SIMPLE PLANNING TOOL

FOR OKLAHOMA CLIMATE HAZARDS

VERSION 1.7 (JANUARY 2023)

SCIPP
A NOAA CAP TEAM

NOAA Climate Adaptation Partnerships
Formerly RISA

TABLE OF CONTENTS
(Subtopics below are clickable)

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 Oklahoma 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 Oklahoma Climate Hazards* was produced by the Southern Climate Impacts Planning Program (SCIPP, www.southernclimate.org).

> **The tool may be accessed online at http://www.southernclimate.org/wp-content/uploads/SPTOK.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

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User Instructions

This document is alphabetically organized by climate hazard (p. 5-17) and three other hazards (p. 18-20). 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 climatology 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.

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 go undetected, and affect 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 these only dates back to 2000.

Historical Climatology			
U.S. Drought Risk Atlas (period of record varies by state) 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 *Oklahoma* to search by state or zoom in on the map, then search by location. **2.** Select a location from the *Station List* on the right → then click *Update Station*. **3.** Below, there are a variety of drought indicator tabs to explore. An example is the *Heatmap* option that shows monthly (or weekly) values of indicators. Oranges (reds) show periods of severe (extreme) drought. Tool Link: http://droughtatlas.unl.edu/Data.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. It can also be used to help estimate the probability of future precipitation and hence drought events. **1.** On the left side column (moving from top to bottom) choose *Oklahoma → Climate division of interest → Annual → Precipitation*. **2.** When the cursor is hovered over a point, the year's total annual rainfall will be displayed. Tool Link: http://charts.srcc.lsu.edu/trends/	
U.S. Drought Monitor Statistics Graph (2000-present) National Drought Mitigation Center	This interactive graphing tool shows the frequency of drought conditions since 2000, along with each drought's maximum intensity and duration (shown by color scale). The U.S. Drought Monitor is the official source for aid decisions by the USDA and several other agencies and programs. **1.** In top banner, next to *Area Type*, choose either *Climate Division* or *County*. **2.** Next to *Area*, either type in *OK* to select climate division of interest or type in county of interest. **3.** Next to *Index*, select *USDM*. **4.** Zoom in by clicking inside graph and dragging over specific time-period. Tool Link: http://droughtmonitor.unl.edu/Data/Timeseries.aspx	
Water Reservoir Visualization Tool (2004-present) Southern Regional Climate Center & the Southern Climate Impacts Planning Program	This interactive tool displays recent and historical reservoir elevations, the relationship between current conservation and flood pool levels, and precipitation data from nearby stations all on one page. If correlated to drought cycles and/or precipitation trends, this tool can be used to show the impacts of drought on water supplies which can affect drinking and irrigation water supplies. **1.** In upper left, under *State*, select *Oklahoma*. **2.** Select a reservoir from the map or drop-down list. **3.** Scroll down and use select information provided. Tool Link: http://reservoir.srcc.lsu.edu/	

Future Trend	
	Drought has always been part of Oklahoma's climate because of highly variable precipitation patterns. However, droughts are projected to increase in severity and frequency due to climate change. Even if annual precipitation amounts do not change much, higher temperatures will increase evaporation from lakes, soils, and plants, stressing agriculture and natural systems. Models project that Oklahoma will experience a decrease in soil moisture across all seasons by the end of the century, with the greatest decrease in the summer (Wehner et al. 2017). Further, rising temperatures will lead to increased demand for water and energy, which could stress natural resources (Shafer et al. 2014).

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, county, or tribe in Oklahoma 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 1895. Other stations, such as those run by the Oklahoma Mesonet, have only existed since 1994 but have a relatively high spatial density. **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 under-estimate 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 Oklahoma State Climatologist, Gary McManus, at gmcmanus@mesonet.org or 405-325-2541.**

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 the global climate is changing at a rate at which we have not experienced before in modern times, and increasing evidence shows that humans are a primary influence behind this rate of change. However, the changes we are experiencing and can expect to experience in Oklahoma 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. For 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 beyond the scope of this project and the expertise of the authors. If future resources support further research, additional versions of the *Simple Planning Tool for Oklahoma Climate Hazards* may include impact data.

Cold Extremes

Data Limitations: Oklahoma 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 record dating back to the 19th century; however, some station locations include gaps in records that could be subject to technical issues or changes in monitoring location.

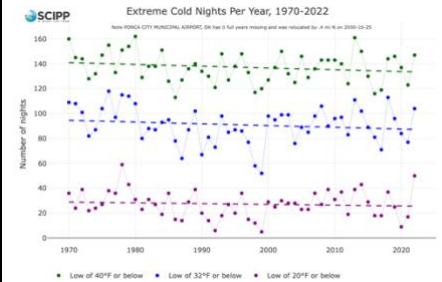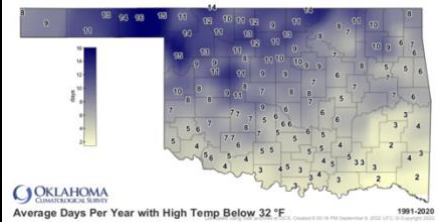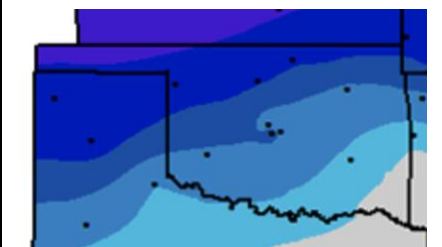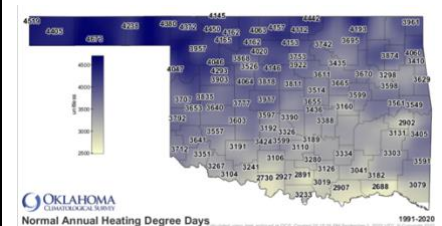| Historical Data			
	Temperature Trends Dashboard (1970-2022) Southern Climate Impacts Planning Program	This tool shows temperature trends at individual stations across Oklahoma, including trends in extremely cold nights, seasonal extreme and average high/low temperatures, and heating degree days, since 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/	
	Highs and Lows Below 32°F (1991-2020) Oklahoma Climatological Survey	These static maps show the average number of days each year that the high and low temperature is less than 32°F. The maps can be used to understand the total number of days per year in which in which your area might experience high or low temperatures below freezing. **1.** Scroll to the middle of the page. **2.** Click on map of interest from the following: *average number of days with highs below 32°F* and *average number of days with lows below 32°F.* Tool Link: http://climate.ok.gov/index.php/climate	
	Wind Chill Days and Hours (1973-2019) Midwest Regional Climate Center	This set of maps depict the average number of days, day 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 top right side of the map. Tool Link: https://mrcc.purdue.edu/clim/windChill/index.jsp	
	Average Annual Heating Degree Days (1991-2020) Oklahoma Climatological Survey	This static map shows the average annual heating degree days (HDD), a measurement used to quantify the demand for energy needed to heat buildings. **1.** Scroll to the middle of the page. **2.** Click on *average annual heating degree days (HDD)* link. Tool Link: http://climate.ok.gov/index.php/climate	

Cold Extremes (Continued)

Historical Data

Freeze Dates

(1991-2020)

Oklahoma Climatological Survey

These static maps show the average dates of earliest first fall freeze, average first fall freeze, latest first fall freeze, earliest final spring freeze, average final spring freeze, and latest final 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. Scroll to middle of page to view the *Fall and Spring Freeze Maps*. **2.** Click one of the six map options to view a larger map.

Tool Link: http://climate.ok.gov/index.php/climate
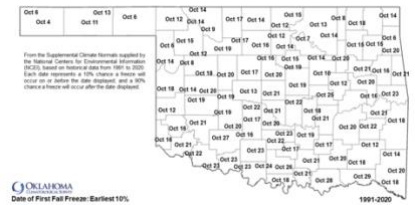
Record Low Temperatures

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

Southern Regional Climate Center

This tool displays the lowest recorded temperature 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/

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/
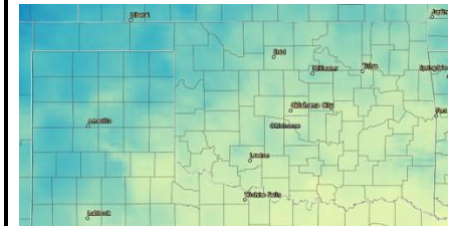
Oklahoma has consistently observed a below average number of very cold winter nights since 1990 (Frankson et al. 2022). Historically unprecedented winter warming is projected by the end of the 21st century under a higher emissions scenario. Extreme cold events will continue to impact Oklahoma; however, they will occur less frequently and with less intensity (Vose et al. 2017). 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. By mid-century, models are projecting that Oklahoma will see 10 to 30 fewer days below 32°F, with the greater reduction being across the northern two-thirds of the state. 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 (Vose et al. 2017). Read more about future cold extremes in the resources found in Appendix C.

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, these only date back to 2000.

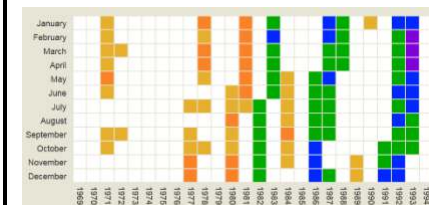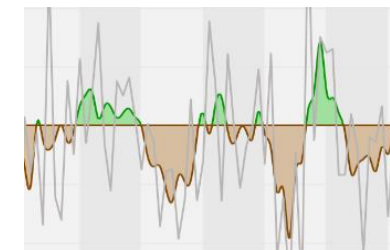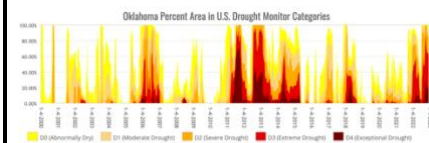| Historical Data			
	U.S. Drought Risk Atlas (Period of record varies by station; up to ~110 years) National Drought Mitigation Center	This interactive tool provides historical drought indices at a local level and can identify drought periods at different levels of severity, duration, and frequency. **1.** On the left side, select *Oklahoma* 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. It can also be used to help estimate the probability of future precipitation and hence drought events. **1.** On the left side column (moving from top to bottom) choose *Oklahoma → Climate Division of Interest → Season of Interest → Precipitation*. **2.** Hovering the curser 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* on the bottom left.	
		Tool Link: http://charts.climate.lsu.edu/trends/	
	U.S. Drought Monitor Time Series (2000-present) National Drought Mitigation Center	This interactive graphing tool shows the frequency of drought conditions since 2000, along with each drought's maximum intensity and duration (shown by color scale). The U.S. Drought Monitor is the official source for aid decisions by the USDA and several other agencies and programs. **1.** In the top banner, next to *Area Type* choose either *Climate Division* or *County* **2.** Next to *Area*, either type in *OK* to select climate division of interest or type in county of interest. **3.** Next to *Index*, select *USDM*. **4.** Zoom in by clicking inside graph and dragging over a specific time-period.	
		Tool Link: https://droughtmonitor.unl.edu/DmData/TimeSeries.aspx	

Drought (Continued)

Historical Data

**National Water Information System Tool**

(Period of record varies by station; up to ~70 years)

U.S. Geological Survey

This interactive tool displays recent and historical reservoir storage and streamflow, along with water quality and meteorological parameters. If correlated to periods of drought, this tool can be used to show the impacts of drought on water resources which can affect drinking and irrigation water supplies.

1. Select a county from the list. **2.** Under *Water Level/Flow Parameters*, select *Reservoir storage* and/or *Streamflow*. **3.** Under *Choose Output Format*, scroll down to *Retrieve data for*. Select the option *for the date range:* and enter your desired dates. Some stations go back as far as 1950. If you select this year, the graph will display all available data. **4.** Under *Output Options*, select *Graphs of data with long-term statistics* to display the data in a graph. **5.** Click *Submit*. **6.** The results page includes graphs of all stations in the county.

Tool Link: https://waterdata.usgs.gov/ok/nwis/uv?referred_module=sw&search_criteria=county_cd&submitted_form=introduction
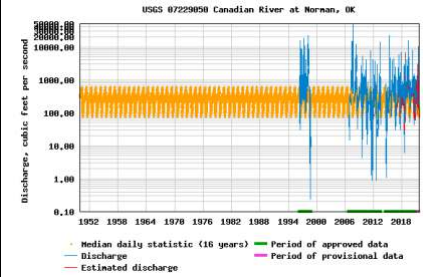
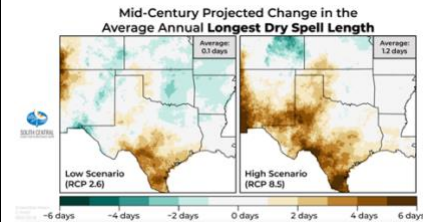## Future Trends

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. for 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 Oklahoma's climate because of highly variable precipitation patterns. However, droughts are projected to increase in severity and frequency in the future (Frankson et al. 2022). Even if annual precipitation amounts do not change much, higher temperatures will increase evaporation from lakes, soils, and plants, stressing agricultural and natural systems. Models project that Oklahoma will experience a decrease in soil moisture across all seasons by the end of the century, with the greatest decrease in the summer (Wehner et al. 2017). Further, rising temperatures will lead to increased demand for water and energy, which could stress natural resources (Shafer et al. 2014). Read more about future drought in the resources found in Appendix C.

Hail

Data Limitations: Hail data are not of sufficient quality to robustly determine historical trends and is 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 acknowledgement to assess the number of hail days instead of individual hail reports has mitigated some of the biases.

Historical Data

Severe Hail Days Per Year

(1986-2015)

NOAA/National Weather Service Storm Prediction Center

This map shows the average number of days per year in which severe hail reports were received in your area during the period noted. The map gives you a sense of the approximate number of days each year that you can expect to see severe hail (1-inch or greater in diameter) in your area. The 2-inch or greater map is also available for viewing.

1. Click on the link below to go to the website **2.** Select *1.00-Inch Hail Days* or *2.00-Inch Hail Days.*

Tool Link: http://climate.ok.gov/index.php/climate/category/tornadoes_severe_storms
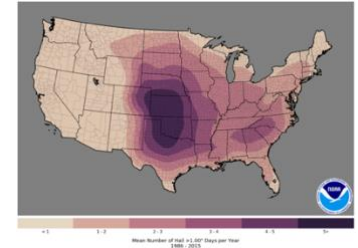
Severe Hail Reports

Hail: (1955-present)
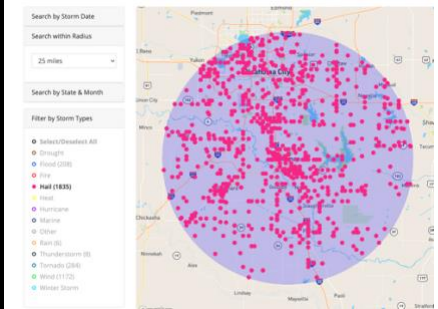
Southern Regional Climate Center

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

1. On left side of screen, click on *Search with Radius*. **2.** Choose the diameter of the area of which you want to investigate (25 or 50 miles). **3.** 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 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 shows you 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 *Oklahoma* → 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.** Under *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.***

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

Future Trends

Hail is commonly associated with severe thunderstorms. Climate models project an increase in the frequency and intensity of severe thunderstorms, and events with *large* hail are projected to increase (Kossin et al. 2017). At the same time, models project an overall decrease in the number of days with hail per year (Brimelow 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).

Heat Extremes

Data Limitations: Oklahoma generally has good quality long-term data records for temperature values, however, the consistency of cumulative years on record vary by station. The majority of stations consist of a large record dating back up to the 19th century, however, some station locations include gaps in records that could be subject to technical issues or changes in monitoring location.

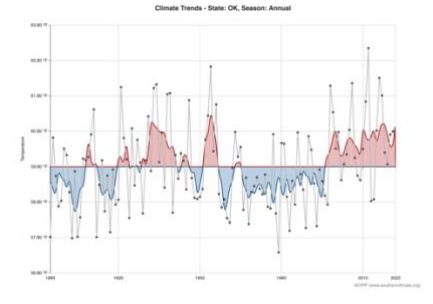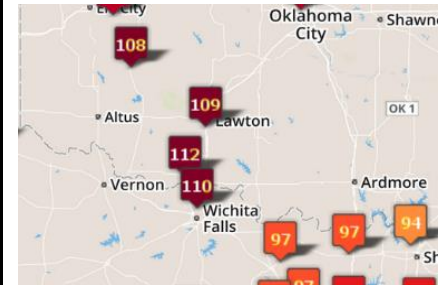|			
Historical Data	**Historical Climate Trends Tool** (1895-present) Southern Climate Impacts Planning Program	This interactive graphing tool shows annual, seasonal, and monthly temperature trends by state and climate division. It can be used to gain a general understanding of temperature trends and show previous periods of higher temperatures, as well as years of extreme temperature. It could also be used to help estimate the probability of future extreme temperature events. **1.** On left side of screen (from top to bottom) select *Oklahoma → 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/	
	Climate Extremes Tool -Temperature (Period of record varies by station; up to ~120 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 left side of screen (from top to bottom) select *Records For A Month → High Max Temperature → Month of Interest → Go*. **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→ Go*. **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/	
	Temperature Trends Dashboard (1970-2022) Southern Climate Impacts Planning Program	This tool shows temperature trends at individual stations across Oklahoma, 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/	
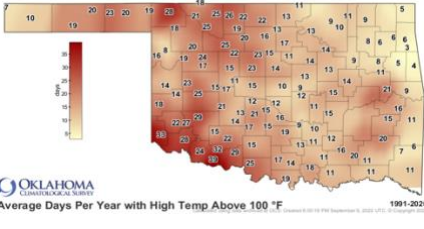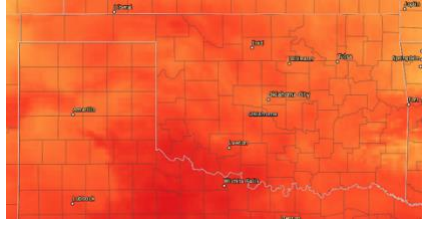
Heat Extremes (Continued)

Historical Data	**Heat Index Days and Hours** (1973-2018) Midwest Regional Climate Center	This set of maps depict the average number of days, day 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, 110°F, 105°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 heat index value of interest to view the corresponding data on the map. **3.** To interpret the colors, see the legend on the top right side of the map. Took Link: https://mrcc.purdue.edu/clim/heatIndex/index.jsp	
	Average Number of Days with Highs Above 90°F or 100°F; Cooling Degree Days (1991-2020) Oklahoma Climatological Survey	These static maps show the average number of days per year when the high temperature is above 90°F or 100°F. There is also a map of the average annual cooling degree days between 1991-2020. **1.** Scroll to the second row of maps on the page. **2.** Click on *Average number of days with highs above 90°F* (or *100°F*), or *Normal Annual Cooling Degree Days (CDD)*. Tool Link: http://climate.ok.gov/index.php/climate	
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 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. **1.** Type in the city or county you are interested in. **2.** Click *Climate Maps*. **3.** From the drop-down menu, select *Days w/ max temp > 90* (or other option up to *105°F*), *Days w/ min temp > 80°F* (or *90°F*), or *Cooling Degree Days* **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. Tool Link: https://crt-climate-explorer.nemac.org/	

Heat Extremes (Continued)

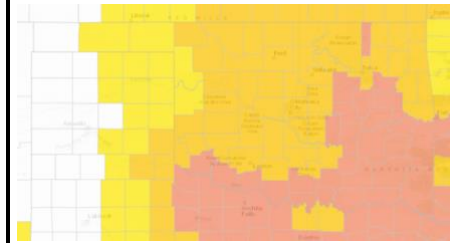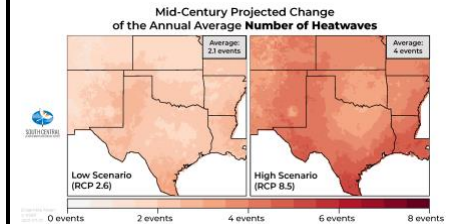|			
Future Trends	**Killer Heat Tool** (1971-2099) Union of Concerned Scientists	This interactive mapping tool shows the number of days with maximum heat index above 90°F, 100°F, 105°F, and 'off the charts' (exceeding the upper limits of the NWS heat index scale) for each U.S. county over the historical 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. **1.** At the top of the tool, click the *Above 90*, *Above 100*, *Above 105*, or *Off the Charts* 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 *with no action on climate change, with slow action on climate change,* or *with rapid action on climate change* for the *Midcentury* or *Late Century* 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 *Military Bases at Risk* tab at the top of the page. Tool Link: https://ucsusa.maps.arcgis.com/apps/MapSeries/index.html?appid=e4e9082a1ec343c794d27f3e12dd006d	
	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 United States since the mid-1960's (Wuebbles et al. 2017b). Warming in Oklahoma has occurred mostly during the winter and spring seasons (Frankson et al. 2022). As the global temperature continues to increase, the occurrence and intensity of extreme heat events are projected to increase as well (Wuebbles et al. 2017b). As seen from the Climate Explorer tool, the average temperature across Oklahoma is projected to increase by up to 7°F and the number of days over 100°F could increase by ~15-45 days per year by mid-century, depending on the emissions scenario. Read more about future heat extremes in the resources found in Appendix C.		

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.

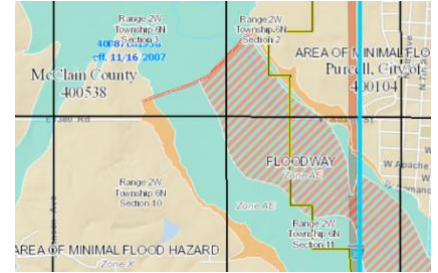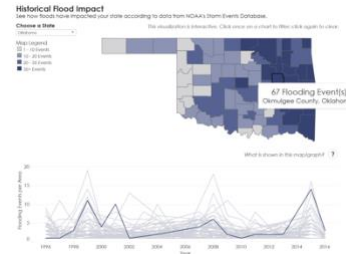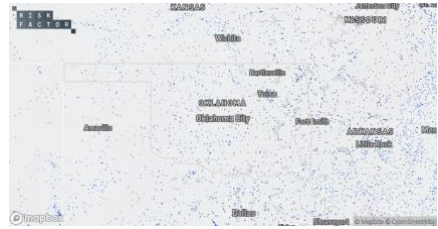|			
Historical Data	**Climate Extremes Tool - Precipitation** (Period of record varies by station; up to ~120 years) Southern Regional Climate Center	Interactive map shows precipitation extremes at airport weather stations, which can be used to show some previous heavy rainfall occurrences (i.e. the highest rainfall totals do not necessarily occur at airport weather stations). **1.** Pan and zoom to location of interest. **2.** To obtain *High precipitation records by month:* On left side of screen select *Records For A Month → High Precipitation → Month of interest → Go.* **3.** Measurement unit is inches. Mouse over icon for record details (date of occurrence and station record). **4.** To obtain *All-time records:* Select *All-Time Records → High Precipitation → Go.* Tool Link: https://www.srcc.tamu.edu/extremes/	
	NOAA Atlas 14 Precipitation Frequency Data Server (Last updated in 2013) 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. Such values will be available through an additional tool in the near future. **1.** Click on *Oklahoma* from the map. A new screen will open. **2.** To select a location, either enter the desired location, station, or address manually OR select a station from 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	
	Historical Climate Trends Tool (1895-present) Southern Climate Impacts Planning Program	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, must be correlated with other data. **1.** On the left side of the screen, select *Oklahoma*. **2.** Select climate division of interest or 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 (>=)* 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/	

Historical Data

FEMA Flood Map Service Center

Federal Emergency Management Agency

Website can be used to locate and identify flood hazard zones in a jurisdiction and produce maps for inclusion 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: 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.*

1. Enter an address, place, or coordinates in the search bar near the top of the page. **2.** Click *Search*. **3.** Click *Streets* view in upper right corner of the map. **4.** The panel of land outlined in light blue is the one that will be mapped. If you need a different panel, click on the one of interest (Zoom out if needed. It may take a few seconds for it to be selected). **5.** Zoom in to view details in map such as those shown at right. Note legend below map and effective date in bold above the map. **6.** To download a black & white static image of full original FIRM panel, click on *Map Image* icon. **7.** To access a colored map, click on *Dynamic Map* icon. You may need to disable your browser's pop-up blocker.

Tool Link: https://msc.fema.gov/portal

Flood Impacts by River Crest Height

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

National Weather Service Arkansas-Red Basin River Forecast Center

Interactive tool shows a summary of flood impacts for location of interest. It can be used to show the extent of flood events.

1. On map, pan and zoom to area of interest. **2.** Double-click on stream gauge of interest (small circle) on the map. **3.** Click *River at a Glance* tab near top of page. **4.** Left column: Select gauge of interest. Right column: At a minimum, select *Flood Impacts*, *Location Map*, *Record Crest History*. **5.** Click *Make my River Page!* **6.** Information you selected will be displayed on a new page.

Tool Link: https://www.weather.gov/abrfc/

Historical Flood Risk and Costs

(1996-present)

Federal Emergency Management Agency

Map visualization and graphs show 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 *Choose a State*, select *Oklahoma*. **2.** Oklahoma 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

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 *Flood Factor* 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/

Future Trends

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Climate Explorer – Climate Maps and Graphs Tools

(1950-2099)

NOAA Climate Program Office and National Environmental Modeling and Analysis Center

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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/

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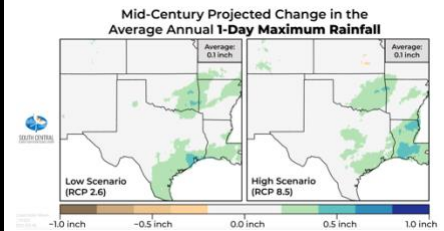**Precipitation Projections**

(2036-2099)

South Central Climate Adaptation Science Center

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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/

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Mid-Century Projected Change in the Average Annual **1-Day Maximum Rainfall**

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Heavy rainfall and flooding have always been part of Oklahoma's climate. Annual precipitation has increased over the vast majority of Oklahoma, with the highest change occurring in winter. According to Easterling et al. (2017), heavy rainfall (top 1% of annual events) increased by 12% between 1958 and 2016. Seasonally, rainfall is projected to increase in winter and spring and decrease in summer and fall by the end of the 21st century, but projected changes are small compared to natural variations. There is strong confidence that there will continue to be an increase in the frequency and intensity of heavy rainfall events over the 21st century (Easterling et al. 2017), which increases the chance of flooding. However, flooding is a locally complex phenomenon and can be exacerbated by human action (or inaction) as much as it can be caused by atmospheric conditions.

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.

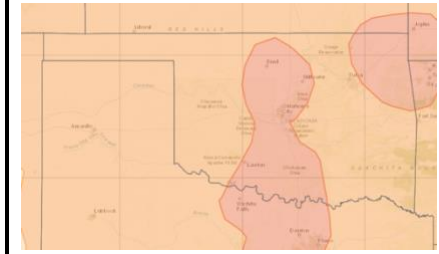|			
Historical Data	**Lightning Climatology Tool** (1995-2019) NOAA/National Weather Service Storm Prediction Center	This tool provides a daily and hourly lightning climatology, showing the probability of at least one cloud-to-ground (CG) lightning strike occurring each day of the year or each 1-hour 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 (1996-2016) NOAA National Severe Storms Laboratory/ Cooperative Mesoscale Meteorological Studies	These static maps show the cloud to ground lightning density (strikes per km^2) over Oklahoma, averaged over the years 1996-2016. There are five maps on the website that display annual and seasonal (winter, spring, summer, and fall) densities. **1.** Click on the link to access the Oklahoma Climatological Survey's *Tornadoes & Severe Storms* climatology page. **2.** Select lightning map(s) of choice from the following: *Yearly Lighting Density, Winter Lightning Density, Spring Lighting Density, Summer Lightning Density, Fall Lightning Density.* **3.** Analyze your lightning frequency based on county lines. Tool Link: http://climate.ok.gov/index.php/climate/category/tornadoes_severe_storms	
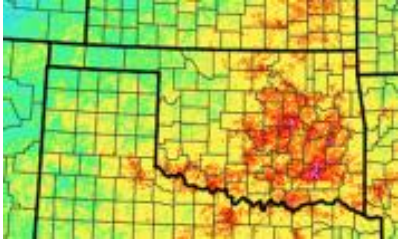
Lightning (Continued)

Historical Data	**Vaisala Annual Lightning Report** (Varies by year of report) Vaisala	This static report has been updated annually since 2017 and includes maps of average cloud-to-ground flash density and total lightning density for the previous 5-10 years in the U.S. It offers high-resolution local and county-level maps and information. **1.** Click on the link to access Vaisala's homepage. **2.** In the search bar at the top of the page, type *annual lightning report* then click the button. **3.** In the list of search results, scroll to find the most recent lightning report, such as *Annual Lightning Report 2020*. **4.** Select your desired report and click the title to download the PDF. Scroll down the document to view U.S. Cloud-to-Ground Flash Density Maps in high resolution and aggregated by county. Took Link: Vaisala.com	
Future Trends	Lightning is associated with thunderstorms, so as more favorable environments for thunderstorms are expected across the United States, increases in lightning are also projected. Studies have shown an increase in lightning associated with severe storms (Schultz et al. 2011). Climate models project an increase in the frequency and intensity of *severe* thunderstorms (Kossin et al. 2017), therefore, lightning occurrences are likely to 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).		

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).

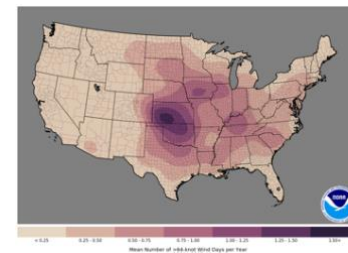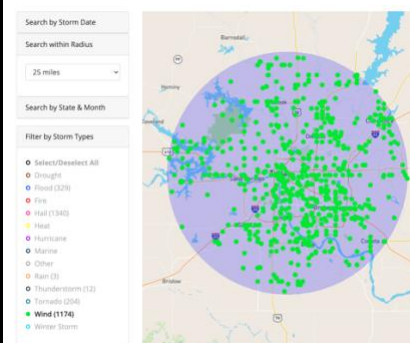|			
Historical Data	**Severe T-Storm Wind Days Per Year** (1986-2015) NOAA/National Weather Service Storm Prediction Center	This map shows you the average number of days per year in which severe thunderstorm wind reports were received in your area. The map gives you a sense of the approximate number of days each year that you can expect to see severe thunderstorm winds (57 mph or greater) in your area. **1.** Click on the link to access the Oklahoma Climatological Survey's *Tornadoes & Severe Storms* climatology page. **2.** Select *50 Knot Wind Days* or *65 Knot Wind Days*. Tool Link: http://climate.ok.gov/index.php/climate/category/tornadoes_severe_storms	
	Severe T-Storm Wind Reports Wind: (1955-present) Southern Regional Climate Center	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 close to your area. **1.** On left side of screen, click on *Search within Radius*. **2.** Choose the diameter of the area of which you want to investigate (25 or 50 miles). **3.** Select *Wind* (de-select Torn and Hail). **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, *Recent Storm Reports* and *Historical Storm Reports*. 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 *Scale* column headers to sort by the highest wind value. Tool Link: https://www.srcc.tamu.edu/storm_reports/	
	Severe T-Storm Watch Climatology Map (1993-2012) NOAA/National Weather Service Storm Prediction Center	This map shows you 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). **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 the *average number of severe thunderstorm 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	Damaging winds in Oklahoma are associated with severe thunderstorms. More favorable environments for severe thunderstorms are expected and increases in severe wind occurrences are projected. Climate models project an increase in the frequency and intensity of severe thunderstorms over the Southern Great Plains, especially during the peak storm season (March, April, May). Uncertainty remains, however, in the assumption that the favorable environments will reach their potential of producing damaging winds (Kossin et al. 2017).		

Tornado

Data Limitations: Tornado reports prior to around 1980 were compiled from written records. Consequently, many tornadoes may have gone unreported or multiple tornadoes may have been listed as a single track. 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**. For more information, select either *Track* or *County* and click on area of interest on the map.

Tool Link: http://mrcc.purdue.edu/gismaps/cntytorn.htm#
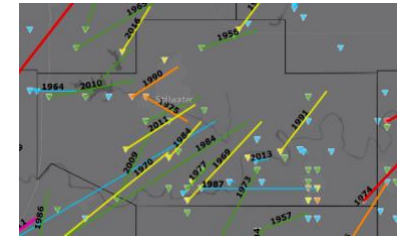
Tornado Risk Assessment

(1950-2019)

NOAA/National Weather Service Storm Prediction Center

This site is 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 per 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 zip code of interest. **2.** Click *Run*. **3.** Details about tornadoes that have occurred within selected area are displayed on the page.

Tool Link: http://www.spc.noaa.gov/climo/online/probs/
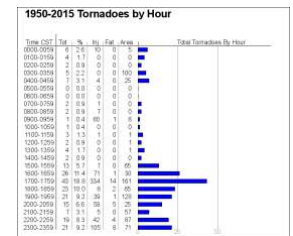
Tornado Days Maps

(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. Click on the link to access the Oklahoma Climatological Survey's *Tornadoes & Severe Storms* climatology page. **2.** Select from the following: *Tornado Days*, *EF1+*, *EF2+,* or *EF4+ Tornado Days*.

Tool Link: http://climate.ok.gov/index.php/climate/category/tornadoes_severe_storms

Tornado Watch Climatology Map
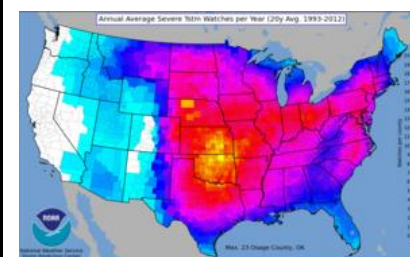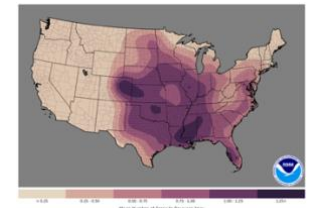
(1993-2012)

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/
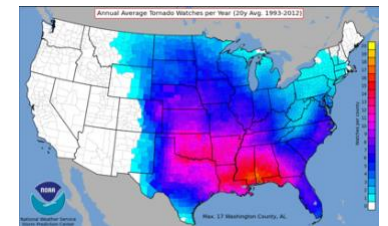
Future Trends

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). In other words, increasingly, when tornadoes occur, they are more likely to occur in conjunction with a tornado outbreak. It is currently difficult to account for tornadoes in climate models because they occur on a very small scale. Therefore, more research is needed to understand how climate change is influencing tornadoes (Walsh et al. 2014). Progress has recently been made, however, in understanding how the large-scale climate system relates to the conditions that support tornadoes. As such, climate models project an increase in the frequency and intensity of severe thunderstorms, which can include tornadoes, most commonly during the months of March, April, and May. However, confidence in the details of this projected increase remains low (Kossin et al. 2017).

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.

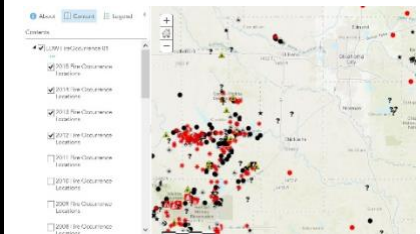|			
Historical Data	**National Interagency Fire Occurrence** (1992-2018) K. C. Short/ U.S. Department of Agriculture Forest Service	This interactive tool can be used to show locations of reported fire occurrences between 1992-2018, in and near a county or city. Individual years can be viewed to determine 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 Oklahoma 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 *OK* → 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 righthand 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	
	Southern Wildfire Risk Assessment Portal (Wildfire Ignition Density: 1997-2002; other layers based on various risk assessments) Southern Group of State Foresters	This interactive tool can be used to identify areas within and/or near a city that are at greatest risk of wildfire. It is especially useful for identifying risk areas in the wildland-urban interface and to help prioritize areas where tactical analyses, community interaction, or mitigation treatments might be necessary to reduce risk. *Note: There is a learning curve associated with this tool. Public Viewer is accessible to anyone. Professional Viewer is also free but requires account request.* **1.** Click on the link and select *Public Viewer* near the bottom of the screen. **2.** Pan and zoom-in on the map to area of interest. **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.** Pan and zoom-in or -out on map as needed. *Note: Data are displayed at a very fine (25-meter) resolution.*	
		Tool Link: https://www.southernwildfirerisk.com/	
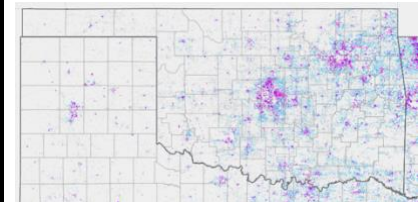
Wildfire (Continued)

<table>
<tr>
<td rowspan="3">Historical Data</td>
<td>Prescribed Fire Climatology

(1996-2015)

Southern Climate Impacts Planning Program</td>
<td>This scientific report includes a series of static graphics and tables. It can be used to identify the best months to conduct prescribed burns as a wildfire management strategy. Coupled with tools such as SouthWR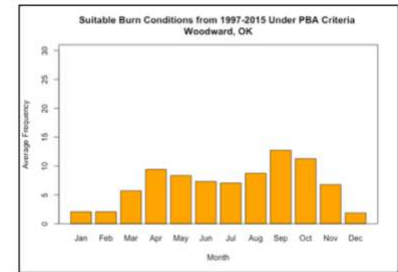AP, one can target locations and timing for safe burning along the wildland-urban interface. The report describes the average, minimum, and maximum number of days with a consecutive 4-hour period suitable for prescribed fire as a management tool to reduce vegetation fuel load and improve vegetation health.

1. Click on the report link. 2. Tables and Figures relevant to Oklahoma: Tables 2 and 7, Figures, 7, 8, 13-17, 25.

Tool Link: https://www.southernclimate.org/wp-content/uploads/Changing_Fire_Regimes.pdf</td>
<td></td>
</tr>
<tr>
<td>Wildland-Urban Interface

(1990, 2000, 2010)

University of Wisconsin-Madison SILVIS Lab</td>
<td>This interactive tool shows WUI (Wildland-Urban Interface) in 1990, 2000, and 2010 for locations of interest.

1. Zoom into desired location(s) on map. 2. On left side of screen, select year → base map → and layer opacity of interest. Note: Oklahoma-specific data and map files (down to the county level) are available by scrolling down the page.

Tool Link: http://silvis.forest.wisc.edu/data/wui-change</td>
<td></td>
</tr>
<tr>
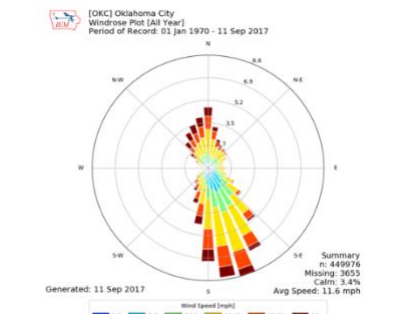<td>Wind Rose Plots

(Period of record varies by station; up to ~85 years)

Iowa Environmental Mesonet, Iowa State University</td>
<td>View common and prominent wind speeds and directions for your area. Plots can be viewed either by month or by the full years on record. This tool can be used to describe general climate and the predominant direction in which air pollutants flow. It may also be useful for understanding how wildfire events may evolve or play out in a community.

1. In the Select By Network section, choose Oklahoma ASOS then click Switch Network. 2. Select station of interest, either from list or map, then click Select Station. 3. You will be brought to a new page. Near the top of the page, click on the Wind Roses tab. 4. Yearly climatology is displayed at the top of the page and monthly climatologies are displayed below that.

Tool Link: https://mesonet.agron.iastate.edu/sites/locate.php</td>
<td></td>
</tr>
<tr>
<td>Future Trends</td>
<td colspan="3">Between 1984 and 2011, the number of large wildfires increased in the Southern Plains, which includes Oklahoma (Wehner et al. 2017). Wildfires in Oklahoma are dependent upon current weather conditions, seasonal climate patterns, vegetation conditions, and an available source for ignition (such as a spark, flame, or intentional). Given this complex relationship, the future trend for wildfire is also complex. However, projected increases in temperatures that can dry fine fuels such as grasses and enhanced wet/dry cycles that promote vegetation growth and drying or dormancy, coupled with population growth along the wildland-urban interface, suggests the risks of wildfires is likely to continue to increase. Read more about future wildfire risk in the resources found in Appendix C.</td>
</tr>
</table>

Winter Storm (Ice, Sleet, Snow)

Data Limitations: Long term records are limited across the state, especially in southeast Oklahoma. 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).

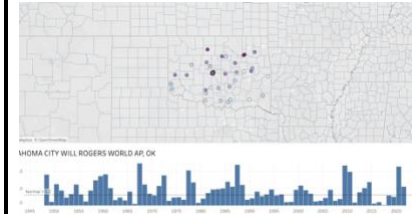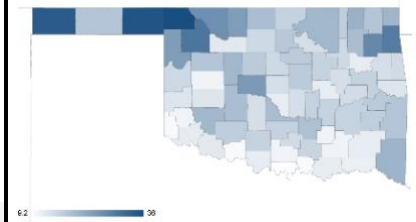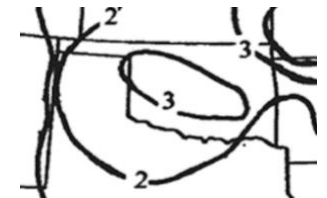|			
Historical Data	**Snowfall Climatology Toolbox** (Period of record varies by station; ~30-100+ years) Midwestern Regional Climate Center	This interactive tool shows normal (1991-2020) annual and monthly snowfall, average annual number of days with snow totals at certain thresholds, average first 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 *OK* 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 ~130 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(s) of interest on the top right side of the map. **2.** Mouse over county of interest for information on the maximum snowfall event on record. **3.** A table below the map shows location (by county and station), date of event, and snowfall total details. Tool Link: https://www.ncdc.noaa.gov/snow-and-ice/snowfall-extremes/OK	
	Ice Storm Climatology (1948-2000) Changnon and Karl, 2003 (open access)	These are static images within a scientific report. Shows the average annual number of days with freezing rain (Fig. 2) and month of highest average number of freezing rain days (Fig. 9). For reference when viewing these figures, Oklahoma typically sees 2-3 freezing rain events per year, most commonly in January. To view, **1.** Click on the *Full Text* tab and scroll to the bottom of the page. **2.** View full sized images of Fig 2. and Fig. 9 by clicking on respective images. Figures in https://doi.org/10.1175/1520-0450(2003)042<1302:TASVOF>2.0.CO;2	 Average annual number of days with freezing rain, 1948-2000
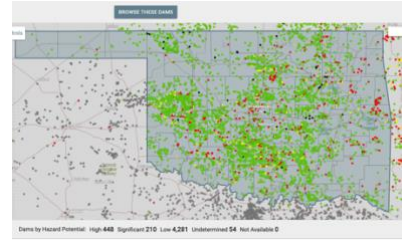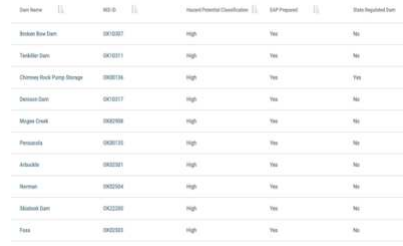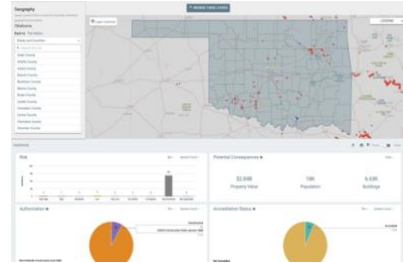
Future Trends

Years consisting of a large number of snowfall days declined significantly across the southern United States between 1930 and 2007. Models suggest that although the number of snowfall events will likely continue to decrease given overall atmospheric warming, when snow does occur, accumulations will be greater due to increases in atmospheric moisture (Krasting et al. 2013). There is significant uncertainty surrounding the future of ice storms in Oklahoma. Observational data limitations and the complexity of the events themselves make it difficult to determine with much specificity whether patterns have and/or will change. Models show that by mid-century there will generally be a northward shift of the rain, sleet and snow dividing line across the central United States. This shift will add to the complexity of determining precipitation type for winter events (rain, ice, or snow) in Oklahoma, however, the increase in atmospheric moisture may bring an increase to the amount of precipitation that does fall (Easterling et al. 2017).

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 Oklahoma. The dam inventory is limited to dams with a height of at least 25 feet and exceed 15 acre-feet in storage or at least 50 acre-feet of storage and exceed six feet in height unless the dam is classified a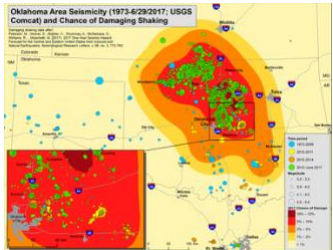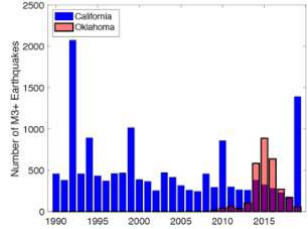s high hazard potential. The high hazard potential dam is a dam where failure will probably cause loss of human life regardless of the physical condition of the structure.

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 Oklahoma, 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 *Oklahoma*. For specific counties, you can then select a county within Oklahoma from the same menu or click on the map after Oklahoma is selected. **2.** The map then zooms in to Oklahoma 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 tool allows you to view the details of individual dams within the state of Oklahoma. **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 *Oklahoma* 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 Oklahoma 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/	
	National Levee Database (Levee Inventory: 1882-present) U.S. Army Corps of Engineers	This tool allows you to 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 *Oklahoma*. **3.** The results page shows a map of all Oklahoma 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.** Explore the map as you see fit or click on the county of interest on the left side of the page 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 Oklahoma 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. Most dams are at or near their 50 year design life, so the probability of failures 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. New development downstream of existing dams increase the potential consequences that would occur if a dam were to fail. Major dam failures across Oklahoma are few since owners are required to perform routine inspections and maitence (OWRB 2019).		

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	Shows past earthquakes on a zoomable map and can be used to show previous occurrences. **1.** Under *Basic Options*, select the *Magnitude*, the *Date and Time*, and the *Geographic Region* to plot. Choose a *Custom* date and time with a start date such as "1900-01-01 00:00:00" to view long-term trends. You can select a *Custom Geographic Region* and draw a rectangle over Oklahoma by using the + button to zoom to the state. **2.** Click *Search*. **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. Tool Link: https://earthquake.usgs.gov/earthquakes/search/	
	Oklahoma Area Seismicity Map, includes induced seismicity (1950-2017) U.S. Geological Survey	Shows the historical seismicity across the state (single points) along with the chance of damaging shaking in 2017 (contoured colors). Note: The 2017 Chance of Damage accounts for induced seismicity from wastewater disposal well injections associated with oil and gas plays. Can be used to help determine the risk of a damaging earthquake in your area. Tool Link: https://www.usgs.gov/media/images/oklahoma-area-seismicity-1973-june-2017	
	Oklahoma vs. California Earthquakes Bar Graph (1990-2019) U.S. Geological Survey	Shows the annual number of M3.0+ earthquakes in Oklahoma vs. California over time in a bar graph format. Can be used to show how the risk of earthquakes increased in the last decade. Tool Link: https://www.usgs.gov/media/images/number-m3-earthquakes-oklahoma-vs-california-1990-2019	
	Oklahoma Earthquake Information Page U.S. Geological Survey	Additional information about earthquakes in Oklahoma. Click on links of interest. Tool Link: https://www.usgs.gov/natural-hazards/earthquake-hazards/science/information-region-oklahoma?qt-science_center_objects=0#qt-science_center_objects	
Future Trends	Prior to 2009, Oklahoma experienced 1-2 earthquakes per year that were magnitude 3.0 or greater. The rate of M3.0+ earthquakes increased to a peak of about 3 per day in 2015 concurrent with a statewide increase in wastewater injection into deep underground strata (Andrews and Holland 2015). As wastewater injection volumes have declined by over half, compared with 2015, the rate of M3.0+ earthquakes have decreased to less than 1 per day in late 2018. Thus, the future seismic hazard is interlinked with wastewater disposal well activity but will likely remain elevated, compared to background tectonic rates, for at least the next decade (OGS 2017).		

Poor Air Quality (Dust, Pollutants, Smoke)

Data Limitations: Geographical and spatial gaps exist, 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.

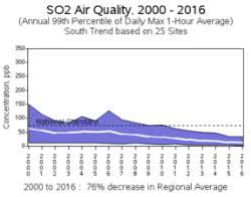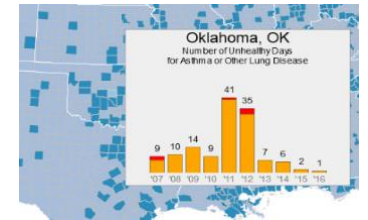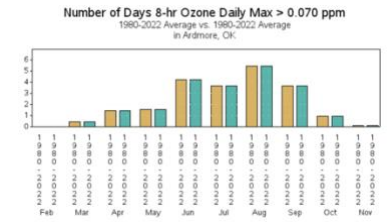|			
Historical Data	**Air Trends** (Period varies by pollutant; up to 1980-2021) U.S. Environmental Protection Agency	This page contains links to graphs of the annual national and regional trends for the 5 AQI pollutants as well as for lead. **1.** To obtain graphs, scroll down the page slightly and click on pollutant link of interest in the *Air Quality Trends* section. **2.** When the regional trend is available, it will be located under *National Trends*. Under the *Regional Trends* section of the page, click *South* to view the graph. You can also click *View the chart data in Microsoft Excel* below the graph to download the data. Tool Link: https://www.epa.gov/air-trends	
	Air Compare (2012-2021) U.S. Environmental Protection Agency	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 *Basic Info* tab at the top of the page, then *Data Limitations* on the right side of the page. Note: For information on the predominant directions in which air pollutants flow, refer to the Wind Rose Plots tool in the Wildfire section, p.21. **1.** Scroll down until you see the U.S map. **2.** In the upper left-hand corner of the map, click on *Trends*, then select group of interest. **3.** Click a county of interest to obtain graph of annual statistics. **4.** For data broken down into months, click on *Seasons* in upper left-hand corner, then select group of interest. Tool Link: https://www3.epa.gov/aircompare/#trend	
	Ozone Exceedances (1980-present) U.S. Environmental Protection Agency	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. **1.** Under *Geographic Area,* select a city or county (Oklahoma cities listed: Ardmore, Lawton, McAlester, Miami, Oklahoma City, Ponca City, Tahlequah, and Tulsa) **2.** Under *Baseline Period*, select either a single year or a multi-year period and the year(s) in which you are interested in. **3.** Under *Comparison Period*, 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 *Use ALL Monitors* when comparing time periods if data aren't available for both periods. **5.** Click *Plot Data*. Tool Link: https://www.epa.gov/outdoor-air-quality-data/air-data-ozone-exceedances	
	Outdoor Air Quality Data (Period varies by pollutant; up to 1980-present) U.S. Environmental Protection Agency	This multiyear 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. **1.** Under *Pollutant,* select pollutant of choice. (e.g., Ozone, All AQI Pollutants) **2.** Under *Period*, select a beginning and ending year **3.** *Under Geographical Area,* select a city or county (Note: cities available are listed in the Ozone Exceedances tool above). **4.** Click *Plot Data.* Tool Link: https://www.epa.gov/outdoor-air-quality-data/air-data-multiyear-tile-plot	
Future Trends	Dramatic improvements in air quality have occurred over the past half-century due to technological innovations and federal regulations, and continued technological innovation and enforcement of federal regulations should result in additional air quality improvement (ODEQ 2018). However, the projected increased frequency and intensity of droughts will make it easier for dry soil to become airborne, which can lower air quality and cause breathing and visibility problems (EPA 2016a). Hotter temperatures can increase the formation of ground-level ozone, which has a variety of health effects including asthma and respiratory problems. Air quality may also worsen during wildfire periods (EPA 2016b).		
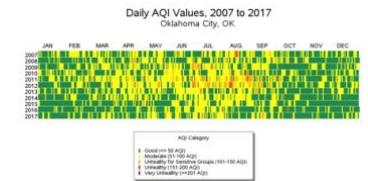
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Appendix A - Hazard Definitions

Cold Extremes

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.

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 Niña 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 (2018) 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 size. 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 a severe storm.

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 2012). 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.

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, although new detection systems allow accurate identification of lightning strikes allowing analysis of lightning frequency.

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 Oklahoma 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 uncontainable 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 Oklahoma, 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; values below 200 indicate high fuel moisture making ignition unlikely; 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 Oklahoma between November and March and are usually created by large low-pressure systems moving rapidly across the country. In Oklahoma, ice storms 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: 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 is 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; these are the most damaging. Rayleigh, or surface, waves move vertically, giving an undulating motion.

The Meers fault, located in southwest Oklahoma, has the potential for producing a strong earthquake. Additionally, Oklahoma 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, although the number of earthquakes declined beginning in 2016 as regulations were implemented. An earthquake caused by the New Madrid fault, situated in the Mississippi Valley, could also impact Oklahoma.

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.

Poor Air Quality (Dust, Pollutants, Smoke)

Definition: A measure of the monitored natural and man-made pollutants in an area.

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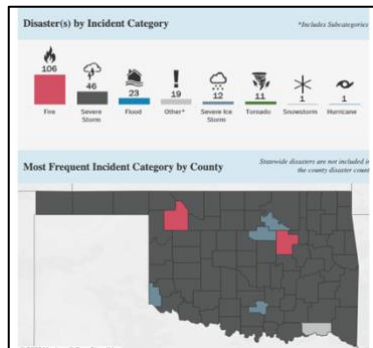
This page contains an interactive tool that allows the exploration of historic federal disaster declarations by state, county, hazard, and year. To access information from this page, first select a date range and state/territory from the menus. Information on federally declared disasters within the selected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

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: Oklahoma's tribal nations are not currently represented in this tool because 1) they 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 v.1.8* is geared towards providing Oklahomans with the most accurate and trustworthy data sources. The tool also identifies future climate trends for each hazard. As noted in the *A Note About Climate Change* (p. 5) 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.

Oklahoma State Climate Summary (2022): https://statesummaries.ncics.org/chapter/ok/

This report from the NOAA National Centers for Environmental Information (NCEI) provides a state-specific summary of observed and projected changes in Oklahoma's climate, including the change in extreme weather events that affect the state. Three key messages of the summary highlights are provided at the beginning of the report. The NOAA State Climate Summaries were originally created to put National Climate Assessment information into a state-level context, and the report is updated each year.
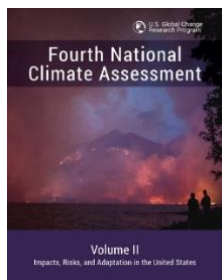
NCA4 Volume II: Impacts, Risks, and Adaptation in the U.S. (2018): https://www.globalchange.gov/nca4

The National Climate Assessment is the most accurate state-of-the-science in the U.S. agreed upon in the science community. This report was produced by a team of more than 300 experts guided by a Federal Advisory Committee, which was extensively reviewed by the public and experts including federal agencies and a panel of the National Academy of Sciences. 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. Focusing on regional chapters, the NCA4 Volume II is a technical scientific assessment of climate change-related impacts, risks, and adaptation in the United States, as described in the NCA4 Volume 1: Climate Change Special Report (CSSR).

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 United States. 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.
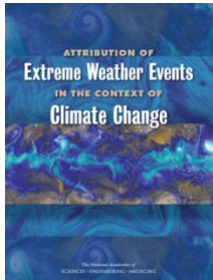
Attribution of Extreme Weather Events in the Context of Climate Change (2016):
https://www.nap.edu/catalog/21852/attribution-of-extreme-weather-events-in-the-context-of-climate-change (To access for free, report can be viewed online or a PDF can be downloaded by creating a free account.)

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 necessarily 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 1-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 Oklahoma.

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.

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 Oklahoma 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 Oklahoma 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

Oklahoma Comprehensive Water Plan (https://www.owrb.ok.gov/ocwp/pdf/2012Update/OCWP%20Executive%20Rpt%20FINAL.pdf): This executive report provides details of the current (2012) Oklahoma Comprehensive Water Plan, created by the Oklahoma Water Resources Board (OWRB). It provides an overview of water resources in Oklahoma, including water planning and management, surface and groundwater availability and quality, current and projected water demand, and policy recommendations and implementation. The next plan will be available in 2025 and will include a narrower focus than the 2012 plan. OWRB identified the most critical water resource issues in the state through extensive engagement from local experts and will propose more implementation strategies and funding solutions. It will also integrate Oklahoma's first State Flood Plan, which will identify flood mitigation projects and floodplain management strategies. Read more about the upcoming plan at https://www.owrb.ok.gov/ocwp/2025OCWP.php.

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