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Unprecedented 2016 at Flower Garden Banks National Marine Sanctuary

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The spectacular biological diversity of coral reefs can be attributed to two of their most dominant characteristics: the variety of habitats created by a reef's physical structure and the variety of intimate partnerships between the organisms that occupy those habitats. Of course corals are the foundation of both these reef attributes. Their limestone skeletons form the essential structure of tropical reefs, and the close association of coral with symbiotic algae sustains coral nutrition and powers the construction of coral skeletons.

All remains well on a reef as long as the algae-coral symbiosis remains intact, and fish and other reef organisms pack the habitats formed by living coral. This vitality of the coral reef community is on full display at Flower Garden Banks National Marine Sanctuary in the northwest Gulf of Mexico. The immense corals and brimming habitats of the Flower Garden Banks have defied the trend of decreasing abundance and condition of coral and reef inhabitants documented in recent years on coral reefs around the world (Kiene 2015, Johnston et al. 2016). That is until 2016.

Two significant events at the sanctuary last year have given marine scientists pause to consider if the Flower Garden Banks's reefs are no longer bucking the trend and are yielding to a rapidly changing marine environment. In July 2016, an area of one of the banks exhibited a "die-off" of coral and other invertebrates that affected 6.5 acres of the sanctuary. The other event began in October 2016 when corals on both banks "bleached" in numbers never seen before.

While the culprit in the bleaching event is known (an extended period of seawater temperature in excess of 30° C at the sanctuary), what caused the die-off of reef organisms in July is still under investigation. What both events have in common though, is that they stunned marine scientists by their abrupt severity, and that they occurred on a scale not seen at the Flower Garden Banks before. In addition, the events are comparable to changes in reef condition that have previously decimated coral reefs in other parts of the tropical world. Are these events harbingers of future disruptions in the ecological fabric of the coral reefs in the northwest Gulf of Mexico, and if so, is there anything that can be done to lessen their impact?

Mysterious "Die-Off"

On July 25, the sanctuary's research team was conducting annual coral monitoring procedures at East Flower Garden Bank when a nearby group of recreational divers radioed the sanctuary's research vessel about seeing an area of unusually murky water and dying coral and invertebrates. When the research team was able to get to the area (about 900 feet from where they were working) and jump in the water, they were "shocked" by what they found: hazy green water and death of all invertebrates and benthic algae (Fig 1) (Hickerson 2016, Beach 2016, http://flowergarden.noaa.gov/newsevents/massmortalityresponsearticle.html). A call from their satellite phone went out to NOAA scientists, who relayed the observations to the international coral reef science community to

seek perspectives on what might be causing the problem.

Researchers from Texas A&M University, University of South Florida, Rice University, Baylor University and University of North Carolina sprang into action. Several response cruises and reviews of remote sensing data suggest that recent flooding in the Midwest had caused exceptional freshwater discharges into the Gulf of Mexico from rivers in Texas and Louisiana, and reduced salinities of the water in the vicinity of the Flower Garden Banks (Fig 2). Nutrients contained in such discharges can create conditions of reduced oxygen in coastal water through the process of eutrophication, causing what are known as "dead zones" (http://www.noaa.gov/media-release/average-dead-zone-for-gulf-of-mexico-predicted). The question was, and remains, how could this process be responsible for what was found 100 miles offshore on the crest of a bank in 80 feet of water that rises 250 feet above the surrounding sea floor (Fig 3)?

Impacts caused by the freshwater discharge would likely be restricted to surface waters, unless decomposing phytoplankton and other organic matter associated with the runoff settled onto the reefs. One clue is in the distinct stratification of the die-off. A sharp threshold was evident at which death occurred below and the reef remained healthy above. This would suggest that water density or temperature concentrated water with lethal conditions at the seafloor. Alternatively, the lethal conditions could have come from below. The Flower Garden Banks are features created by the movement of salt deposits deep below the continental shelf. Brine and methane seeps are common in the deeper parts of the northwestern Gulf of Mexico, creating pools and flows of salt and methane enriched water at the seafloor. Could a discharge of saline

Figure 1. Die-off (white areas) of reef community at Flower Garden Banks seen in July 2016. Diver shows scale. Photo by FGBNMS/G.P. Schmahl.

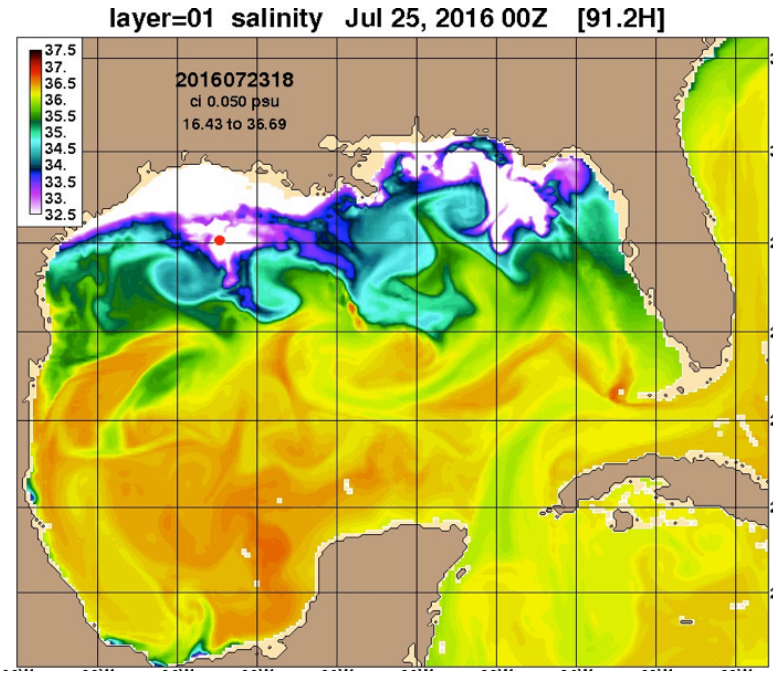

Figure 2. Significant sea surface salinity changes in the northern Gulf of Mexico by river discharges on July 25, 2016. East Flower Garden Bank indicated by red dot. Image by Navel Research Lab Real-time HYCOM Nowcast/Forecast System: https://www7320.nrlssc.navy.mil/GLBhycom1-12/glfmex.html

enriched water come from beneath the seafloor causing the death, or was it a combination of factors that came together to cause the unusual conditions? What is sure is that sanctuary researchers will continue to monitor the recovery and any new signs of mortality in the area to help diagnose what did the damage, and to be alerted if it returns.

Extraordinary Coral Bleaching Event

Bleaching of corals has been observed at the Flower Garden Banks several times in the past (Hagman and Gittings 1992, Precht et al. 2008, Johnson et al. 2013), but due to the high latitude and depth of its coral reefs, the warm water conditions that caused it were fortunately short-lived and kept the bleaching events from becoming lethal to most of its affected corals. However, 2016 was different.

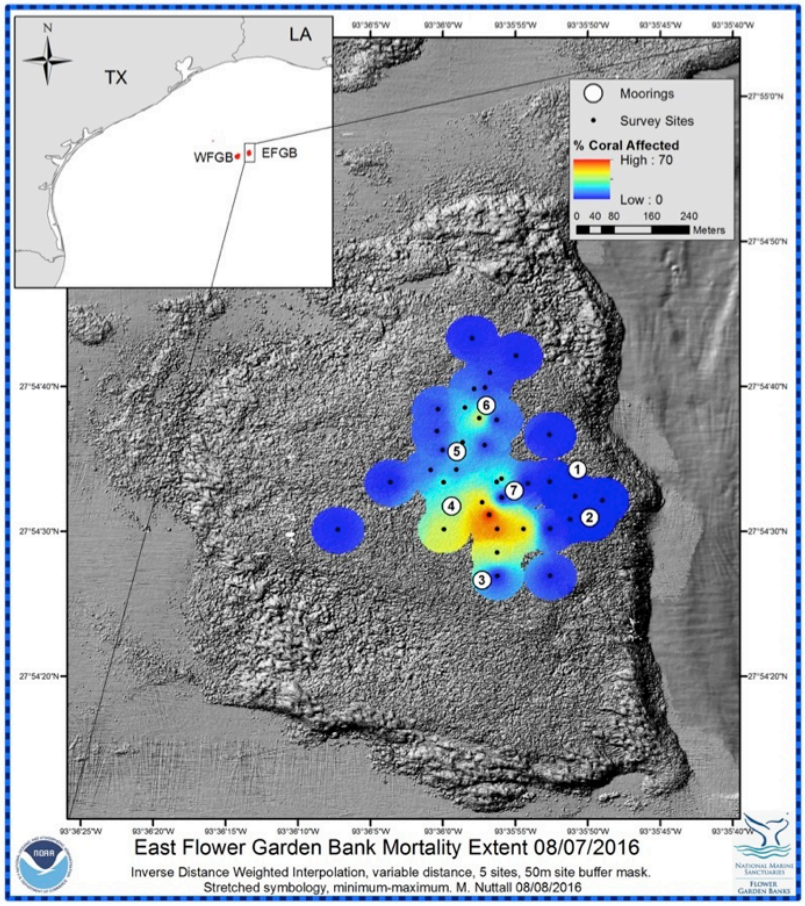

Figure 3. Documented extent of the mortality event. Numbers are mooring buoys. Highest percent of corals affected are concentrated in an area near moorings 3, 4, and 7. Map by FGBNMS/Marissa Nuttall.

Coral "bleaching" is when a coral loses its symbiotic partner, a dinoflagellate of the genus Symbiodinium (generally called "symbiotic algae" or "zooxanthellae"), which is found in the gastric tissue of the coral. These partners aid the coral's metabolism and growth. They also give the coral their color, and when they are lost, the coral animal is transparent and reveals their underlying white calcium carbonate skeleton. Thus, the term "bleaching." The loss of zooxanthellae occurs when corals are stressed by changes in certain water conditions, particularly a rise in water temperatures above 30° C (Brown 1997). If high temperature conditions last too long, a bleached coral will starve and die. If the temperatures decrease, corals can regain their symbiotic algae and survive - that is as long as other impacts, such as diseases or water quality problems, don't kill the coral while it is weakened by its lack of zooxanthellae-supplied nutrition. For more about the unprecedented nature of 2016 for coral reefs around the world, see Hughes et al (2017): https://coralreefwatch.noaa.gov/satellite/publications_hughes-etal_nature_20170316.php.

A monitoring mission to the Flower Garden Banks in early October 2016 found more corals had bleached in the sanctuary than ever seen before (Fig 4) (http://flowergarden.noaa.gov/newsevents/2016bleachingarticle.html). Up to 46% of the corals within the sanctuary's long-term monitoring stations were exhibiting signs of bleaching stress, with 24% at East Flower Garden Bank and 10% at West Flower Garden Bank totally bleached (lost enough of their symbiotic zooxanthellae to be completely white in color). Temperature records from monitoring stations in the sanctuary indicated that from

July through September water temperatures on the reef were in excess of 30° C for 30 days, a period longer than has been recorded before. Differences between the amount of bleaching at the two sanctuary banks that compose the sanctuary are likely a reflection of spatial and temporal variations in water temperature over the period (Fig 5). However, the unusual nature of the extent of bleaching at both banks caused sanctuary scientists to be concerned as they planned for a February mission to the sanctuary to assess if the corals would recover.

Low water visibility and rough seas challenged the work by the science team during the first week of February, but they were undaunted in their mission. What was the outcome of last year's bleaching event? Their tenacity prevailed and the scientists were able to confirm that the majority of the bleached corals at the East Flower Garden Bank monitoring stations had recovered most, if not all, of their symbionts and appeared to once again be healthy (Fig 6). Only a few corals died as a result of the bleaching event. This is very good news, but the questions remains: Are the coral reefs at the Flower Garden Banks being subjected to a long-tem pattern of sustained higher temperatures during peak temperature months, and what do the recent bleaching responses say about the future for the corals in the sanctuary?

Resilient or Just Lucky?

Coral reefs around the world in 2016 were subjected to the most severe coral bleaching events yet seen, with places like the Great Barrier Reef losing many of its corals to the bleaching (http://news.nationalgeographic.com/2016/03/160321-coral-bleaching-great-barrier-reef-climate-change/).

Figure 4. Bleaching of corals at Flower Garden Banks October 5, 2016. Photo: Emma Hickerson.

Research suggests that corals that experience stresses like coral bleaching, but survive, may be - or become - more resistant and resilient to future anomalies in their environmental conditions. Some corals - whether through their genetics, the type of symbionts they have, or a conditioning they have received by previous stress events - recover quickly from bleaching or seem unaffected by higher temperature (http://www.reefresilience.org/coral-reefs/stressors/bleaching/resistance-tolerance-and-recovery/). If a warmer world,

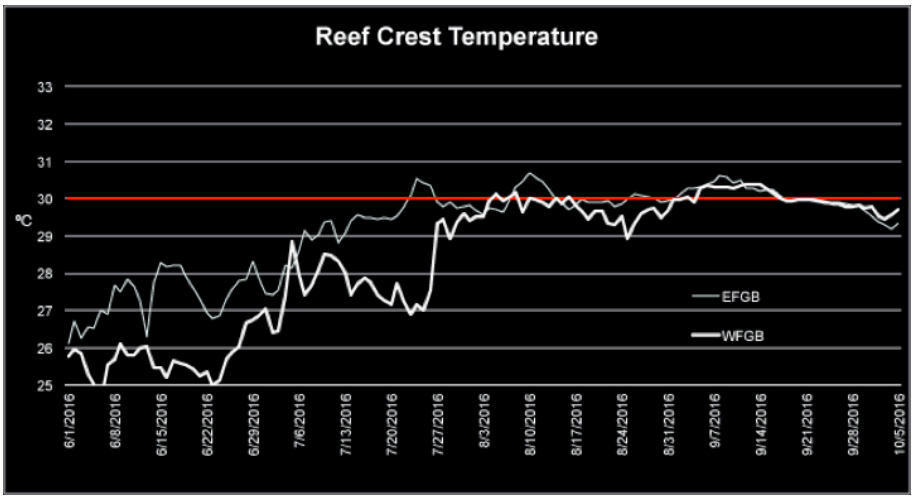

Figure 5. Water temperature records at 60 ft depth on the reef crest at the Flower Garden Banks. Coral bleaching is most likely to occur at temperatures above 30° C (red line). Graph indicates that East Flower Garden Bank (EFGB) had 35 days over 30° C and West Flower Garden Banks (WFGB) had 21 days over 30° C. 35 days over 30° C and West Flower Garden Banks (WFGB) had 21 days over 30° C.

Figure 6. Sequence of photographs of the same monitoring station at the East Flower Garden Bank taken before, during, and after the 2016 coral bleaching event. In the February 2017 photo, most of the corals have returned to having normal zooxanthellae density, white circles are areas of the corals that remain pale in color, and red circles are areas that have died as a result of the bleaching. Photos by NOAA/FGBNMS.

and a subsequent warmer ocean, are inevitable, then these resilient and resistant characteristics of corals may provide a key to coral reef survival as our planet changes.

The Flower Garden Banks offer an important laboratory to explore coral resilience. Is the recovery of its corals following last year's major bleaching event a result of an inherent resilience built into the Flower Garden Banks' corals, or were they just lucky that water temperature patterns in 2016 were survivable? Did the corals "gain" from the bleaching event, making the sanctuary's corals stronger to survive future temperature anomalies? As a consequence, is there anything we can do to help corals build resilience as they face a different temperature regime in the future? These are important questions that can be addressed in the sanctuary, while at the same time having important application to the future coral reefs around the world.

Unfortunately, the part of the East Flower Garden Bank that experienced the die-off wasn't resilient or lucky. The conditions that caused such a dramatic death of all the invertebrates in a distinct area of reef appeared to arrive quickly, and then just as quickly, disappeared. Was this event something unique to the Flower Garden Banks resulting from a rare cascade of lethal local conditions, or a new phenomenon of larger consequence to coral reefs that is yet to be determined? No matter if it will ever be known what caused this event, and whether it will happen again, the investments in ecosystem science, annual long-term monitoring programs, and protection at the Flower Garden Banks will pay dividends far beyond the sanctuary boundaries and the time period in which they are made. The ability to document the unprecedented events of 2016 is a measure of those dividends.

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Drought Update

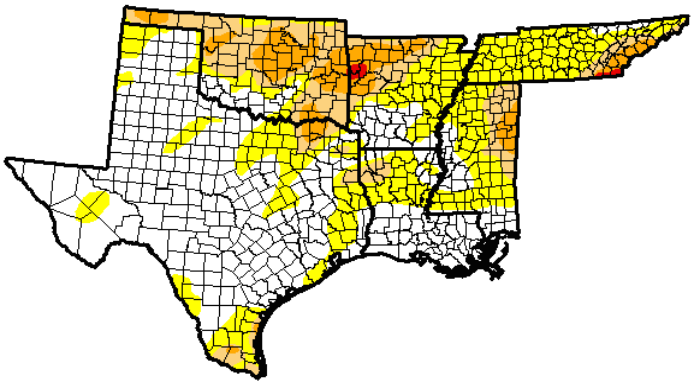
Luigi Romolo and Rudy Bartels, Southern Regional Climate Center

Over the month of February, 2017, drought conditions remained similar to January. There were a few areas that went from normal to abnormally dry, including eastern Arkansas, and much of western Tennessee. Areas of Oklahoma, Arkansas, and Tennessee are still exhibiting severe and extreme drought conditions.

On February 7, 2017, there were a dozen tornadoes reported in southeast Louisiana and central Mississippi, which caused 31 injuries and damaged over 70 homes. There were many wind and hail reports in these areas as well.

On February 14, 2017, seven tornadoes touched down in Southeastern Texas with one tornado injuring six people. The tornadoes snapped many large trees and limbs, with damages to multiple homes. There were multiple reports of flipped over RVs in Matagorda, Texas and wind reports of over 80 mph (128.75 kph). In Fort Bend, Texas, there was a tornado that rated as an EF-2 and damaged over 40 homes.

On February 28, 2017, there were several tornadoes and dozens of wind and hail reports scattered over northern Arkansas and western Tennessee. According to KATV News in Little Rock, Arkansas, several people were injured as a result of a Tornado in White County, Arkansas. Dozens of homes were also reported damaged.



Released Thursday, March 2, 2017
Richard Heim NCEI/NOAA

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	51.08	48.92	19.35	7.59	0.35	0.00
Last Week *2/21/2017*	65.18	34.82	16.94	6.57	0.24	0.00
3 Months Ago *11/29/2016*	35.60	64.40	49.52	32.07	13.67	1.34
Start of Calendar Year *1/3/2017*	53.95	46.05	27.69	11.09	1.11	0.00
Start of Water Year *9/27/2016*	76.89	23.11	6.74	1.89	0.28	0.11
One Year Ago *3/1/2016*	80.47	19.53	0.55	0.00	0.00	0.00

Intensity:

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

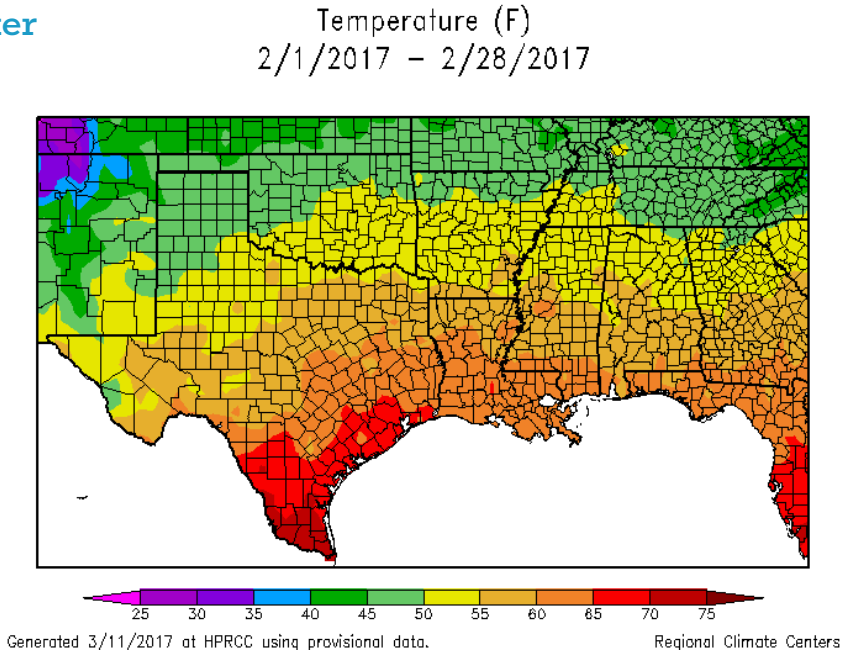
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

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

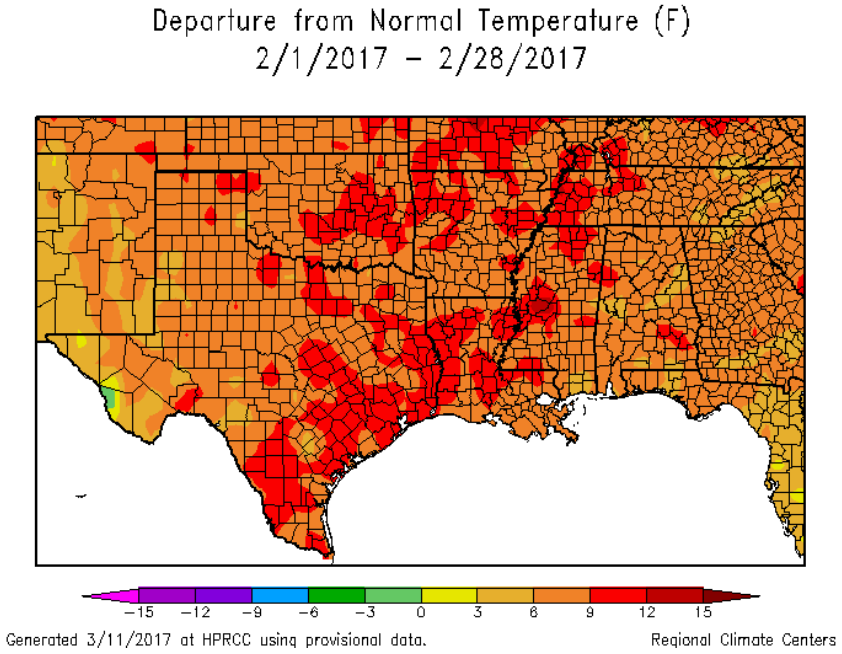
Temperature Summary

Luigi Romolo and Rudy Bartels,
Southern Regional Climate Center

February was a warmer than normal month for all six states in the Southern Region. In fact, the temperature rankings for each state are in the top three, with four of the states having their warmest February on record. For the region as a whole, it was the warmest February on record. Temperatures generally averaged between 6 to 9 degrees F (3.33 to 5.00 degrees C) above normal in all of the southern region states. The central portion of the region also exhibited temperature anomaly lusters of 9 to 12 degrees F (5.00 to 6.66 degrees C) above normal. The statewide monthly average temperatures were as follows: Arkansas reporting 52.30 degrees F (11.28 degrees C), Louisiana reporting 61.70 degrees F (16.50 degrees C), Mississippi reporting 57.40 degrees F (14.11 degrees C), Oklahoma reporting 50.30 degrees F (10.17 degrees C), Tennessee reporting 48.70 degrees F (9.28 degrees C), and Texas reporting 58.50 degrees F (14.72 degrees C). The state-wide temperature rankings for February are as follows: Arkansas (first warmest), Louisiana (first warmest), Mississippi (second warmest), Oklahoma (third warmest), Tennessee (second warmest), and Texas (first warmest). All state rankings are based on the period spanning 1895-2017.



Average February 2017 Temperature across the South

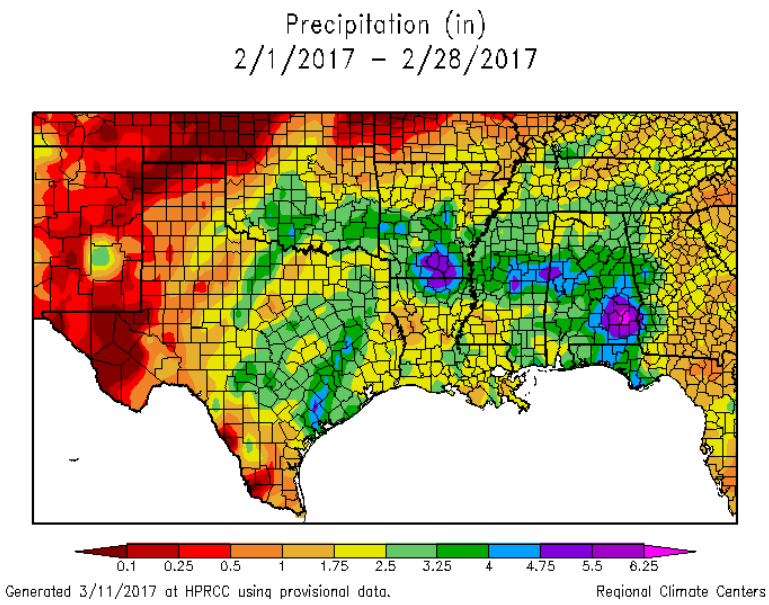


Average Temperature Departures from 1971-2000 for February 2017 across the South

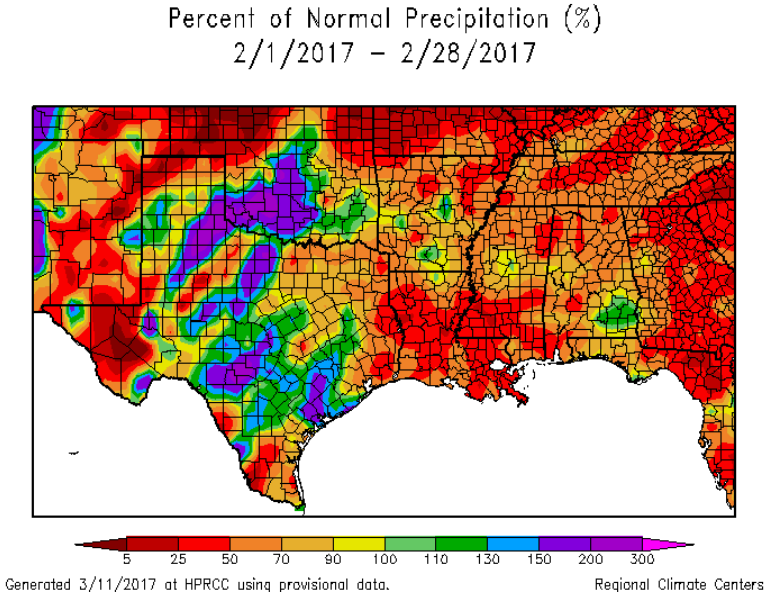
Precipitation Summary

Luigi Romolo and Rudy Bartels, Southern Regional Climate Center

Precipitation values for the month of February varied spatially across the Southern Region. Precipitation totals in Texas and Oklahoma ranged between 130 to over 200 percent of normal. By contrast, conditions were quite dry across much of Louisiana, Southern Mississippi, and Tennessee with most stations reporting between 25 to 70 percent of normal. In Arkansas precipitation values were mixed in that there were clusters of normal, below normal and above normal levels of precipitation values, ranging between 25 to 130 percent of normal. This was also the case in Northern Mississippi. The state-wide precipitation totals for the month are as follows: Arkansas reporting 2.68 inches (68.07 mm), Louisiana reporting 2.35 inches (59.69 mm), Mississippi reporting 3.04 inches (77.22 mm), Oklahoma reporting 2.01 inches (51.05 mm), Tennessee reporting 2.28 inches (57.91 mm), and Texas reporting 1.67 inches (42.42 mm). The state precipitation rankings for the month are as follows: Arkansas (thirty-ninth driest), Louisiana (sixteenth driest), Mississippi (twenty-second driest), Oklahoma (thirty-fourth wettest), Tennessee (fourteenth driest), and Texas (fifty-seventh wettest). All state rankings are based on the period spanning 1895-2017.

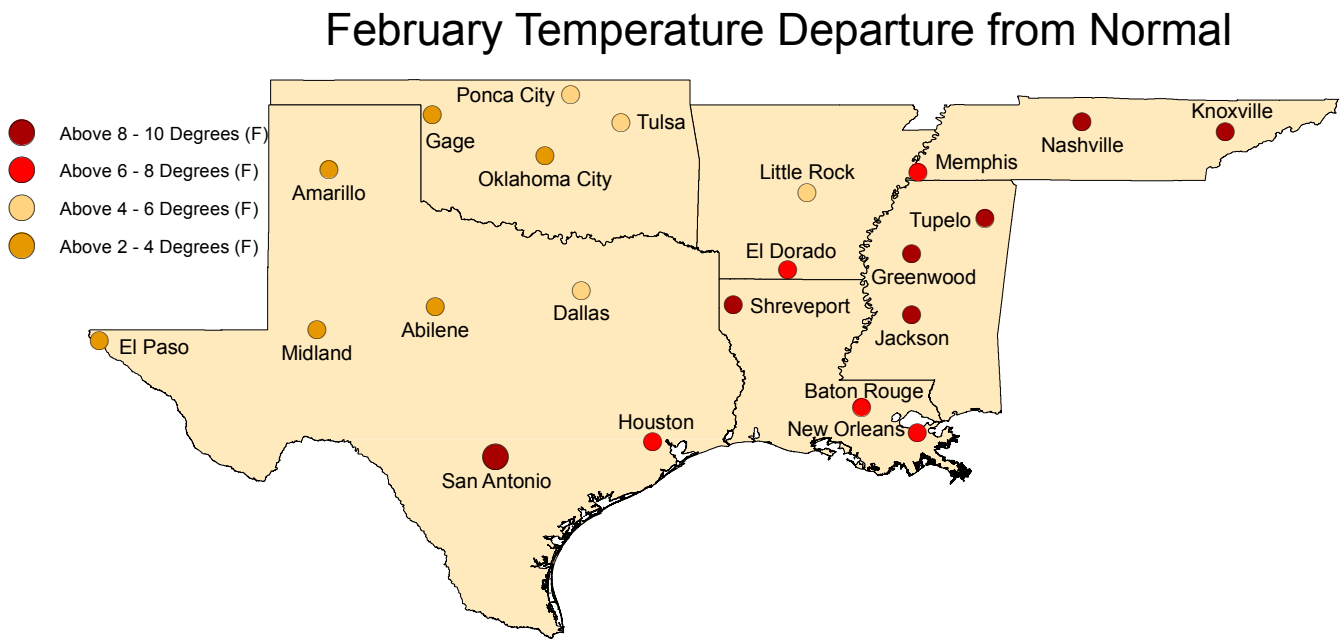


February 2017 Total Precipitation across the South

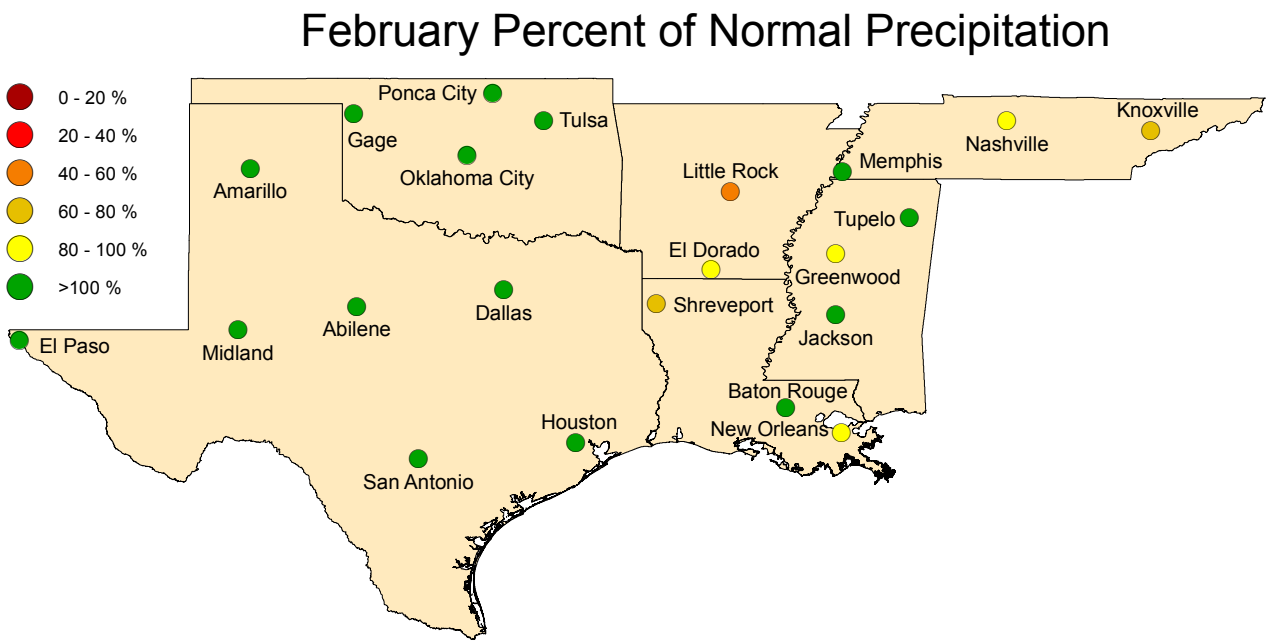


Percent of 1971-2000 normal precipitation totals for February 2017 across the South

Regional Climate Perspective in Pictures



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



February 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 February 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	60.9	41.2	50.8	6.9	78	01/12	14	01/07+	3.95	-0.35	92
Little Rock, AR	55.1	37.3	46.2	5.4	75	01/31+	12	01/07	1.47	-2.08	41
Baton Rouge, LA	69.7	48.9	59.3	7.6	82	01/18+	21	01/08	9.68	3.96	169
New Orleans, LA	69.0	51.3	60.1	6.7	80	01/20	27	01/07	4.90	-0.25	95
Shreveport, LA	65.0	45.5	55.3	8.5	81	01/12	18	01/08	2.56	-1.64	61
Greenwood, MS	61.6	42.4	52.0	8.6	77	01/12	12	01/08	4.23	-0.29	94
Jackson, MS	65.6	44.7	55.2	9.5	80	01/17	17	01/08+	7.90	2.93	159
Tupelo, MS	59.6	41.9	50.8	9.1	77	01/14	12	01/08	5.77	1.29	129
Gage, OK	52.0	24.4	38.7	4.0	76	01/30	-3	01/07+	2.70	2.14	482
Oklahoma City, OK	54.3	28.7	41.5	2.3	79	01/11	-3	01/07	1.57	0.18	113
Ponca City, OK	51.3	27.8	39.5	4.6	73	01/30+	3	01/07	2.62	1.62	262
Tulsa, OK	53.5	30.5	42.0	4.3	78	01/11	7	01/07	3.42	1.76	206
Knoxville, TN	54.9	39.5	47.2	9.0	68	01/25+	7	01/08	3.37	-0.95	78
Memphis, TN	56.4	40.6	48.5	7.3	76	01/12	13	01/08+	4.26	0.28	107
Nashville, TN	55.0	39.1	47.0	9.3	72	01/16	8	01/08	3.34	-0.41	89
Abilene, TX	59.1	35.4	47.2	2.3	81	01/11	9	01/07	1.93	0.91	189
Amarillo, TX	52.4	26.4	39.4	2.4	78	01/09	-3	01/07	3.17	2.45	440
El Paso, TX	59.6	37.9	48.8	3.7	72	01/11+	26	01/07	1.05	0.65	262
Dallas, TX	62.0	40.4	51.2	5.3	80	01/31+	14	01/07	4.39	2.26	206
Houston, TX	69.4	50.4	59.9	6.8	81	01/12	21	01/07	6.09	2.71	180
Midland, TX	60.5	35.0	47.8	3.9	83	01/11	11	01/07	1.12	0.56	200
San Antonio, TX	69.6	45.5	57.5	5.7	83	01/21	19	01/08	2.72	0.96	155

Summary of temperature and precipitation information from around the region for February 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.

An Ice Age Louisiana Shoreline

Barry Keim, Louisiana State Climatologist, Louisiana State University

Given all of the discussion about landloss and eroding coastlines in Louisiana, it is hard to imagine that there was time in our distant past, when our coastline was located about 100 miles offshore from its current location. Well, OK, this took place about 18,000 years ago! To place this in some perspective, I need to give you little tutorial of the Pleistocene Epoch. The Pleistocene began about 1.8 million years ago, and ever since, earth's climate has oscillated between glacial periods, which lasted about 90,000 years, and interglacials, which lasted approximately 10,000 years. So obviously, we've had many oscillations over this time period. During glacial periods, earth's climate was considerably colder than our modern climate - to the tune of about 8-10°F colder for the globe. During these glacial events, snow would accumulate over land, which would be preserved due to the colder temperatures, especially at the higher latitudes. As snow piled up on the landscape, it would get converted to firn (granular ice), which would eventually change into continental glacial ice due to compression, and the glaciers spanned vast areas. Figure 1 shows what the extent of glaciation was during the maximum of our last glaciation - called the Wisconsin Glacial in the U.S. - which peaked about 18,000 years ago. A vast ice sheet, many miles thick covered all of Canada, and even parts of the northern United States. Note that this has occurred numerous times over the past 1.8 million years. What makes this relevant to Louisiana is that when all of this water is tied up in glaciers that rest on land, it leaves less water in the ocean basins, and sea level is significantly lower. Due to that vast glacier over Canada and Eurasia, mean sea level was about 400 feet lower than it is today, and Louisiana's coast extended all the way out to near the edge of the current continental shelf (Figure 2). As result, Louisiana was much larger than it is today, but then again, we had no state boundaries 18,000 years ago! The climate then began to warm and we moved in to the current interglacial period, which started about 11,500 years ago - a period known as the Holocene. With the warming, came the melting of the continental glaciers, and sea level rose about 400 feet to its current level. Four hundred foot swings in mean sea level over the Pleistocene surely places our current issues with sea level rise in some perspective. I'm not exactly sure what it all means, but it's something to think about. E-mail me with questions or feedback at keim@lsu.edu.

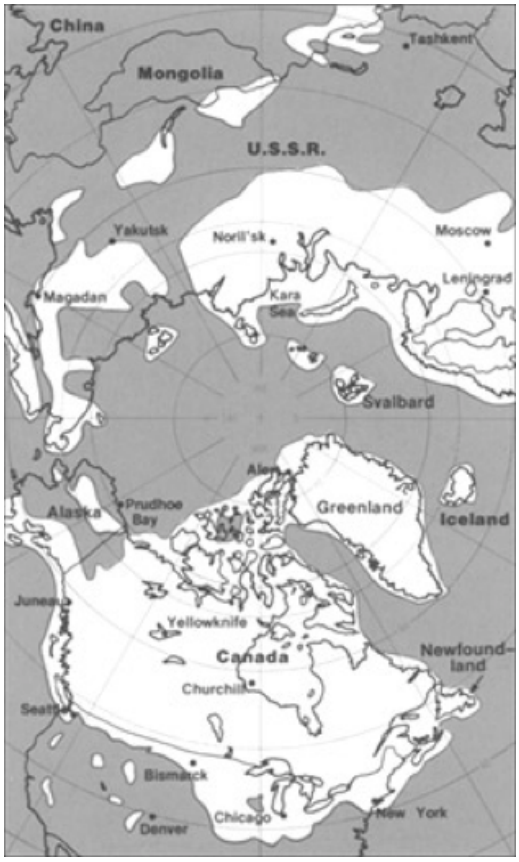


Figure 1. Laurentide ice sheet over North America at its maximum extent about 18,000 years ago. Image is in the public domain and can be accessed at https://en.wikipedia.org/wiki/Laurentide_Ice_Sheet#/media/File:Pleistocene_north_ice_map.jpg.

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