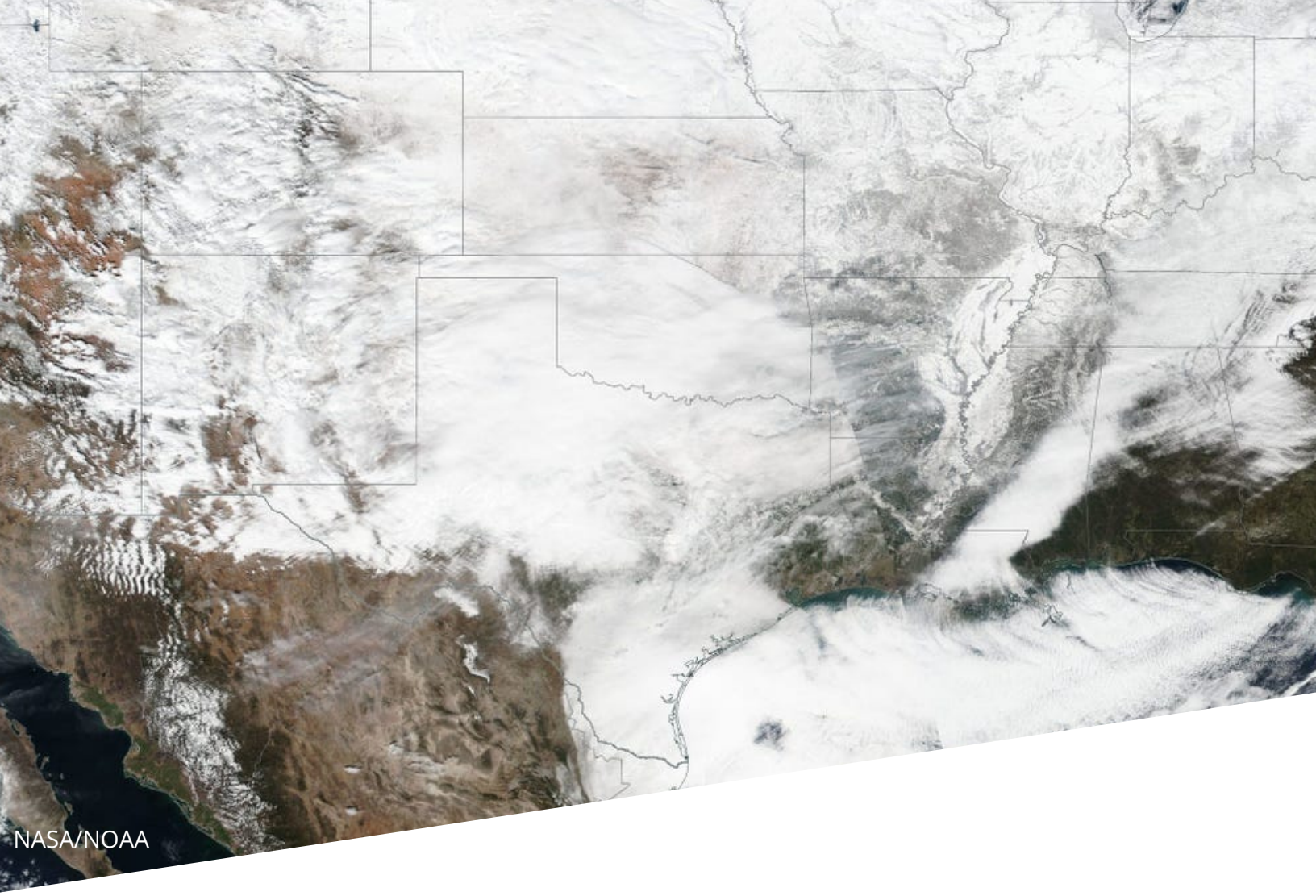

NASA/NOAA

FEBRUARY 2021: EXTREME COLD,SNOW, AND ICE IN THE SOUTH CENTRAL U.S.

APRIL 2021 | DARRIAN BERTRAND AND SIMONE SPEIZER

SCIPP
A NOAA RISA TEAM

SUGGESTED CITATION

Bertrand, D. and S. Speizer, 2021: February 2021: Extreme Cold, Snow, and Ice in the South Central U.S. Southern Climate Impacts Planning Program, 30 pp. http://www.southernclimate.org/documents/Feb2021ExtremeCold.pdf.

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INTRODUCTION

February 2021's weather was a wild ride for many across the U.S. Many records were broken from a strong arctic blast of cold air that extended south of the Mexico border, and wintry precipitation covered much of the country. While the extent of the winter storm traversed coast to coast, this summary will cover the Southern Climate Impacts Planning Program (SCIPP) region of Oklahoma, Texas, Arkansas, and Louisiana (Fig. 1). We'll be diving into the weather pattern, records, the context of this event relative to climatology, past historic events, impacts, and hazard mitigation successes.

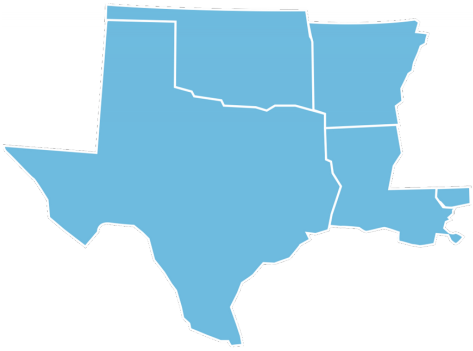


Figure 1. SCIPP Region

EVENT HIGHLIGHTS

- **Extreme Cold Temperature and Snow:**
  - **Nearly 3,000 long-term temperature records were broken/tied in February in the SCIPP region.**
  - **All 120 OK Mesonet stations were below 0°F at the same time for the first time.**
  - **Some areas were below freezing for nearly 2 weeks.**
  - **This was the coldest event in the region in over 30 years.**
  - **73% of the U.S. was covered in snow on February 16th.**
  - **Snow fell as far south as Galveston and 10-20" were reported in AR.**
- **Impacts**
  - **$195-295 billion in total losses have been estimated.**
  - **Nearly 200 fatalities were attributed to the event in TX.**
  - **Rolling power outages occurred in all SCIPP states. TX power outages were prolonged and more severe with millions of customers without power for days.**
  - **Natural gas was the most affected energy source.**
  - **Minority communities were the hardest hit in TX.**
- **Hazard Mitigation Successes**
  - **El Paso's investment in equipment weatherization and a new power grid led to few power outages.**
  - **Cities across the region, such as Oklahoma City and Tulsa, communicated hazards, urged energy and water conservation, and took preliminary actions to keep roads more clear and keep the community safe.**

TIMELINE

Feb. 7
Cold front reached OK, TX; period of freezing precipitation

Feb. 13
First large winter storm reached SCIPP region

Feb. 15
Coldest morning with widespread record low temperatures

Feb. 16-17
Second winter storm reached SCIPP region

Feb. 20
Temperatures rose above freezing for entire region

WEATHER PATTERN

An arctic air mass brought record-breaking cold temperatures, heavy snow, and ice to the south central U.S. in mid-February. On February 7th, a strong cold front reached the Oklahoma and Texas Panhandles and moved southward throughout the next several days. As cold air plunged southward, freezing fog, freezing rain, and sleet developed across parts of all states in the SCIPP region (Oklahoma, Texas, Arkansas, and Louisiana), creating hazardous icy conditions on roads and bridges. These conditions were only a precursor to the two winter storms to come.

The first large winter storm arrived in the SCIPP region on February 13th from the Pacific Northwest, leading to widespread wintry precipitation that extended across much of the country. National Weather Service (NWS) offices across the region forecasted the event well and ensured their populations had enough time to prepare for the event. The event was expected to be so widespread that NWS Winter Storm Warnings extended from eastern Colorado and much of New Mexico all the way to northwest Pennsylvania and covered nearly every county of the SCIPP region (Fig. 2). Wind chill warnings also covered the region, and wind chill temperatures dropped lower than -20°F as far south as north central Texas on the morning of February 15th.

Wind chills at some sites in Oklahoma were as cold as -30°F (2). On Valentine's Day weekend, snow fell where temperatures were much below freezing in the northern parts of the region, while southern Texas, Arkansas, and Louisiana received sleet and freezing rain (Fig. 3). A second storm system, also originating from the Pacific Northwest, brought additional snow and ice to the region on February 16th-17th as the cold temperatures remained. These conditions allowed rime ice to form in locations like Lake Thunderbird in Norman, OK (Fig. 4).

According to NOAA's National Operational Hydrologic Remote Sensing Center (NOHRSC), snow covered 73.2% of the U.S. by February 16th, the highest daily snow coverage since 2003 (5). Between the two winter storms, more than 4 inches of snow was measured across much of the south central U.S., and a large swath of southern Arkansas received 10-20 inches of snow (Fig. 5). Snow even covered beaches in Galveston, TX - a rare sight (Fig. 6). Snowfall rates were as high as 2 inches per hour in Arkansas (7). The snow was light and fluffy due to a higher than usual snow ratio. This ratio is typically estimated at 10:1 (10 inches of snow per 1 inch of liquid that falls). In some cases the ratio was 20:1 during these events, allowing snow to accumulate quickly (8). With strong winds, the snow was blown into large drifts in many areas, which made measurements difficult.

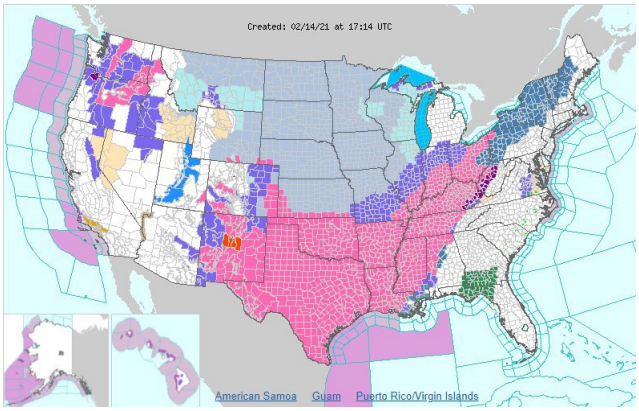


Figure 2. NWS warnings, where pink represents winter storm warnings. Source: NWS (1)

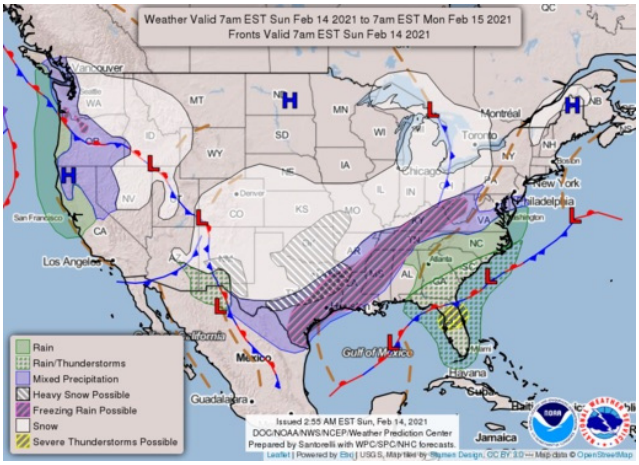


Figure 3. Forecast graphic from Feb. 14th-15th, 2021. Source: Weather Prediction Center (3)

Figure 4. Rime ice formed along the shores of Lake Thunderbird in Norman, OK. Source: L. Forney (4)

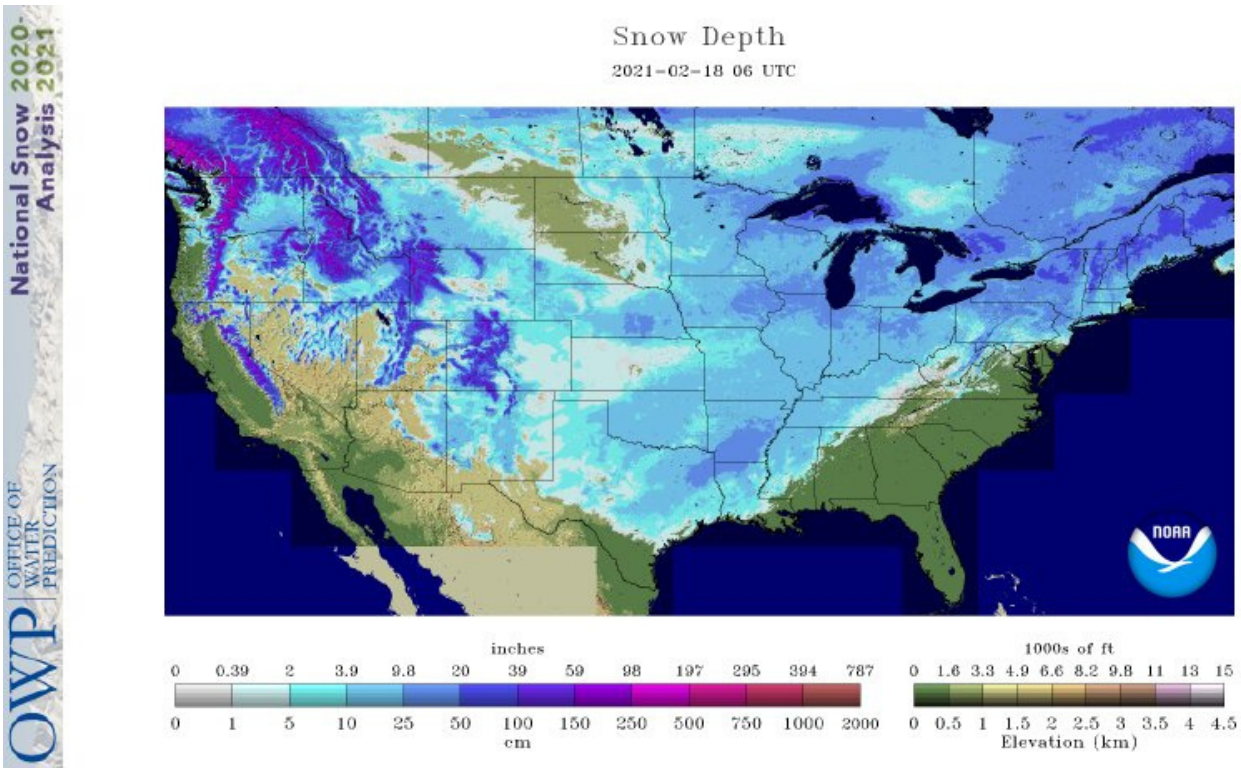


Figure 5. Snowfall depth in inches on Feb. 18, 2021. Source: National Operational Hydrologic Remote Sensing Center (5)

Figure 6. Snow-covered beach in Galveston, TX. Source: Galveston County - The Daily News (6)

How did the extremely cold air plunge so far south? The answer lies in stratospheric warming and the polar vortex. In early January 2021, there was stratospheric warming in the Arctic, or warmer temperatures in one of the middle layers of the atmosphere near the North Pole. When this occurs, it can cause the Arctic Oscillation, or the circulation pattern in the Arctic that drives storm patterns from north to south, to change phases and cause the polar jet stream to move farther south (9). The polar vortex can also weaken when the polar jet stream that usually flows from west to east changes directions and slows. The polar vortex then takes on a wavy shape which allows cold air to emerge to the south within a few weeks (Fig. 7). But why did the cold air stick around for so long in the south central U.S.? Typically, the waves shown on the right side of Figure 7 would continue to meander and the cold air mass would move out of the area. However, a blocking pattern of high pressure was present, holding the cold air in place during this event.

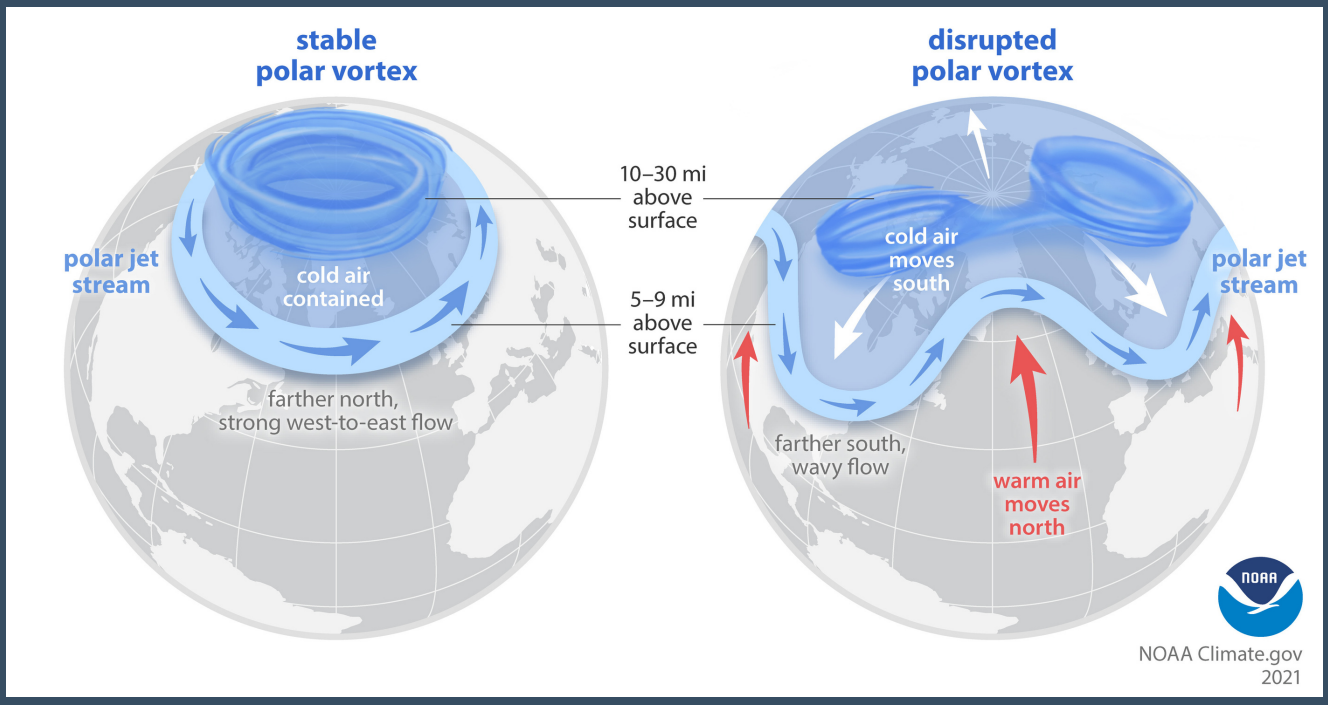


Figure 7. A stable polar vortex (left) and disrupted polar vortex that allows cold air to meander farther south (right). Source: NOAA Climate.gov (10)

RECORDS AND CLIMATOLOGY

A range of records were broken across the south central U.S. during February 2021. According to NOAA's National Centers for Environmental Information (NCEI), there were 2,782 preliminary station records broken or tied for coldest minimum or maximum temperature in the SCIPP region in February. This number may increase as time progresses and some potential records are evaluated. A breakdown by state is shown in Table 1, where it's evident that more coldest maximum temperature records were set than coldest minimum temperatures, showing the significance of the arctic blast. In other words, daytime high temperatures were very cold. Stations were selected from the daily Global Historical Climatology Network (GHCN) dataset and were required to have at least 30 years of data available and met requirements for missing data (11). Thus, these values exclude records from the Oklahoma Mesonet and West Texas Mesonet which began taking measurements in 1997 and 1999, respectively. These records refer to the calendar day; therefore, if a record occurred on Feb. 15th, 2021, then it was the coldest day of all historical Feb. 15ths. In Oklahoma, all 120 Mesonet sites were below 0°F on February 16th for the first time since stations began recording temperature in 1997. There were 96 stations that broke their all-time record for coldest minimum temperature (12).

Table 1. Long-term* Temperature Records Tied or Broken in the SCIPP Region in Feb. 2021

	Oklahoma		Texas		Arkansas		Louisiana	
Timescale	**Daily**	**Monthly**	**Daily**	**Monthly**	**Daily**	**Monthly**	**Daily**	**Monthly**
Coldest Minimum Temperature	**103**	**15**	**851**	**136**	**276**	**29**	**96**	**10**
Coldest Maximum Temperature	**135**	**28**	**886**	**97**	**318**	**56**	**117**	**8**

***Preliminary data from NOAA NCEI Daily Weather Records; stations selected from GHCN with 30+ years of data available (11)**

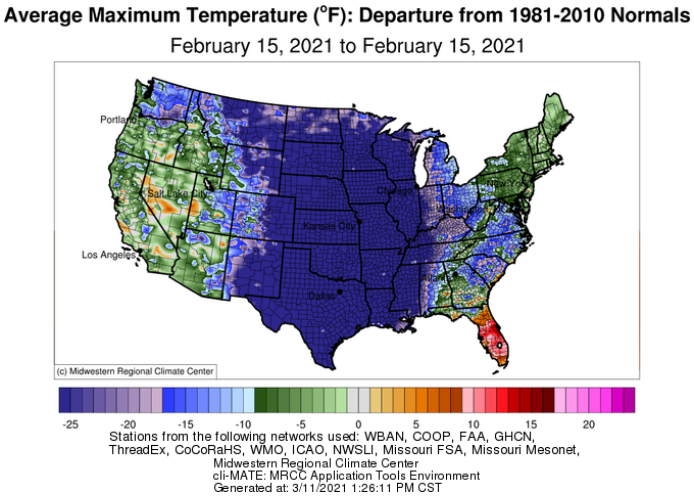


Figure 8. Average maximum temperature departure from normal. Source: Midwest Regional Climate Center (13)

On the coldest day of February 15th, maximum temperatures were more than 25°F below normal (defined as the 30-year average from 1981-2010) across a large swath of the middle of the country (Fig. 8). SCIPP's Climograph Tool was a great method to view just how far temperatures departed from normal. This tool provides the range of daily temperature values and normal values for stations across the U.S. using data from SC-ACIS, a climate data management system (14). Until the arctic air reached Oklahoma City, temperatures had been within the normal range. As the cold front moved through, the temperatures dramatically dropped, shown as a large dip on the graph of Figure 9. While the normal maximum temperature for Oklahoma City on February 15th is 54°F, this day in 2021 was only 4°F. In other words, an incredible 50°F below normal. The following morning, the minimum temperature dropped to a bitter -14°F, or 47°F below normal. Statewide, Oklahoma's average temperature on February 15th was -0.7°F. That broke the 1989 record of 1.9°F (12). As far south as Del Rio, TX, the average temperature was only 22°F, or 35°F below normal, on the 15th. In New Orleans, the daily coldest minimum and maximum temperature records were broken on February 15th-16th, with the coldest temperature at the airport recording 27°F.

Furthermore, many monthly records were broken. Monthly records are defined as a daily value exceeding all other historical values of that location for the month. For example, Billings, OK, recorded a maximum temperature of 1°F on Feb. 16th, 2021. This broke the monthly coldest maximum temperature record, which means this was the coldest maximum temperature recorded during any day in February of that station's history. Dr. Becky Bolinger, the Assistant State Climatologist of Colorado, produced national maps of

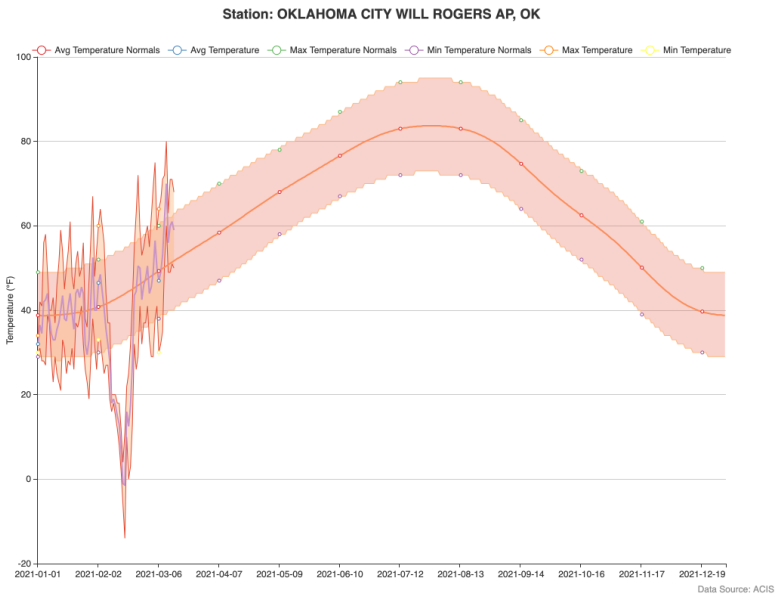


Figure 9. Climograph tool of temperature ranges in February 2021 in Oklahoma City. Source: SCIPP and Southern Regional Climate Center (14)

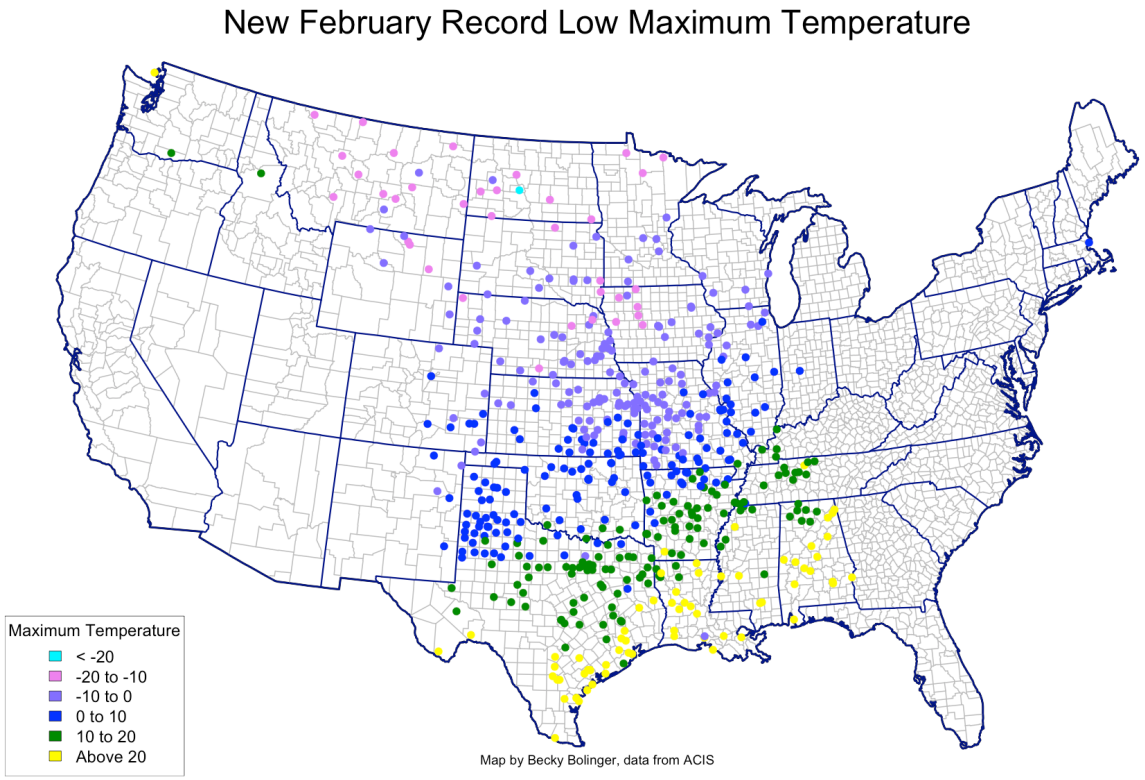


Figure 10. New monthly coldest maximum temperature records for February 2021. Each dot represents a location where the monthly record was broken. Source: Dr. Becky Bolinger (15)

monthly coldest minimum and maximum temperature records for February using long-term stations (15). The coldest maximum temperature records were more extensive across the central U.S. than coldest minimum temperatures (Fig. 10). Over 100 monthly coldest minimum temperature records were broken or tied in Texas (Table 1). Not only did the air temperature records break in many cases, but the amount of time that the cold remained also broke records. For example, a station in Monroe, LA, set an all-time record of 141 consecutive hours below freezing and even the airport in New Orleans was below freezing for 23 consecutive hours. The longest streak of consecutive hours below freezing recorded by the Oklahoma Mesonet was the Lahoma station. Between February 6th and February 20th, Lahoma was below freezing for 334 consecutive hours, or nearly 2 weeks (12). An Automated Surface Observing System (ASOS) station at the Oklahoma City airport broke a record with 5 consecutive days below 20°F; the previous record was 5 days in 1983 (12, 16). At the San Antonio Stinson Municipal Airport, maximum temperatures have only reached or dropped below freezing for 5 days since measurements began in 1941, and 4 of these 5 days were recorded in February 2021. In Fayetteville, AR, the record for consecutive days below freezing was broken with an 11-day streak below freezing. Those are just a few examples of long-lasting cold air across the SCIPP region.

TEMPERATURE

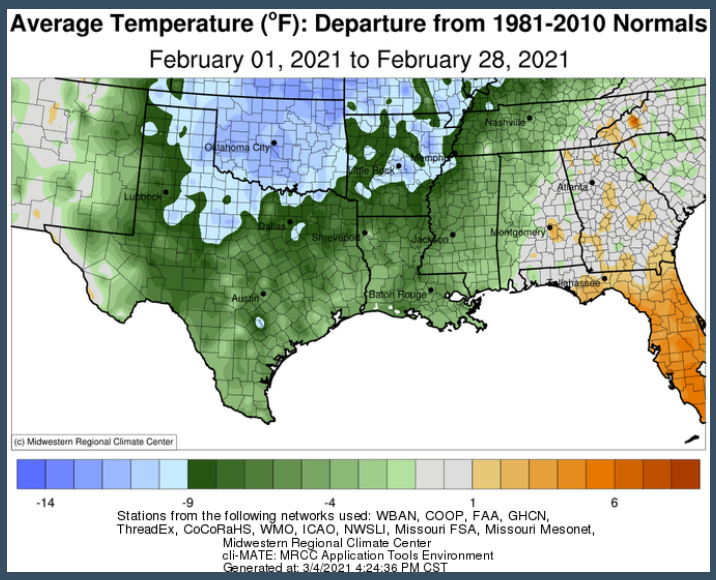


Figure 11. Average temperature departure from normal. Source: Midwest Regional Climate Center (13)

PRECIPITATION

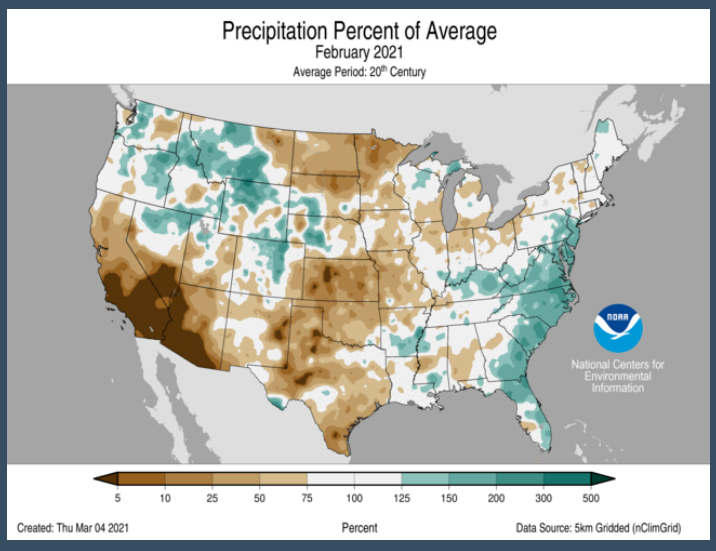


Figure 12. Precipitation percent of average, where brown colors across OK and TX represent drier than average conditions. Source: NCEI (19)

For the month of February, average temperatures were below normal across the SCIPP region (Fig. 11). Oklahoma saw the highest departure from normal, ranging about 10-15°F colder than average across the state. According to NCEI (17), statewide average temperature rankings for February were: 6th coldest in Oklahoma (31.3°F), 11th coldest in Texas (44.2°F), 7th coldest in Arkansas (35.2°F), and 17th coldest in Louisiana (48.1°F). Nationwide, it was the coldest February since 1989 and the 19th coldest February on record with an average temperature of 30.6°F (18). Despite the relatively large snowfall totals, precipitation for much of the central U.S., including Oklahoma, Texas, and northern Arkansas, was below average for the month (Fig. 12). Unfortunately, the snow was not the wet, heavy snow that can provide moisture to soils but a light, drier snow, accumulating in drifts, which did not provide the needed moisture. The melted snow led to only 0.5 inches or less of liquid equivalent in many places across Oklahoma (20).

COMPARISON TO PAST HISTORIC EVENTS: 1899 | 1983 | 1989 | 2011

FEBRUARY 1899

Many new records were set across the central U.S. and SCIPP region in February 2021, but how did this event compare to the past? Other years where countless records were set include 1899, 1983, 1989, and 2011. In February of 1899, known as the "Great Arctic Outbreak", an arctic system from the Pacific brought a series of cold fronts to the U.S. that caused millions of dollars (without inflation!) in crop damages and about 100 fatalities (21). This event still holds some cold temperature records for the Southern Plains. In fact, the coldest temperature ever recorded in Texas was -23°F on Feb. 12th, 1899 in Tulia, located in the southern Panhandle. New minimum temperature records from February 13th, 1899 were recorded in the *Monthly Weather Review* (Fig. 13). The Weather Bureau provided a forecast of freezing temperatures on February 10th to Oklahoma and Texas 1-2 days in advance. At the time, this was a quick turn around... Think of how far modeling and forecasting has come!

Across the country, people gave praise to the Weather Bureau for their timely forecast that allowed them to prevent additional loss to property and life. The Abilene West Texas Sentinel reported, "If everyone interested...had taken prompt advantage of the warning, there is no telling how much saving in the matter of livestock alone would have resulted. Where the telegraph and telephone could not be used, messengers were sent out to warn people to get ready for the cold wave" (21). It was so cold that the Mississippi River was frozen in many places and ice reached New Orleans on February 20th, where as much as 2 inches of ice was reported in the river during the event. Snow and ice also accompanied this event due to an area of low pressure alongside the subfreezing temperatures. Coastal areas of

Station.	Lowest previous temperature recorded.	Minimum temperature February 13, 1899.	Departure below lowest previous temperature.
Concordia, Kans	−25	−26	1
Dodge, Kans	−20	−24	4
Wichita, Kans	−14	−22	8
Oklahoma, Okla	−11	−18	7
Amarillo, Tex	−14	−16	2
Abilene, Tex	− 5	− 6	1
Palestine, Tex	− 1	− 4	3
San Antonio, Tex	6	4	2
Galveston, Tex	11	6	5
Springfield, Mo	−17	−28	11
Little Rock, Ark	− 5	−12	7
Nashville, Tenn	−10	−12	2
Chattanooga, Tenn	− 7	−10	3
Shreveport, La	1	− 4	5
Vicksburg, Miss	3	zero	3
New Orleans, La	15	7	8
Mobile, Ala	12	− 1	13
Montgomery, Ala	5	− 4	8
Atlanta, Ga	− 2	− 6	4
Savannah, Ga	12	8	4
Jacksonville, Fla	14	10	4

Figure 13. Coldest temperatures recorded on February 13, 1899 compared to previous record cold temperatures. Source: *Monthly Weather Review* (21)

Louisiana, Mississippi, and Alabama received 2 inches of snow between February 10th-14th (22). Another storm system off the Atlantic coast brought several inches of snow to the mid-Atlantic and Northeast as well. This event was similar to February 2021 in that both events included several rounds of arctic cold air that allowed freezing temperatures and snow to occur very far south.

DECEMBER 1983

December 1983 was another case of extreme cold and wintry precipitation in the south central U.S. as several cold fronts and upper level systems occurred. On December 15th, a cold front and low pressure system brought subfreezing temperatures and several inches of snow across Oklahoma and northern Texas. Several areas of Texas and Oklahoma received at least 4 inches of snow and some as much as 8 inches (23, 24). This round of winter weather left about 15,000 electric customers without power for 36 hours in Texas. Only a few days later on the 17th, another cold front arrived in the SCIPP region, causing wind chills to fall to -35°F in parts of Oklahoma the next day. Furthermore, freezing rain arrived a few days later and covered the southern part of the state with ice. Additional cold fronts brought even colder temperatures to the region by Christmas, dropping wind chills to -50°F in some areas of Oklahoma, and the state was covered in snow and ice by the 28th. Records for coldest December were set in Oklahoma City, Tulsa, Amarillo, and Fort Smith. In Oklahoma, the monthly average temperature dropped to 25.7°F, the coldest December on record (25). Between December 18th-28th, the Dallas-Fort Worth International Airport was below freezing for 295 consecutive hours, or almost 2 weeks. In the ArkLaTex area, the Red River froze and temperatures were at or below freezing for 138 hours (26). Nationwide, this was the coldest December on record with an average temperature of 25.5°F (18). The prolonged cold and wintry precipitation caused damage to infrastructure and crops, disrupted power and water service, and resulted in more than 500 lives lost nationwide (24). This was another case of several rounds of arctic air and moisture giving way to prolonged record cold in the region.

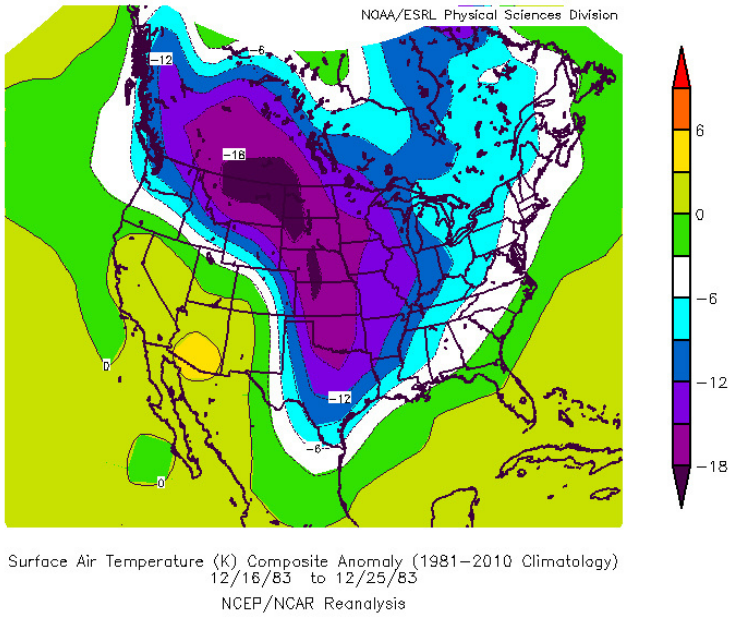


Figure 14. Average temperature departure from normal (degrees Celsius) between December 16th-25th, 1983. Source: NOAA Physical Sciences Laboratory (27)

DECEMBER 1989

Just 6 years later in December 1989, another series of arctic air masses further broke local records. That month was ranked the 5th coldest December on record nationally with an average temperature of 27.7°F (17). During this event, a large high pressure system from the north pushed south through the central U.S. and brought some of the coldest temperatures recorded in the SCIPP region (Fig. 15). Between December 14th-25th, 242 daily temperature records (coldest minimum or maximum) were tied or broken in the SCIPP region, most of which were in Arkansas and Texas (11).

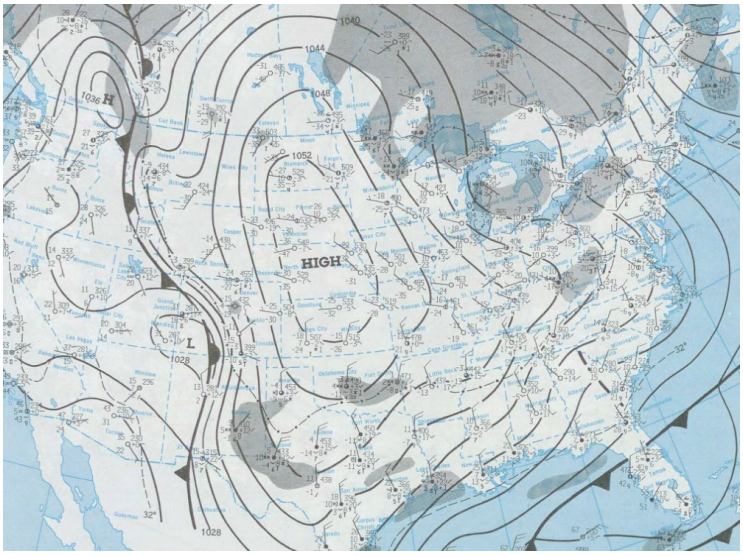


Figure 15. Map of surface observations from December 22nd, 1989. Source: NWS Central Illinois (28)

Wind chills in Oklahoma were a bone-chilling -30°F to -50°F (27). Although many impacts were in the Southern Plains, a low pressure system in Florida, along with freezing or subfreezing temperatures as far south as Miami, FL, brought historic snow and cold temperatures to the southeast and mid-Atlantic as well (30). The event falls in the NOAA Billion Dollar Disaster list, costing $1.5 billion (CPI-adjusted) in damages across the central and eastern U.S. due to infrastructure damages, such as frozen pipes and citrus crop loss (30, 31).

FEBRUARY 2011

Lastly, February 2011 is one of the most recent historic winter weather events. From January 31st to February 1st, a strong cold front and a storm system that moved in from the southwest U.S. brought blizzard conditions to Oklahoma and snow and sleet to west and north Texas (32). A large area of central and northeastern Oklahoma received between 8-15 inches of snow and over 40 mph winds, causing snow to drift several feet high in some areas. In the Dallas area, Super Bowl events were disrupted due to snow and freezing temperatures. Six contractors were even hit with ice that fell from the Cowboys Stadium (33). A week after these blizzard conditions, another arctic air mass progressed south from Canada while a storm system from the northwest U.S. approached the Southern Plains. On February 8th, widespread snowfall totals of 8-12 inches were reported in northern Oklahoma. The Will Rogers Airport in Oklahoma City measured 18 inches of snow between the two storms during the 10-day period

(34). The Ozark Mountains of northwest Arkansas received 2 feet of snow. With several inches of snow on the ground from both winter storms and light winds on February 10th, the coldest temperatures made their appearance. The Nowata Mesonet site in Oklahoma measured the all-time coldest temperature recorded in Oklahoma of -31°F on February 10th, breaking the previous record of -27°F from 1905 (Fig. 16). The coldest wind chill value ever recorded by the Oklahoma Mesonet was also reached at -47°F in Medford on this day. In the SCIPP region, 764 long-term stations tied or broke their daily coldest minimum or maximum temperature record, mostly in northern Oklahoma and the Texas Panhandle (11). In northern Oklahoma, 18 of these stations broke their all-time coldest minimum temperature record as well.

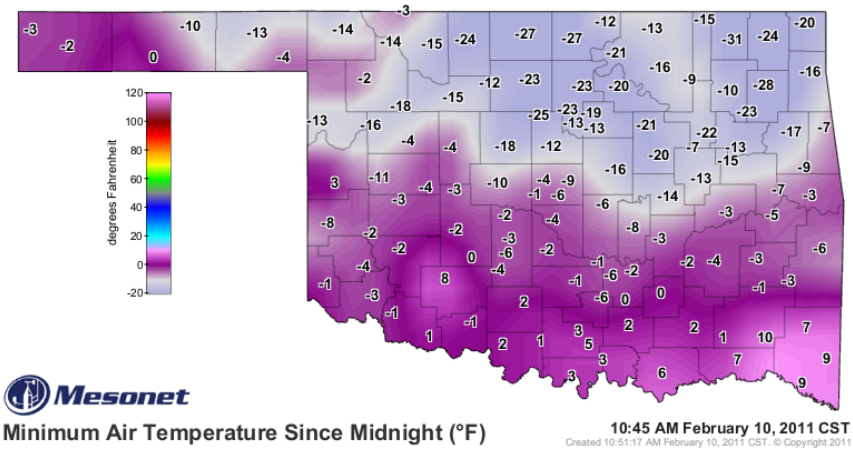


Figure 16. Minimum air temperature on Feb. 10th, 2011 in Oklahoma. Source: Oklahoma Mesonet (35)

PAST HISTORIC EVENTS SUMMARY

There is a commonality between several past historic winter weather events and February 2021. While each event had its own unique characteristics, multiple rounds of arctic cold fronts that traversed southward to the Southern Plains provided an opportunity for prolonged bitter cold conditions. Maps produced by climatologist Dr. Brian Brettschneider display the lowest temperatures that occurred in February 1899, December 1983, December 1989, and February 2021 from long-term station data (Fig. 17). Each pattern of cold temperatures appears similar between the events, but 1899 contained the most widespread cold temperatures across the U.S. A noticeable difference in February 2021 is the concentrated cold air in the central U.S. and less extreme cold on the coasts than past events. In the SCIPP region, December 1989 and February 2021 had similar temperature ranges across Oklahoma and Texas, but colder air below 10°F occurred farther south into Louisiana in 1989. So was February 2021 the coldest winter event in the U.S.? No, but there were still plenty of records broken and impacts that occurred. Furthermore, February 2021 was the coldest winter weather event in over 30 years for many in the SCIPP region, providing some of the coldest temperatures seen in a generation.

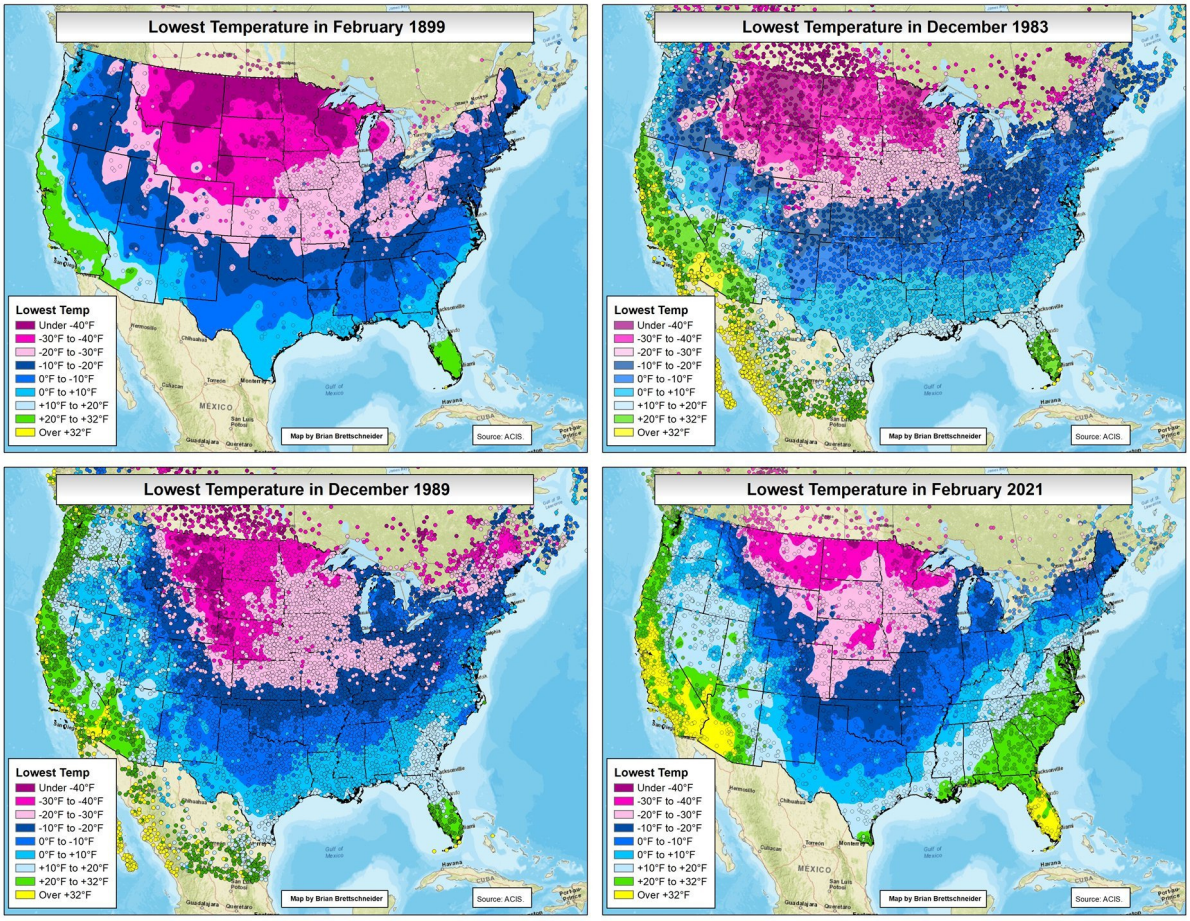


Figure 17. Comparison of minimum temperatures from past historic events. Source: Dr. Brian Brettschneider (Twitter handle @Climatologist49) (36)

WHAT ABOUT CLIMATE CHANGE?

Since the late 1970s, daily record high temperature records have outpaced daily record low temperature records (37). Record low temperatures are expected to become more rare over time. The Arctic is projected to be warmer in the future as well, and understanding links between a warmer Arctic and its effects on winter weather in the Northern Hemisphere is an active area of research. Some scientists hypothesize that as the Arctic rapidly warms due to climate change, there could be disruptions in atmospheric circulations, such as the jet stream. This may allow colder air to escape southward into the U.S. and cause us to have more variable or extreme winter weather (38, 39, 40). Others argue that climate change is unlikely to affect the jet stream and winter weather events (41, 42). If climate change does lead to more frequent cold air outbreaks, such an effect would have to be very substantial in order to overcome the warming trend over time. More research is needed to better understand and predict the impacts of climate change on winter weather.

IMPACTS TO THE SCIPP REGION

The extreme cold and frozen precipitation in February 2021 substantially impacted the SCIPP region. Some of the effects, such as power outages and water supply issues, were felt immediately by millions of residents. The scope of long-term economic and environmental impacts is not yet fully known. Disaster declarations were issued statewide for Oklahoma, Texas, and Louisiana, providing some federal relief to communities affected by the winter storms (43).

ENERGY

During the winter weather event, millions of people in the SCIPP region lost power, with outages ranging in duration from several hours to several days (44, 45). In Louisiana, for example, power outages were estimated in the tens of thousands, with most losses of power in the Baton Rouge area (46). Some of these outages were due to icy conditions that took down trees and power lines, while others were planned, rolling outages that shifted from one place to another to manage energy demand during the peak of the cold (46). Short-term rolling outages were also implemented across Oklahoma and Arkansas and customers were urged to conserve energy (45, 47). Outages were likely mitigated in Oklahoma and parts of Arkansas and the Texas Panhandle because of their participation in the Southwest Power Pool (SPP). The SPP is a regional transmission organization mandated by the Federal Energy Regulatory Commission that ensures power reliability and competitive wholesale prices to the central U.S. (48). Utility and transmission companies across 17 states in the central U.S. are members. This event was the first time the SPP had to order controlled outages (49).

Fig. 18. Long lines formed to get propane in Houston. Source: Washington Post/Getty Images (52)

Though all states in the SCIPP region faced energy issues, the scale of the energy crisis in Texas was unparalleled. Texas, unlike other states in the U.S., has its own electricity grid that is largely unconnected to grids in other states (50). This Texas-specific grid extends through about 90% of the state, excluding El Paso, the upper Panhandle, and parts of east Texas, and is managed by the Electric Reliability Council of Texas (ERCOT, 50). According to ERCOT, during the winter weather event the Texas grid was minutes away from a complete collapse that could have led to months-long

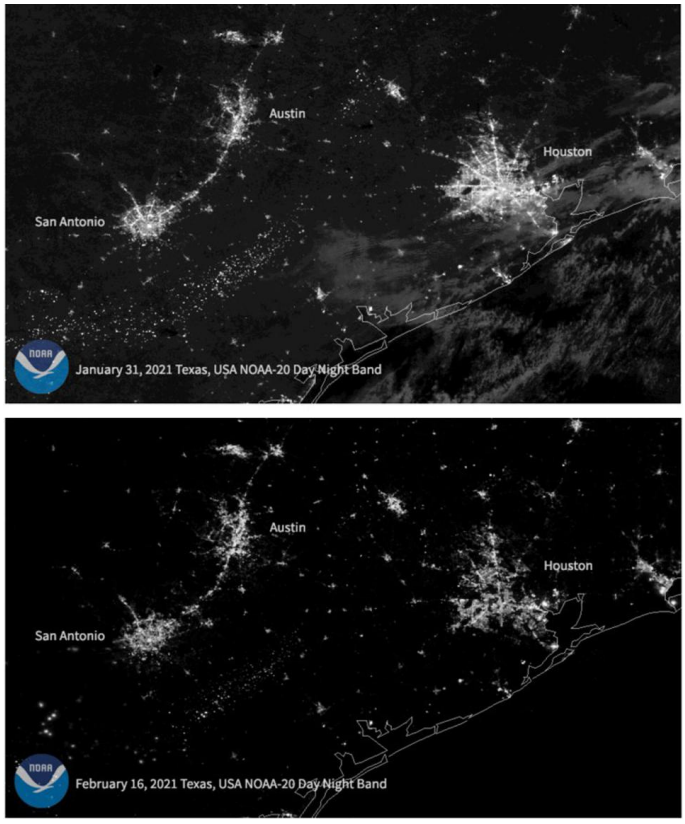


Fig. 19. Satellite images for January 31, 2021 (top) and February 16, 2021 (bottom) showing power outages in Texas, NOAA (53)

outages (51). To prevent such a total failure of the electricity grid, Texas grid operators implemented forced power outages to reduce energy demand (51). The resulting outages are estimated to have affected at least 4.5 million people in Texas, leaving them without electricity and heat during much of the most extreme cold temperatures (50). Though forced outages like these are usually rolling, hundreds of thousands of Texas residents lost power for days on end as the strain on the grid was too high for operators to be able to shift power between locations (51).

The near-breakdown of the Texas grid arose partly due to surges in energy demand, similar to those that occurred in other states (44). Demand, peaking at 69,000 megawatts, exceeded ERCOT's worst case estimate of 67,000 megawatts, which was based on conditions like those of the 2011 ice storm (44). However, not only did demand spike during the storm, but electricity production also dropped substantially as power plants unprepared for the extreme cold were forced to shut down (44). At one point, the state had around 45,000 megawatts of power production outages, more than double ERCOT's worst case prediction (44).

The winter weather disrupted the production of many sources of energy, but the most consequential impacts were on natural gas (Fig. 20). Natural gas is the largest source of electricity and heat in Texas, especially when demand is high, and losses of natural gas power generation far exceeded those of all other sources during the storm (50, 44). According to ERCOT, problems in the natural gas system were the main cause of the drop in power generation that led to the blackouts (54). At some natural gas production sites, wells became too cold to yield gas, while at others, power outages meant that electric pumps needed to lift the gas from the ground could no longer run (54). Extremely cold temperatures also caused natural gas pipelines to freeze, both at production sites and along transmission routes (54). Natural gas power plants tend not to store much fuel onsite, so these problems in gas extraction and transmission, as well as the increased use of gas for heating during the extreme cold, led to supply issues that forced many plants to shut down (54). Once out of operation, plants were often unable to restart in the cold conditions (44). These difficulties were

compounded by high gas prices that led some generators to stop producing power when doing so ceased to be profitable. Furthermore, some plants were already offline before the storm due to planned maintenance (44).

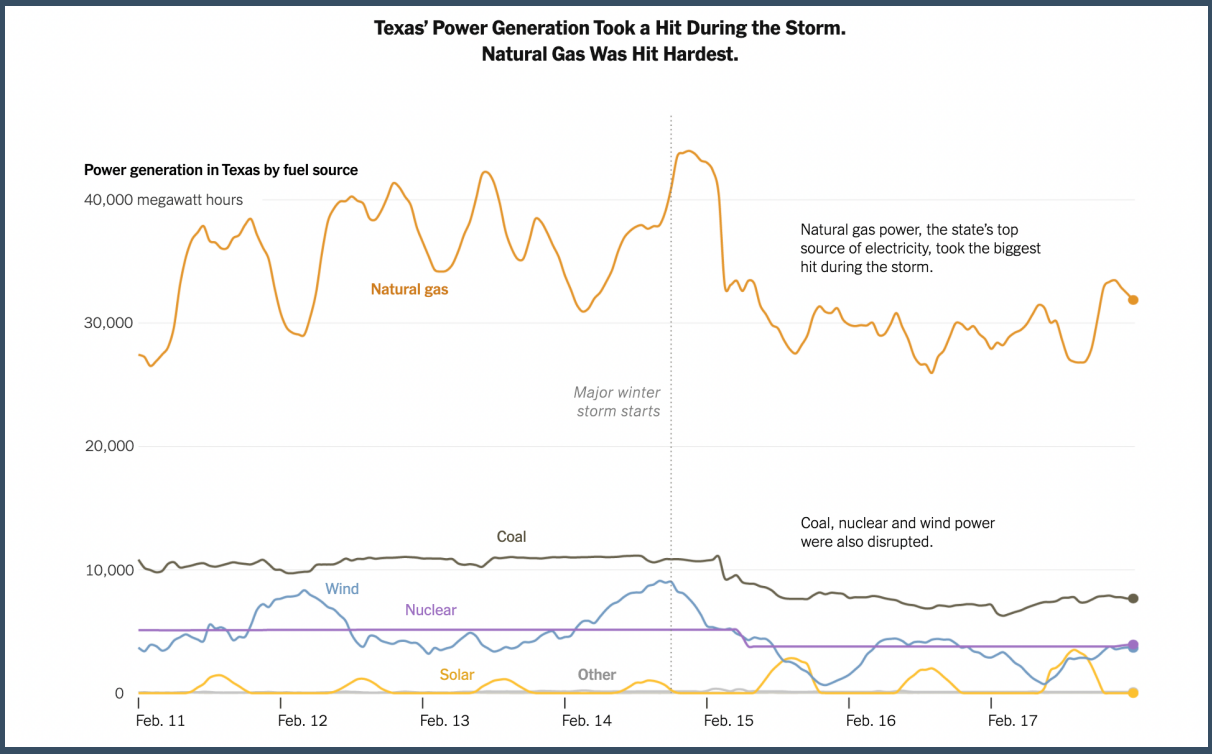


Fig. 20. Texas' power generation by fuel source, showing a reduction in wind, coal, nuclear, and natural gas generation. Natural gas generation was the most affected fuel source. Source: New York Times (44)

Fig. 21. Cold weather caused natural gas pipeline compressors to be inoperable. Source: Wall Street Journal (55)

While issues with natural gas caused most of the power production outages, effects of the weather on other sources of energy were also substantial. At least one nuclear power plant partly shut down, and production of energy from coal was also disrupted, with many of these facilities impacted by frozen instruments (54). Wind turbines, unprepared for the cold temperatures, also froze (56).

COULD THE ENERGY CRISIS HAVE BEEN AVOIDED?

All of these disruptions in energy production stemmed, in large part, from a lack of preparation for extreme winter weather conditions. Natural gas power plants and production facilities can be "winterized," or prepared for winter weather, with strategies like insulating pipelines (57). In northern states where extreme cold is more common, these methods prevent substantial power disruptions during winter storms (57). Similarly, furnishing wind turbines with cold weather packages, which allow for precautionary measures like heating turbine parts and lubricants, can help them withstand extremely cold temperatures (56). Wind turbines in Northern Europe function dependably in subzero temperatures as many of these turbines are constructed with cold temperature steels, special lubricants, and anti-icing systems for blades (Fig. 22). Wind turbines in the northern U.S. are equipped to withstand very cold temperatures as well. Turbines that lack some of these design features can be upgraded to prepare them for winter weather, for example, by adding installed heating (56). In Texas, many of these winterization methods for wind turbines, natural gas facilities, and other energy sources have not been implemented (57). Unlike in other states, power generators are not required to prepare their infrastructure for extremely cold conditions (57). Because ERCOT does not cross state boundaries, it is exempt from Federal regulations that may have required such cold-weather methods. Though some generators did upgrade their equipment following the 2011 winter storm, these enhancements were not mandatory, and were not enough to keep most of the plants functioning during the severe conditions of the 2021 event (56).

The relative separation of Texas's grid from the rest of the country also exacerbated its vulnerability to the winter weather. The Texas electricity grid only has a few limited connections to Mexico and the eastern U.S. (57). Because of this isolation, as well as the fact that other regions also faced their own increases in energy needs amidst the winter weather, Texas was unable to receive substantial inputs of power from other places to help meet its surge in demand (57).

Fig. 22. Wind turbines equipped for cold temperatures in Finland. Source: Giles Clarke/Getty Images (56)

WATER

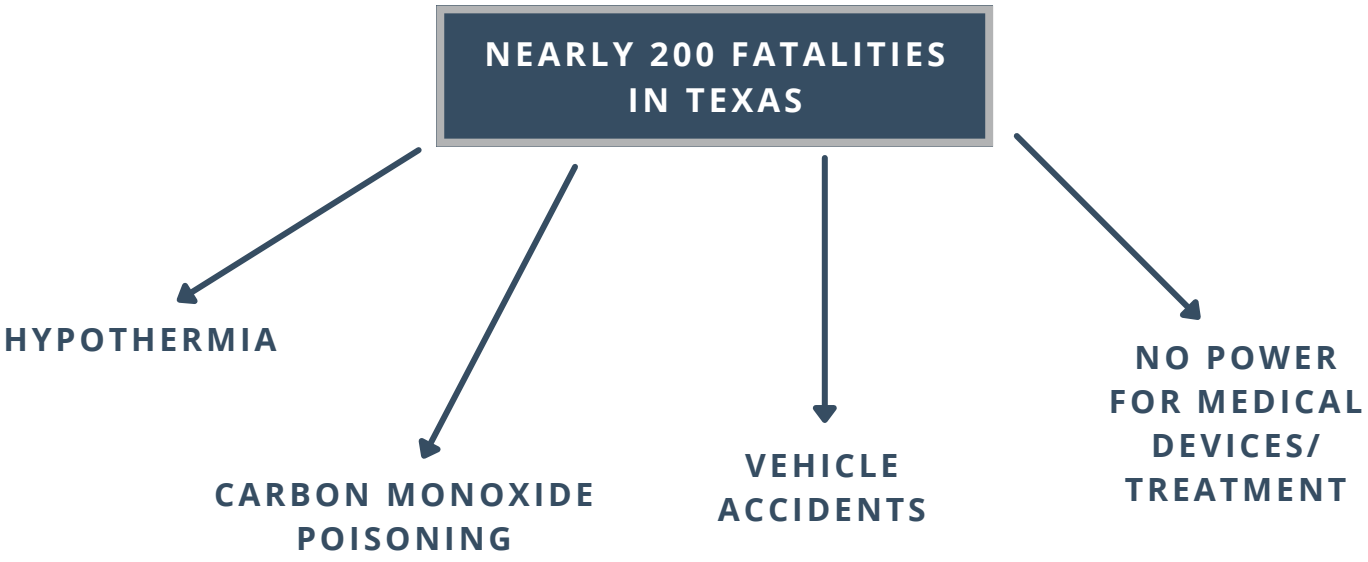
Power outages forced many water treatment plants to close, causing water supply issues across the SCIPP region (58). These water supply challenges were compounded by the frigid temperatures that froze and burst water pipelines, as well as by many residents leaving taps dripping in order to try to prevent pipes in their homes from freezing (59, 60). In many water systems, the reduction in water supply and increase in demand caused water pressure to fall below the limit needed to maintain water quality, prompting officials to issue boil water advisories (59). In Texas, nearly 12 million people were instructed to boil their tap water before consuming it (60). Residents without power, and thus unable to boil their water, were told to attempt to get bottled water (60, Fig. 23). In some cities such as Austin and San Antonio, certain areas lost water access altogether. At one point, nearly all residents in Harris County, TX, had low or no water pressure (59, 61). In Louisiana, pumped water outages and boil water advisories affected nearly 1 million residents, with about a quarter of those experiencing pumped water outages (62). Water systems across Arkansas and Oklahoma also faced water pressure problems, and boil water advisories were issued in several cities in both states, including Mayflower, AR, Benton, AR, Shawnee, OK, and Blackwell, OK (63, 64, 65).

Figure 23. Austinites line up for bottled water at Anderson High School on Sunday, Feb. 21, 2021 in Austin. Source: American-Statesman/USA TODAY (66)

HEALTH

Low water supply and power outages, combined with the direct hazards from the winter weather itself and the ongoing COVID-19 pandemic, led to considerable threats to health and safety. Without electricity or heating, many people faced extremely cold temperatures even inside of their homes (67). In an effort to stay warm, some idled their cars indoors or turned on barbecue pits or charcoal grills in enclosed areas, leading to hundreds of cases of carbon monoxide poisoning across the state, some of which were fatal (68). In Louisiana, at least one person died from a fall during the icy conditions, and vehicle accidents across the region also claimed lives (67). Even as injuries sustained during the winter weather event--particularly hypothermia and carbon monoxide poisoning--caused

emergency rooms to swell with patients, many hospitals faced shortages of water and power outages that hindered their ability to provide care (69). In Texas, many kidney dialysis clinics closed due to water and power outages, forcing patients requiring regular dialysis to seek treatment at hospitals, which placed further strain on medical centers already affected by the COVID-19 pandemic (69, 70). At least one person died after being unable to obtain dialysis treatment at a hospital that did not have water (71). A detailed investigation into Texas fatalities from the Houston Chronicle found that 194 deaths were attributed to the winter weather event and dozens more in other southern states lost their lives due to the winter storm, with most deaths related to hypothermia (72, 73). This number could increase as more investigations continue.



INFRASTRUCTURE

The winter weather also led to a variety of impacts on buildings, transportation systems, and other sectors. In some homes, pipes froze and burst, causing ceilings to collapse (74). Low water pressure created problems for fire departments, forcing firefighters to adjust their strategies for fire control (74). Many flights across the region were cancelled as well. For example, on February 17th, the lack of water led to flight cancellations or diversions from Houston Hobby Airport (45, 74). The snow and ice that fell during the winter storm led to dangerous roadway conditions across the SCIPP region, with substantial vehicle accidents occurring near Oklahoma City, OK, and Fort Worth, TX (75, 76). The accident in Fort Worth involved 133 cars and killed 6 people (76). The treacherous road conditions, combined with other impacts of the winter storm, also caused delays in COVID-19 vaccine shipments across the entire U.S. (77). Many of the effects on vaccine rollout were

particularly acute in SCIPP states, where the weather also closed vaccination clinics and led to postponements of inoculations (77).

Figure 24. Highway ramp in Houston closed due to snow. Source: Xinhua News Agency/Getty Images (78)

Figure 25. Frozen water fountain in Richardson, TX. Source: Lm Otero/AP (79)

ECONOMY

The economic consequences of the winter weather event are just beginning to come to light. Power outages forced factories, businesses, and food processing plants to close, leading to losses of economic activity (80). The agricultural sector was also substantially impacted by the winter weather, as the frigid temperatures froze crops across the region (80). In Texas, vegetables in the Rio Grande Valley were devastated by the storm, and the state lost about half of its citrus harvest (80). The impacts of these losses could persist into the coming years, as citrus trees take time to replace (80). On an individual level, many homeowners faced extremely high electricity bills, repair costs from burst pipes and property damages, and losses of wages from the time when they could not work during the storm (81, 82). According to preliminary estimates, insured losses from the winter weather are likely to be around $10-20 billion in Texas alone (83). Power grid operators and

electricity generators also incurred substantial costs. For example, the Oklahoma Municipal Power Authority estimated that the winter weather event cost $60 million, losses that they intend to spread over the next 7 years (84). In Texas, ERCOT set electricity rates at their highest price point for an extended period of time, leading to an estimated $16 billion in fees that added to the losses that many power companies and others in the state faced during the storm (85). Overall, economic losses due to the winter weather have been estimated to be between $195-295 billion, though this assessment will likely be refined in the future (80).

ENVIRONMENT

Like the economic effects, the environmental repercussions of the winter storms will continue to emerge in the coming months. Following the storms, the Texas Parks and Wildlife Department noted reports of dead birds and bats, as well as sightings of live bats that had suffered from dehydration, starvation, or very low body temperatures (86). The Department stated that it expects there may have been losses of axis deer, blackbuck, and nilgai antelope, but does not predict substantial direct effects on native deer, such as white-tailed or mule deer (86). There is concern, however, that the extreme cold might have harmed plants critical to native deer habitat in some regions (86). For example, in southern Texas, some shrubs that had grown leaves before the storm lost those leaves and turned brown following the freeze, and winter herbaceous vegetation was also damaged (86). Along the coast, biologists are worried that the frigid temperatures may have killed or severely harmed mangroves, highly cold-sensitive trees and shrubs that form the foundation of important coastal ecosystems (87). Reports are also accumulating of substantial fish kills, both along the Texas coast and in lakes in inland states such as Arkansas (88). Though many of these ecological consequences are currently hypothetical or poorly understood, with time and research scientists will better understand the extent of these impacts and their long term implications. Other environmental effects of the winter weather also included substantial emissions of air pollution; during the freeze and the resulting power outages, oil refineries, chemical processors, and other industrial plants in Texas emitted 3.5 million pounds of extra air pollution (89).

SOCIETY

Excess pollution, like many of the consequences of the winter storm, disproportionately impacted low-income communities and communities of color (90). In Texas, as well as throughout the U.S., areas around industrial plants often include a majority of Black or Latino residents. Therefore, pollution emitted by those facilities often leads to disproportionate negative health effects (90). Communities of color were also some of the hardest hit by blackouts, water shortages, and bursting pipes during the winter storm (82). Many lower income individuals were particularly vulnerable to the impacts from the weather, as they lacked the financial resources necessary to gather supplies before the event or to respond to property damage caused by the freeze (82). These disparities were particularly visible during the Texas energy crisis. Throughout the state, utility companies prioritized providing power to downtown areas with critical infrastructure such as hospitals, often resulting in the electricity staying on in nearby wealthy neighborhoods (82). In contrast, long-lasting blackouts occurred in regions farther from the critical infrastructure areas, where low-income families were more likely to live (82). In Austin, for example, the downtown area stayed electrified during much of the winter weather event while east Austin, a historically Black and Latino area, lost power (82, Fig. 26).

Fig. 26. View of power outages next to downtown Austin, TX. Source: CBS Austin (91)

LOCAL HAZARD MITIGATION SUCCESSES

Though the winter weather affected energy systems across Texas, its impacts were not uniform. Locations outside of the Texas-specific electricity grid operated by ERCOT tended to experience short, rolling outages rather than the days-long blackouts common in the rest of Texas (50). For example, in El Paso, TX, very few customers lost power during the winter weather event, and those that did experienced outages lasting 10 minutes or less (92). In contrast to much of the rest of the state, after the 2011 freeze the city of El Paso and El Paso Electric invested substantially in both grid and equipment weatherization, including preparing their infrastructure to handle temperatures as low as -10°F, and built a new power plant (50). These upgrades helped the city largely maintain its power throughout the February 2021 extreme cold event and provides a great example of local adaptation efforts leading to success (92). Connections to part of the national electricity grid which enabled access to backup energy sources, and the ability to shift one of their natural gas plants to temporarily run on diesel fuel, also benefited El Paso during the storm and its aftermath (92). Following the storm, local officials in El Paso noted that their ability to avoid the energy crisis that overwhelmed much of the rest of the state was a testament to the success of their weatherization and preparation efforts over the previous 10 years (92).

Although communities across Oklahoma temporarily lost power through rolling outages and had issues with water, including boil advisories, low water pressure, and pipe breaks, cities and power and water companies communicated risks and preparation well during this event. For example, Oklahoma Gas and Electric Company

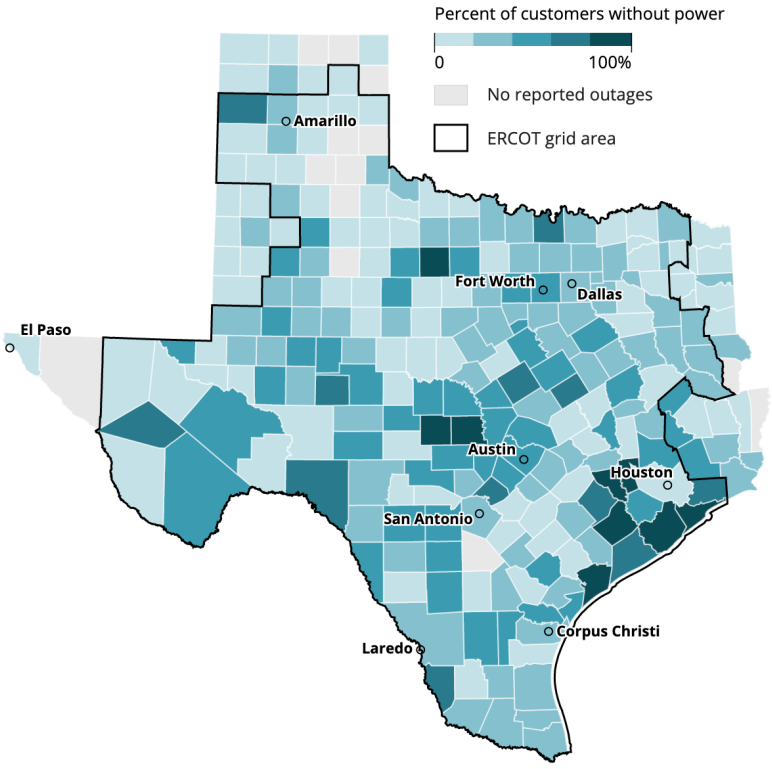


Fig. 27. Power outages in TX from 10-11am on Feb. 16th, 2021. Source: Texas Tribune/PowerOutage.us (50)

(OG&E), Public Service Company of Oklahoma (PSO), and Oklahoma Natural Gas (ONG) urged their customers to conserve power in order to not overwhelm the grid and natural gas supply. The City of Oklahoma City and the City of Tulsa communicated that their officials were preparing for the winter storms several days in advance and throughout the event by treating roads, preparing extra crews to respond to waterline breaks, and offering warm spaces for vulnerable populations (93, 94). They also urged residents to conserve both energy and water.

SUMMARY

February 2021 brought widespread extreme cold temperatures to the central U.S. and wintry precipitation to the SCIPP region. Multiple cold fronts and storm systems prolonged the cold temperatures, breaking many daily and monthly temperature records. Some areas remained below freezing for nearly 2 weeks. February's monthly temperature average was below normal in every SCIPP state, and even though several inches of snow fell, precipitation was still below normal for parts of Oklahoma, Texas, and Arkansas. Compared to previous historic winter weather events that occurred in 1899, 1983, 1989, and 2011, the February 2021 event was not the coldest to occur in the SCIPP region but it was still very impactful.

This winter weather event caused many impacts to the SCIPP region, affecting the economy, energy, water, infrastructure, environment, health, and society. This event has been placed on the NOAA Billion Dollar Disasters list, and an economic research firm in Texas has already estimated a loss of between $200-300 billion, including loss of income and business disruption (31, 80). These economic assessments do not capture the loss of over 200 lives, however. Most of the deaths occurred in Texas and were caused by hypothermia amidst the prolonged power outages resulting from the energy crisis (73).

Some cities' hazard mitigation measures paid off. For example, El Paso, TX, winterized their power infrastructure and built a new power plant after the extreme cold in 2011, resulting in very few power outages in February 2021. Other cities, like Tulsa, OK, and Oklahoma City, OK, communicated mitigation measures well to the public, treated roads in advance and throughout the storm, hired extra crews for waterline breaks, and offered warm shelters. February 2021 was a historic event that many will remember and a reminder of the importance of hazard mitigation for winter storms, even in typically warm Southern states.

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