

Hail:
(1955-present)

Southern Regional Climate Center

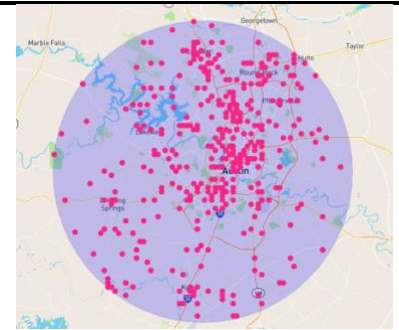
This interactive tool displays the historical record for individual severe hail reports in your area. It can be used to determine hail events that have impacted your area.

1. On the left side of the screen, click on *Search within Radius*. 2. Choose the diameter of the area of which you want to investigate (25 or 50 miles). 3. Under *Filter by Storm Types* select *Hail* (de-select Tornado and Wind). 4. Pan, zoom, and then click on the map area of interest. 5. Reports are displayed on the map and in two tables below the map.

Map: Mouse over individual storm reports for details.

Tables: There are two tables, *Recent Storm Data* and *Historical Storm Data*. Click on a column header to sort by column of interest. For example, to view the dates in which the largest hail occurred, click on the *Scale* column headers to sort by the largest hail values.

Tool Link: https://www.srcc.tamu.edu/storm_reports/



Storm Events Database

Hail:
(1955-present)

NOAA National Centers for Environmental Information

This interactive tool displays the historical record for individual severe hail reports *by county*. It can be used to determine hail events that have impacted your area or close to your area.

1. On the bottom left, under *Select State or Area*, choose *Texas* → then *Search*. 2. From top to bottom, select a specific *Begin* and *End Date*, as well as *County* of interest. 3. Under *Event Type(s)*, select *Hail*. 4. Expand *Advanced Search and Filter Options* → *Hail Filter*, select hail size of interest. 5. Press *Search*. Summary results are presented in a table. **Note:** This tool can be used to analyze a variety of additional hazards with various time periods, and hail data goes as far back as 1955. This database is likely incomplete and does not account for all hail events.

Tool Link: <https://www.ncdc.noaa.gov/stormevents/>

Location	County/Zone	SL	Date	Tim
Totals: (for 500 results below)				
LOCKETT	WILBARGER CO.	TX	10/08/1999	17:11
(RBD)RED BIRD ARPT DA	DALLAS CO.	TX	11/22/1999	18:4
DALLAS	DALLAS CO.	TX	11/22/1999	18:5
VERNON	WILBARGER CO.	TX	12/02/1999	16:11
BLUE GROVE	CLAY CO.	TX	12/02/1999	18:3
PERRIN	JACK CO.	TX	12/02/1999	20:4
MYRA	COOKE CO.	TX	12/02/1999	21:0
LAKE BRIDGEPORT	WISE CO.	TX	12/02/1999	21:2
LAKE BRIDGEPORT	WISE CO.	TX	12/02/1999	21:5
BOWIE	MONTAGUE CO.	TX	12/02/1999	21:5
DECATUR	WISE CO.	TX	12/02/1999	22:1
DECATUR	WISE CO.	TX	12/02/1999	22:2
DECATUR	WISE CO.	TX	12/02/1999	22:2
DECATUR	WISE CO.	TX	12/02/1999	22:4

Future Trends

Hail is commonly associated with severe thunderstorms, and northern Texas had the highest frequency of large hail from 1986-2015 (SPC 2016). Climate models project an increase in the atmospheric conditions that tend to favor severe thunderstorms, especially favoring events capable of producing *large* hail (Kossin et al. 2017). This increase in large hail will likely occur in the springtime, but an increase in temperature will lead to less hail overall, especially in summer (Nielsen-Gammon et al. 2021). Confidence in the projections is currently low, however, due to the isolated and sporadic nature of hail events and limited comprehensive datasets which make it difficult to track long-term trends (Wuebbles et al. 2017a).

Heat Extremes

Data Limitations: Texas generally has good quality long-term data records for temperature values, however, the consistency of cumulative years on record varies by station. The majority of stations include long records that date back to the early 20th century (Nielsen-Gammon 2011), however, some station locations include gaps in records that could be subject to technical issues or changes in monitoring location.

Historical Data

Historical Climate Trends Tool

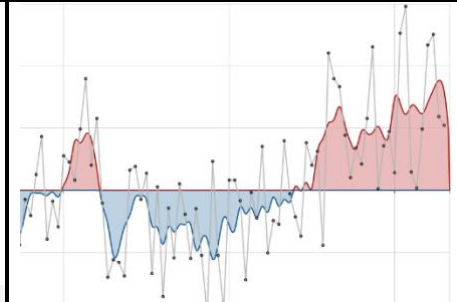
(1895-present)

Southern Climate Impacts Planning Program

This interactive graphing tool shows annual, seasonal, and monthly temperature trends by state and climate division. It can be used to gain a general understanding of temperature trends and show previous periods of higher temperatures, as well as years of extreme temperature.

1. On the left side of the screen (from top to bottom) select *Texas* → *Climate Division of Interest* → *Season of Interest* → *Temperature*. **2.** For more information on how to interpret the chart, click on *Chart Info*.

Tool Link: <http://charts.climate.lsu.edu/trends/>



Temperature Trends Dashboard

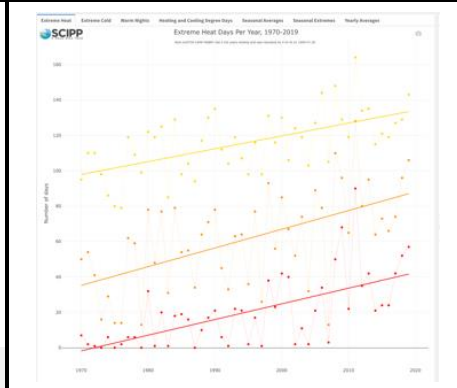
(1970-2022)

Southern Climate Impacts Planning Program

This tool shows temperature trends at individual stations across Texas, including trends in extremely hot days, warm nights, seasonal extreme and average high/low temperatures, and cooling degree days, since 1970.

1. At the top of the tool, click the *Extreme Heat*, *Warm Nights*, *Heating and Cooling Degree Days*, *Seasonal Averages*, or *Seasonal Extremes* tab. **2.** The default station is in Abilene, TX. To choose a station nearest to you, use the map on the right. Zoom in and click any of the blue dots to change stations. You can also select a station under the *Station* drop-down menu on the left of the page. **3.** Use the graph to determine the trend (if any) for your selection. Solid lines represent significant trends. **4.** Mouse over individual data points to view more information. **5.** For seasonal selections, make sure you select a season in the *Season* drop-down menu on the left of the screen.

Tool Link: https://scipprisa.shinyapps.io/SCIPP_temp_dash/



Climate Extremes Tool - Temperature

(Period of record varies by station; up to ~125 years)

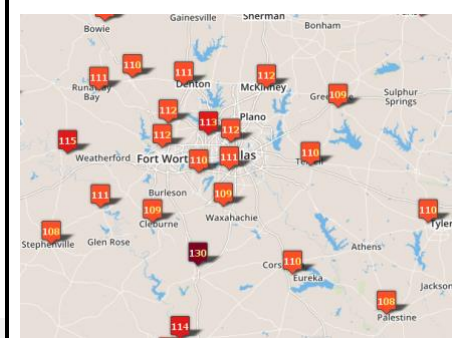
Southern Regional Climate Center

This interactive tool shows temperature extremes at point locations. It can be used to show the severity of past events that have occurred in a region of interest. Highlighted below are two ways the tool can be used to analyze heat extremes:

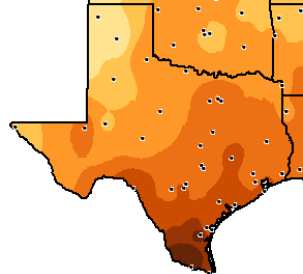
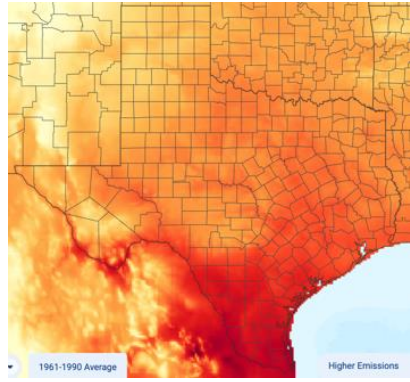
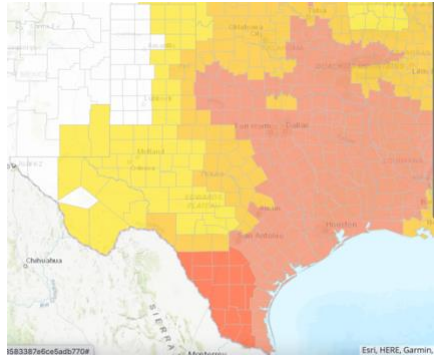
(a) High temperature records by month: **1.** On the left side of the screen (from top to bottom) select *Records For A Month* → *High Max Temperature* → *Month of Interest* → *Submit*. **2.** Mouse over icons for record details including station name, date of occurrence, and station period of record.

(b) All-time records: **1.** Select *All-Time Records* → *High Max Temperature* → *Submit*. **2.** Mouse over icons for record details including station name, date of occurrence, and station period of record. **Note:** For more information, select the *Help* or *About* tabs.

Tool Link: <https://www.srcc.tamu.edu/extremes/>



Heat Extremes (Continued)

Historical Data	<p>Heat Index Days and Hours (1973-2018) Midwest Regional Climate Center</p>	<p>This set of maps depict the average number of days, days with 3 or more hours, and average number of hours per year with heat index values at or above a variety of thresholds (e.g., 95°F, 105°F, 110°F).</p> <p>1. Near the top of the page, click on the map link of interest out of the three options: <i>Average Number of Days</i>, <i>Days with 3 or More Hours</i>, or <i>Average Number of Hours</i>. 2. Right above the map, mouse over the heat index value of interest to view the corresponding data on the map. 3. To interpret the colors, see the legend in the upper-right corner of the map.</p> <p>Tool Link: https://mrcc.purdue.edu/clim/heatIndex/index.jsp</p>	
Future Trends	<p>Climate Explorer – Climate Maps and Graphs Tools (1950-2099) NOAA Climate Program Office and National Environmental Modeling and Analysis Center</p>	<p>The Climate Explorer is an interactive tool that allows you to view and compare the average number of warm nights, extremely hot days, and cooling degree days per year for the historical period and in the future under both higher and lower emissions scenarios.</p> <p>1. Type in the city or county you are interested in. 2. Click <i>Climate Maps</i>. 3. From the drop-down menu, select <i>Days w/ max temp > 90</i> (or other option up to 105°F), <i>Days w/ min temp > 80°F</i> (or 90°F), or <i>Cooling Degree Days</i>. 4. Next to the drop-down menu, select <i>Map</i>. 5. Use the middle slider on the map to compare averages between historical, lower, and higher emissions scenarios. (Use the bottom drop-down menus to choose variables and the slider on the bottom right to choose a decade to compare with.) On the map, zoom in to the county level and click a county to view the associated values. 6. To view this information over time (1950-2099) for a single location, click the <i>Graph</i> tab at the top of the map and type a location at the top.</p> <p>Tool Link: https://crt-climate-explorer.nemac.org/</p>	
	<p>Killer Heat Tool (1971-2099) Union of Concerned Scientists</p>	<p>This interactive mapping tool shows the number of days with maximum heat index above 90°F, 100°F, 105°F, and 'off the charts' (exceeding the upper limits of the NWS heat index scale) for each U.S. county over the historical baseline (1971-2000), mid-century (2036-2065), and late century (2070-2099). Future projections include scenarios for no action, slow action, and rapid action on climate change.</p> <p>1. At the top of the tool, click the <i>Above 90</i>, <i>Above 100</i>, <i>Above 105</i>, or <i>Off the Charts</i> tab. 2. Zoom in to the desired area on the map. The default map displays historical number of days above the threshold. 3. Click the county of interest to view the historical number of days per year above the selected heat index threshold. 4. On the left panel, scroll through the text and select a future scenario <i>with no action on climate change</i>, <i>with slow action on climate change</i>, or <i>with rapid action on climate change</i> for the <i>Midcentury</i> or <i>Late Century</i> time frame. 5. Click the county of interest to view the number of days per year above the selected heat index threshold for the scenario and time frame selected. 6. This information is also available for military bases in the U.S., accessible through the <i>Military Bases at Risk</i> tab at the top of the page.</p> <p>Tool Link: https://ucsusa.maps.arcgis.com/apps/MapSeries/index.html?appid=e4e9082a1ec343c794d27f3e12dd006d</p>	

Heat Extremes (Continued)

Future Trends

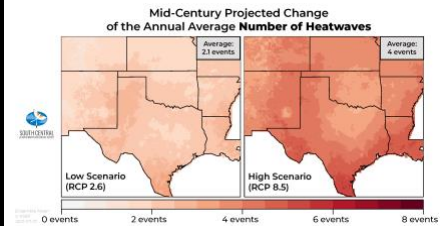
Temperature Projections - Heatwaves (2036-2099)

South Central Climate Adaptation Science Center

This webpage includes several temperature projections, including the projected number of heatwaves per year, for the south-central U.S. during the mid-century (2036-2065) and end-of-century (2070-2099) time frames under low and high emissions scenarios.

1. The projections are grouped by mid-century and end-of-century. Scroll down to *Projected Change of the Annual Average Number of Heatwaves* for the time frame you're interested in. **2.** The maps in the middle of the page show the projections under a low emissions scenario on the left and high emissions scenario on the right. The average value in the top right of each map represents the average for the entire region, so use the legend below the map to estimate the value for your area. **Note:** Click the map to view a larger version. **3.** On either side of the page is a text summary of the projections for both emissions scenarios. **Note:** You can use these maps to view the range of projected values, as the future value will likely fall somewhere in between the low and high emissions scenarios.

Tool Link: <https://southcentralclimate.org/resources/climate-projections/temperature-projections/>



The frequency and intensity of heatwaves and extreme heat events have increased across the U.S. since the mid-1960's (Wuebbles et al. 2017b). As the global temperature continues to increase, the occurrence and intensity of extreme heat events are projected to increase across all parts of Texas. The warmest temperature of the year could increase by 4-6°F across Texas by the middle of the century under a higher emissions scenario, and western Texas could receive ~20-55 more days above 100°F under a lower emissions scenario (Vose et al. 2017; U.S. Fed. Gov. 2021). Read more about future heat extremes in the resources found in Appendix C.

Western TX: Southwest Texas is expected to have one of the largest increases in the number of days over 100°F in the state, with up to 80+ more days by the end of the century under a higher emissions scenario (Kloesel et al. 2018; U.S. Fed. Gov. 2021; Dixon et al. 2020).

Central TX: One study on heat waves in cities showed that while extreme heat waves in Dallas are starting later, the heat waves are longer and the season for them is getting longer as well (Shafiei Shiva et al. 2019). Extreme heat events are projected to increase in the future, and the number of 100°F days per year across central Texas could double by 2036, with higher frequency in southern Texas (Nielsen-Gammon et al. 2021). By the end of the century, southern Texas could receive up to 90+ more days above 100°F per year under a higher emissions scenario and 60+ more days under a lower emissions scenario (U.S. Fed. Gov. 2021; Dixon et al. 2020).

Eastern TX: The increase in number of days above 100°F in coastal areas is smaller than other regions of Texas (Kloesel et al. 2018). However, the area from Beaumont to Corpus Christi has historically experienced no or few days above 100°F per year on average. Therefore, an increase of 30-45 days projected in this area by the end of the century under a higher emissions scenario, or even up to 15 days under a lower emissions scenario by 2050, would be a large change and have impacts to coastal populations (U.S. Fed. Gov. 2021). Further inland in eastern Texas, the number of days over 100°F could increase by 30-90 days by the end of the century for either low or high emissions scenario (U.S. Fed. Gov. 2021).

Heavy Rainfall and Flooding

Data Limitations: There is a relatively long historical record of precipitation data. However, a lack of spatial density of stations combined with highly variable precipitation across the state means that some rainfall events, including high rainfall amounts, may not be adequately represented in the data. Also, flood risk depends on a precipitation event, preceding events, the built environment, and flood mitigation techniques. Flooding can and does occur outside of the Federal Emergency Management Agency (FEMA) Special Flood Hazard Areas. Flood impacts are extremely localized, so the data listed below may not adequately represent a single community or neighborhood flood risk or history.

Historical Data

Climate Extremes Tool – Precipitation

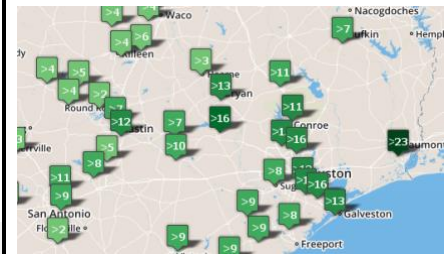
(Period of record varies by station; up to ~125 years)

Southern Regional Climate Center

Interactive map shows daily precipitation extremes at airport weather stations, which can be used to show some previous heavy rainfall occurrences (i.e., the highest rainfall totals do not necessarily occur at airport weather stations).

1. Pan and zoom to the location of interest.
2. To obtain *High precipitation records by month*: On the left side of the screen, select *Records For A Month* → *High Precipitation* → *Month of interest* → *Submit*.
3. The measurement unit is inches. Mouse over the icon for record details (date of occurrence and station record).
4. To obtain *All-time records*: Select *All-Time Records* → *High Precipitation* → *Submit*.

Tool Link: <https://www.srcc.tamu.edu/extremes/>



NOAA Atlas 14 Precipitation Frequency Data Server

(Last updated in 2018)

NOAA Hydrometeorological Design Studies Center

Interactive tool shows rainfall frequency estimates for select durations (e.g., 3-, 12-, and 24-hours) and recurrence intervals (e.g., 100-, 500-, and 1000-years) with 90% confidence intervals. Probable maximum precipitation (PMP) values are not represented in this tool.

1. Click on *Texas* from the map. A new screen will open.
2. To select a location, either enter the desired location, station, or address manually OR double-click the interactive map.
3. Precipitation frequency estimates will be displayed in both table and graph forms below.
4. For additional help, select *FAQ* from the left-hand menu, then refer to the *Section 5* link under section 1.1.

Tool Link: <https://hdsc.nws.noaa.gov/hdsc/pfds/index.html>

PDS-based precipitation frequency estimates with 90% conf.

Duration	1	2	5	10	25	50
3-min	0.017 (0.015-0.022)	0.031 (0.027-0.036)	0.041 (0.035-0.047)	0.056 (0.049-0.063)	0.071 (0.062-0.080)	0.086 (0.076-0.096)
15-min	0.017 (0.015-0.022)	0.031 (0.027-0.036)	0.041 (0.035-0.047)	0.056 (0.049-0.063)	0.071 (0.062-0.080)	0.086 (0.076-0.096)
30-min	0.017 (0.015-0.022)	0.031 (0.027-0.036)	0.041 (0.035-0.047)	0.056 (0.049-0.063)	0.071 (0.062-0.080)	0.086 (0.076-0.096)
1-hr	0.017 (0.015-0.022)	0.031 (0.027-0.036)	0.041 (0.035-0.047)	0.056 (0.049-0.063)	0.071 (0.062-0.080)	0.086 (0.076-0.096)
3-hr	0.017 (0.015-0.022)	0.031 (0.027-0.036)	0.041 (0.035-0.047)	0.056 (0.049-0.063)	0.071 (0.062-0.080)	0.086 (0.076-0.096)
6-hr	0.017 (0.015-0.022)	0.031 (0.027-0.036)	0.041 (0.035-0.047)	0.056 (0.049-0.063)	0.071 (0.062-0.080)	0.086 (0.076-0.096)
12-hr	0.017 (0.015-0.022)	0.031 (0.027-0.036)	0.041 (0.035-0.047)	0.056 (0.049-0.063)	0.071 (0.062-0.080)	0.086 (0.076-0.096)
24-hr	0.017 (0.015-0.022)	0.031 (0.027-0.036)	0.041 (0.035-0.047)	0.056 (0.049-0.063)	0.071 (0.062-0.080)	0.086 (0.076-0.096)

Historical Climate Trends Tool

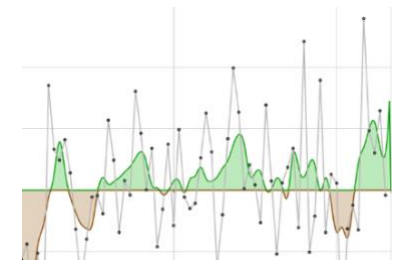
(1895-present)

Southern Climate Impacts Planning Program

This tool shows precipitation trends by state and climate division, annually, seasonally, and by month. Years, seasons, or months with high precipitation totals may be indicative as years with flood events during one or more parts of the year, however, this must be correlated with other data.

1. On the left side of the screen, select *Texas*.
2. Select the climate division of interest or the entire state.
3. Select annual, season, or month of interest.
4. Select *Precipitation*.
5. For more information on how to interpret the chart, click on *Chart Info* on the bottom left.

Tool Link: <http://charts.climate.lsu.edu/trends/>



Climate Explorer – Extreme Events Tool

(Period of record varies by station; up to ~100+ years)

NOAA Climate Program Office and National Environmental Modeling and Analysis Center



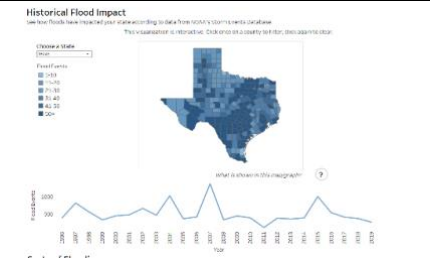
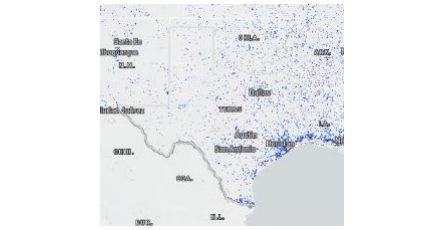
The Climate Explorer is an interactive tool that allows you to view the number of extreme rainfall events per year for a station's period of record.

1. Type in the city or county you are interested in.
2. Click *Extreme Events*.
3. From the top menu, select a *Threshold* in inches (e.g., 1 in).
4. You can choose whether or not to select an option from the *Percentiles* drop-down menu, from the 10th to 90th percentile.
5. Choose *at least* (\geq) from the next drop-down menu.
6. Select a *Duration* in days (e.g., 1 day).
7. Choose a station (red dot) on the map.
8. The resulting plot displays a bar chart with days per year (or multiday duration you chose) with precipitation reaching your selected threshold. Hover your mouse over the bars to view yearly information. Under the chart on the right side is a *Plain-language description* that summarizes the number of times the threshold was reached over the station's period of record and the yearly average occurrence.

Tool Link: <https://crt-climate-explorer.nemac.org/>



Heavy Rainfall and Flooding (Continued)

Historical Data	Flood Impacts by River Crest Height (Period of record varies by gauge; up to ~110+ years) National Weather Service Advanced Hydrologic Prediction Service	Interactive tool shows a summary of flood impacts for location of interest. It can be used to show the extent of flood events. 1. Under the <i>NWS River Forecast Centers</i> menu to the right of the map, choose between the Arkansas-Red Basin, Lower Mississippi River, or West Gulf River Forecast Center to access stations for your region. 2. On the map, pan and zoom to the area of interest. Double-click on the stream gauge of interest on the map. 3. Click <i>River at a Glance</i> tab near the top of the page. 4. Left column: Select gauge of interest. Right column: At a minimum, select <i>Flood Impacts</i> , <i>Location Map</i> , <i>Record Crest History</i> . 5. Click <i>Make my River Page!</i> 6. Information you selected will be displayed on a new page. Tool Link: https://water.weather.gov/ahps/	<p>44 Expect near catastrophic flood depths up to 19 feet to wreak havoc shores of Lake Texoma. Many homesteads are flooded or cut off to threatened. Flood levels nearly match those of the flood crest of May 43</p> <p>43 Expect near catastrophic flood depths up to 18 feet to cause destruction... to the shores of Lake Texoma.. Many homesteads are flooded highways and railroads are threatened.</p> <p>42 Expect near catastrophic flood depths up to 17 feet to cause destruction County... to the shores of Lake Texoma.. Many homesteads are flooded highways and railroads are threatened.</p> <p>41 Flood depths up to 16 feet will cause destruction in the Washita River in Johnston County. Many homesteads may be flooded or cut off to threatened.</p> 
	FEMA Flood Map Service Center Federal Emergency Management Agency	This website can locate and identify flood hazard zones in a jurisdiction and produce maps for use in a hazard mitigation plan. When combined with other map layers, it can provide a spatial relationship between flood hazard zones and critical facilities and infrastructure. Note that the 100-yr floodplain is an estimate used for insurance and regulatory purposes. Floods can and do occur outside of the areas depicted. Note: <i>This tool is a little more involved than some of the others and it is helpful to use a larger computer screen because of the amount of data shown.</i> 1. Enter an address, place, or coordinates in the search bar. 2. Click <i>Search</i> . 3. Click <i>Streets</i> view in upper right corner. 4. The panel of land outlined in light blue is what will be mapped. If you need another panel, click on the one of interest. (Zoom out if needed. It may take a few seconds.) 5. Zoom in to view details. Note the legend below the map and effective date in bold above the map. 6. To download a black and white static image of full original FIRM panel, click on the <i>Map Image</i> icon. To access a colored map, click on the <i>Dynamic Map</i> icon. You may need to disable your browser's pop-up blocker. Tool Link: https://msc.fema.gov/portal	
	Historical Flood Risk and Costs (1996-present) Federal Emergency Management Agency	This map visualization and graph shows state and county flood events that are documented in NOAA's Storm Events Database. It shows the number of flood events by county and costs of flooding based on average National Flood Insurance Program and FEMA's Individual and Household Program payments. 1. Under <i>Choose a State</i> , select <i>Texas</i> . 2. Texas statistics will be displayed on the page. 3. If you wish to view statistics by county, click on a county on the map displayed on the page. Tool Link: https://www.fema.gov/data-visualization-floods-data-visualization	<p>Historical Flood Impact</p> <p>Select Tools were made possible by data from NOAA's Storm Events Database</p> <p>This visualization is interactive. Click on a county for more data.</p> 
Future Trends	Risk Factor (Present risk and 30-year future projections) First Street Foundation	This tool provides information on flood risk and how it is changing. It shows the trend in number of properties at risk, a specific property's flood risk score, the flood history of an area, how an area's flood risk is expected to change in the next 30 years, and community solutions for flood mitigation. 1. Type in the address, zip code, or city of interest 2. Click the <i>Flood Factor</i> tab near the top of the page. 3. Scroll down and use the tabs on the left side of the page or scroll to the topic of interest. Tool Link: https://riskfactor.com/	

Heavy Rainfall and Flooding (Continued)

Future Trends

Climate Explorer – Climate Maps and Graphs Tools

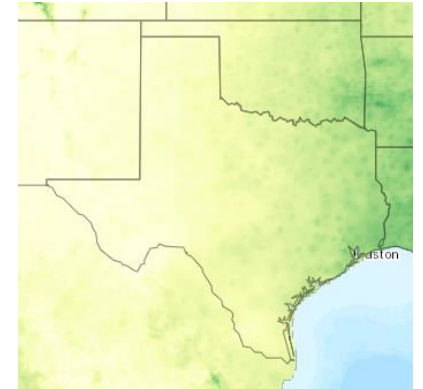
(1950-2099)

NOAA Climate Program Office and National Environmental Modeling and Analysis Center

The Climate Explorer is an interactive tool that allows you to view and compare the average number of days with precipitation greater than 1", 2", or 3" per year for the historical period and in the future under both higher and lower emissions scenarios.

1. Type in the city or county you are interested in. **2.** Click *Climate Maps*. **3.** From the leftmost drop-down menu, select *Days w/ 1" Precipitation* (2" and 3" thresholds are also available). **4.** Next to the drop-down menu, select *Map*. **5.** Use the middle slider on the map to compare averages between historical, lower, and higher emissions scenarios. (Use the bottom drop-down menus to choose variables and the slider on the bottom right to choose a decade to compare with.) On the map, zoom in to the county level and click a county to view the associated values. **6.** To view this information over time (1950-2099) for a single location, click the *Graph* tab at the top of the map and type a location at the top. **Note:** *Precipitation projections have a high range of uncertainty.*

Tool Link: <https://crt-climate-explorer.nemac.org/>



Precipitation Projections

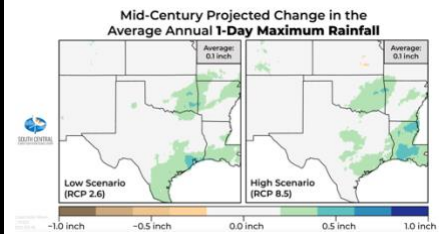
(2036-2099)

South Central Climate Adaptation Science Center

This webpage includes several precipitation projections for the south-central U.S. during the mid-century (2036-2065) and end-of-century (2070-2099) time frames under low and high emissions scenarios.

1. The projections are grouped by mid-century and end-of-century. Scroll down to *Projected Change in the Average Annual 1-Day (or 5-Day) Maximum Rainfall* for the time frame you're interested in. **2.** The maps in the middle of the page show the projections under a low emissions scenario on the left and high emissions scenario on the right. The average value in the top right of each map represents the average for the entire region, so use the legend below the map to estimate the value for your area. **Note:** *Click the map to view a larger version.* **3.** On either side of the page is a text summary of the projections for both emissions scenarios. **Note:** *You can use these maps to view the range of projected values, as the future value will likely fall somewhere in between the low and high emissions scenarios.*

Tool Link: <https://southcentralclimate.org/resources/climate-projections/precipitation-projections/>



Texas's rainfall varies dramatically across the state. There is a west to east gradient with the driest regions receiving less than 10 inches of rain per year and the wettest seeing over 50 (Kloesel et al. 2018). According to Easterling et al. (2017), 95th percentile rainfall days are projected to increase in frequency by more than 35% across the US. While overall annual precipitation amounts are not projected to change much, heavy precipitation events may increase in frequency and intensity (Kloesel et al. 2018). Because increased rainfall amounts will be countered by infrastructure such as dams and dry soils capable of absorbing moisture, it is difficult to determine a trend for river flooding. However, the threat of urban flooding will increase (Nielsen-Gammon et al. 2021). Read more about future heavy rainfall events in the resources found in Appendix C.

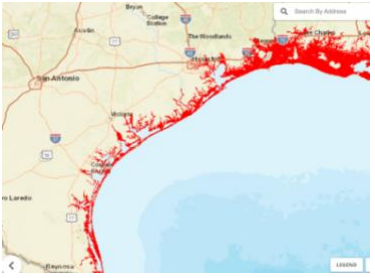
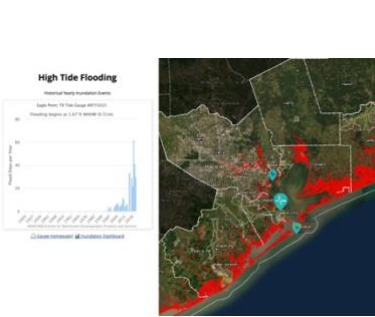
Western TX: The heaviest 1% of rainfall events are projected to increase by up to 20% in intensity under a higher emissions scenario by the end of the century in western Texas (Hayhoe et al. 2018). Far western Texas is expected to have the smallest change in extreme rainfall in the state.

Central TX: The heaviest 1% of rainfall events are projected to increase by up to 30% in intensity under a higher emissions scenario by the end of the century in central Texas, especially in the south-central area of the state (Hayhoe et al. 2018).

Eastern TX: Eastern Texas is expected to receive the highest increase in rainfall in the state, and the heaviest 1% of rainfall events are projected to increase by up to 40% in intensity under a higher emissions scenario by the end of the century (Hayhoe et al. 2018). With the possibility of more intense rainfall from tropical storms as well as increased sea level rise, flooding risks further increase in coastal Texas. Intense rainfall from tropical storms have increased by 5-7% compared to a century ago (Kloesel et al. 2018). Flooding from tropical storms can cause overflow of sewage systems and contaminants of water resources, displacement of communities, disruption of critical services, and more.

High Tide Flooding

Data Limitations: The tide-gauge network is sparse, so there is a lack of tide data for many coastal communities and inconsistent periods of record for locations that do have gauges. Tide gauges can also be placed in harbors and locations with protective housing that can reduce wave effects, which can prevent measurements of higher-frequency wave effects (Sweet et al. 2022). There is not a long-term record in many areas, and models that increase data coverage often underestimate water levels in areas with frequent tropical storms (Muis et al. 2016).

Historical Data	Coastal Flood Exposure Mapper National Oceanic and Atmospheric Administration	<p>This interactive mapping tool shows susceptible areas to high tide flooding, water depth from sea level rise, storm surge from different hurricane categories, and FEMA flood zones. Users can overlay societal, infrastructure, and ecosystem exposures.</p> <p>1. Click <i>Get Started</i>. 2. Zoom in to the area of interest. 3. Click the layers icon in the bottom-left corner to change the map. 4. To view areas susceptible to high tide flooding, click the <i>High Tide Flooding</i> option under <i>Hazard Layers</i>. 5. Click any of the exposure layers, such as <i>Critical Facilities</i>, to add additional information to the map.</p> <p>Tool Link: https://coast.noaa.gov/floodexposure/</p>	
	Sea Level Rise Viewer (High Tide: period of record varies by location; up to 100 years) National Oceanic and Atmospheric Administration	<p>This mapping tool visualizes impacts from sea level rise and allows users to choose different water levels to view sea level rise projections, overlay community vulnerability, and view high tide flooding frequency.</p> <p>1. Click <i>Get Started</i>. 2. Zoom into the area of interest. The default map is current water level where darker blues are greater water depths. 3. Click <i>High Tide Flooding</i> on the lefthand menu. Red areas represent shallow coastal flooding areas and tide gauges are shown at select locations (may have to zoom in to view these). 4. Click a tide gauge icon on the map to view a graph of yearly high tide flooding events per year at that location. Note: access the legend by clicking the middle icon on the top right of the screen.</p> <p>Tool Link: https://coast.noaa.gov/slr/</p>	

High Tide Flooding (Continued)

Historical Data

Gulf Tree

(Time frame varies by product)

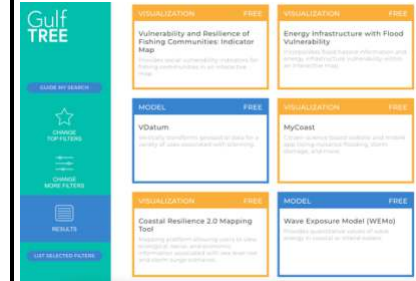
Northern Gulf of Mexico Sentinel Site Cooperative, Gulf of Mexico Climate Resilience Community of Practice, & Gulf of Mexico Alliance Resilience Team

This decision support site guides users to the high tide/nuisance flooding tools and resources they need along the Gulf Coast through several filters of information, including how much time and effort they're willing to spend on the tool.

1. Choose a *Filtered Search* to look through all filter categories on one page or choose *Guide My Search* to walk through questions step by step to achieve what you're looking for. **2a.** If you chose the *Filtered Search*, first navigate to *Geographic Scope*. Click the *Texas* drop-down menu and choose *Shoreline* to select all coastal counties or choose specific one(s). **2b.** Under *Tool Function*, select what you'd like to use high tide flooding information for. **2c.** Under *Cost*, choose *Free*. **2d.** Under *Level of Effort*, choose from low, moderate, or high (will determine how advanced the tool is). **2e.** Under *Climate Change Topics*, select the drop-down for *Flooding*, then check the box for *Nuisance Flooding*. Explore other drop-down menus in this section to add more filters for additional topics. **2f.** Click *View Tool Matches* on the top right to go to the results page. Click any of the tools or resources to go to that site.

3a. If you chose *Guide My Search*, Gulf Tree will walk you through the same filters by asking 6 questions. For step 1 (*Tool Function*), check the box for why you need a high tide flooding tool, then click *Submit*. If you're not sure which option to use, you can *Skip* this step. **3b.** Step 2 (*Topic Area*) includes a filter for what aspect of the topic you're interested in. Click the drop-down menu for *Flooding* and check the box for *Nuisance Flooding*, then click *Submit*. **3c.** On Step 3 (*Location*), click the *Texas* drop-down menu, then choose *Shoreline* to select all coastal counties or choose specific one(s). Then, click *Submit*. **3d.** For Step 4 (*Level of Effort*), choose how much effort you'd like to put into the tool, which will determine how advanced the tool is. Then, click *Submit*. **3e.** For Step 5 (*Tool Cost*), choose *Free*, then click *Submit*. **3f.** Click *Leave Guided Search and View Matches* to go to the results page or go back to a previous page on the left menu to change your selected options. Click any of the tools or resources to go to that site. **4.** To create a new search, click *Reset All Filters* at the top right of the results page.

Tool Link: <http://gulftree.org/>



High Tide Flooding (Continued)

Future Trends

Climate Explorer – High-Tide Flooding Tool

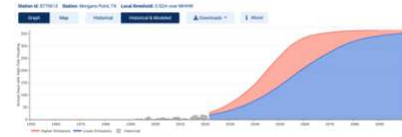
(1950-2099)

NOAA Climate Program Office and National Environmental Modeling and Analysis Center

The Climate Explorer is an interactive tool that provides the annual number of days with high-tide flooding for the historical period (up to 1950-present) and modeled projections (present-2099) under a lower and higher emissions scenario.

1. Type in the city or county you are interested in. **2.** Click *High-Tide Flooding*. **3.** Click a station (blue dot) on the map. **4.** The resulting graph shows the annual days with high-tide flooding. The gray bars represent historical observations and the curves from the present year through 2099 represent the modeled/projected values, where red displays the higher emissions scenario and blue shows the lower emissions scenario. **5.** Hover your mouse over the graph to view the observed or projected values.

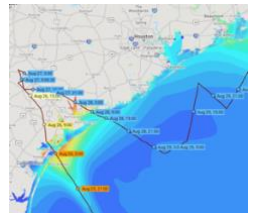
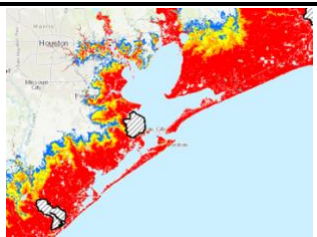
Tool Link: <https://crt-climate-explorer.nemac.org/>



As sea levels rise, coastal flooding is expected to increase by causing more frequent high tide flooding events that reach further inland (Sweet et al. 2022). The 2022 NOAA Sea Level Rise Technical Report (Sweet et al. 2022) determined high tide flooding from the mean higher high water (MHHW), which is the average height of the highest tide recorded at a tide station each day during the recording period. By 2050, minor/disruptive high tide events (0.5 m above MHHW) are projected to occur more than twice as often than in 2020, and major/often destructive events (1.2 m above MHHW) may occur 5 times more often along the western Gulf Coast (Sweet et al. 2022). The U.S. coasts are experiencing a flood regime shift, in which high tide flooding events have increased, and only 1-2 feet of sea level rise will transition more “nuisance” flooding events to more moderate to major flooding events. Read more about future high tide flooding in the resources found in Appendix C.

Hurricane/Tropical Storm/Storm Surge

Data Limitations: Tropical Cyclone (TC) data prior to the satellite era is limited, since only land and ship observations were available. This can make it difficult to conclude whether TC activity is increasing or if it is due to better observation systems (Walsh et al. 2015). Similarly, there are gaps in storm surge data with older storms. Storm surge models do not handle leveed areas well, and modeling water levels under levee failure scenarios is complex.

Historical Data	Coastal Emergency Risks Assessment (2012-present) Louisiana State University, Louisiana Sea Grant	This tool allows users to view current, recent, and storm-specific water heights above Mean Sea Level and wind speed. For specific storms, you can also view the storm track and inundation depth above ground. Note: <i>to access all features, you may need to sign up and request a free account.</i> 1. Select a day or storm of interest at the top left. 2. Zoom into the area of interest to view sea level anomalies. 3. Use the options on the right of the screen to choose other variables to view. Tool Link: https://cera.coastalrisk.live/	
	Storm Surge Risk Maps NOAA National Hurricane Center	This mapper allows users to assess their storm surge risk at various hurricane intensities by displaying the maximum possible storm surge for each storm category. This tool can be used to assist in forming evacuation plans for both individuals and decisions makers. 1. Zoom to the area of interest. 2. Click through the different categories to view storm surge levels for that area at different hurricane strengths. Tool Link: https://experience.arcgis.com/experience/203f772571cb48b1b8b50fdcc3272e2c	

Hurricane/Tropical Storm/Storm Surge

Historical Data

SURGEDAT: The World's Storm Surge Data Center

(Time frame varies by product; up to ~140 years)

Southern Climate Impacts Planning Program

SURGEDAT is an extensive storm surge database for the Gulf of Mexico and East Coast. This site provides access to data and several storm surge tools. The following are active and open to the public:

Live Storm Updates and Archive: <http://surge.climate.lsu.edu/>

This page allows the user to choose a tropical storm/hurricane of interest and view the associated storm surge levels, sea level pressure, and wind speed and direction.

1. Select the current storm or click the archive link and select a past storm of interest. **2.** A new page will open with a graph of storm surge levels at different station locations over the duration of the event and a map of the storm path and gauge locations. **3.** Hover over the storm path on the map to view the wind speed and direction, moving speed, and pressure for points along the path of the storm.

Global Peak Surge Map: <http://surge.climate.lsu.edu/data.html#GlobalMap>

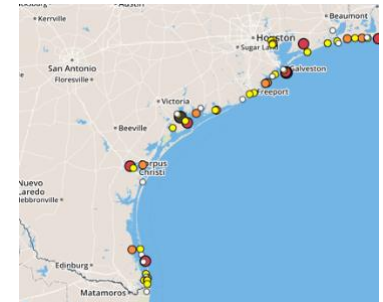
This page allows the user to view the peak recorded storm surge at a location of interest since 1880.

1. Zoom and pan to the area of interest on the map. **2.** Click on a dot to view peak surge information. **3.** A box will appear that describes the observation type, associated storm, location name, year, and the maximum water level recorded at that location.

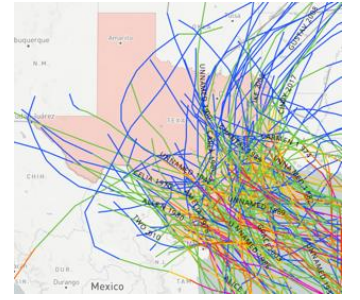
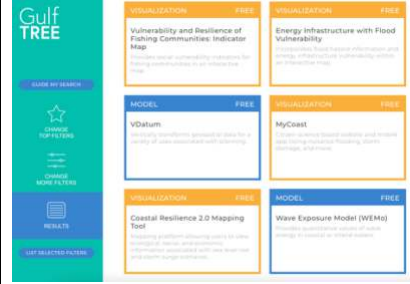
Interactive Surge Map: <https://surgedat.climate.lsu.edu/surge/>

This tool allows users to view a table of storm surge history and graphs of return periods, storm surge heights by year, and ranking of storm surge heights for a selected area.

1a. Search by Storm: Choose a storm and then year from the drop-down menus. **1b.** Click an icon on the map to view the peak storm surge/tide at that gauge for the selected storm. A list of the peak storm surge/tide values for each gauge are in the table below the map. **2a. Search by Location:** Enter a latitude (top box) and longitude (bottom box) if known and choose a distance from that point. If the coordinates are unknown, then first choose a distance from the drop-down menu, then click the map to select your desired location. **2b.** Graphs on the right provide information about return periods with associated surge heights, surge heights by year, and a ranking of surge heights for the area within the red circle on the map. Return period graphs use the average values over the red circle area on the map. The table below the map shows the peak storm surge/tide value for each storm within the red circle area on the map and information of the gauge the peak was recorded at.



Hurricane/Tropical Storm/Storm Surge (Continued)

Historical Data	<p>Historical Hurricane Tracks</p> <p>(1851-present)</p> <p>National Oceanic and Atmospheric Administration</p>	<p>This interactive tool allows users to explore past hurricanes. It provides detailed information on nearly 200 storms for Texas alone. It allows users to view information on the category, pressure, wind speed, and track as well as a link to the official National Hurricane Center report on the tropical cyclone.</p> <p>1. Type in location, year, or storm of interest (i.e., <i>Texas</i>) 2. A map will appear with the tropical storm tracks that match your search. 3. At the top left of the map, filter by category, sea level pressure, year, area, month, or ENSO cycle to narrow down storms. 4. Click on the storm track on the map or the event on the left menu to view detailed information on the event. 5. Click the PDF icon in the top right of the information box to view the official report on the storm (if available) or the “i” icon for more details.</p> <p>Tool Link: https://coast.noaa.gov/hurricanes/-map=4/32/-80</p>	
	<p>Gulf Tree</p> <p>(Time frame varies by product)</p> <p>Northern Gulf of Mexico Sentinel Site Cooperative, Gulf of Mexico Climate Resilience Community of Practice, & Gulf of Mexico Alliance Resilience Team</p>	<p>This decision support site guides users to the storm surge tools and resources they need along the Gulf Coast through several filters of information, including how much time and effort they’re willing to spend on the tool.</p> <p>1. Choose a <i>Filtered Search</i> to look through all filter categories on one page or choose <i>Guide My Search</i> to walk through questions step by step to achieve what you’re looking for. 2a. If you chose the <i>Filtered Search</i>, first choose the <i>Geographic Scope</i>. Click the <i>Texas</i> drop-down menu and choose <i>Shoreline</i> to select all coastal counties or choose specific one(s). 2b. Under <i>Tool Function</i>, select what you’d like to use storm surge information for. 2c. Under <i>Cost</i>, choose <i>Free</i>. 2d. Under <i>Level of Effort</i>, choose from low, moderate, or high (will determine how advanced the tool is). 2e. Under <i>Climate Change Topics</i>, select the drop-down for <i>Flooding</i>, then check the box for <i>Storm Surge</i>. Explore other drop-down menus in this section to add more filters for additional topics. 2f. Click <i>View Tool Matches</i> on the top right to go to the results page. Click any of the tools or resources to go to that site.</p> <p>3a. If you chose <i>Guide My Search</i>, Gulf Tree will walk you through the same filters by asking 6 questions. For step 1 (<i>Tool Function</i>), check the box for why you need a storm surge tool, then click <i>Submit</i>. If you’re not sure which option to use, you can <i>Skip</i> this step. 3b. Step 2 (<i>Topic Area</i>) includes a filter for what aspect of the topic you’re interested in. Click the drop-down menu for <i>Flooding</i> and check the box for <i>Storm Surge</i>. Then, click <i>Submit</i>. 3c. On Step 3 (<i>Location</i>), click the <i>Texas</i> drop-down menu, then choose <i>Shoreline</i> to select all coastal counties or choose specific one(s). Then, click <i>Submit</i>. 3d. For Step 4 (<i>Level of Effort</i>), choose how much effort you’d like to put into the tool, which will determine how advanced the tool is. Then, click <i>Submit</i>. 3e. For Step 5 (<i>Tool Cost</i>), choose <i>Free</i>, then click <i>Submit</i>. 3f. Click <i>Leave Guided Search and View Matches</i> to go to the results page or go back to a previous page on the left menu to change your selected options. Click any of the tools or resources to go to that site. 4. To create a new search, click <i>Reset All Filters</i> at the top right of the results page.</p> <p>Tool Link: http://gulftree.org/</p>	
Future Trends	<p>While uncertainty exists in climate models, current research projects the overall frequency in hurricanes to decrease, but their intensity may increase (Nielsen-Gammon et al. 2021; Runkle et al. 2022). Water temperatures in the Gulf have increased, providing fuel for hurricanes and causing harm to coastal ecosystems (Kloesel et al. 2018). Furthermore, rapidly intensifying hurricanes have occurred more frequently in recent years and are projected to increase in the future (Bhatia et al. 2022; Emanuel 2017). This phenomenon and a growing population along the coast create an increased risk and exposure to this threat. Future sea level rise also exacerbates storm surge levels. A 1-meter rise in sea level can cause a doubling of storm surge risk (Nielsen-Gammon et al. 2021). Read more about future hurricanes, tropical storms, and storm surge in the resources found in Appendix C.</p>		

Lightning

Data Limitations: Historically, most lightning data have been proprietary, therefore, climatological records of the hazard are limited. However, a new NOAA satellite became operational in late 2017 and contains a significant technological advancement called the Geostationary Lightning Mapper (GLM). The GLM can detect the presence of total lightning including in-cloud, cloud-to-cloud, and cloud-to-ground. While this advancement will not provide historical lightning data, it will add to the climatological record as time goes on.

Historical Data

Lightning Climatology Tool

(1995-2019)

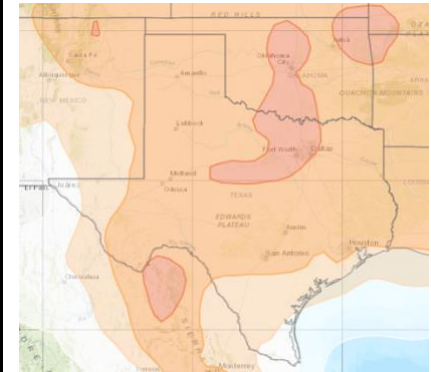
NOAA/National Weather Service Storm Prediction Center

This tool provides a daily and hourly lightning climatology, showing the probability of at least one cloud-to-ground (CG) lightning strike occurring each day of the year or each 1-hour or 4-hour period throughout the day. It can be used to assess the time of day and time of year with the highest probability of CG lightning.

1. Zoom in to your area of interest on the map. **2.** The default map shows the daily (24-Hour) lightning probability on January 1, as indicated in the map title. To select a 1-Hour or 4-Hour climatology, hover your mouse over the *Lightning* tab at the top of the page and select *1-Hour* or *4-Hour*. To view other days or hours, move the horizontal scroll bar under the map. **Note:** the map title and scroll bar show hours in UTC format. **3.** Click your area of interest on the map to view the probability of CG lightning occurring on that day or hour for that area. **4.** Click the *Time Series* button within the pop-up box to view a graph of average CG lightning probability for your selected daily/hourly option. You can use this graph for a quick assessment of the time of year/day that location experiences the most CG lightning. Hover your mouse over the graph for details. **Note for hourly options:** the box shows local time, unlike the map title. The 4-hour graph will show the probability of at least one CG lightning strike occurring within a 4-hour window (e.g., the value for 12pm will show the probability of lightning occurring between 8am-12pm). **5.** If you selected the 1-hour or 4-hour option, click the *Heat Map* button within the pop-up box to view a graph of 1-hour or 4-hour lightning climatology by both day of year (horizontal axis) and time of day (vertical axis). Darker colors represent a higher probability. Hover your mouse over the graph to assess what time of year and day that lightning is more likely to occur in your area.

Tool Link:

<https://www.spc.noaa.gov/climo/dataviewer/?mode=climo&category=ltg&product=ltgday>



Annual and Monthly Distributions of Cloud-to-Ground Lightning

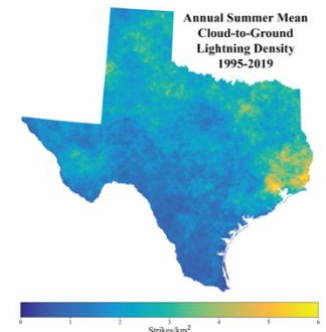
(1995-2019)

NOAA National Severe Storms Laboratory / Cooperative Institute for Mesoscale Meteorological Studies

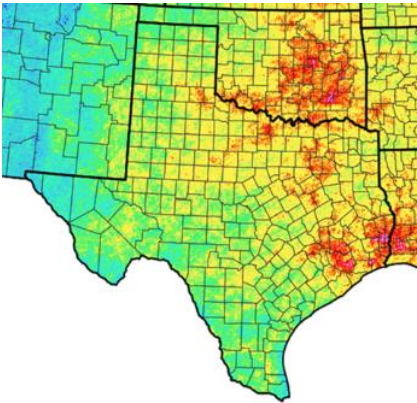
These static maps show the cloud to ground lightning density (strikes per km²) over Texas, averaged over the years 1995-2019. There are five maps on the document that display annual and seasonal (winter, spring, summer, and fall) densities.

1. Click on the link below. **2.** Click *Download the Document*. Annual and seasonal maps are displayed with a brief description.

Tool Link: <https://www.southernclimate.org/index.php/documents/texas-lightning-climatology/>



Lightning (Continued)

Historical Data	<p>Vaisala Annual Lightning Report and Global Lightning Density Map</p> <p>(Varies by year of report)</p> <p>Vaisala</p>	<p>This Annual Lightning Report page provides annual reports since 2017 that contain maps of average cloud-to-ground flash density and total lightning density for the previous 5-10 years in the U.S. The reports also offer high-resolution local- and county-level maps and information. Other features of this site are an archive of past annual reports, supplemental statistics, and a global lightning density map with county-level data.</p> <p>1. Click on the link to access Vaisala’s Annual Lightning Report page. 2. Scroll down to the <i>Resources</i> section and click the most recent <i>Annual Lightning Report</i>. 3. Scroll down the document to view various maps, such as total lightning density and cloud-to-ground flash density maps in high resolution and aggregated by county. 4. To view average lightning density for each county, click the <i>Global lightning density map</i> from the Annual Lightning Report homepage. 5. Zoom in until you see county-level data. 6. Hover your mouse over a county to view the total lightning density per km²/year from 2016-2021. Note: this map may be updated yearly, so check the <i>About</i> section on the left to confirm the time period.</p> <p>Took Link: Vaisala.com</p>	
Future Trends	<p>Studies have shown an increase in lightning associated with severe storms (Schultz et al. 2011). Climate models project an increase in the types of weather conditions that favor severe thunderstorms (Kossin et al. 2017), therefore, lightning occurrences may increase. Confidence in the projections is currently low, however, due to the isolated and sporadic nature of lightning events and limited comprehensive datasets which make it difficult to track long-term trends (Wuebbles et al. 2017a).</p>		

Sea Level Rise

Data Limitations: The tide-gauge network is sparse, so there is a lack of tide data for many coastal communities and inconsistent periods of records for locations that do have gauges. Satellite measurements provide better coverage, but do not provide a long-term record. Therefore, it can be difficult to obtain local long-term trends. Sea level rise projections include uncertainties in the rate of ice sheet melting in Greenland and Antarctica, changes in the Gulf Stream and land motion, and future greenhouse gas emissions.

Historical Data

Gulf Tree

(Time frame varies by product)

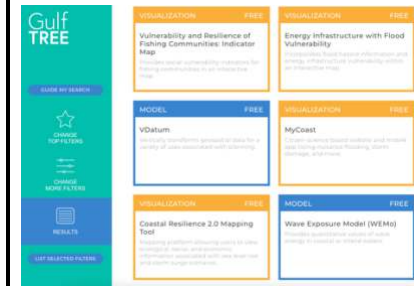
Northern Gulf of Mexico Sentinel Site Cooperative, Gulf of Mexico Climate Resilience Community of Practice, & Gulf of Mexico Alliance Resilience Team

This decision support site guides users to the sea level rise tools and resources they need along the Gulf Coast through several filters of information, including how much time and effort they're willing to spend on the tool.

1. Choose a *Filtered Search* to look through all filter categories on one page or choose *Guide My Search* to walk through questions step by step to achieve what you're looking for. **2a.** If you chose the *Filtered Search*, first navigate to *Geographic Scope*. Click the *Texas* drop-down menu and choose *Shoreline* to select all coastal counties or choose specific one(s). **2b.** Under *Tool Function*, select what you'd like to use sea level rise information for. **2c.** Under *Cost*, choose *Free*. **2d.** Under *Level of Effort*, choose from low, moderate, or high (will determine how advanced the tool is). **2e.** Under *Climate Change Themes*, select the box for *Sea Level Rise*. **2f.** Under *Climate Change Topics*, select the drop-down for *Flooding*, then check the box for *Sea Level Rise* if you are interested in flooding associated with sea level rise. Explore other drop-down menus in this section to add more filters for additional topics. **2g.** Click *View Tool Matches* on the top right to go to the results page. Click any of the tools or resources to go to that site.

3a. If you chose *Guide My Search*, Gulf Tree will walk you through the same filters by asking 6 questions. For step 1 (*Tool Function*), check the box for why you need a sea level rise tool, then click *Submit*. If you're not sure which option to use, you can *Skip* this step. **3b.** Step 2 (*Topic Area*) includes a filter for what aspect of the topic you're interested in. Click the drop-down menu for *Flooding* and check the box for *Sea Level Rise* if you are interested in flooding associated with sea level rise. Then, click *Submit*. **3c.** On Step 3 (*Location*), click the *Texas* drop-down menu, then choose *Shoreline* to select all coastal counties or choose specific one(s). Then, click *Submit*. **3d.** For Step 4 (*Level of Effort*), choose how much effort you'd like to put into the tool, which will determine how advanced the tool is. Then, click *Submit*. **3e.** For Step 5 (*Tool Cost*), choose *Free*, then click *Submit*. **3f.** Click *Leave Guided Search and View Matches* to go to the results page or go back to a previous page on the left menu to change your selected options. Click any of the tools or resources to go to that site. **4.** To create a new search, click *Reset All Filters* at the top right of the results page.

Tool Link: <http://gulftree.org/>



Sea Level Rise (Continued)

Future Trends

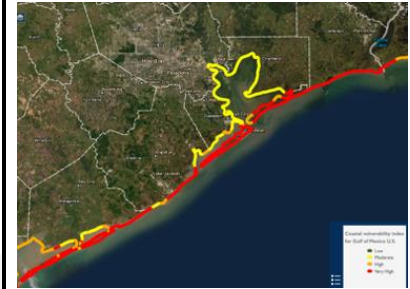
Coastal Change Hazards Portal

(Shoreline Change Forecasts: 50-100 years)

U.S. Geological Survey

Access this tool to view the Coastal Vulnerability Index and forecasted shoreline changes from sea level rise. **1.** To view projections of vulnerability to sea level rise, zoom in to the area of interest **2.** Select *Sea-Level Rise* from the righthand menu. **3.** Select *Coastal Vulnerability Index* then the option for the *Gulf of Mexico* to view an area's vulnerability to sea level rise. Or select *Shoreline Change Forecasts* → *Probabilities of Shoreline Change for Contiguous U.S.* then select one of the retreat/advance options (e.g., *Probability of high shoreline retreat*) to view the probability of future shoreline change over the next 50-100 years. Click the colored line on the map or refer to the legend to determine the risk value or long-term change at that location.

Tool Link: <https://marine.usgs.gov/coastalchangehazardsportal/>



Sea Level Rise Viewer

(SLR: Present-2100, Local Scenarios: 2000-2100)

National Oceanic and Atmospheric Administration

This mapping tool visualizes impacts from sea level rise and includes local photo simulations of what future sea level rise may look like at select locations. The tool allows users to choose different water levels to view sea level rise projections, overlay community vulnerability, and view local scenarios by year.

1. Click *Get Started*. **2.** Zoom into the area of interest. The default map is current water level where darker blues are greater water depths. **3.** Adjust the vertical slider on the left to project different water levels. **4.** To view a photo with simulated water levels, click an icon on the map. **5.** Click *Local Scenarios* on the lefthand menu to view local water levels by year and for different scenarios. Click any icon on the map to change locations. **6.** Click *Vulnerability* on the lefthand menu to overlay social and economic data to see the potential impact to sea level rise. **Note:** access the legend by clicking the middle icon on the top right of the screen.

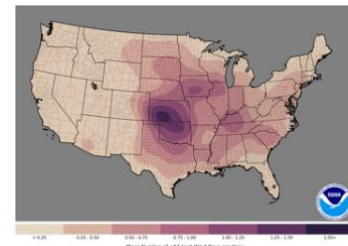
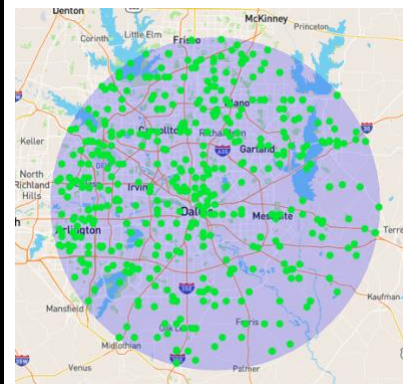
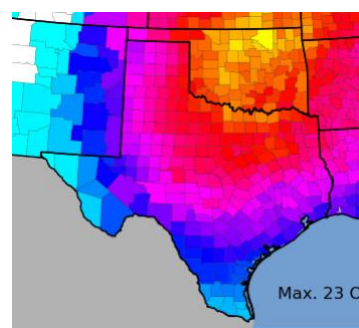
Tool Link: <https://coast.noaa.gov/slr/>



Sea level on the Gulf Coast is projected to increase by 14-18 inches by 2050, which is more than the rise measured over the last 100 years (Sweet et al. 2022). Based on current emissions, 2 feet of sea level rise is expected along the U.S. coast between 2020-2100 (Sweet et al. 2022). Without reducing emissions, 3.5-7 feet of sea level rise may occur by 2100. The western Gulf Coast has the highest rates of sea level rise because of the high rates of subsidence. Sea level rise exacerbates coastal flooding and increases saltwater intrusion, which contaminates fresh groundwater supplies. Researchers are actively working to improve ice sheet dynamics and sea level rise modeling to further understand and enhance future projections. Read more about future sea level rise in the resources found in Appendix C.

Severe Thunderstorm Wind

Data Limitations: Population and temporal biases (i.e., greater number of reports in recent decades), a limited number of weather stations that record wind speed, and the fact that severe thunderstorm winds can be very localized, mean that data are not of sufficient quality to robustly determine whether there have been trends over a long period of time (e.g., 100+ years).

Historical Data	<p>Severe T-Storm Wind Days Per Year (1986-2015) NOAA/National Weather Service Storm Prediction Center</p>	<p>This map shows you the average number of days per year in which severe thunderstorm wind reports were received in your area. The map gives you a sense of the approximate number of days each year that you can expect to see severe thunderstorm winds (50 knots or greater) in your area.</p> <p>1. Click on the link and scroll to the wind climatology maps. 2. Select the map of interest to view the full-sized map.</p> <p>Tool Link: https://www.spc.noaa.gov/wcm/#30yrclimo</p>	
	<p>Severe T-Storm Wind Reports Wind: (1955-present) Southern Regional Climate Center</p>	<p>This interactive tool shows you the historical record for individual severe thunderstorm wind reports (gust of 57 mph or greater) in your area. It can be used to determine severe thunderstorm wind events that have impacted your area or nearby.</p> <p>1. On the left side of the screen, click on <i>Search within Radius</i>. 2. Choose the diameter of the area of which you want to investigate (25 or 50 miles). 3. Select <i>Wind</i> (de-select other hazards). 4. Pan, zoom, and then click on the map area of interest. 5. Reports are displayed on the map and in two tables below the map. 6. Map: Mouse over individual storm reports for details. 7. Tables: There are two tables, <i>Recent Storm Reports</i> and <i>Historical Storm Reports</i>. Click on column header to sort by column of interest. For example, to view the dates in which the highest wind occurred, click on the <i>Scale</i> column headers to sort by the highest wind value.</p> <p>Tool Link: https://www.srcc.tamu.edu/storm_reports/</p>	
	<p>Severe T-Storm Watch Climatology Map (1993-2012) NOAA/National Weather Service Storm Prediction Center</p>	<p>This map shows a 20-year climatology of severe thunderstorm watches. From this map, you can get a sense of the approximate number of days each year you can expect to have a severe thunderstorm watch issued for your county(ies).</p> <p>1. Under the <i>Storm Prediction Center WCM Page</i> banner near the top of the page, click on the <i>Watch Frequency Maps</i> link. 2. Scroll down a bit until you see <i>20y SPC Watch Climatology</i>. 3. Click on the <i>Average number of severe thunderstorm watches per year</i> image to view it in larger form. Note: this WCM page contains a lot of other statistics about the hail, severe thunderstorm, and tornado products that come out of the NWS Storm Prediction Center if you are interested in digging deeper into the data.</p> <p>Tool Link: http://www.spc.noaa.gov/wcm/</p>	
Future Trends	<p>Damaging winds in Texas are associated with severe thunderstorms, as well as hurricanes. More favorable environments for severe thunderstorms are expected, especially during the peak storm season (March-May), so associated increases in severe wind occurrences are projected. It is not known, however, whether the favorable environments will reach their potential of producing damaging winds (Kossin et al. 2017). Historically, severe thunderstorm winds have occurred most often in northern and northeast Texas.</p>		

Tornado

Data Limitations: Tornado reports prior to the 1980s were compiled from written records. Consequently, many tornadoes were unreported or multiple tornadoes may have been listed as a single event. Tornado tracking is unique as occurrences are recorded either by damage assessments or visual accounts (Kossin et al. 2017). Advanced radar technology, increases in population in rural areas, usage of video and social media, emphasis on documentation, and improvements in communication have resulted in an increase in the number of reports, especially among weaker (EF0-EF1) tornadoes. As these systematic biases are present, use caution when using long term trends as they are based solely on the number of reports.

Historical Data

Tornado Tracks Tool (1950-2021) Midwestern Regional Climate Center

This is an interactive tool that shows historical tornado track details by track location or county. Consider nearby storm tracks, even if they did not hit your location, because small changes in storm motion can bring a tornado into your town.

1. Select area of interest either by zooming or entering a location into the search box. **2.** Use panel on the left side of the screen to select variables of interest. Options include by *Magnitude*, *Year Range*, *Month*, and *Casualties*. **3.** To view information about a tornado track, select *Track* in the left panel and hover your mouse over the track on the map. **4.** To view an image of all tornado tracks in a county, click *County* from the left panel and click a county on the map.

Tool Link: <http://mrcc.purdue.edu/gismaps/cntyrtorn.htm>

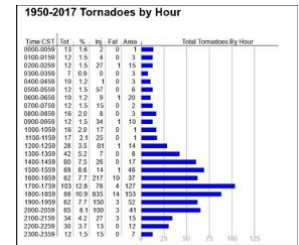


Tornado Risk Assessment (1950-2019) NOAA/National Weather Service Storm Prediction Center

This site displays a series of graphs that shows tornado occurrences and statistics based on a given point. Statistics include F/EF scale frequency and probabilities of strikes occurring by month and time of day.

1. Click on the black bar at the top of the page (bar includes location, radius, and time period information) and provide the zip code of interest. A suggested radius input is 40 km (~25 mi). **2.** Click *Run*. **3.** Details about tornadoes that have occurred within the selected area are displayed on the page.

Tool Link: <http://www.spc.noaa.gov/climo/online/probs/>

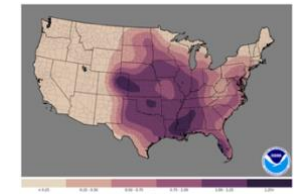


Tornado Days Maps (1986-2015) NOAA/National Weather Service Storm Prediction Center

These static maps show the average number of tornado days per year for all magnitudes (separate maps show EF1+, EF2+, and EF4+ days) within 25 miles of any point from 1986-2015. Tornado frequencies at a given location can be compared to nearby and regional locations.

1. Under the *Storm Prediction Center WCM Page* banner near the top of the page, click on the *30-Year Severe Climatology* link. **2.** Click on a tornado climatology map of interest to view it in larger form.

Tool Link: <http://www.spc.noaa.gov/wcm/>

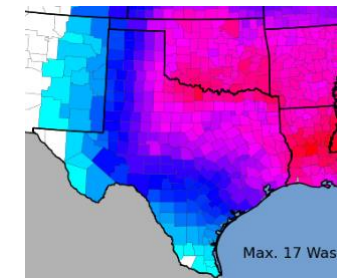


Tornado Watch Climatology Map (1993-2012) NOAA/National Weather Service Storm Prediction Center

This map shows you a 20-year climatology of tornado watches. From this map you can get a sense of the approximate number of days each year you can expect to have a tornado watch issued for your county(ies).

1. Under the *Storm Prediction Center WCM Page* banner near the top of the page, click on the *Watch Frequency Maps* link. **2.** Scroll down a bit until you see *20y SPC Watch Climatology*. **3.** Click on *Average number of tornado watches per year* image to view it in larger form. **4. Note:** This WCM page contains a lot of other statistics about the hail, severe thunderstorm and tornado products that come out of the NWS Storm Prediction Center if you are interested in digging deeper into data.

Tool Link: <http://www.spc.noaa.gov/wcm/>



Future Trends

Records over the past 40 years show that there has been an increase in the frequency of days with a large number of tornadoes (i.e., tornado outbreaks). However, there has also been a decrease in the frequency of days with tornadoes (Kossin et al. 2017), meaning that more tornadoes are occurring on tornado outbreak days than isolated days. However, the trends that cause this may not continue (Nielsen-Gammon et al. 2021). Because the severe thunderstorms that produce tornadoes happen on such a small scale, climate models are not confident in the direct trends of these storms. However, if one looks at the larger scale “ingredients” needed for these storms, there will likely be more days where such storms are viable (Nielsen-Gammon et al. 2021). Historically, tornadoes have occurred more frequently in northern and northeast Texas.

Wildfire

Data Limitations: A systematic, national collection of wildfire reports did not begin until the early 1990s. Many analyses are based on only a few years of data, which may not capture multi-year variability or trends. Further, fires accounted for by local jurisdictions may not always translate into national databases.

Historical Data

National Interagency Fire Occurrence

(1992-2018)

K. C. Short/ U.S. Department of Agriculture, Forest Service

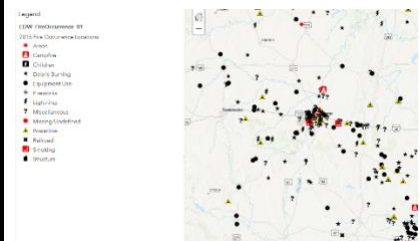
This interactive tool can be used to show locations of reported fire occurrences between 1992-2018, in and near a county or city. Individual years can be viewed to determine relative risk. Many fires in urban areas are not reported to the U.S. Forest Service database, however, so it may under-represent fire risk in urban areas. **Note:** *There is a learning curve associated with this tool and it is helpful to use a larger computer screen because of the amount of data shown.*

1. Click on the *Map View* link below. 2. Next to *View In*, click *ArcGIS Online map viewer*. A new internet browser tab will open. 3. On the left side of the screen, under Contents, expand *EDW FireOccurrence5thEdition 01* on the top by clicking the arrow to the left of the name. 4. Select year(s) of interest or *All Years* (last in the list). 5. Zoom in on map if data are not shown. 6. To view Texas fires only, hover your mouse over the year of choice in the lefthand menu and click on the filter icon (fourth from the left). 7. Select *STATE* in left drop-down menu → In far-right box enter *TX* → Click *APPLY FILTER*. 8. A table containing the details of each fire can be viewed by clicking the table icon (two icons left of the filter icon when you hover over the lefthand menu). 9. The map symbols represent varying causes of wildfire occurrences. To view the legend, click on the legend button at the top right of the lefthand menu. 10. To view data on an individual fire, open the table from Step 8 and then click on the fire symbol of interest on the map. In the top right-hand corner of the table, click on the three horizontally lined tab and select *Show Selected Records*. Details of the selected fire will be displayed in the table. 11. Refer to the paper linked below for table column definitions. **Note:** *Additional filters can be applied by clicking on the filter icon again and choosing desired selections (e.g., the column *STAT_CAUSE_DESCR* describes the cause of the fire).*

Map View:

https://apps.fs.usda.gov/arcx/rest/services/EDW/EDW_FireOccurrence5thEdition_01/MapServer

Original Paper (open access): https://www.fs.usda.gov/rm/pubs_other/rmrs_2014_short_k001.pdf



Texas Wildfire Risk Explorer

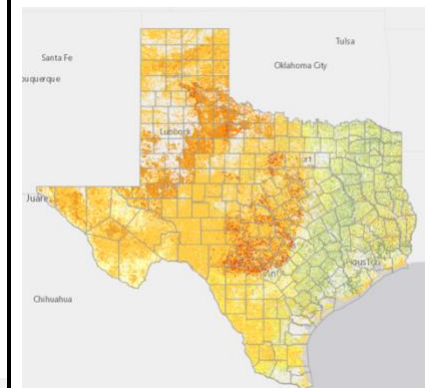
(Wildfire Ignitions: 2005-2021)

Texas A&M Forest Service

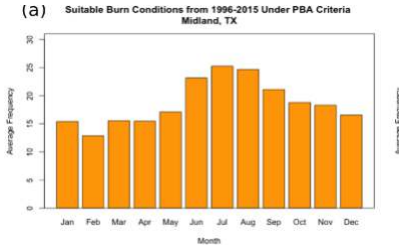
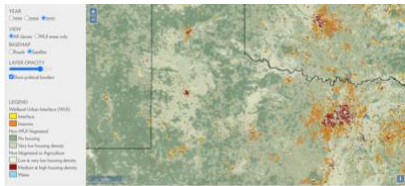
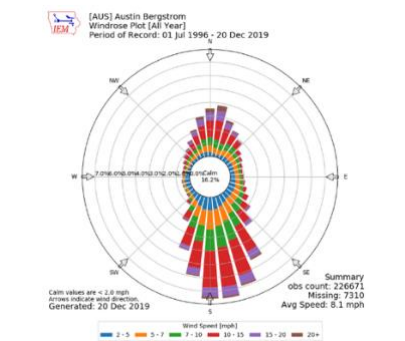
This interactive tool within the Texas Wildfire Risk Assessment Portal (TxWRAP) can be used to identify areas within Texas that are at greatest risk of wildfire. It is especially useful for identifying areas of risk in the wildland-urban interface and prioritizing areas where tactical analyses, community interaction, or mitigation treatments might be necessary to reduce risk. **Note:** *Basic Viewer is accessible to anyone. Advanced Viewer is also free but requires account request.*

1. Choose *Basic* or *Advanced Viewer*. 2. Pan and zoom in to the area of interest on the map. 3. Click on *Map Themes* in the upper left-hand corner. 4. Under the *Wildfire Risk* section on the left side of the screen, select the layer you want to view. Details about each layer can be found by hovering over the circular "i" icon. 5. To compare layers, such as WUI Response Index and Community Protection Zones, click on the icon to the right of the search icon on the top right of the map. You can choose two selections from drop-down menus. 6. View historical wildfire ignition locations in the Historical Fire Occurrence section. **Note:** *Data are displayed at a very fine (25-meter) resolution.*

Tool Link: <https://wrap.texaswildfirerisk.com/Map/Public/#whats-your-risk>



Wildfire (Continued)

Historical Data	<p>Prescribed Fire Climatology (1996-2015)</p> <p>Southern Climate Impacts Planning Program</p>	<p>This document includes a series of static graphics and tables within a scientific report. It can be used to identify the best months to conduct prescribed burns as a wildfire management strategy. Coupled with tools such as TxWRAP, one can target locations and timing for safe burning along the wildland-urban interface. The report describes the average, minimum, and maximum number of days with a consecutive 4-hour period suitable for prescribed fire as a management tool to reduce vegetation fuel load and improve vegetation health.</p> <p>Tables and Figures relevant to Texas: Tables 2, 9, and 10; Figures 9-22, Figures 27-49 in Appendix A-C, Figures 7-9 in Appendix D.</p> <p>Paper Link: https://www.southernclimate.org/wp-content/uploads/Changing_Fire_Regimes.pdf</p>	
	<p>Wildland-Urban Interface (1990, 2000, 2010)</p> <p>University of Wisconsin-Madison SILVIS Lab</p>	<p>This interactive tool shows WUI (Wildland-Urban Interface) changes between 1990, 2000, and 2010 for locations of interest. It shows the effects of housing growth on the environment and which areas may need more local land management related to WUI issues.</p> <p>1. Zoom in to the desired location on the map. 2. On the left side of the screen, select year, base map, and layer opacity of interest. Note: Texas-specific data and map files (down to the county level) are available by scrolling down the page.</p> <p>Tool Link: http://silvis.forest.wisc.edu/data/wui-change</p>	
	<p>Wind Rose Plots (Period of record varies by station; up to ~85 years)</p> <p>Iowa Environmental Mesonet, Iowa State University</p>	<p>View common and prominent wind speeds and directions for your area. Plots can be viewed by monthly average and by the long-term yearly average. This tool can be used to view the wind climatology and the predominant direction in which air pollutants flow. It may also be useful for understanding how wildfire events may evolve in a community.</p> <p>1. In the <i>Select By Network</i> section, choose <i>Texas ASOS</i> then click <i>Switch Network</i>. 2. Select station of interest, either from the list or map, then click <i>Select Station</i>. 3. You will be brought to a new page. Near the top of the page, click on the <i>Wind Roses</i> tab. 4. The yearly climatology is displayed at the top of the page, and monthly climatologies are displayed below that. Click <i>View Raw Data</i> on any plot to view more details.</p> <p>Tool Link: https://mesonet.agron.iastate.edu/sites/locate.php</p>	
Future Trends	<p>Between 1984 and 2011, the number of large wildfires increased in Texas (Wehner et al. 2017). Wildfires in Texas are dependent upon current weather conditions, seasonal climate patterns, vegetation conditions, and an available source for ignition (such as a spark, flame, or intentional ignition). Given this complex relationship, the future trend for wildfire is also complex. Read more about future wildfire risk in the resources found in Appendix C.</p> <p>Western TX: In western Texas and the Panhandle, an increase in dryness will decrease vegetation and provide less fuel for the fires (Nielsen-Gammon et al. 2021). While there's a risk of wildfires increasing across the state, it may increase more slowly in western Texas.</p> <p>Central TX: Some models show that central Texas is the transition zone in the changing fire regime with increased fire probability to the east (Stambaugh et al. 2018).</p> <p>Eastern TX: In more vegetated, humid areas, like eastern Texas, wildfires may become more frequent with increased dryness of vegetation, and the wildfire season and the affected area is projected to expand (Nielsen-Gammon et al. 2021).</p>		

Winter Storm (Ice, Sleet, Snow)

Data Limitations: Long-term records are limited, as ice storm/freezing rain data are very limited due to the complexity of observational accounts (e.g., rain, freezing rain, and snow can occur at a single station during a single event).

Historical Data

Snowfall Climatology Toolbox

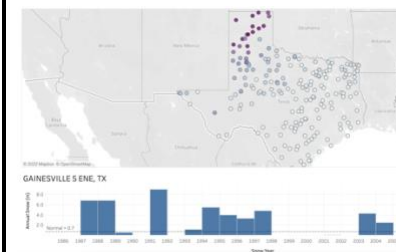
(Period of record varies by station; ~30-100+ years)

Midwestern Regional Climate Center

This interactive tool shows normal (1991-2020) annual and monthly snowfall, average annual number of days with snow totals at certain thresholds, average first and last snow date, and record 1-day snowfall. The map displays normal values while the graph below it shows the variable by year.

1. Position map to area of interest or choose TX in the *State Selection* drop-down menu on the right. 2. On the top of the screen, select a variable you're interested in (e.g., *Annual Snowfall*). Some variables have options on the right side of the screen to select, such as a month to display for monthly snowfall or a snow threshold. 3. For most variables, the map displays the normal/average value for the variable you selected. For *Record 1-Day Snowfall*, it shows the record value at each point. The legend for the colored points is on the top-right side of the screen. 4. The graph below the map shows more details, such as the values per year instead of an average. **Note:** The map default shows stations with data from at least 1991-2020. If you'd like to see longer time frames, you can move the slider under the Data Available Since option on the right. When you select a different start year, it will only show stations with available data.

Tool Link: https://mrcc.purdue.edu/mw_climate/snowfallClimatology/snowfallClimatology.html



Snowfall Extremes

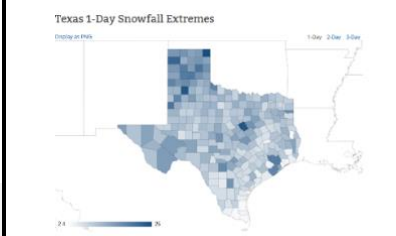
(Period of record varies by location; up to ~120 years)

NOAA National Centers for Environmental Information

This interactive static map shows the 1-day, 2-day, and 3-day snowfall maximums by county.

1. Select the day-length of interest on the top right side of the map. 2. Click on the county of interest for information on the maximum snowfall event on record for your selected time period. 3. A table below the map shows location (by county and station), date of event, and snowfall total details. Click the top of the right two columns to sort by date or value.

Tool Link: <https://www.ncdc.noaa.gov/snow-and-ice/snowfall-extremes/TX>



Ice Storm Climatology

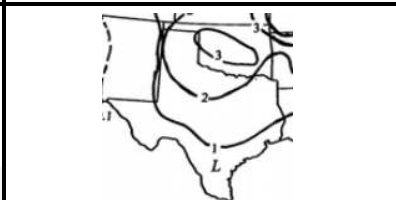
(1948-2000)

Changnon and Karl, 2003 (open access)

These are static images within a scientific report. The analysis includes the average annual number of days with freezing rain (Fig. 2) and month of highest average number of freezing rain days (Fig. 9). Texas typically experiences 1-2 freezing rain events per year, most commonly in January.

To view, click on the *Full Text* tab and scroll to the bottom of the page where figures are located.

Figures in [https://doi.org/10.1175/1520-0450\(2003\)042<1302:TASVOF>2.0.CO;2](https://doi.org/10.1175/1520-0450(2003)042<1302:TASVOF>2.0.CO;2)



Future Trends

Years consisting of a large number of snowfall days declined significantly across the southern U.S. between 1930 and 2007. Models suggest that the number of snowfall events will likely continue to decrease given overall atmospheric warming. Models also show that by mid-century there will generally be a northward shift of the rain, sleet, and snow dividing line across the central U.S. This shift will add to the complexity of determining precipitation type for winter events (rain, ice, or snow) in north Texas. Overall, the frequency of snowfall and freezing rain events is expected to decline with rising air temperatures (Nielsen-Gammon et al. 2021). Read more about future winter storms in the resources found in Appendix C.

Western TX: The Texas Panhandle has experienced the most snow in the state (Nielsen-Gammon et al. 2021). As mentioned above, the northward shift of the rain/wintry precipitation dividing line and warmer temperatures are expected to decrease the frequency of winter storms.

Central TX: North central Texas is another area with more frequent snow occurrence and the frequency decreases to the south (Nielsen-Gammon et al. 2021). Warmer temperatures in the future are expected to decrease the amount and frequency of snowfall. Freezing rain occurrence is more uncertain in the future but expected to decline too.

Eastern TX: Eastern Texas has experienced the lowest frequency in snow occurrence, especially along the coast and further south. However, northeast Texas has experienced the most freezing rain events in the state (Nielsen-Gammon et al. 2021). With warmer temperatures in the future, freezing rain may decrease but there is uncertainty in the future occurrence of the weather pattern associated with such events.

Dam or Levee Failure

Data Limitations: The tools below do not provide dam or levee failure information but rather information on the locations of and pertinent details about dams and levees in Texas. The dam inventory is limited to dams with a height of at least 25 feet and which exceed 15 acre-feet in storage, or those with a height of at least six feet and 50 acre-feet of storage unless the dam is classified as high hazard potential. The high hazard potential dam is a dam where failure will probably cause loss of human life regardless of the physical condition of the structure.

Historical Data

National Inventory of Dams by State

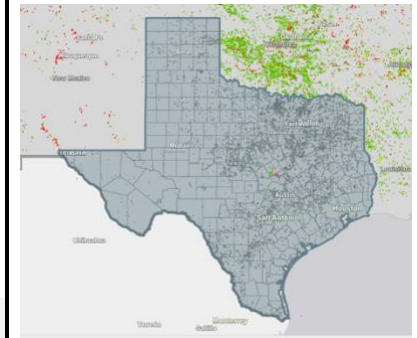
(1900-present)

U.S. Army Corps of Engineers

This tool provides you with an overview of the dams in Texas, including the number by hazard potential, height, owner type, primary type, primary purpose, and completion date.

1. Scroll down until you see a map. On the drop-down menu to the left of the map, select *Texas*. For specific counties, you can then select a county within Texas from the same menu or click on the map after Texas is selected. 2. The map then zooms in to Texas and shows all dam locations. A summary of dams in the state is visible above the map. 3. To view dams by hazard potential, click the *Layer Controls* button on the top left of the map, then click *Categorize by* and choose *Dams by Hazard Potential*. The number of dams in each category are shown under the map. Other categories can be mapped as well. 4. Click *Browse These Dams* above the map to access a list of dams with more information.

Tool Link: <https://nid.sec.usace.army.mil/>



National Inventory of Dams Interactive Report

(1900-present)

U.S. Army Corps of Engineers

This report allows you to view the details of individual dams within the state of Texas.

1. At the top of the page, click on the *Advanced Search* tab. 2. On the top left of the page in the *Location* box, select *State* for the *Geography Type*, then type *Texas* in the space below. Click *UPDATE RESULTS* above this area. 3. Click the *DAM DETAILS* tab near the top of the page to access a chart of all Texas dams and associated information. 4. Choose which columns to display by clicking *Columns*, then select/de-select the columns as needed. 5. To sort by column, click the arrow to the right of the column header. **Note:** You can narrow results by selecting additional options on the left of the page (such as *Hazard Potential Classification* to view high hazard dams). Click *UPDATE RESULTS* for any changes made to update the list.

Tool Link: <https://nid.sec.usace.army.mil/>

Search	Map	Hazard Potential Classification	DAM Purpose	DAM Registered
Advanced Search	1007463	Not Available	No	No
Other Springs Arroyo Dam	1007519	Not Available	No	No
Lindsey Dam	1007583	Not Available	No	No
Coyote Creek Ranch Dam	1007527	Not Available	No	No
Elbow Lake Dam	1004053	Not Available	Not Reported	No
Phon Phady Park Dam	1007128	Not Available	No	No
Broken Oak Dam	1007548	Not Available	No	No
Wash Ranch Dam	1007516	Not Available	No	No

National Levee Database

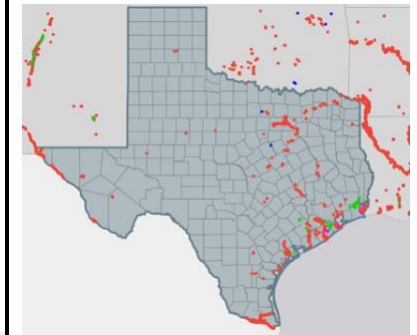
(Levee Inventory: 1882-present)

U.S. Army Corps of Engineers

This tool allows you to explore levees in your area, including location, year constructed, length, number of people and structures at risk should failure occur, property values in the risk area, and more.

1. At the top of the page, click *Dashboard*. 2. On the left drop-down menu, click *Texas*. 3. The results page shows a map of all Texas levees, and the dashboard provides information about systems at risk, potential consequences, authorization type, and other measures. A summary of levees in the state are visible above the map. 4. To zoom into a smaller area, click on the county of interest on the left side of the page or on the map to update the dashboard. 5. To view more details about each levee, click *BROWSE THESE LEVEES* above the map. 6. Click the *DETAILS* tab near the top of the page to access a chart of all Texas levees and associated information. 7. Choose which columns to display by clicking *Columns*, then select/de-select the columns as needed. 8. To sort by column, click the arrow to the right of the column header. **Note:** You can narrow results by selecting additional options on the left of the page (such as *Authorization Category*). Click *UPDATE RESULTS* for any changes made to update the list.

Tool Link: <https://levees.sec.usace.army.mil/#/>



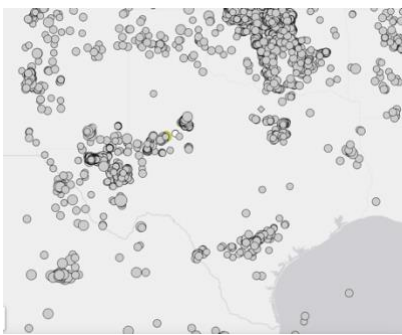
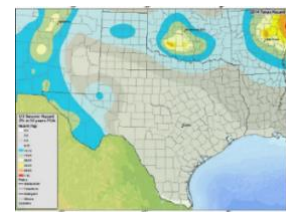
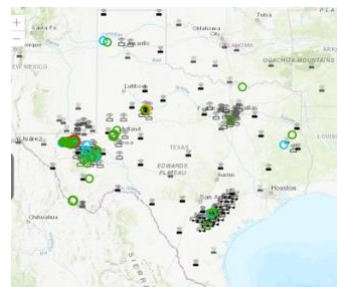
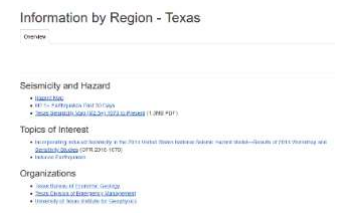
Future Trends

Increases in extreme rainfall (Easterling et al. 2017) may increase the likelihood of dam failure, however, this is highly dependent upon the quality of the structures. The average age of dams in Texas is 58 years and with a 50-year design life, the probability of failure increases with time. Dams that are not well maintained have an increased likelihood of failure. Washed out spillways, deteriorated primary spillway conduits, collapsed riser structures, and slope instability can lead to a dam breach. Furthermore, sediment buildup in reservoirs leads to a decreased capacity, which in turn decreases flood storage. In recent years, Texas has seen multiple dam failures associated with excessive rainfall events. Different jurisdictions across Texas make dam regulation difficult and many dams across the state are in "poor" condition (Sadasivam 2019). Increased heavy rainfall events will heighten the risk of dam failure.

Earthquake

Data Limitations: Globally, scientific understanding of earthquake processes is somewhat limited, and the available history of seismicity is typically too short to establish reliable spatiotemporal patterns of large earthquake occurrences (Stein et al. 2012).

Historical Data

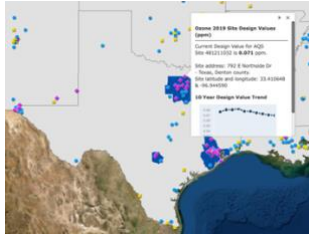
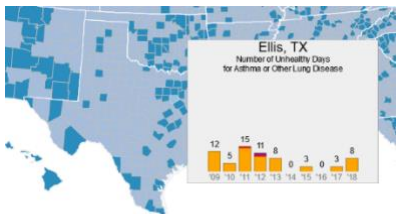
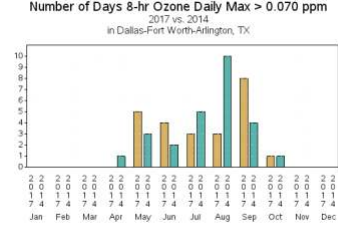
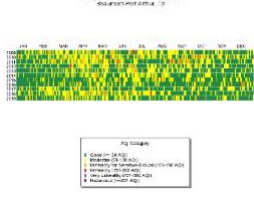
Earthquake Catalog (Period of record varies by location; up to ~100 years) U.S. Geological Survey	<p>This tool shows past earthquakes on a zoomable map and can be used to show previous occurrences.</p> <p>1. Under <i>Basic Options</i>, select the <i>Magnitude</i>, <i>Date and Time</i>, and <i>Geographic Region</i> to plot. Choose a <i>Custom</i> date and time with a start date such as “1970-01-01 00:00:00” to view long-term trends. Select a <i>Custom</i> Geographic Region for Texas by clicking <i>Custom</i>, then zooming into the pop-up map and drawing a rectangle around Texas. 2. Click <i>Search</i>. 3. A map with all earthquakes meeting your chosen criteria are shown and a list of earthquakes are on the left of the page. 4. View the map legend by clicking the key icon on the top right of the map area. To learn more about specific events, click any point on the map or select an event from the list. You can also sort by date or magnitude.</p> <p>Tool Link: https://earthquake.usgs.gov/earthquakes/search/</p>	
2014 Seismic Hazard Map - Texas (1964-2014) U.S. Geological Survey	<p>This map shows the chance of damaging shaking (contoured colors). It can be used to help determine the risk of a damaging earthquake in your area.</p> <p>Tool Link: https://www.usgs.gov/media/images/2014-seismic-hazard-map-texas</p>	
TexNet Earthquake Catalogue (2017-present) TexNet, Bureau of Economic Geology, UT Austin	<p>This catalog includes an interactive map and tables that show various earthquake datasets for Texas.</p> <p>1. Using the date range selectors on the left toolbar or the timeline at the bottom of the page, select the range of interest, then select the magnitude range. The legend of earthquake magnitude and station type is on the left. 2. Use the map to pan and zoom to the area of interest. 3. Click <i>Show Table</i> on the top of the page to view more details.</p> <p>Tool Link: https://www.beg.utexas.edu/texnet-cisr/texnet/earthquake-catalog</p>	
Texas Earthquake Information Page U.S. Geological Survey	<p>Additional information about earthquakes in Texas can be found on this page. Click on links of interest.</p> <p>Tool Link: https://www.usgs.gov/natural-hazards/earthquake-hazards/science/information-region-texas?qt-science_center_objects=0#qt-science_center_objects</p>	

Future Trends

The rate of magnitude-3 or greater (M3+) earthquakes in Texas has increased by about 2 to 12 events per year since 2008, and the number of M3+ earthquakes has increased eightfold since 2017 (Douglas 2022). This can be partially attributed to wastewater injection and other human activity. Human-caused earthquakes in Texas will likely continue in the absence of increased restrictions on wastewater injection (Frohlich et al. 2016; Skoumal and Trugman 2021).

Poor Air Quality (Dust, Pollutants, Smoke)

Data Limitations: Geographical and spatial gaps exist for air quality data, especially in rural areas. However, areas distant from monitoring stations typically experience consistently good air quality. Also, there is no single air pollutant relevant to every discussion, so there is no single way to express air quality (Tracking California 2021). Monitoring frequency varies by pollutant (e.g., carbon monoxide, nitrogen dioxide, sulfur dioxide, and lead). Tools often display data for the five air pollutants that make up the Air Quality Index (AQI): carbon monoxide, nitrogen dioxide, ozone, particulate matter (PM10 and PM2.5), and sulfur dioxide.

Historical Data	<p>Nonattainment Areas for the Criteria Pollutants</p> <p>U.S. Environmental Protection Agency</p>	<p>This interactive tool displays areas that are not within EPA regulations of the criteria pollutants as well as trends in these pollutants at monitoring sites.</p> <p>1. Zoom and pan to the area of interest. 2. Select the criteria of interest. The year listed in each tab represents the year in which the EPA standard for that parameter was set. 3. Select the desired monitoring site for more information, including data trends.</p> <p>Tool Link: https://epa.maps.arcgis.com/apps/MapSeries/</p>	
	<p>Air Compare</p> <p>(2012-2021)</p> <p>U.S. Environmental Protection Agency</p>	<p>This interactive map displays county-based trends for the five AQI air pollutants that may affect human health. For data limitations specific to this tool, including the pollutants that are accounted for in the analyses, click on the <i>Basic Info</i> tab at the top of the page, then <i>Data Limitations</i> on the right side of the page. Note: For information on the predominant directions in which air pollutants flow, refer to the <i>Wind Rose Plots</i> tool in the <i>Wildfire</i> section, p.31.</p> <p>1. Scroll down until you see the map. 2. In the upper lefthand corner of the map, click on <i>Trends</i>, then select category of interest. 3. Zoom in and click county of interest to obtain a graph of annual statistics. Counties shaded darker blue have data available. You can click multiple counties to compare locations. Each graph appears above the map. 4. For data broken down into months, click on <i>Seasons</i> in the upper lefthand corner, then select the group of interest.</p> <p>Tool Link: https://www3.epa.gov/aircompare/#trend</p>	
	<p>Ozone Exceedances</p> <p>(1980-present)</p> <p>U.S. Environmental Protection Agency</p>	<p>This interactive graphing tool compares 8-hour ozone exceedances between two years or multi-year periods for a city or county. Comparisons are shown by day, month, and year. The ozone exceedance level for this tool is 0.070ppm.</p> <p>1. Under <i>Geographic Area</i>, select a city/county of interest 2. Under <i>Baseline Period</i>, select either a single year or a multi-year period and the year(s) in which you are interested. 3. Under <i>Comparison Period</i>, select either a single year or a multi-year period and the year(s) in which you are interested in. 4. You may need to uncheck <i>Use ALL Monitors</i> when comparing time periods if data aren't available for both periods. 5. Click <i>Plot Data</i>.</p> <p>Tool Link: https://www.epa.gov/outdoor-air-quality-data/air-data-ozone-exceedances</p>	<p>Number of Days 8-hr Ozone Daily Max > 0.070 ppm 2017 vs. 2014 in Dallas-Fort Worth-Arlington, TX</p>  <p>Note: Based on sites common to both periods Source: U.S. EPA AirData <https://www.epa.gov/air-data> Generated: January 24, 1920</p>
	<p>Outdoor Air Quality Data</p> <p>(Period varies by pollutant; up to 1980-present)</p> <p>U.S. Environmental Protection Agency</p>	<p>This multi-year tile plotting tool shows the daily AQI pollutant values for a specific location or time period. Each tile represents one day of the year and is color-coded based on the AQI level for that day.</p> <p>1. Under <i>Pollutant</i>, select pollutant of choice (e.g., Ozone, All AQI Pollutants). 2. Under <i>Period</i>, select a beginning and ending year (maximum of 25 years). 3. Under <i>Geographical Area</i>, select a city or county. Note: cities available are listed in the <i>Ozone Exceedances</i> tool above. 4. Click <i>Plot Data</i>. The legend is located below the plot.</p> <p>Tool Link: https://www.epa.gov/outdoor-air-quality-data/air-data-multiyear-tile-plot</p>	<p>Daily AQI Values, 2000 to 2019 Houston, TX</p> 
Future Trends	<p>While many metropolitan areas in Texas exceed national standards for air quality, from 2000-2020 there were great improvements due to increased research and mitigation efforts, even with population increases (TCEQ 2021). If these efforts continue, so will air quality improvements (Allen et al. 2018). If not, air quality conditions may worsen in the future. Increasing temperatures are tied to increasing ozone levels closer to pollution sources, which cause health issues such as asthma and respiratory problems. A longer wildfire season may also lead to an increased amount of ozone and particulate matter, and a lengthened pollen season may increase the allergens in the air (Nolte et al. 2018).</p>		

Acknowledgements

The *Simple Planning Tool for Texas Climate Hazards* is a result of SCIPP's engagement with emergency managers and planners in Oklahoma, Arkansas, and Texas. We thank the following practitioners for their involvement in various capacities: Robert Hill, Paula Dennison, Danielle O'Neal, Michael McAnelly, and Chance Sparks. We also thank undergraduate student James Cuellar for his assistance with earlier versions.

A note of thanks is also extended to the individuals who assisted in reviewing sections of and/or provided additional information for the tool: Kristin Calhoun (Cooperative Institute for Mesoscale Meteorological Studies/National Severe Storms Laboratory), Patrick Marsh (NWS Storm Prediction Center), John Nielsen-Gammon (Texas A&M University), and Rick Smith (National Weather Service Norman Forecast Office).

References

- Allen, D., E. McDonald-Buller, and G. McGaughey, 2018. State of the Science of Air Quality in Texas: Summary of Scientific Projects and Findings from the Texas Air Quality Research Program (AQRP) 2010-2017. Texas Air Quality Research Program, <http://aqrp.ceer.utexas.edu/publications.cfm>.
- American Meteorological Society (AMS), 2020: Glossary of Meteorology, <https://glossary.ametsoc.org/wiki/Welcome>.
- Bhatia, K., and Coauthors, 2022: A potential explanation for the global increase in tropical cyclone rapid intensification. *Nature Communications*, **13**, 6626 (2022), <https://doi.org/10.1038/s41467-022-34321-6>.
- Changnon, S.A. and T.R. Karl, 2003: Temporal and spatial variations of freezing rain in the contiguous United States: 1948-2000. *J. Appl. Meteor. Climatol.*, **42**, 1302-1315, [https://doi.org/10.1175/1520-0450\(2003\)042<1302:TASVOF>2.0.CO;2](https://doi.org/10.1175/1520-0450(2003)042<1302:TASVOF>2.0.CO;2).
- Dixon, K.W., A.M. Wootten, M.J. Nath, J. Lanzante, D.J. Adams-Smith, C.E. Whitlock, C.F. Gaitán, and R.A. McPherson, 2020: South Central Climate Projections Evaluation Project (C-PrEP), South Central Climate Adaptation Science Center, Norman, Oklahoma, USA, doi: <https://doi.org/10.21429/12gk-dh47>.
- Douglas, E., 2022: Earthquakes in Texas doubled in 2021. Scientists Cite Years of Oil Companies Injecting Sludgy Water Underground. Texas Tribune, <https://www.texastribune.org/2022/02/08/west-texas-earthquakes-fracking/#:~:text=More%20than%20200%20earthquakes%20of,University%20of%20Texas%20at%20Austin>.
- Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017: Precipitation change in the United States. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 207-230, doi: 10.7930/J0H993CC.
- Emanuel, K., 2017: Will Global Warming Make Hurricane Forecasting More Difficult? *Bulletin of the American Meteorological Society*, **98**(3), 495-501, <https://doi.org/10.1175/BAMS-D-16-0134.1>.
- Frohlich, C., H. DeShon, B. Stump, C. Hayward, M. Hornbach, and J.I. Walter, 2016: A historical review of induced earthquakes in Texas. *Seismological Research Letters*, **87**(4), <https://www.beg.utexas.edu/files/texnet-cisr/pubs/Frohlich%20et%20al.%20SRL%202016.pdf>.
- Guttman, N.V., and R.G. Quayle, 1996: A historical perspective of U.S. climate divisions. *Bull. Amer. Meteor. Soc.*, **77**, 293-303, [https://doi.org/10.1175/1520-0477\(1996\)077<0293:AHPOUC>2.0.CO;2](https://doi.org/10.1175/1520-0477(1996)077<0293:AHPOUC>2.0.CO;2).
- Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner, 2018: Our Changing Climate. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72-144, doi: 10.7930/NCA4.2018.CH2.
- Kloesel, K., B. Bartush, D. Brown, J. Lemery, X. Lin, C. Loeffler, G. McManus, E. Mullens, J. Nielsen-Gammon, M. Shafer, C. Sorenson, S. Sperry, D. Wildcat, and J. Ziolkowska, 2018: Southern Great Plains. In *Impacts, Risk, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 987-1035, doi: 10.7930/NCA4.2018.CH23.
- Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner, 2017: Extreme storms. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 257-276, doi: 10.7930/J07S7KXX.
- Muis, S., M. Verlaan, H. C. Winsemius, J. Aerts, and P. Ward, 2016: A global reanalysis of storm surges and extreme sea levels. *Nature Communications*, **7**, <https://doi.org/10.1038/ncomms11969>.
- National Hurricane Center (NHC), 2022a: Surge Overview, <https://www.nhc.noaa.gov/surge/>.
- National Hurricane Center (NHC), 2022b: Storm Surge Frequently Asked Questions, <https://www.nhc.noaa.gov/surge/faq.php#2>.

- National Ocean Service (NOS), 2021: What Is High Tide Flooding, <https://oceanservice.noaa.gov/facts/high-tide-flooding.html>.
- National Oceanic and Atmospheric Administration (NOAA), 2022: The State of High Tide Flooding and Annual Outlook, https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html].
- National Weather Service (NWS), 2009: National Weather Service Glossary, w1.weather.gov/glossary.
- National Weather Service (NWS), 2018, personal communication with Rick Smith, National Weather Service Norman Forecast Office.
- Nielsen-Gammon, J., 2011. The Changing Climate of Texas. In: *The Impact of Global Warming on Texas*, pp. 39-68. University of Texas Press, www.jstor.org/stable/10.7560/723306.6.
- Nielsen-Gammon, J., and Coauthors, 2020: Unprecedented drought challenges for Texas water resources in a changing climate: What do researchers and stakeholders need to know? *Earth's Future*, **8**(8), <https://doi.org/10.1029/2020EF001552>.
- Nielsen-Gammon, J. and Coauthors, 2021. *Assessment of Historic and Future trends of Extreme Weather in Texas, 1900-2036*. Texas A&M University, Office of the Texas State Climatologist, 42 pp, <https://climatexas.tamu.edu/files/ClimateReport-1900to2036-2021Update>.
- Nolte, C.G., P.D. Dolwick, N. Fann, L.W. Horowitz, V. Naik, R.W. Pinder, T.L. Spero, D.A. Winner, and L.H. Ziska, 2018: Air Quality. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 512-538, doi: 10.7930/NCA4.2018.CH13.
- Pathak, A., and A. Fuller, 2021: Vulnerability and Adaptation to Climate Change: An Assessment for the Texas Mid-Coast. Austin, TX: National Wildlife Federation, <https://texaslivingwaters.org/wp-content/uploads/2021/05/Mid-Coast-Assessment.pdf>.
- Runkle, J., K.E. Kunkel, J. Nielsen-Gammon, R. Frankson, S.M. Champion, B.C. Stewart, L. Romolo, and W. Sweet, 2022: State Climate Summary 2022. NOAA Technical Report NESDIS 150-TX. NOAA/NESDIS, Silver Spring, MD, 5 pp, <https://statesummaries.ncics.org/chapter/tx>.
- Sadasivam, N., 2019: Dammed to Fail. Texas Observer, <https://www.texasobserver.org/dammed-to-fail/>.
- Schultz, C.J., W.A. Petersen, and L.D. Carey, 2011: Lightning and severe weather: A comparison between total and cloud-to-ground lightning trends. *Weather and Forecasting*, **26**, 744-755, <https://doi.org/10.1175/WAF-D-10-05026.1>.
- Shafiei Shiva, J., D.G. Chandler, and K.E. Kunkel, 2019: Localized Changes in Heat Wave Properties Across the United States. *Earth's Future*, **7**, 300-319, <https://doi.org/10.1029/2018EF001085>.
- Skoumal, R. J., and D. T. Trugman, 2021: The proliferation of induced seismicity in the Permian Basin, Texas. *Journal of Geophysical Research: Solid Earth*, **126**(6), <https://doi.org/10.1029/2021JB021921>.
- Stambaugh, M.C., R. P. Guyette, E.D. Stroh, M.A. Struckhoff, and J.B. Whittier, 2018: Future southcentral US wildfire probability due to climate change. *Climatic Change*, **147**, 617-631, <https://doi.org/10.1007/s10584-018-2156-8>.
- Storm Prediction Center (SPC), 2016: 30-year Severe Weather Climatology. Storm Prediction Center, <https://www.spc.noaa.gov/wcm/#30yrclimo>.
- Stein, S., R.J. Geller, M. Liu, 2012: Why earthquake hazard maps often fail and what to do about it, *Tectonophysics*, **562-563**, 1-25, <https://doi.org/10.1016/j.tecto.2012.06.047>.
- Sweet, W.V., and Coauthors, 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp., <https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html>.
- Tracking California, 2021: Air Quality Measures and Limitations, <https://trackingcalifornia.org/air-quality/air-contaminant-regulation-and-monitoring>.
- Texas Commission on Environmental Quality (TCEQ), 2021: Air Quality Successes, <https://www.tceq.texas.gov/airquality/airsuccess>.

- University Corporation for Atmospheric Research (UCAR), 2020: What is Air Quality, <https://scied.ucar.edu/learning-zone/air-quality/what-is-air-quality#:~:text=Poor%20air%20quality%2C%20which%20contains,air%20at%20a%20particular%20location>.
- U.S. Drought Monitor (USDM), 2022: Drought Classification, <https://droughtmonitor.unl.edu/About/AbouttheData/DroughtClassification.aspx>.
- U.S. Federal Government, 2021: U.S. Climate Resilience Toolkit Climate Explorer. [Available online at <https://crt-climate-explorer.nemac.org>].
- U.S. Geological Survey (USGS), 2018: Earthquake Glossary, earthquake.usgs.gov/learn/glossary/?term=earthquake.
- U.S. Geological Survey (USGS), 2019: Saltwater Intrusion, https://www.usgs.gov/mission-areas/water-resources/science/saltwater-intrusion?qt-science_center_objects=0#qt-science_center_objects.
- U.S. Global Change Research Program (USGCRP), 2019: Coastal Erosion. U.S. Climate Resilience Toolkit, <https://toolkit.climate.gov/topics/coastal-flood-risk/coastal-erosion>].
- U.S. Society on Dams (USSD), 2018: Glossary. <https://www.ussdams.org/resource-center/glossary>.
- Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner, 2017: Temperature changes in the United States. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 185-206, doi:10.7930/J0N29V45.
- Walsh, K.J.E., J.L. McBride, P.J. Klotzbach, S. Balachandran, S.J. Camargo, G. Holland, T.R. Knutson, J.P. Kossin, T. Lee, A. Sobel, and M. Sugi, 2015: Tropical Cyclones and Climate Change. *WIREs Clim Change*, **7**, 65-89, doi: 10.1002/wcc.371.
- Wehner, M.F., J.R. Arnold, T. Knutson, K.E. Kunkel, and A.N. LeGrande, 2017: Droughts, floods, and wildfires. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 231-256, doi: 10.7930/J0CJ8BNN.
- World Meteorological Organization (WMO), 2016: Guidelines on the Definition and Monitoring of Extreme Weather and Climate Events, https://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/event/related_docs/DraftversionoftheGuidelinesontheDefinitionandMonitoringofExtremeWeatherandClimateEvents.pdf?h2Kr0f7dXp6CXZzoclQYv eoEQ9FNo05r].
- Wuebbles, D.J., D.R. Easterling, K. Hayhoe, T. Knutson, R.E. Kopp, J.P. Kossin, K.E. Kunkel, A.N. LeGrande, C. Mears, W.V. Sweet, P.C. Taylor, R.S. Vose, and M.F. Wehner, 2017a: Our globally changing climate. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 35-72, doi: 10.7930/J08S4N35.
- Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, B. DeAngelo, S. Doherty, K. Hayhoe, R. Horton, J.P. Kossin, P.C. Taylor, A.M. Waple, and C.P. Weaver, 2017b: *Executive Summary of the Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 12-34, doi: 10.7930/J0DJ5CTG.

Appendix A - Hazard Definitions and Descriptions

Cold Extreme

Definition: A cold wave is generally characterized by a sharp and significant drop of air temperature near the surface (maximum, minimum, and daily average) over a large area and persisting below certain thresholds for a localized minimum number of days (WMO 2016).

Note: *There is no universally recognized metric for what constitutes a cold extreme. The World Meteorological Organization recommends characterizing a cold wave by its magnitude, duration, severity, and extent. Magnitude is defined as a temperature drop below certain threshold(s), either as an absolute value or percentiles. These values must be determined by the local climatology. Local NWS offices usually have locally defined thresholds to identify cold waves/extreme cold events.*

Description: Cold extremes occur when polar and arctic air is displaced from polar regions toward the equator. The lack of sunlight in polar regions during winter allows the buildup of cold, dense air. Wiggles in the jet stream allow equator-ward (southward in the Northern Hemisphere) transport of cold air into the continental United States. High-amplitude jet-stream patterns (a series of large troughs and ridges in the upper atmosphere around the globe) allow air masses to move from their source regions.

Drought

Definition: A deficiency of moisture that results in adverse impacts on people, animals, or vegetation over a sizeable area (NWS 2009).

Description: Drought impacts vary based on the duration and intensity of the event. A few dry weeks may affect crops and lawns, while droughts lasting months or years may significantly impact large water resources. At its extreme, nearly decade-long droughts may lead to farm and business foreclosures and mass migration. Some conditions that may lead to drought development include a large-scale, stationary high-pressure system which inhibits precipitation, feedback from dry soils accelerating warming of the air, La Nina which displaces jet streams, or large-scale ocean circulations in the Pacific and Atlantic Oceans. Droughts may happen in any location and at any time of year. Impacts often become severe more quickly for drought occurring during the summer, when evaporative loss is high; however, slower-evolving droughts in the fall and winter can have tremendous economic impacts on winter crops and livestock. Droughts are more frequent in areas where annual evaporation may exceed annual precipitation.

Drought is rated by the weekly U.S. Drought Monitor (2022) on a scale from D0 (abnormally dry) to D4 (exceptional drought). D0 occurs, on average, in any given location about 21-30% of the time. D1, moderate drought, occurs on average 11-20% of the time, or roughly once every 5-10 years. D2, severe drought, occurs 6-10% of the time, or about every 10-20 years. D3, extreme drought, occurs 3-5% of the time and D4, exceptional drought, occurs 0-2% of the time, or about every 50 years. Severity is based upon a variety of drought indicators, impacts, and input from local experts.

Hail

Definition: Showery precipitation in the form of irregular pellets or balls of ice more than 5mm (0.2 inches) in diameter, falling from a cumulonimbus cloud (NWS 2009).

Description: Hail forms by the collision of supercooled drops – raindrops that are still liquid even though the air around them is below freezing. The hailstone grows, supported by the updraft, until it is too heavy to remain aloft. Stronger updrafts generally produce larger hail sizes. Because obtaining large hail sizes requires a strong updraft, the timing of large hail is related to the lifecycle of large cumulonimbus clouds, which peak in intensity during late afternoon and evening hours. Updrafts may also be supported by vertical motion along a boundary, such as a front or mountains.

Hail severity is rated by the diameter of the largest hailstones in a storm. Hail of 1-inch diameter or greater is considered severe.

Heat Extremes

Definition: A heat wave is an occurrence of unusual hot weather (maximum, minimum, and daily average) over a region persisting at least two consecutive days during the hot period of the year based on local climatological conditions, with thermal conditions recorded above given thresholds (WMO 2016).

Note: *There is no universally recognized metric for what constitutes a heat extreme. The World Meteorological Organization recommends characterizing a heat wave by its magnitude, duration, severity, and extent. Magnitude is defined as a thermal measurement such as maximum temperature, or combination of several measurements, exceeding certain threshold(s). These values must be determined by the local climatology. Other studies have used thresholds based on human physiological response to heat, such as consecutive days of maximum or minimum temperatures above a threshold.*

Description: Heat extremes in the central United States occur when a dominant large-scale high-pressure system prevents movement of other air masses into a region. The high-pressure contributes to intense heating from solar radiation, due to a lack of cloud cover, and light winds preventing the dispersion of heat, especially from urban areas. This results in both higher than average maximum and minimum temperatures.

Heavy Rainfall and Flooding

Definition: Heavy rainfall is rain with a rate of accumulation exceeding a specific value that is geographically dependent (AMS 2020). Flooding is any high flow, overflow, or inundation by water which causes or threatens damage (NWS 2009).

Description: Heavy rainfall is a subjective term but is rain falling at a rate more than the underlying surface can handle, causing runoff, inundation of low-lying areas, and flooding. This may include short-duration thunderstorms lasting a few hours or rainfall accumulating over several days. Flooding is the result of heavy rainfall but also the underlying surface. The rate of infiltration (how quickly it is absorbed by the soil), how quickly runoff reaches the creeks and rivers, if there had been prior rainfall, if the ground is frozen, and other local factors affect runoff and flooding. Consequently, a rainfall of a given rate and amount may cause flooding in one circumstance but not in another. Flooding is most likely in low-lying areas, along the edges of water bodies (ponds, lakes, rivers), and over impermeable surfaces (such as streets and parking lots). Primary causes include slow-moving thunderstorms and storms that track over a location in rapid succession, or tropical systems. Flash flooding may occur with intense thunderstorms while river flooding usually requires rainfall accumulated over a longer duration.

Rainfall accumulations may be compared against previous occurrences through the concept of “return-period values”. This is a statistical assessment of the frequency with which similar amounts have been recorded in the past at a specific location. These return periods, such as 1 in 25 years (a 4% chance of occurring in any given year), are not predictive tools – a large event occurring in the recent record does not prevent another similar or larger event occurring shortly after. Also, if heavy rainfall has already occurred, stormwater retention systems may be filled to capacity allowing a smaller event to cause flooding impacts similar to a much larger event. Rainfall rates and accumulations are usually greatest during the spring, summer, and fall, when warm air can hold more water vapor to produce greater rain rates. River flooding is most likely in spring or fall when fronts may stall, giving a focus for thunderstorm development. Tropical systems, either from the Gulf of Mexico or from the Pacific Ocean, can produce among the highest rainfall rates in the state.

High Tide Flooding

Definition: Flooding that leads to public inconveniences such as road closures, occurring when tides reach anywhere from 1.75 to 2 feet above the daily average high tide and start spilling onto streets or bubbling up from storm drains (NOS 2021; NOAA 2022).

Description: Coastal flooding may occur during high tides, even without a strong storm or hurricane. The combination of sea-level rise, land subsidence, and the loss of natural barriers contributes to an increased frequency of flooding capable of closing roads and damaging property. High-tide flooding may also contribute to flooding away from the immediate coast when stormwater systems are unable to drain, such as from a thunderstorm occurring during a high-tide event. The frequency of high-tide flooding along the coast has doubled over the past 30 years (NOS 2021).

High tides occur when the moon is in alignment with the sun, at either a new moon or a full moon phase. This causes slightly higher tides than at other days in the month. If ocean waters are particularly warm or there is a nearby storm system, this can add to high tide levels through thermal expansion or wind and pressure effects.

Hurricane

Definition: A tropical cyclone in the Atlantic, Caribbean Sea, Gulf of Mexico, or eastern Pacific, in which the maximum 1-minute sustained surface wind is 64 knots (74 mph) or greater (NWS 2009).

Description: A hurricane begins as a tropical cyclone, a disturbance that originates over warm ocean waters with organized deep convection and a closed surface wind circulation about a well-defined center. When sustained winds reach 34 knots (39 mph), it is classified as a tropical storm and at sustained winds greater than 64 knots (74 mph) it becomes a hurricane. Each tropical storm or hurricane is given a unique name to track its progress.

Hurricanes need warm ocean waters, an unstable atmosphere, a deep layer of moist air, a pre-existing surface disturbance, and very little vertical wind shear to form. They convert warm, moist air into energy that strengthens the circulation; consequently, when they move over land they weaken quickly. Hurricane season runs from June through December, with a peak around September 10. The Gulf of Mexico peak is usually a few weeks earlier because the shallower water warms faster than the deeper Atlantic Ocean.

Hurricane impacts include winds, storm surge, tornadoes, and inland flooding. Sustained winds over 160 mph with gusts over 200 mph may be recorded in the most intense hurricanes and can extend 30-600 miles away from the storm's center. Tornadoes are often embedded within the rainbands swirling outward from the center and are most common in the right-front quadrant of the storm. Inland flooding may be caused by several feet of rain over a few days, especially for a slow-moving or stalled hurricane. Hurricane Harvey produced 60 inches of rain over a 5-day period.

Lightning

Definition: A visible electrical discharge produced by a thunderstorm. The discharge may occur within or between clouds, between the cloud and air, between a cloud and the ground or between the ground and a cloud (NWS 2009).

Description: Lightning forms from charge separation within thunderstorms, usually cumulonimbus clouds. Lightning is essentially a large spark of static electricity, similar to touching a doorknob on a dry day (although much more powerful). Most lightning forms from streamers that work their way down from the charge centers of clouds toward the ground. When it gets close to the ground, a return stroke is initiated, which we see as a flash of light. Thunder is created by a shock wave from rapid heating of the air to 18,000 degrees – hotter than the surface of the sun.

Lightning is capable of striking as far as 10 miles away from a storm. Distance can be estimated by counting the seconds between the flash and the sound of thunder. It takes 5 seconds for the shockwave to travel one mile. Lightning severity is not rated, but new detection systems allow accurate identification of lightning strikes which enables analysis of lightning frequency.

Saltwater Intrusion

Definition: Movement of ocean (saline) water into a coastal aquifer (AMS 2020).

Description: Saltwater from the ocean may seep into freshwater aquifers in the coastal zone, which may contaminate the water used to irrigate crops or consumed by people. Excessive groundwater pumping, sea level rise, and other factors contribute to the encroachment of seawater into fresh groundwater supplies. Under normal conditions, freshwater moves through the aquifer toward the ocean, keeping saltwater offshore or deep below the fresh water. If the volume of water in the aquifer drops, such as through pumping or drought, or sea level rises, the transition zone moves inland and upward (USGS 2019).

Water resources and agriculture may also be compromised by overland salt deposition from hurricane storm surge. Storm surge may penetrate many miles inland, leaving ocean saltwater behind as it recedes. If the land is not flushed by freshwater from rainfall, the saltwater will evaporate leaving salt deposits behind that are harmful to plant growth.

Sea Level Rise

Definition: Long-term increases in mean sea level, the arithmetic mean of hourly heights observed over some specified period (AMS 2020).

Description: Sea level rise occurs due to a combination of melting glaciers and ice caps and from thermal expansion. A vast amount of water is stored in ice caps, primarily in Antarctica and on Greenland, which accounts for 50 times the volume of water compared to all the available surface water in lakes, rivers, and seasonal ice and snow. As global temperatures warm, ice sheets are melted which add their water to the surface level of the oceans.

As the temperature of water warms, molecules push farther apart, known as thermal expansion. Thermal expansion creates as great a contribution to sea level rise as does melting ice sheets.

Over the past 100 years, global sea level has risen, on average, 4-8 inches. Half of this is due to thermal expansion and the other half from glacial melt. Sea level is projected to increase by at least 3-4 feet by the end of the 21st century. This is enough to move the shoreline inward by 1,000 feet on average and to inundate 7,800 square miles of North America.

Storm Surge

Definition: An abnormal rise in sea level accompanying a hurricane or other intense storm, whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone. Storm surge is usually estimated by subtracting the normal or astronomic tide from the observed storm tide (NWS 2009).

Description: Storm surge is often one of the greatest threats to life and property from a hurricane. Storm surge is a very complex phenomenon because it is sensitive to the slightest changes in storm intensity, forward speed, size (radius of maximum winds), angle of approach to the coast, central pressure (minimal contribution in comparison to the wind), and the shape and characteristics of coastal features such as bays and estuaries. Higher wind speeds from a hurricane lead to increased storm surge. A slower-moving hurricane also leads to higher and broader storm surge inland while a faster-moving hurricane can lead to increased storm surge over open coastal areas. One cause of structural damage from storm surge is the extension of waves further inland that can include water weights of approximately 1,700 pounds per cubic yard. Storm surge can also cause coastal erosion, damaging beaches and coastal roads (NHC 2022a).

Storm surge is observed and measured by NOAA tide stations, FEMA/USGS high water marks, and temporary USGS pressure sensors. NOAA tide stations are a network of continuously operating water level stations throughout the U.S. serving as the foundation for NOAA's tide prediction products and providing data for storm surge estimates. This data is traditionally the most reliable, but there are limited stations. FEMA/USGS high water marks (HWM) are lines found on trees and other structures marking the highest elevation (peak) of the water surface for a flood event created by foam, sand, or other debris. Survey crews are deployed after a storm to locate and record reliable HWMs. GPS methods are used to determine location for coastal HWMs, which are then mapped relative to a vertical reference datum such as NAVD88. This is traditionally the best method for capturing the highest storm surge level. USGS pressure sensors are temporary water-level and barometric-pressure sensors which provide information about storm surge duration, times of surge arrival/retreat, and maximum depths. These sensors are deployed in advance of an upcoming storm in an area in which the highest surge is expected (NHC 2022b).

Tornado

Definition: A violently rotating column of air, usually pendant to a cumulonimbus, with circulation reaching the ground (NWS 2009).

Description: Tornadoes generally form from severe thunderstorms, particularly supercell thunderstorms – those that are isolated with unimpeded inflow of moisture and enhanced by wind shear. Tornadoes may also form along squall lines or in bands of storms associated with hurricanes. Tornadoes require moist air, instability (warm air rising), a source of lift such as a front, dryline, or heating, and wind shear (change in wind direction and speed with height).

Tornadoes can occur at any time of the year in Texas and at any time of the day, although they are most common in spring and summer and in late afternoon to early nighttime hours.

Tornado intensity is rated by the damage they produce, on a scale from EF0 (weak) to EF5 (violent). Strong (EF2-EF3) and violent (EF4-EF5) tornadoes account for only about one-third of all tornadoes, but 97% of fatalities and the vast majority of economic impacts. Tornadoes along squall lines and hurricane bands are more likely to be weak, although widespread severe straight-line winds may accompany these types of storms.

Wildfire

Definition: Any free burning uncontrollable wildland fire not prescribed for the area which consumes the natural fuels and spreads in response to its environment (NWS 2009).

Description: Wildfires occur when weather conditions meet with sufficient fuel and an ignition source. Weather conditions include warm temperatures, low humidity, strong winds, and a period without precipitation allowing fuels to dry. Fuels are vegetation ranging from fine fuels such as grass and pine needles to large woody materials such as trees, dead and decaying logs, and organic material in the soil. Large woody materials are difficult to ignite. The presence of fine fuels allows fire to get started and become intense enough to ignite larger materials. Ignition sources may be natural, such as lightning, or human-caused, such as sparks from equipment, power transformers, a chain dragging behind a vehicle, or heat sources such as discarded cigarettes.

There are two wildfire “seasons” in Texas, although they can happen in any month. Fires are a common occurrence in late winter when dormant vegetation provides fine fuels and warm, windy, dry days provide weather conditions that allow ignition and spread. Summer has higher temperatures that can allow fires to become very intense, but there is typically less wind and consequently less spread. Fire spread may be increased on south-facing slopes, which are usually drier and warmer because of exposure to the sun, windy locations such as canyons, and along steep slopes. Very intense fires may become “crown fires” if they burn to the tops of trees, allowing embers to spread farther and create spot fires. Crown fires are almost impossible to extinguish without cooler, wetter weather conditions.

Fire danger is measured on a Burning Index scale, ranging from 0 to 110+. Values below 20 are considered low fire potential, 40-80 is high, and 110 or higher is extreme. The burning index combines potential energy release (fire intensity), flame length, and rate of spread. The National Weather Service issues Red Flag Warnings when weather conditions are favorable for ignition and spread of wildfires. Another popular index is the Keetch-Byrum Drought Index (KBDI) that considers weather and vegetation conditions. The scale ranges from 0 to 800, where values below 200 indicate high fuel moisture making ignition unlikely and values above 600 are indicative of intense wildfire conditions with any that develop capable of downwind spotting (starting new fires).

Winter Storm (Ice, Sleet, Snow)

Definition: A winter storm is a winter weather event that produces impactful accumulations of freezing rain (ice), sleet, and/or snow (NWS 2018).

Description: Winter storms may include heavy snowfall, blowing and drifting snow, high winds, extreme cold or ice storms. Among the greatest hazards associated with winter storms are traffic accidents. The most extreme instance is a blizzard, which is defined as winds greater than 35 mph, visibility less than ¼ mile, lasting at least 3 hours. New snowfall is not necessary for a blizzard, and blowing snow can similarly obscure visibility.

Winter storms are measured by snowfall accumulation or ice thickness. Winter storms occur in Texas between November and March and are usually created by large low-pressure systems moving rapidly across the country. In Texas, ice storms and freezing rain are a greater threat than blizzards. Access to moisture from the Gulf of Mexico falling over shallow cold air near the surface can produce ice accumulations of two inches or greater with tremendous damage to power distribution.

Dam or Levee Failure

Definition: A catastrophic type of failure characterized by the sudden, rapid, and uncontrolled release of impounded water or the likelihood of such an uncontrolled release. It is recognized that there are lesser degrees of failure and that any malfunction or abnormality outside the design assumptions and parameters that adversely affect a dam's primary function of impounding water is properly considered a failure. These lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure. They are, however, normally amenable to corrective action (USSD 2018).

Description: Dams help address the complex challenge of controlling and distributing water. They have been recognized as a key water management practice dating back to early civilizations of the Americas, ancient Egypt, and China. As water is a part of the hydrologic cycle, dams work to conserve water through reservoirs to prohibit flow back to the ocean. With the advancement of civilization and a growing population, water withheld in such reservoirs are an integral part of society and are a necessary source for energy, drinking water, irrigation practices, etc. Dams also protect areas of development and civilization from floods through flood control measures. Dam safety and maintenance standards have increased over time.

Earthquake

Definition: A sudden slip on a fault, with resulting ground shaking and radiated seismic energy caused by the slip, or by volcanic or magmatic activity, or other sudden stress changes in the earth (USGS 2018).

Description: Earthquakes occur from the sudden release of stress in the Earth's crust. Stress is built up by the motion of tectonic plates. Stress may also be built up through the injection of fluids. During an earthquake, rocks on either side of a fault line move either horizontally or vertically. This movement creates three types of waves: primary, secondary and rayleigh waves. Primary waves spread outward from the epicenter (source of the fracture) as compression, like a spring. Secondary waves vibrate at right angles to the direction of travel, and these are the most damaging. Rayleigh, or surface, waves move vertically, giving an undulating motion. Earthquake intensity is measured on the Moment Magnitude Scale. Each point represents a 10-fold increase in the wave amplitude and a 32-times increase in energy release.

The Meers fault, located in southwest Oklahoma, has the potential for producing a strong earthquake that could affect Texas, usually in the Panhandle. Additionally, Texas experienced a substantial increase in light (M4.0-4.9) and moderate (M5.0-5.9) earthquakes in recent years caused by wastewater injection from oil production, many of which are experienced in West Texas. An earthquake caused by the New Madrid fault, situated in the Mississippi Valley, could also impact Texas.

Poor Air Quality (Dust, Pollutants, Smoke)

Definition: The concentration of pollutants present in the air in a specific location. Poor air quality occurs when there is a high level of pollutants in the air (UCAR 2020).

Description: Air quality problems result from the accumulation of aerosols, such as dust, pollen, smoke, salt, or human-produced chemically-active compounds that build up in an area over time. Under normal conditions, winds disperse these aerosols and compounds, but sustained periods of light winds can allow buildup to unhealthy levels. Many aerosols are produced naturally but may have artificially elevated concentrations through burning (concentration of smoke and carbon monoxide) or agriculture. Industrial activities and urban environments add other sources of pollution, including photochemical smog which is produced from the interaction of sunlight with nitrous oxides (primarily from automobile engines) and volatile organic compounds. Ozone is a component of this smog.

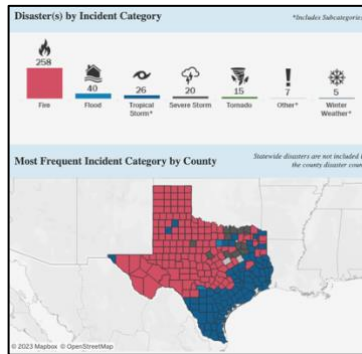
Air quality problems occur when dispersion – the ability of the atmosphere to spread pollutants over a large area – is inhibited. Temperature inversions, where a warm layer of air aloft prevents upward motion, and light winds, such as a large high-pressure system, provide favorable conditions for air quality events. Some pollutants, such as ozone, occur in higher concentrations during higher temperatures and more intense sunlight while others, such as smoke or dust, can accumulate in high concentrations any time of the year. Local and regional landscapes, such as mountain valleys, can also “trap” pollutants. Warmer summertime temperatures are likely to increase the concentration of pollutants such as ozone.

Concentrations of pollutants are measured and averaged over time. A time-averaged concentration is used because exposure to a high concentration of pollutants during a short time might have an impact equivalent to an exposure to a lower concentration over a longer time (American Meteorological Society). When the average exceeds public health regulations over a defined period, such as several hours or a day or a number of days per year, the area is noted as being noncompliant. One way to assess air quality for your location is to look at the daily Air Quality Index (AQI) issued by the U.S Environmental Protection Agency. AQI is calculated for five major pollutants including ground-level ozone, particle pollution (particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide.

Appendix B - Historical FEMA/Presidential Disaster Declarations by State, County, or Tribal Nation

The data visualization interactive reference page below displays statistics of disaster declarations for both states and tribal nations, dating back to 1953.

Disaster Declarations for States and Counties: <https://www.fema.gov/data-visualization-disaster-declarations-states-and-counties>



This page contains an interactive tool that allows the exploration of historic federal disaster declarations by state, county, hazard, and year. To access information from this page, first select a date range and state/territory from the menus. Information on federally declared disasters within the selected region will be displayed below.

The tool provides the following information:

- Number of disasters by hazard type, county, year, and month,
- The cumulative number of disasters by hazard type, and
- The complete list of federal disaster declarations.

Disaster Declarations for Tribal Nations: <https://www.fema.gov/data-visualization-disaster-declarations-tribal-nations>

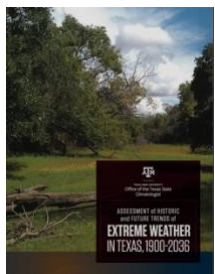
The screenshot shows the FEMA disaster declaration tool interface for tribal nations. It starts with a prompt "First, select a tribal nation." followed by a dropdown menu. Below that, it says "Then, learn about the 1 disasters that have occurred in Alabama and Coushatta Indian Reservation, since 1953." and provides a link to click on an incident to filter the declarations. At the bottom, there's a table with columns for "Year of Declaration" and "Disaster Number". The table shows one entry for the year 1988 with the disaster number 1239.

This page contains an interactive tool that allows the exploration of historic federal disaster declarations by tribal nation, hazard, and year. To access information from this page, first select a tribal nation from the drop-down list. Information on federally declared disasters within the selected region will be displayed below, organized by natural hazard. The in-depth analysis of a selected tribal nation will be similar to the information provided for disaster declarations of states and counties above.

Note: Not all of Texas' Tribal Nations are currently represented in this tool because they 1) have not yet declared a disaster, 2) have not met FEMA's financial threshold, or 3) have received assistance through the state instead of directly from FEMA. The amended 2013 Stafford Act allowing federally recognized tribes to directly declare disasters required a minimum threshold of \$1 million in damages. This large amount made it difficult for tribes to independently qualify for declarations. Beginning in January 2017, however, FEMA released pilot guidance which reduces the disaster declaration eligibility threshold to \$250,000. More information on this pilot guidance can be accessed here: <https://www.fema.gov/disaster/tribal-declarations>.

Appendix C - Climate Change Science and Projection Resources

The *Simple Planning Tool for Texas Climate Hazards v.1.1* is geared towards providing Texans with the most accurate and trustworthy data sources. The tool also identifies future climate trends for each hazard. As mentioned in the *A Note About Climate Change* (p. 4) section, below is a list of credible, up-to-date climate change science resources to consider for additional information beyond what the *Simple Planning Tool* provides.



Assessment of Historic and Future Trends of Extreme Weather in Texas, 1900-2036 (2021):

<https://climatetexas.tamu.edu/files/ClimateReport-1900to2036-2021Update>

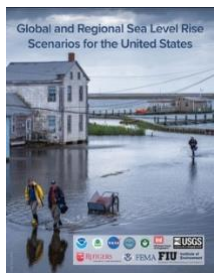
This report from the Office of the Texas State Climatologist at Texas A&M University describes the various natural hazards that threaten Texas. For each hazard, the report discusses the current state, historic trends, and the data available on the hazard. It also discusses the future trend of that hazard, if there is enough evidence to do so.



Climate of the Gulf Coast States: An Examination of Climate Change's Effects Across the Region (2021):

https://www.southernclimate.org/wp-content/uploads/Gulf_Coast_Climate.pdf

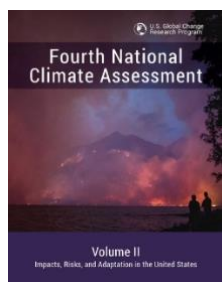
This four-chapter report is a product of FloodWise Communities, a National Academy of Sciences Gulf Research Program project led by the Southern Climate Impacts Planning Program (SCIPP), the Great Lakes Integrated Sciences and Assessments (GLISA), and the University of Oklahoma. The document includes an in-depth examination of the climate in TX, LA, AL, MS, GA, and FL. The chapters include: Geography and Average Climatology, Observed Changes in the Climate, Climate Modeling and Future Climate Change, and Climate Hazards.



Sea Level Rise Technical Report (2022):

<https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html>

This multi-agency report is a product of the Sea Level Rise and Coastal Flood Hazard and Tools Interagency Task Force and provides the most up-to-date sea level rise projections through 2150 for all U.S. coastal waters. This report synthesizes the science of sea level rise, informs decision makers and communities about their potential risks from current and future sea level rise, and is a key input to the Fifth National Climate Assessment (NCA5). A Companion Application Guide to integrate this information into planning processes and adaptation decisions is accessible at <https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html#application-guide> (click Download the Companion Application Guide to access the document).



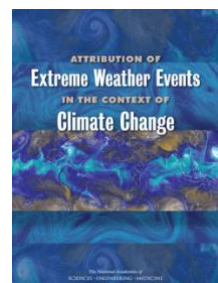
NCA4 Volume II: Impacts, Risks, and Adaptation in the U.S. (2018): <https://www.globalchange.gov/nca4>

The National Climate Assessment is a federally mandated quadrennial assessment of climate change in the U.S. and focus on several topics and sectors. This report was produced by a team of more than 300 experts guided by a Federal Advisory Committee, and was extensively reviewed by federal agency experts, the public, and the National Academies of Sciences, Engineering, and Medicine. Released in November 2018, it represents the second of two volumes of the Fourth National Climate Assessment (NCA4) and builds upon the work of the three previous assessments. There are nationwide and region-specific chapters that provide an assessment of climate change-related impacts, risks, and adaptation in the U.S. The assessment of the physical science used in this report can be read in NCA4 Volume I: Climate Science Special Report.



NCA4 Volume I: Climate Science Special Report (2017): <https://science2017.globalchange.gov>

This stand-alone report is an authoritative assessment of the science relating to climate change and its physical impacts, with a focus on the U.S. Released in November 2017, it was led by NOAA, represents the first of two volumes of the NCA4, and is mandated by the Global Change Research Act of 1990. The CSSR is designed to serve as the foundation for efforts to assess climate-related risks and inform decision-making about responses. The report provides 1) an updated detailed analysis of the findings of how climate change is affecting weather and climate across the United States; 2) an executive summary and other materials that provides the basis for the discussion of climate science found in the second volume of the NCA4; and 3) foundational information and projections for climate change, including extremes, to improve “end-to-end” consistency in sectoral, regional, and resilience analyses.



Attribution of Extreme Weather Events in the Context of Climate Change (2016):

<https://www.nap.edu/catalog/21852/attribution-of-extreme-weather-events-in-the-context-of-climate-change> (To access for free, the report can be viewed online or a PDF can be downloaded by creating a free account.)

This National Academies of Sciences, Engineering, and Medicine report examines the current state of science of extreme weather attribution and identifies ways to move the science forward to improve attributing capabilities. The following infographic provides an overview of the report and how climate change is affecting extreme weather: <https://www.nap.edu/resource/21852/extremeweather-infographic.pdf>.

Appendix D - Incentive and Action Programs for Hazard Risk Reduction

Below is a list of resources providing information on incentive and action programs intended to assist in reducing hazard risk for your community. The list is not comprehensive. Please reference the provided links for more information on each program.

All Hazards

Integrating Hazards into the Comprehensive Plan - Webinar (<https://www.planningforhazards.com/webinars>, scroll to bottom of page): This one-hour webinar focuses on how local governments and communities can reduce their risk and vulnerability by integrating hazard risk reduction strategies into their comprehensive plan. Colorado planners describe the processes, practices used, and lessons they learned when integrating hazards into their comprehensive plans. This webinar was developed in consideration for Colorado, but concepts can be similarly applied and adapted for Texas.

Natural Hazard Mitigation Saves: 2019 Report (<https://www.nibs.org/projects/natural-hazard-mitigation-saves-2019-report>): The National Institute of Building Sciences issued this report to highlight the benefit of four broad avenues for implementing mitigation strategies. (1) The Institute's project team analyzed 23 years of federally funded mitigation grants and found that hazard mitigation funding can save the nation \$6 in future disaster costs for every \$1 spent. (2) The team looked at scenarios that focus on designing new buildings to exceed provisions of the 2015 model building codes, and the findings revealed that investing in exceeding these building codes can save the nation \$4 for every \$1 spent. (3) They analyzed benefits of adopting 2018 I-Codes vs. 1990-era design for buildings and found that there's a national benefit of \$11 for every \$1 spent. (4) The team looked at private-sector retrofit for older buildings. Utilizing more modern retrofitting on existing residential buildings produces \$4 of national benefit for every \$1 invested.

Texas Mitigation Assistance Resource Guide (https://www.fema.gov/sites/default/files/documents/fema_mitigation-assistance-resource-guide-texas.pdf): FEMA Region 6 created this guide to compile many federal and state resources that offer potential funding or technical assistance for mitigation projects into one place. The guide includes a table with the program/resource name, resource type (grant, loan, or technical assistance), hazards addressed, and mitigation type (education and outreach, natural systems protection, planning and regulations, or structure and infrastructure). It also provides more details about the resource and next steps for Texas communities.

Hurricane/Coastal

HazardAware (hazardaware.org): The goal of this tool is to “enable everyone to access hazard, risk, vulnerability, resilience, and mitigation information so that they can make more informed and safer housing choices and learn how to mitigate hazard losses to their current homes.” It provides a HazardAware Score for millions of Gulf Coast homes based on environmental, community, and building characteristics to represent the resilience of the home. After entering an address, HazardAware walks users through several pages of information, including historic and future hazard risks in their community, community factors influencing their disaster resilience, and mitigation options to reduce the risk of their home and increase their home's resilience.

Flooding

National Flood Insurance Program (NFIP) (<https://www.fema.gov/national-flood-insurance-program>): This program “aims to reduce the impact of flooding on private and public structures by providing affordable insurance and encouraging communities to adopt and enforce floodplain management regulations. These efforts help mitigate the effects of flooding on new and improved structures...and reduces the socio-economic impacts of disasters.”

NFIP Community Rating System (CRS) (<https://www.fema.gov/national-flood-insurance-program-community-rating-system#>): CRS “is a voluntary incentive program that recognizes and encourages community floodplain management activities that exceed the minimum NFIP requirements.” As a result, community participation reduces policy holder flood insurance rates and ultimately flood damage to insurable property.

Reduce Flood Risk (<https://www.reducefloodrisk.org/>): This tool was built by the Flood Science Center at the Association of State Floodplain Managers (ASFPM) and was designed to help property owners, buyers, and renters understand what actions they can take to reduce their property’s flood risk. The ASFPM compiled a variety of flood mitigation resources into one simple, interactive platform. It offers a guided search by asking if you’re a property owner, buyer, renter, government official, etc., what type of property you have, the foundation of the property, and more. You can also explore strategies by category. The tool ultimately points users to actions they can take to reduce their property’s flood risk with detailed descriptions about those actions.

Severe Thunderstorms: Wind (Tornadic and Straight-Line) and Hail

Insurance Institute for Business and Home Safety (IBHS) Fortified Homes Program (<https://disastersafety.org/fortified/resources/>): This program is a set of engineering and building standards designed to help strengthen new and existing homes through system-specific building upgrades to minimum building code requirements that will reduce damage from specific natural hazards. Relevant to Texas hazards, their research includes standards for high winds and hail. Some insurance companies offer discounts for having wind-resistant construction and/or hail-resistant shingles. Contact local insurance providers for more information and applicability.

Wildfire

Community Planning Assistance for Wildfire (CPAW) (<https://cpaw.headwaterseconomics.org/resources/>): The CPAW program provides communities with training and technical resources to improve land use planning in the wildland-urban interface. Their list of provided materials includes webinars, presentations, handouts, and posters. **Note:** As this is a national program, some of these materials may not be applicable to Texas conditions.

Wildfire Risk to Communities (<https://wildfirerisk.org/reduce-risk/>): This website provides a list of resources and programs for communities to reduce and manage wildfire risk. The available topics include home ignition zone, home hardening, land use planning, wildfire preparedness, community health, wildfire prevention, wildfire response, fuel treatments, and post-fire recovery. Under any of these topics, users can view relevant information and community tools, including programs available to take action for the community.

Appendix E – Other Miscellaneous Resources

Below is a list of resources that did not fit into any of the other sections, but the authors still felt were useful to include:

Plans

Texas Coastal Resiliency Master Plan (<https://www.glo.texas.gov/coastal-grants/projects/files/Master-Plan.pdf>): The Texas Coastal Resiliency Master Plan was released in 2019 by the Texas General Land Office and was designed to create resilient coastal communities to reduce vulnerability to coastal hazards, including coastal erosion, sea level rise, coastal storm surge, habitat loss and degradation, and water quality degradation. The plan builds off the first version from 2017 and includes resiliency strategies, including high-priority Tier 1 projects, to address these hazards across four coastal regions of Texas. It also provides solutions that can help restore the natural environment.

Surveys

USDA Web Soil Survey (<https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>, click *Start WSS* button towards top of page): With this tool, you can select an area of interest (less than 100,000 acres) and view the type of soil in that area. This provides information on not only what the soil types are in that area, but the qualities and properties of each kind of soil, and how much of that area is made up of each kind of soil. Soil information can be valuable for several types of planning.

National Wetlands Inventory Wetlands Mapper (<https://www.fws.gov/wetlands/data/Mapper.html>): This U.S. Fish and Wildlife Service tool allows users to view wetland types in extreme detail. Simply zoom and pan to, then click on the area of interest. In a popup window, the tool will give you the type of wetland for that area. There is a detailed description of the wetland types as well as reports that are relevant to that area.



Southern Climate Impacts Planning Program

University of Oklahoma • Louisiana State University • Texas
Sea Grant • Adaptation International

www.southernclimate.org



SCIPP
A NOAA CAP TEAM



**Climate Adaptation
Partnerships**
Formerly RISA

