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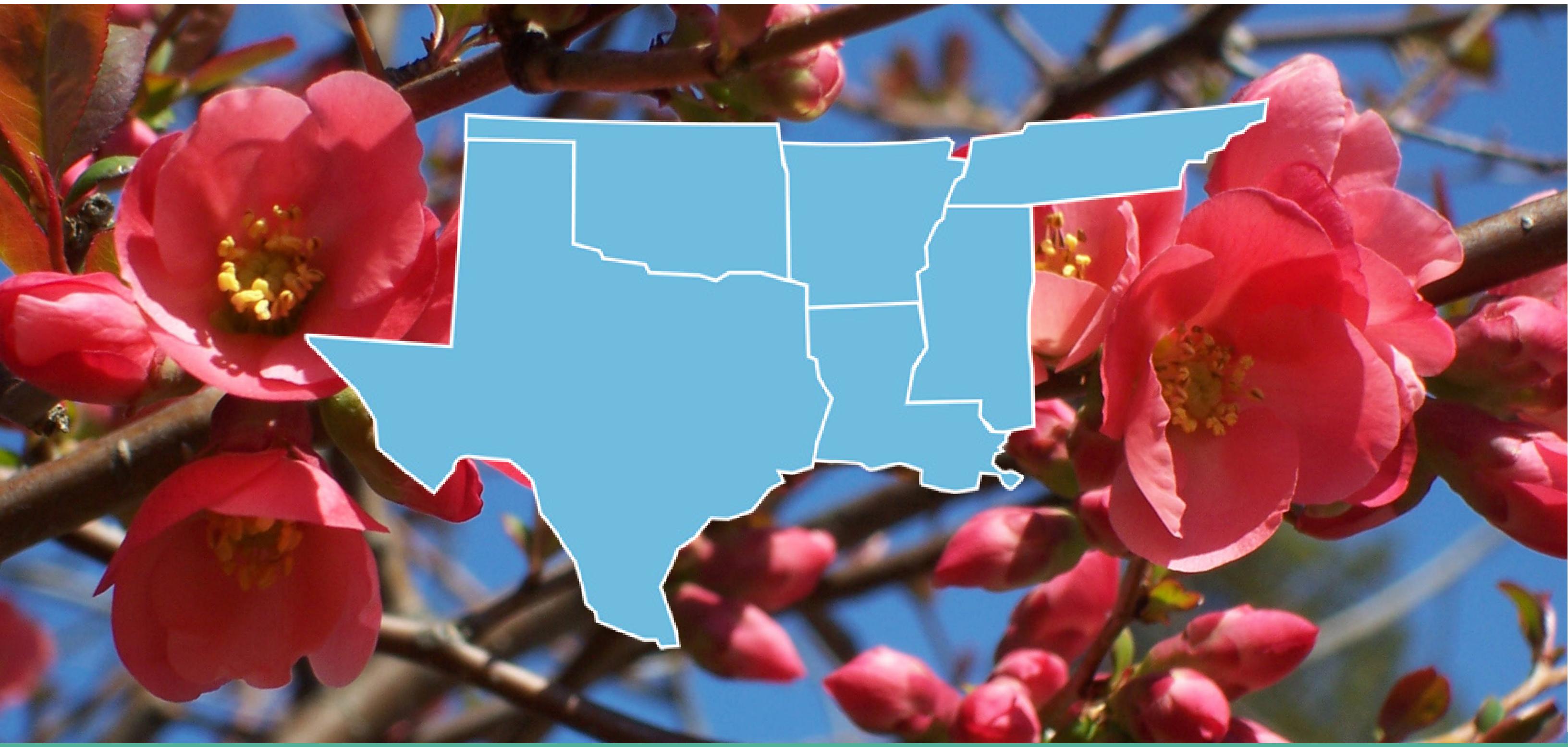

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Past, Present, and Future Implications of Extreme Heat Events on Human Health in the SCIPP region: An Updated Report

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Human sensitivity to weather is considerable and varies through time and space, and over time there is strong evidence of the climate/human health link. More specifically, heat, in the form of excessive heat events (EHEs), causes more deaths than any other weather-related event in the United States [(National Weather Service) NWS, 2009]. Although EHEs are associated with, on average, over 1500 deaths per year in the US (Kalkstein and Greene, 1997; Greene et al., 2011), individual extreme events have attracted the most attention. The most well known example in the United States is the 1995 EHE that resulted in more than 800 deaths in Chicago (Klinenberg 2002; Semenza et al., 1996. Whitman et al., 1997). The summer of 1995, because of this event in Chicago and elsewhere, was a watershed moment in terms of expanding awareness of the impacts of EHEs. However, even after that event, EHEs continue to cause widespread morality. For example, the European EHE in August 2003 was responsible for over 40,000 deaths across Europe (Valleron and Boumendil 2004). These events, and far too many others, show a general lack of awareness of heat as such a deadly killer, and as such, EHEs are associated with a largely avoidable loss of life.

An extreme heat event is much more than high temperatures, however. Individuals are exposed, and thus respond to all weather variables interacting simultaneously on the body. Thus, human health and comfort are impacted by a number of meteorological variables (e.g., temperature, humidity, pressure, cloud cover, and wind speed). To account for this, it is necessary to develop a holistic way to identify and assess those EHEs and high-risk situations which could negatively affect human health. One such commonly used approach is a “spatial synoptic classification” (SSC; Greene and Kalkstein, 1996, Sheridan, 2002; Kysely and Huth 2004; Gosling et al., 2009, Dixon, et al., 2016). The SSC examines a range of meteorological variables, and classifies each day at a particular location into one of several homogeneous weather types. The spatial synoptic classification identifies the spatial occurrences of air masses, and thus, in each city, each day is classified into one of six main airmass categories, or is considered a transition between the categories. The general conditions associated with each airmass category have been identified in a number of publications (Sheridan, 2002, Greene and Kalkstein, 1996; Greene, et al., 2011, Greene, et al., 2016, etc.). Previous research has shown that for most locations, two hot weather situations (dry tropical [dt] air and extreme moist tropical air [mt+]) are associated with statistically significantly elevated mortality, and that these air masses also are associated with a high percentage of days with the greatest mortality totals. The first step in the development of a model to identify and estimate EHE-associated mortality, then, is to combine these two conditions, and then build an algorithm to examine and assess the heat risks. A model combining the EHE weather types with the suite of meteorological variables (e.g., temperature, dew point, etc.) and other non-meteorological variables (e.g., time of season, consecutive EHE days) within each day as the predictors and temporally adjusted acute daily mortality as the predictand is then developed for each city under analysis to determine specific EHE-attributable mortality, if any (Kalkstein et al. 2008; Greene et al., 2011; Greene et al., 2016).

This paper shows some results from a new study that examined all cities in the contiguous US that contain 1,000,000 people according to the 2010 census. Although the study included over 50 cities in the US, this paper will focus on those cities in the SCIPP region that met the inclusion criteria (Austin, Dallas, Houston, Memphis, New Orleans, Nashville, Oklahoma City, San Antonio). The results discussed below update previous efforts by the authors using older meteorological data and climate models that have been reported in this bulletin (Greene and Kalkstein, 2013). Table 1 shows the average number of EHE days experienced each summer for the past (1975-2010) as well as the estimated number of EHE-associated deaths for each of the cities. As can be seen, these results vary dramatically by location, which fits previous research into the geographical variability of the climate/health relationship. For example, previous research has shown that EHE-related mortality increases with increasing inter- and intra-seasonal climate variability (e.g., Kalkstein et al., 2010; Chestnut et al., 1998; Sheridan et al., 2009). Conversely, cities with low excess mortality are often associated in locations with low climatic variability. This is particularly true for many cities in SCIPP region. Houston, for example, has low variability, and although it averages 19 EHE days per year, there is no significant climate/mortality relationship. For New Orleans, there are approximately 10 EHE days per year, which have been associated with, on average, 15 deaths. Overall, for the eight large cities in the SCIPP area that have been analyzed, the totals are approximately 90 excess deaths per year on average. Dallas is the most vulnerable city, with 22 EHE days and approximately 36 EHE-attributable deaths in an average summer. These values can vary tremendously from year-to-year, as shown in Figures 1 and 2, which show the historical temporal variability in EHEs and associated deaths across the region. For Dallas, for example, there is a range from 1 EHE day and 0 deaths (in 2002) to 65 EHE days and 190 EHE-attributable deaths (in 1980) during the period of study for this analysis. It can be seen that 1980 was associated with the highest amount of EHE-attributable deaths for 5 of the 7 cities in the region that had a heat/morality relationship. The other deadliest year was 1981, which was the highest for the two remaining cities (New Orleans, San Antonio). Other prominent years for both EHEs and EHE-attributable mortality include 1999 through 2001. An analysis of Figure 1 and 2 shows an increase in the number of EHE days, but not in the number of related mortality, which suggests the impact of coordinated efforts to reduce EHE-attributable mortality since the 1995 events discussed above.

After the retrospective analysis was undertaken, we used climate models and different emission

Table 1. Historical excessive heat events and related mortality, 1975-2010.

	EHE days	EHE Related Mortality
Location	Historical Annual Median	Historical Annual Median
Austin, TX	22	4
Dallas, TX	22	36
Houston, TX	19	0
Memphis, TN	15	19
Nashville, TN	10	6
New Orleans, LA	10	15
Oklahoma City, OK	20	8
San Antonio, TX	15	2

scenarios to examine the potential change in EHEs and EHE-related mortality in the SCIPP region for mid-century and end of century estimates of climate. Previous research has shown that climate models generally project increasing temperatures in the coming decades, and many regions of the United States can anticipate more frequent and severe EHEs in the future (e.g., Meehl and Tebaldi 2004; O'Neill and Ebi 2009). For the future estimates in this study, results from the downscaled Earth System Model from the Geophysical Fluid Dynamic Laboratory were used (Dunne, et al., 2013). Table 2 shows the estimated number of EHE days and deaths under two greenhouse gas emissions scenarios to illustrate the potential impacts of climate change. The first scenario assumes no global carbon emissions reductions ("business as usual", labeled "high emissions"), and a second scenario (labeled "low emissions") assumes some global effort to reduce overall greenhouse gasses in the atmosphere (see Kalkstein and Greene 1997; Greene, et al., 2011 for details). Results illustrate the potential dramatic impact of climate change, with the number of EHE days increasing for the eight cities as a whole from between 300-367% for mid-century (depending on the emissions scenario) to almost 500% at the end of the century for the business as usual estimate. For example, New Orleans and Nashville in particular are projected to have a tremendous increase in EHE days toward the latter half of the

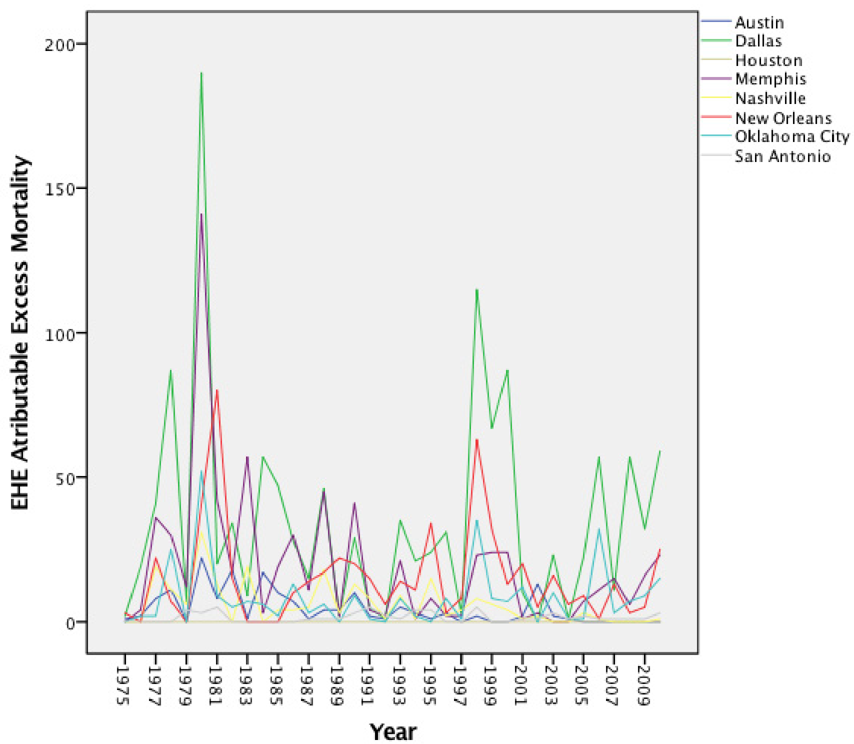

Figure 1. Excessive heat event attributable deaths over time.

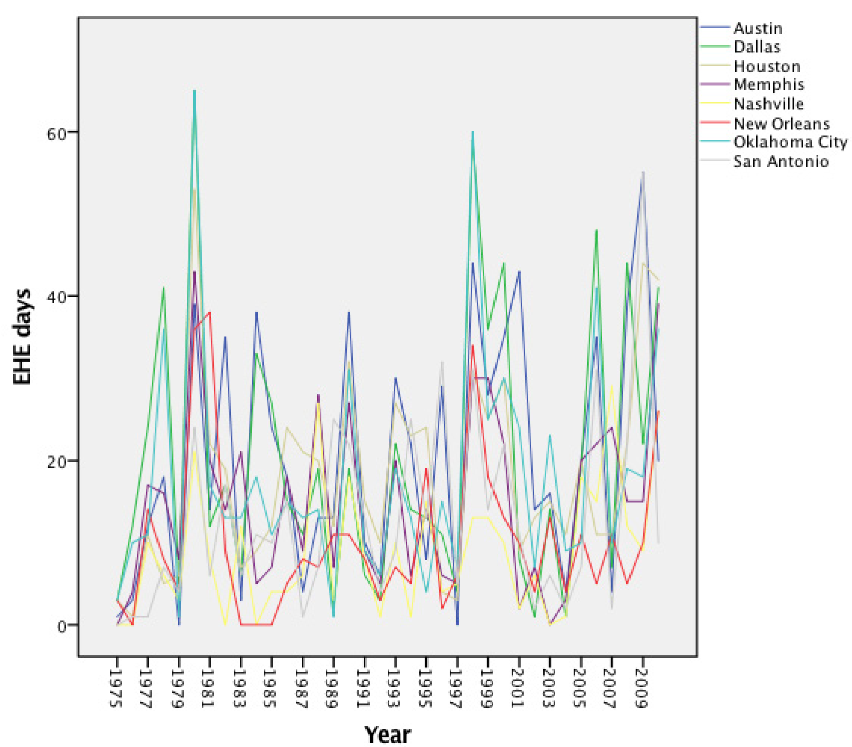

Figure 2. Excessive heat event days over time.

21st century. An examination of the estimated EHE days also illustrate the importance of an effective carbon reduction strategy, as the high emission-related deaths are almost double those for the low emissions scenarios overall, and even less for some of the cities (such as Oklahoma City, where the low emission values are approximately 1/3 of the high emission EHE associated deaths).

These numbers do not account for any growth or demographic changes in the cities over time, nor in any reduction in EHE-attributable excess mortality due to intervention and adaptation strategies. Our efforts over the past 20 years have show that such efforts reduce excess mortality. For example, Philadelphia's excess mortality from the July 1995 EHE was significantly lower per 100,000 population when compared to Chicago, which may partially be attributed to the particularly strong efforts by the Philadelphia Department of Public Health (Ebi et al., 2004). In Summer 1995, Philadelphia had just started an innovative synoptic-based heat warning system, while Chicago had no such system in place. The dramatic difference in the EHE-related mortality showed that an effective EHE response effort has positive public health benefits. A three-year study examining the impact of this warning approach showed that during the mid-1990's Philadelphia's program was estimated to have saved over 100 lives and millions of dollars (Ebi et al., 2004). These intervention and adaptation efforts include programs such as SSC-based heat health warning systems, which are in place in dozens of cities worldwide, as well as improved EHE forecasting and increased commitment of resources to EHE education, notification, and response measures.

The results shown and discussed here are an example of what might happen with EHE-related mortality should there be no effort to minimize the negative impacts of human-induced climate change and if there are no increased efforts like the ones listed above to respond to what will surely be an increase in EHEs in the futures. However, by examining the results of successful programs in the past, we can see that there is strong evidence that the impact of the most silent of weather-related disasters can be reduced through increased awareness, education, and that combining efforts of appropriate agencies as well as local officials and stakeholders we can work towards reducing such impacts in the future.

Table 2. Estimated future excessive heat events and associated deaths.

	Projected number of EHE days				Projected number of deaths attributable to EHEs			
	Projected Annual Average				Projected Annual Average			
	Mid-Century (2046 to 2055)		End of the Century (2091-2100)		Mid-Century (2046 to 2055)		End of the Century (2091-2100)	
Location	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Austin, TX	57	58	57	63	36	36	36	40
Dallas, TX	54	59	67	73	174	318	252	417
Houston, TX	29	75	37	88	0	0	0	0
Memphis, TN	58	60	69	74	205	216	280	390
Nashville, TN	67	67	75	80	137	148	170	208
New Orleans, LA	33	50	70	91	40	74	92	134
Oklahoma City, OK	47	60	64	75	23	38	59	131
San Antonio, TX	54	60	68	82	41	46	86	91

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Drought Update

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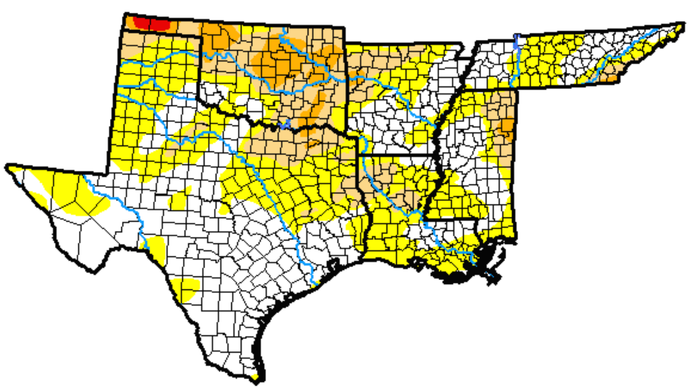
Over the month of March, 2017, drought conditions improved for some parts of the region, such as areas in Tennessee and Arkansas. There were a few areas that went from normal to abnormally dry, including northern Texas and southern Louisiana. Areas of Oklahoma and northeastern Mississippi are experiencing severe drought, with the panhandle of Oklahoma reporting extreme drought.

On March 24, 2017, seven tornadoes were reported in the southern region in Texas, Louisiana, Arkansas, and Tennessee. Six people were injured in Faulkner, Arkansas. In De Soto, Louisiana twelve railroad cars were blown off the track as 100 mph (160.9 kph) winds blew through the area. In Bienville, Louisiana 100 mph (160.9 kph) winds were also reported, which damaged a roof to a church in the area.

On March 28, 2017, there were 21 tornado reports in Texas. In Howard, Texas, there were reports of tennis ball sized hail that broke many skylights on a home.

On March 29, 2017, there were 18 tornado reports in the southern region in the states of Texas, Louisiana, Arkansas, and Mississippi. In Oakdale, Louisiana a tornado damaged a gas station canopy. There were also over 50 damaging wind reports total in Texas, Louisiana, and Mississippi.



Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	42.89	57.11	20.12	5.60	0.40	0.00
Last Week *03-21-2017*	36.01	63.99	23.43	9.15	0.72	0.00
3 Months Ago *12-27-2016*	42.70	57.30	31.21	10.68	0.84	0.00
Start of Calendar Year *01-03-2017*	53.95	46.05	27.69	11.09	1.11	0.00
Start of Water Year *09-27-2016*	76.89	23.11	6.74	1.89	0.28	0.11
One Year Ago *03-29-2016*	77.17	22.83	4.14	0.00	0.00	0.00

Released Thursday, March 30, 2017

Eric Luebehusen U.S. Department of Agriculture

Intensity:

- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Above: Drought conditions in the Southern Region. Map is valid for March 28, 2017. Image is courtesy of National Drought Mitigation Center.

Temperature Summary

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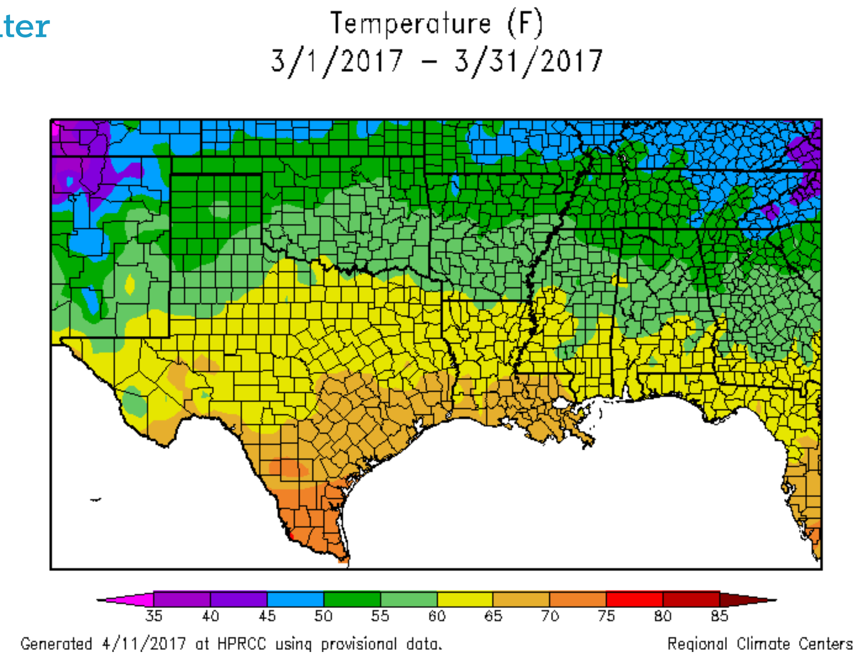
Southern Regional Climate Center

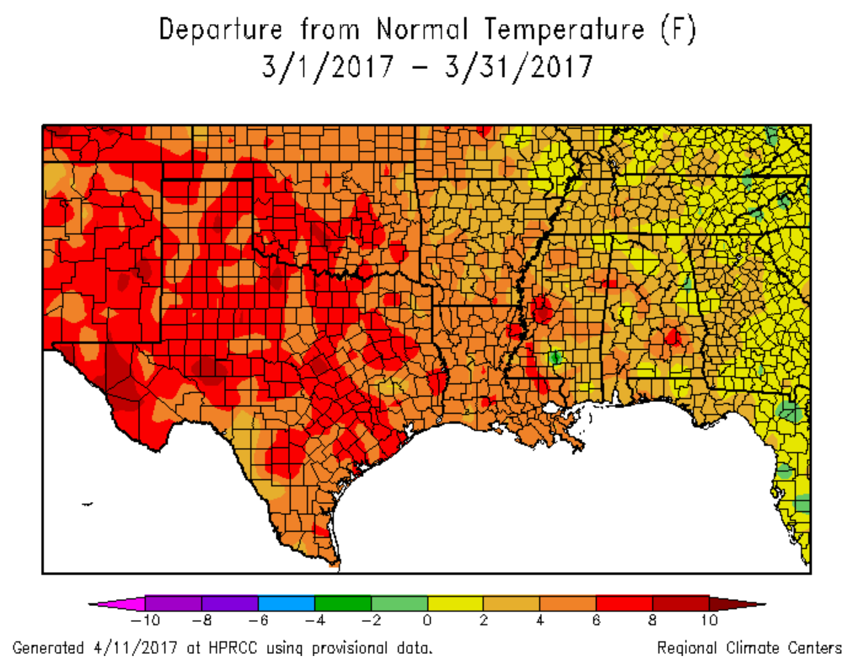
March was a warmer than normal month for four states in the southern region, Texas, Oklahoma, Arkansas, and Louisiana. Whereas the temperatures were near normal for Mississippi and Tennessee. For the region as a whole, it was warmer than normal. Temperatures generally averaged between 2 to 6 degrees F (1.11 to 3.33 degrees C) above normal in all of the southern region states. The western portion of the region exhibited temperature anomaly clusters of 6 to 10 degrees F (3.33 to 5.55 degrees C) above normal.

The statewide monthly average temperatures were as follows: Arkansas reporting 55.70 degrees F (13.17 degrees C), Louisiana reporting 64.30 degrees F (17.94 degrees C), Mississippi reporting 60.00 degrees F (15.56 degrees C), Oklahoma reporting 56.20 degrees F (13.44 degrees C), Tennessee reporting 51.10 degrees F (10.61 degrees C), and Texas reporting 63.70 degrees F (17.61 degrees C).

The state-wide temperature rankings for March are as follows: Arkansas (eighteenth warmest), Louisiana (tenth warmest), Mississippi (fifteenth warmest), Oklahoma (sixth warmest), Tennessee (thirty-fourth warmest), and Texas (second warmest). All state rankings are based on the period spanning 1895-2017.



Average March 2017 Temperature across the South



Average Temperature Departures from 1971-2000 for March 2017 across the South

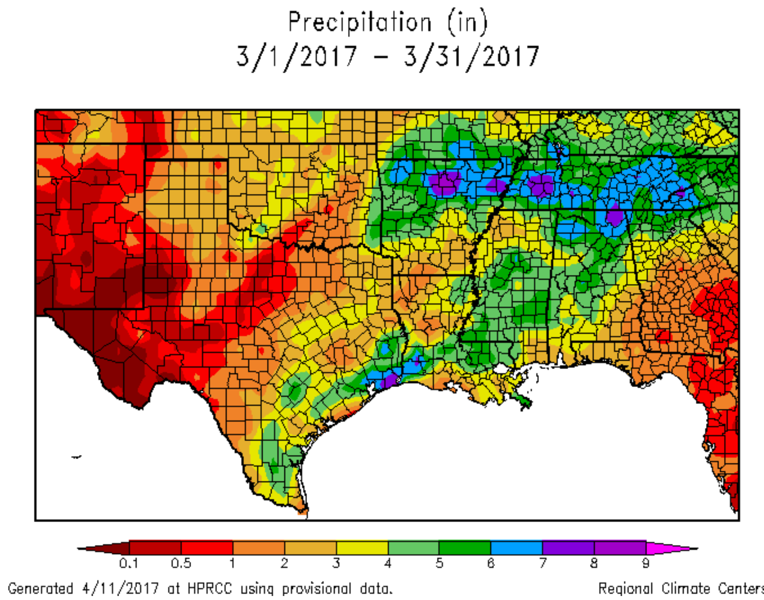
Precipitation Summary

Kyle Brehe and Rudy Bartels,
Southern Regional Climate Center

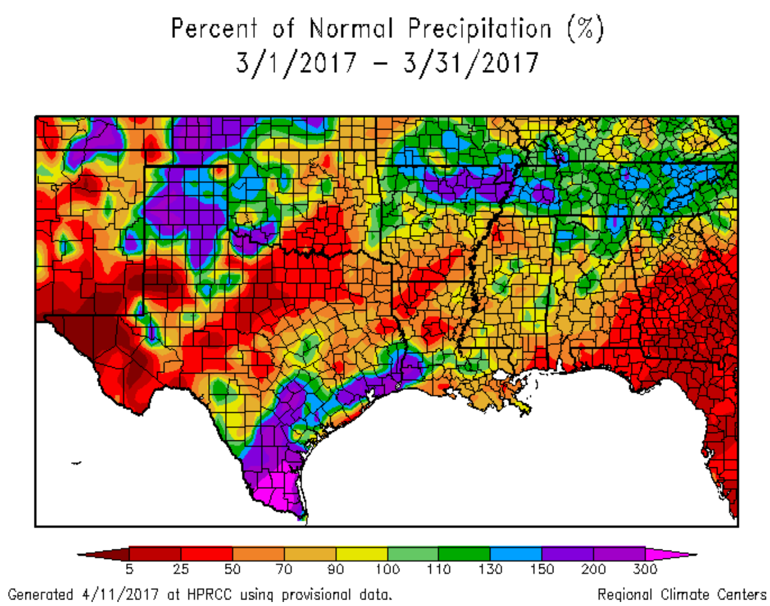
Precipitation values for the month of March varied spatially across the Southern Region. Precipitation totals in the northern and southern parts of Texas, the panhandle of Oklahoma, and northern Arkansas ranged between 150 to over 300 percent of normal. By contrast, conditions were quite dry across much of Louisiana, Mississippi, and eastern Oklahoma with most stations reporting between 25 to 70 percent of normal. In Arkansas, Oklahoma, Louisiana and Texas precipitation values were mixed in that there were clusters of normal, below normal and above normal levels of precipitation values. Tennessee reported above normal precipitation for most of the state, ranging from 110 to 200 percent above normal.

The state-wide precipitation totals for the month are as follows: Arkansas reporting 4.61 inches (117.09 mm), Louisiana reporting 3.51 inches (89.15 mm), Mississippi reporting 4.20 inches (106.68 mm), Oklahoma reporting 2.54 inches (64.52 mm), Tennessee reporting 5.83 inches (148.08 mm), and Texas reporting 1.87 inches (47.50 mm).

The state precipitation rankings for the month are as follows: Arkansas (fifty-ninth driest), Louisiana (thirty-eighth driest), Mississippi (thirtieth driest), Oklahoma (fifty-fourth wettest), Tennessee (forty-fourth wettest), and Texas (forty-ninth wettest). All state rankings are based on the period spanning 1895-2017.

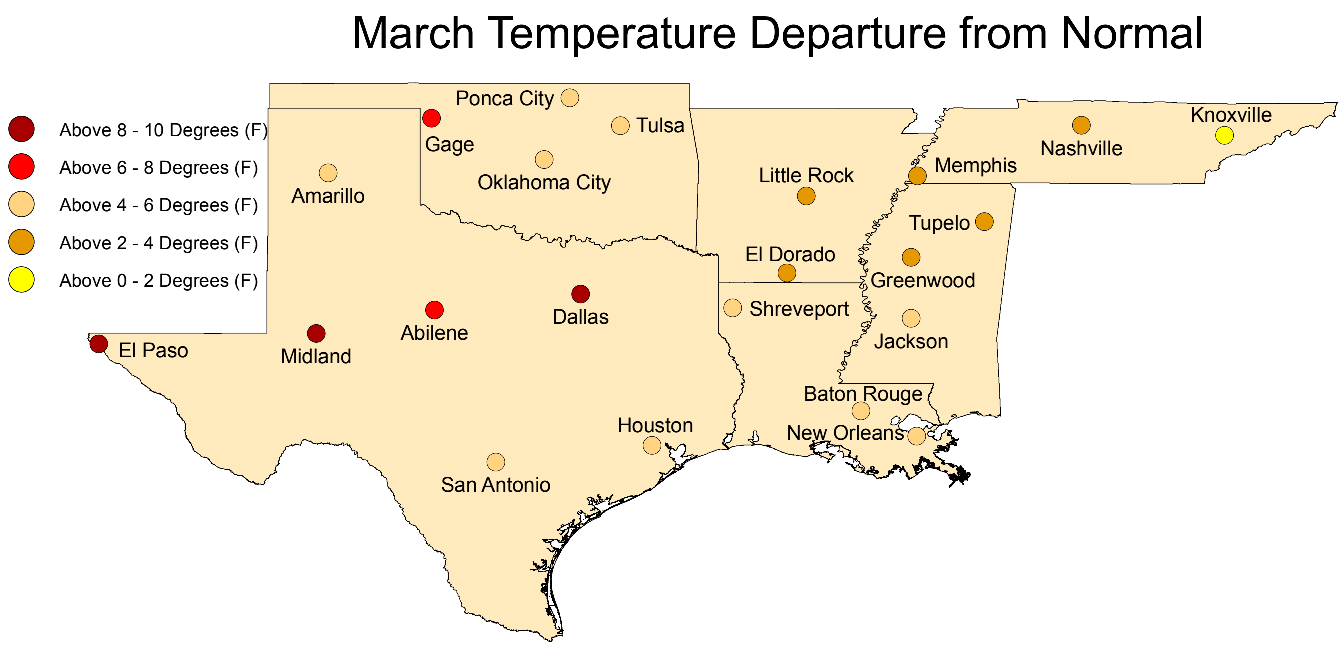


March 2017 Total Precipitation across the South

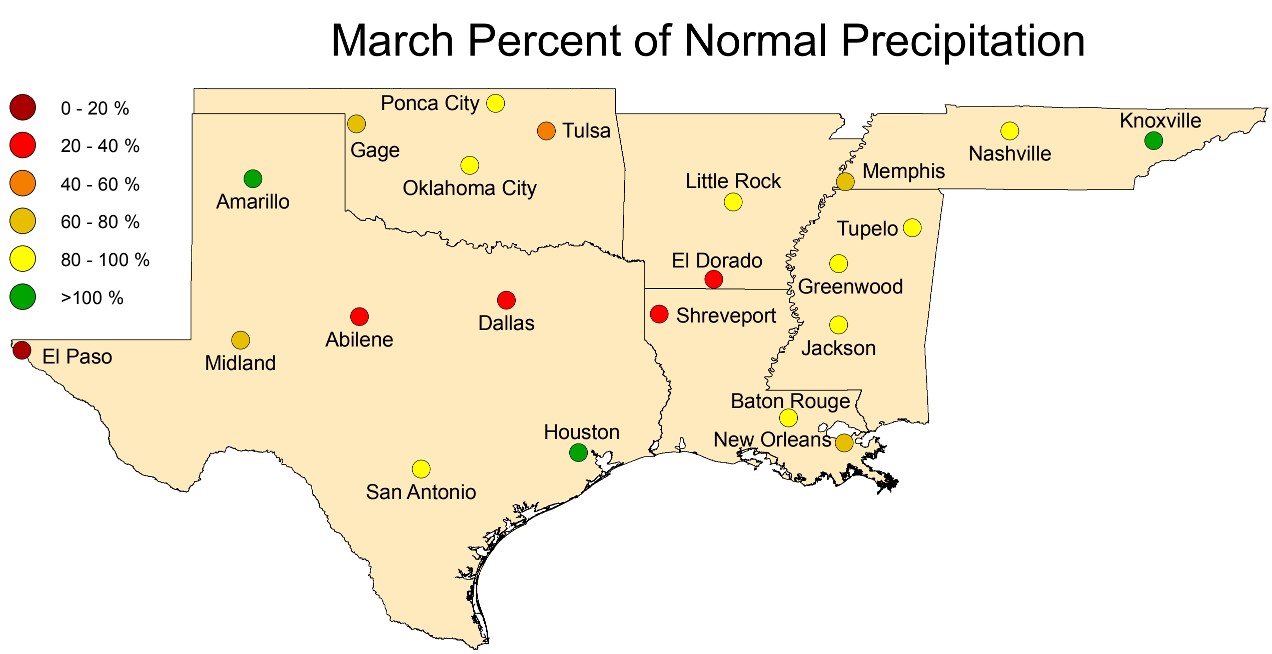


Percent of 1971-2000 normal precipitation totals for March 2017 across the South

Regional Climate Perspective in Pictures



March 2017 Temperature Departure from Normal from 1971-2000 for SCIPP Regional Cities



March 2017 Percent of 1971-2000 Normal Precipitation Totals for SCIPP Regional Cities

Climate Perspective

State	Temperature	Rank (1895-2011)	Precipitation	Rank (1895-2011)
Arkansas	52.30	1st Warmest	2.68	39th Driest
Louisiana	61.70	1st Warmest	2.35	16th Driest
Mississippi	57.40	2nd Warmest	3.04	22nd Driest
Oklahoma	50.30	3rd Warmest	2.01	34th Wettest
Tennessee	48.70	2nd Warmest	2.28	14th Driest
Texas	58.50	1st Warmest	1.67	57th Wettest

State temperature and precipitation values and rankings for March 2017. Ranks are based on the National Climatic Data Center's Statewide, Regional, and National Dataset over the period 1895-2011.

Station Summaries Across the South

Station Summaries Across the South

Station Name	Temperatures								Precipitation (inches)		
	Averages				Extremes				Totals		
	Max	Min	Mean	Depart	High	Date	Low	Date	Obs	Depart	%Norm
El Dorado, AR	71.7	47.5	59.6	3.8	86	03/20	29	03/14	1.71	-3.04	36
Little Rock, AR	68.1	44.6	56.4	3.0	86	03/21	28	03/15	3.87	-0.81	83
Baton Rouge, LA	76.9	56.1	66.5	5.0	86	03/29+	39	03/16	3.74	-0.67	85
New Orleans, LA	75.5	59.2	67.3	4.7	83	03/29+	44	03/16+	2.88	-1.67	63
Shreveport, LA	75.3	52.1	63.7	5.8	88	03/20	34	03/14	1.45	-2.69	35
Greenwood, MS	70.4	48.0	59.2	3.7	87	03/21	29	03/15	3.97	-0.34	92
Jackson, MS	74.0	50.4	62.2	5.3	87	03/21	34	03/16+	4.52	-0.52	90
Tupelo, MS	67.6	45.2	56.4	2.4	87	03/21	27	03/15	4.11	-0.71	85
Gage, OK	70.8	38.2	54.5	7.2	95	03/19	19	03/12	1.34	-0.54	71
Oklahoma City, OK	69.5	44.7	57.1	4.9	91	03/20	28	03/14+	2.60	-0.46	85
Ponca City, OK	66.4	41.4	53.9	5.1	90	03/19	24	03/02	2.25	-0.46	83
Tulsa, OK	68.5	44.7	56.6	5.3	92	03/20	28	03/14+	1.77	-1.52	54
Knoxville, TN	63.1	40.9	52.0	1.7	81	03/21	21	03/16	5.73	1.39	132
Memphis, TN	66.9	47.1	57.0	3.0	85	03/20	25	03/15	3.61	-1.55	70
Nashville, TN	65.1	41.9	53.5	3.5	84	03/20	21	03/16	4.02	-0.09	98
Abilene, TX	75.8	49.5	62.7	6.3	92	03/21	30	03/02	0.42	-1.32	24
Amarillo, TX	70.7	37.1	53.9	6.0	92	03/19	22	03/01	1.98	0.59	142
El Paso, TX	79.6	50.4	65.0	8.4	93	03/22	41	03/02	T	-0.26	0
Dallas, TX	76.8	54.6	65.7	8.1	92	03/20	37	03/14	1.06	-2.41	31
Houston, TX	77.9	58.5	68.2	5.5	87	03/27	43	03/14	5.63	2.22	165
Midland, TX	79.2	49.8	64.5	8.9	96	03/21	36	03/02	0.48	-0.12	80
San Antonio, TX	76.9	58.1	67.5	5.3	86	03/31+	45	03/14	2.09	-0.22	90

Summary of temperature and precipitation information from around the region for March 2017. Data provided by the Applied Climate Information System. On this chart, "depart" is the average's departure from the normal average, and "% norm" is the percentage of rainfall received compared with normal amounts of rainfall. Plus signs in the dates column denote that the extremes were reached on multiple days. Blueshaded boxes represent cooler than normal temperatures; redshaded boxes denote warmer than normal temperatures; tan shades represent drier than normal conditions; and green shades denote wetter than normal conditions.

Measuring Carbon Dioxide – The Keeling Curve

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Over a half century ago, Dr. Charles David Keeling began working with carbon dioxide levels in the air. One of his first discoveries was that atmospheric carbon dioxide levels had a daily cycle - levels would fall throughout the day, and increase at night. This was in response to vegetation utilizing the carbon dioxide in photosynthesis during the daylight hours, and through respiration (exhaling) at night. The Scripps Institute for Oceanography notes that Keeling made another unique discovery during his experiments. He discovered that whenever he measured carbon dioxide levels at remote locations, he would always come up with nearly the same carbon dioxide level, which at the time was about 310 parts per million (ppm). This would be measured away from cities, which are an obvious source of carbon dioxide (from cars, power plants, etc.), or large stands of trees, which serve to remove carbon dioxide through photosynthesis, hence making a large stands of trees a sink for the carbon dioxide. So at these remote locations, there appeared to be a stable background level of (310 ppm) carbon dioxide in the atmosphere.

Keeling, along with some other research scientists, wanted to know just how stable were these atmospheric carbon dioxide levels. As a result, they embarked upon a carbon dioxide measuring program, with the primary station being located in Mauna Loa, Hawaii. Mauna Loa is the largest volcano in mass and volume on earth and rises to 13,679 feet above mean sea level. But more importantly, it is positioned at great distance from any significant sources or sinks of carbon dioxide. As such, this station provides a nearly unbiased estimate of the world-wide carbon dioxide levels, and I note that these measurements have been cross-checked at many other remote locations across the world, including Antarctica.

The Keeling station at Mauna Loa began monitoring in 1958 and still monitors carbon dioxide levels continuously today (Figure 1). When measurements began in the 1950s, levels

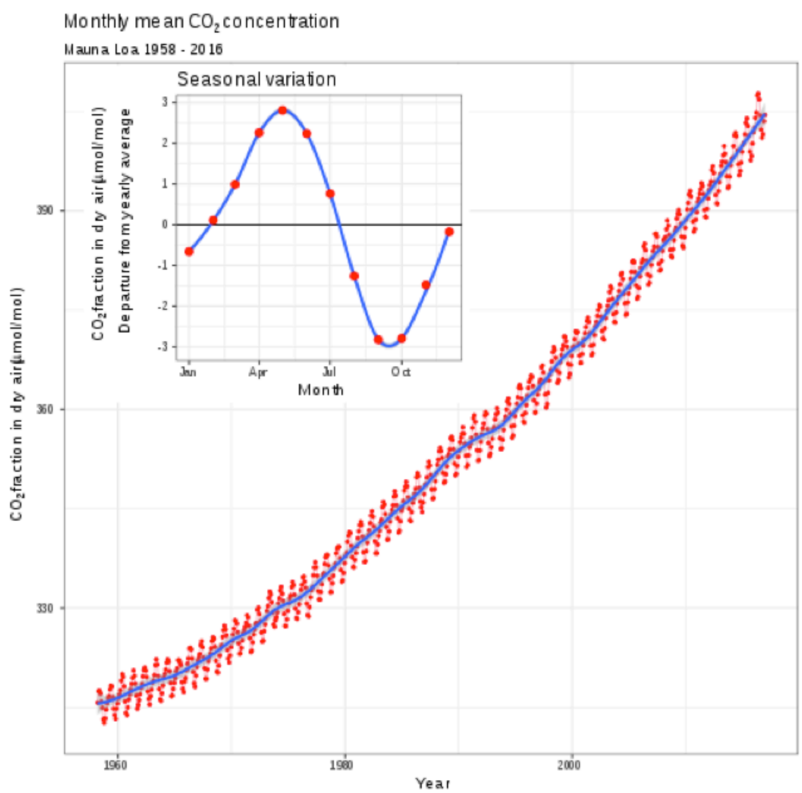

Figure 1. Laurentide ice sheet over North America at its Figure 1. The Keeling Curve from 1958-2016, showing increasing atmospheric carbon dioxide levels at Mauna Loa, Hawaii. Data are from Pieter Tans of NOAA/ESRL and Ralph Keeling of Scripps Institution of Oceanography. Graphic is available at https://en.wikipedia.org/wiki/Keeling_Curve#/media/File:Mauna_Loa_CO2_monthly_mean_concentration.svg.

were near 310 ppm as noted, but they were around 260-280 ppm in the mid-1800s. Today, carbon dioxide levels have risen to 408 ppm (as of Spring 2017). Also noticeable in Figure 1 is the seasonal ebbs and flows in the levels, much like Keeling discovered on a daily basis. Atmospheric carbon dioxide levels rise from late September through the winter and peak in mid-April, marking the start of the growing season in the Northern Hemisphere. Once the growing season kicks in, photosynthesis then begins to remove carbon dioxide from the atmosphere, and atmospheric carbon dioxide levels then decline from mid-April through mid-September, and the cycle repeats. More importantly, however, with each passing year, despite the seasonal cycle, the levels continue to climb. It is data like these that quite clearly show we are altering the atmospheric chemistry through the burning of fossil fuels. I also note that this just one of several greenhouse gases that is showing remarkable increases over time. I know there are varying interpretations of what this all means, but one thing no one can refute is that fact that we're performing a global experiment on ourselves, and we really don't know very many of the outcomes, e.g., how might this affect extremes in climate, ocean health, changes in vegetation. And that my friends, is a very scary thought. E-mail me with questions or feedback at keim@lsu.edu.

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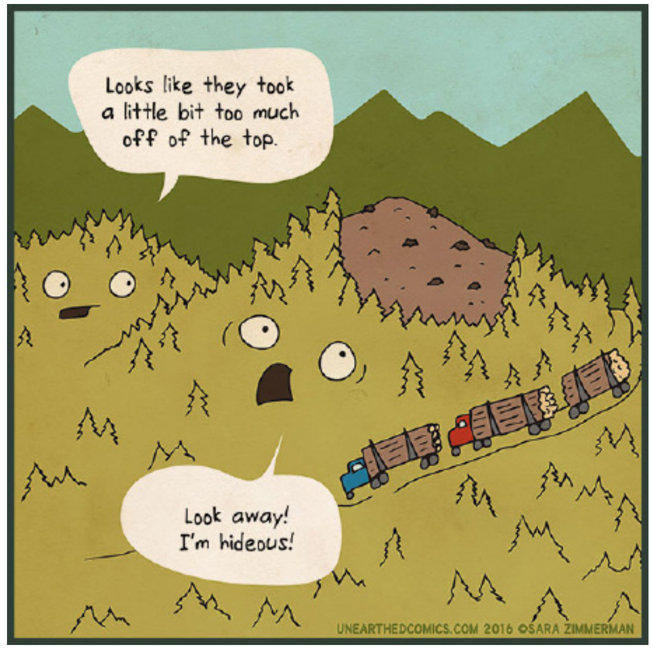

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