WEATHER AND CLIMATE

Rising global average temperature is associated with widespread changes in weather patterns. Scientific studies indicate that extreme weather events such as heat waves and large storms are likely to become more frequent or more intense with human-induced climate change. This chapter focuses on observed changes in temperature, precipitation, storms, and droughts.

WHY DOES IT MATTER?

Long-term changes in climate can directly or indirectly affect many aspects of society in potentially disruptive ways. For example, warmer average temperatures could increase air conditioning costs and affect the spread of diseases like Lyme disease, but could also improve conditions for growing some crops. More extreme variations in weather are also a threat to society. More frequent and intense extreme heat events can increase illnesses and deaths, especially among vulnerable populations, and damage some crops. Similarly, increased precipitation can replenish water supplies and support agriculture, but intense storms can damage property, cause loss of life and population displacement, and temporarily disrupt essential services such as transportation, telecommunications, energy, and water supplies.

Summary of Key Points

U.S. and Global Temperature. Average temperatures have risen across the contiguous 48 states since 1901, with an increased rate of warming over the past 30 years. Seven of the top 10 warmest years on record have occurred since 1998. Average global temperatures show a similar trend, and the top 10 warmest years on record worldwide have all occurred since 1998. Within the United States, temperatures in parts of the North, the West, and Alaska have increased the most.

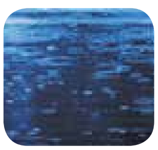
High and Low Temperatures. Many extreme temperature conditions are becoming more common. Since the 1970s, unusually hot summer temperatures have become more common in the United States, and heat waves have become more frequent—although the most severe heat waves in U.S. history remain those that occurred during the "Dust Bowl" in the 1930s. Record-setting daily high temperatures have become more common than record lows. The decade from 2000 to 2009 had twice as many record highs as record lows.

Weather and Climate

Weather is the state of the atmosphere at any given time and place. Most of the weather that affects people, agriculture, and ecosystems takes place in the lower layer of the atmosphere. Familiar aspects of weather include temperature, precipitation, clouds, and wind that people experience throughout the course of a day. Severe weather conditions include hurricanes, tornadoes, blizzards, and droughts.

Climate is the long-term average of the weather in a given place. While the weather can change in minutes or hours, a change in climate is something that develops over longer periods of decades to centuries. Climate is defined not only by average temperature and precipitation but also by the type, frequency, duration, and intensity of weather events such as heat waves, cold spells, storms, floods, and droughts.

While the concepts of climate and weather are often confused, it is important to understand the difference. For example, the eastern United States experienced a cold and snowy winter in 2013/2014, but this short-term regional weather phenomenon does not negate the long-term rise in national and global temperatures, sea level, or other climate indicators. It may be helpful to think about the difference between weather and climate with an analogy: weather influences what clothes you wear on a given day, while the climate where you live influences the entire wardrobe you buy.



U.S. and Global Precipitation. Total annual precipitation has increased in the United States and over land areas worldwide. Since 1901, precipitation has increased at an average rate of 0.5 percent per decade in the contiguous 48 states and 0.2 percent per decade over land areas worldwide. However, shifting weather patterns have caused certain areas, such as Hawaii and parts of the Southwest, to experience less precipitation than usual.

Heavy Precipitation. In recent years, a higher percentage of precipitation in the United States has come in the form of intense single-day events. Nationwide, nine of the top 10 years for extreme one-day precipitation events have occurred since 1990. The occurrence of abnormally high annual precipitation totals (as defined by the National Oceanic and Atmospheric Administration) has also increased.

Drought. Average drought conditions across the nation have varied since records began in 1895. The 1930s and 1950s saw the most widespread droughts, while the last 50 years have generally been wetter than average. However, specific trends vary by region. A more detailed index developed recently shows that between 2000 and 2013, roughly 20 to 70 percent of the United States experienced drought at any given time, but this index has not been in use for long enough to compare with historical drought patterns.

A Closer Look: Temperature and Drought in the Southwest. The southwestern United States is particularly sensitive to changes in temperature and thus vulnerable to drought, as even a small decrease in water availability in this already arid region can threaten natural systems and society.

Tropical Cyclone Activity. Tropical storm activity in the Atlantic Ocean, the Caribbean, and the Gulf of Mexico has increased during the past 20 years. Increased storm intensity is closely related to variations in sea surface temperature in the tropical Atlantic. However, changes in observation methods over time make it difficult to know for sure whether a long-term increase in storm activity has occurred. Records collected since the late 1800s suggest that the actual number of hurricanes per year has not increased.

U.S. and Global Temperatures

This indicator describes trends in average surface temperature for the United States and the world.

KEY POINTS

- Since 1901, the average surface temperature across the contiguous 48 states has risen at an average rate of 0.14°F per decade (see Figure 1). Average temperatures have risen more quickly since the late 1970s (0.31 to 0.48°F per decade). Seven of the top 10 warmest years on record for the contiguous 48 states have occurred since 1998, and 2012 was the warmest year on record.
- Worldwide, 2001–2010 was the warmest decade on record since thermometer-based observations began. Global average surface temperature has risen at an average rate of 0.15°F per decade since 1901 (see Figure 2), similar to the rate of warming within the contiguous 48 states. Since the late 1970s, however, the United States has warmed faster than the global rate.
- Some parts of the United States have experienced more warming than others (see Figure 3). The North, the West, and Alaska have seen temperatures increase the most, while some parts of the Southeast have experienced little change. However, not all of these regional trends are statistically significant.

Temperature is a fundamental measurement for describing the climate, and the temperature in particular places can have wide-ranging effects on human life and ecosystems. For example, increases in air temperature can lead to more intense heat waves, which can cause illness and death, especially in vulnerable populations. Annual and seasonal temperature patterns also determine the types of animals and plants that can survive in particular locations. Changes in temperature can disrupt a wide range of natural processes, particularly if these changes occur more quickly than plant and animal species can adapt.

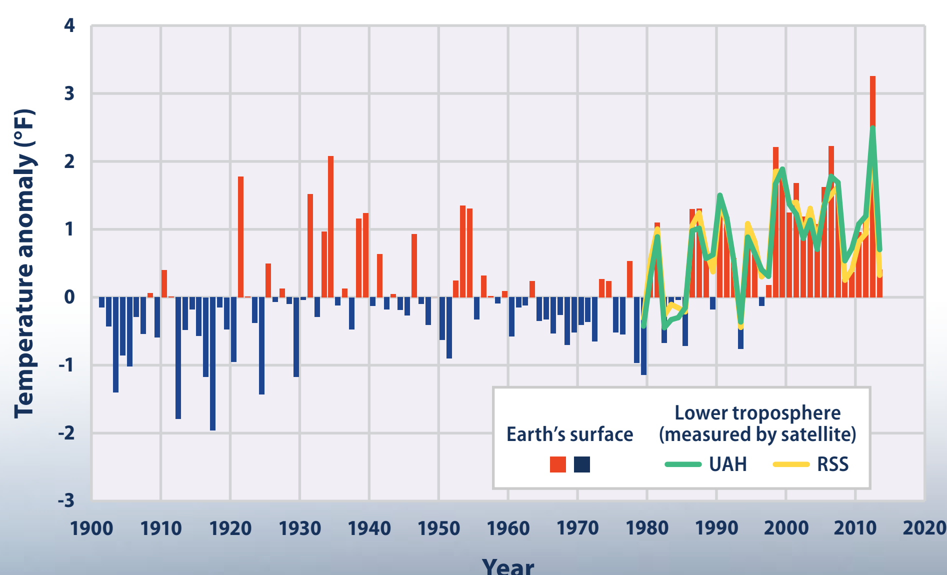
Concentrations of heat-trapping greenhouse gases are increasing in the Earth's atmosphere (see the Atmospheric Concentrations of Greenhouse Gases indicator on p. 20). In response, average temperatures at the Earth's surface are rising and are expected to continue rising. However, because climate change can shift the wind patterns and ocean currents that drive the world's climate system, some areas are warming more than others, and some have experienced cooling.

ABOUT THE INDICATOR

This indicator examines U.S. and global surface temperature patterns from 1901 to the present. U.S. surface measurements come from weather stations on land, while global surface measurements also incorporate observations from buoys and ships on the ocean, thereby providing data from sites spanning much of the surface of the Earth. For comparison, this indicator also displays satellite measurements that can be used to estimate the temperature of the Earth's lower atmosphere since 1979.

This indicator shows anomalies, which compare recorded annual temperature values against a long-term average. For example, an anomaly of +2.0 degrees means the average temperature was 2 degrees higher than the long-term average. This indicator uses the average temperature from 1901 to 2000 as a baseline for comparison. Annual anomalies are calculated for each weather station, starting from daily and monthly average temperatures. Anomalies for broader regions have been determined by dividing the country (or the world) into a grid, averaging the data for all weather stations within the grid, and then averaging the grid cells together (for Figures 1 and 2) or displaying them on a map (Figure 3). This method ensures that the results are not biased toward regions that happen to have many stations close together.

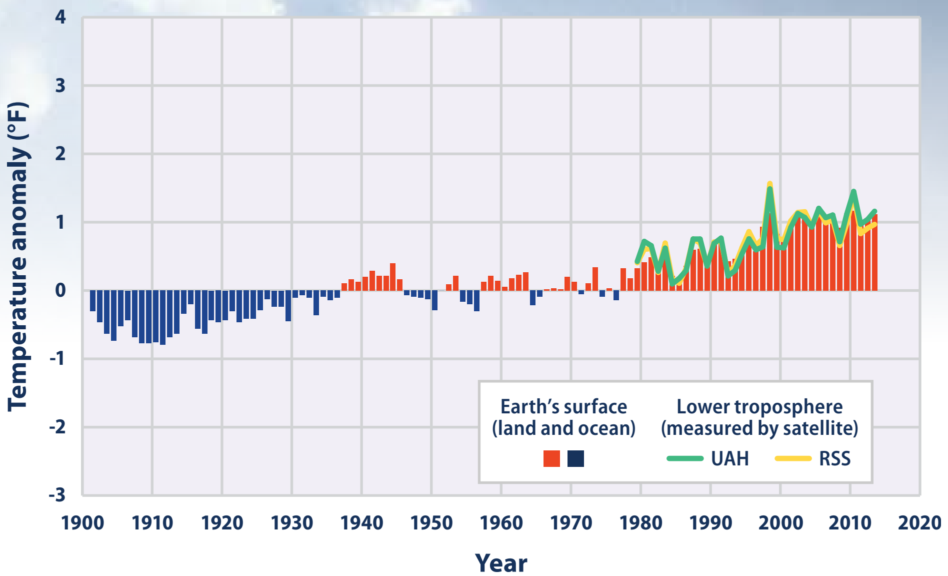
Figure 1. Temperatures in the Contiguous 48 States, 1901–2013



This figure shows how annual average temperatures in the contiguous 48 states have changed since 1901. Surface data come from land-based weather stations. Satellite measurements cover the lower troposphere, which is the lowest level of the Earth's atmosphere. "UAH" and "RSS" represent two different methods of analyzing the original satellite measurements. This graph uses the 1901–2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time.

Data source: NOAA, 2014[1]

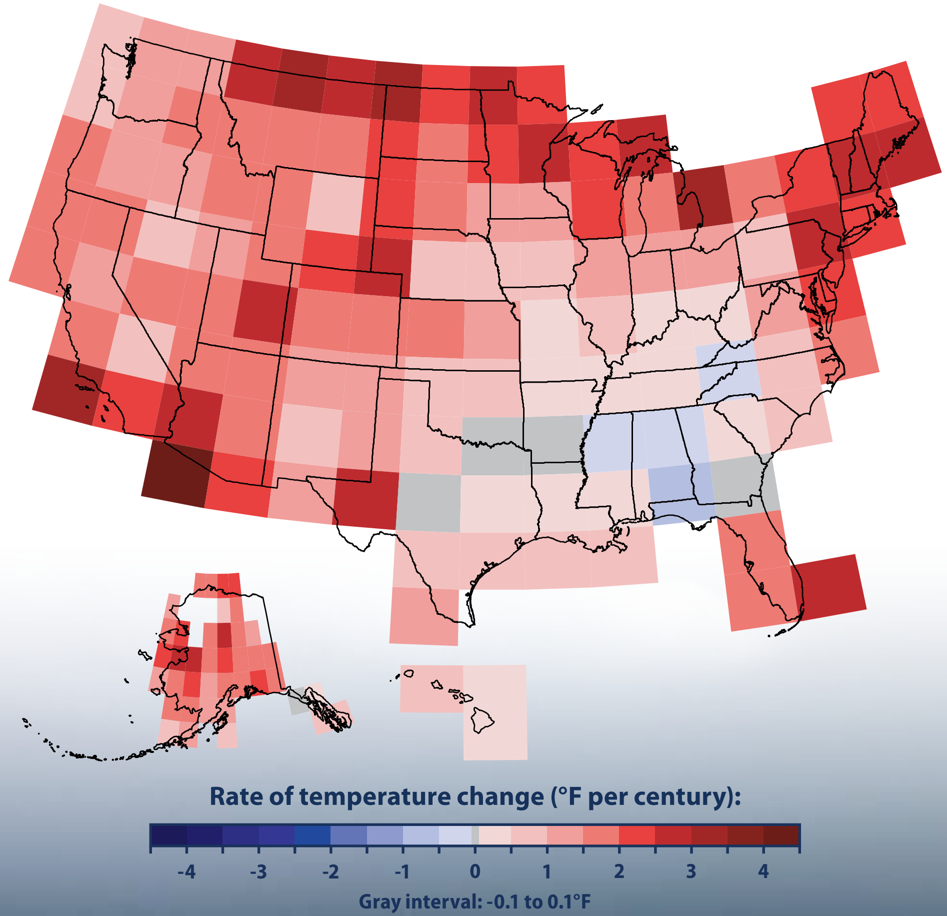
Figure 2. Temperatures Worldwide, 1901–2013



This figure shows how annual average temperatures worldwide have changed since 1901. Surface data come from a combined set of land-based weather stations and sea surface temperature measurements. Satellite measurements cover the lower troposphere, which is the lowest level of the Earth's atmosphere. "UAH" and "RSS" represent two different methods of analyzing the original satellite measurements. This graph uses the 1901–2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time.

Data source: NOAA, 2014[2]

Figure 3. Rate of Temperature Change in the United States, 1901–2012



This figure shows how annual average air temperatures have changed in different parts of the United States since the early 20th century (since 1901 for the contiguous 48 states, 1905 for Hawaii, and 1918 for Alaska).

Data source: NOAA, 2013[3]

INDICATOR NOTES

Data from the early 20th century are somewhat less precise than more recent data because there were fewer stations collecting measurements at the time, especially in the Southern Hemisphere. However, the overall trends are still reliable. Where possible, the data have been adjusted to account for any biases that might be introduced by factors such as station moves, urbanization near the station, changes in measuring instruments, and changes in the exact times at which measurements are taken.

DATA SOURCES

The data for this indicator were provided by the National Oceanic and Atmospheric Administration's National Climatic Data Center, which maintains a large collection of climate data online at: www.ncdc.noaa.gov/oa/ncdc.html. The surface temperature anomalies shown here were calculated based on monthly values from a network of long-term monitoring stations. Satellite data were analyzed by two independent groups—the Global Hydrology and Climate Center at the University of Alabama in Huntsville (UAH) and Remote Sensing Systems (RSS)—resulting in slightly different trend lines.

High and Low Temperatures

This indicator describes trends in unusually hot and cold temperatures across the United States.

KEY POINTS

- Heat waves in the 1930s remain the most severe heat waves in the U.S. historical record (see Figure 1). The spike in Figure 1 reflects extreme, persistent heat waves in the Great Plains region during a period known as the "Dust Bowl." Poor land use practices and many years of intense drought contributed to these heat waves by depleting soil moisture and reducing the moderating effects of evaporation.[4]
- Nationwide, unusually hot summer days (highs) have become more common over the last few decades (see Figure 2). The occurrence of unusually hot summer nights (lows) has increased at an even faster rate. This trend indicates less "cooling off" at night.
- The 20th century had many winters with widespread patterns of unusually low temperatures, including a particularly large spike in the late 1970s (see Figure 3). Since the 1980s, though, unusually cold winter temperatures have become less common—particularly very cold nights (lows).

Unusually hot or cold temperatures can result in prolonged extreme weather events like summer heat waves or winter cold spells. Heat waves can lead to illness and death, particularly among older adults, the very young, and other vulnerable groups (see the Heat-Related Deaths indicator on p. 76). People can also die from exposure to extreme cold (hypothermia). In addition, prolonged exposure to excessive heat and cold can damage crops and injure or kill livestock. Extreme heat can lead to power outages as heavy demands for air conditioning strain the power grid, while extremely cold weather increases the need for heating fuel.

Record-setting daily temperatures, heat waves, and cold spells are a natural part of day-to-day variation in weather. However, as the Earth's climate warms overall, heat waves are expected to become more frequent, longer, and more intense.[5,6] Higher heat index values (which combine temperature and humidity to describe perceived temperature) are expected to increase discomfort and aggravate health issues. Conversely, cold spells are expected to decrease. In most locations, scientists expect daily minimum temperatures—which typically occur at night—to become warmer at a faster rate than daily maximum temperatures.[7] This change will provide less opportunity to cool off and recover from daytime heat.

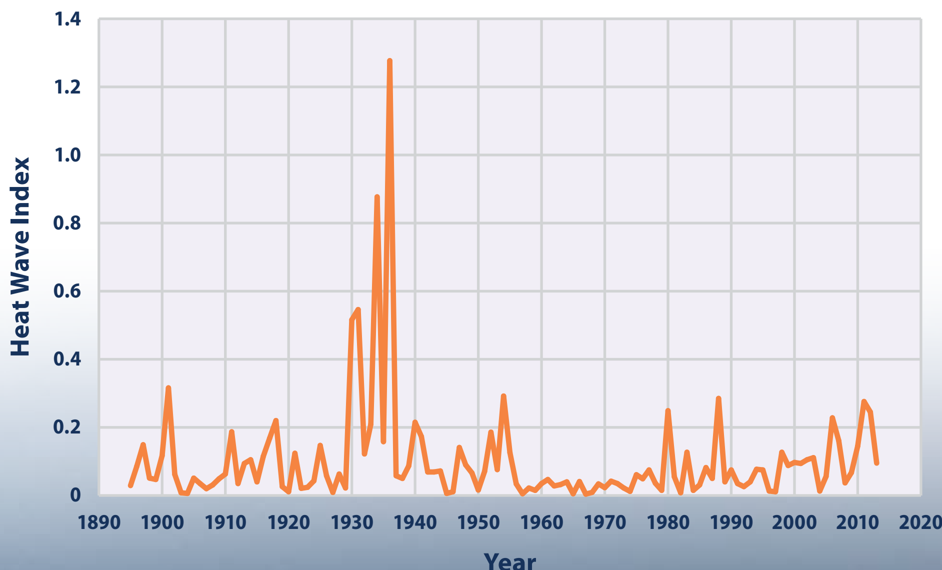
ABOUT THE INDICATOR

This indicator examines trends in unusual temperatures from several perspectives:

- The size and frequency of prolonged heat wave events (Figure 1).
- Unusually hot summer temperatures and cold winter temperatures nationwide (Figures 2 and 3).
- The change in the number of days with unusually hot and cold temperatures at individual weather stations (Figures 4 and 5).
- Changes in record high and low temperatures (Figure 6).

The data come from thousands of weather stations across the United States. National patterns can be determined by dividing the country into a grid and examining the data for one station in each cell of the grid. This method ensures that the results are not biased toward regions that happen to have many stations close together.

Figure 1. U.S. Annual Heat Wave Index, 1895–2013



This figure shows the annual values of the U.S. Heat Wave Index from 1895 to 2013. These data cover the contiguous 48 states. Interpretation: An index value of 0.2 (for example) could mean that 20 percent of the country experienced one heat wave, 10 percent of the country experienced two heat waves, or some other combination of frequency and area resulted in this value.

Data source: Kunkel, 2014[8]

Figure 1 shows the U.S. Annual Heat Wave Index, which tracks the occurrence of heat wave conditions across the contiguous 48 states from 1895 to 2013. While there is no universal definition of a heat wave, this index defines a heat wave as a period lasting at least four days with an average temperature that would only be expected to occur once every 10 years, based on the historical record. The index value for a given year depends on how often heat waves occur and how widespread they are.

Figures 2 and 3 show trends in the percentage of the country's area experiencing unusually hot temperatures in the summer and unusually cold temperatures in the winter. These graphs are based on daily maximum temperatures, which usually occur during the day, and daily minimum temperatures, which usually occur at night. At each station, the recorded highs and lows are compared with the full set of historical records. After averaging over a particular month or season of interest, the coldest 10 percent of years are considered "unusually cold" and the warmest 10 percent are "unusually hot." For example, if last year's summer highs were the 10th warmest on record for a particular location with more than 100 years of data, that year's summer highs would be considered unusually warm. Data are available from 1910 to 2013 for summer (June through August) and from 1911 to 2014 for winter (December of the previous year through February).

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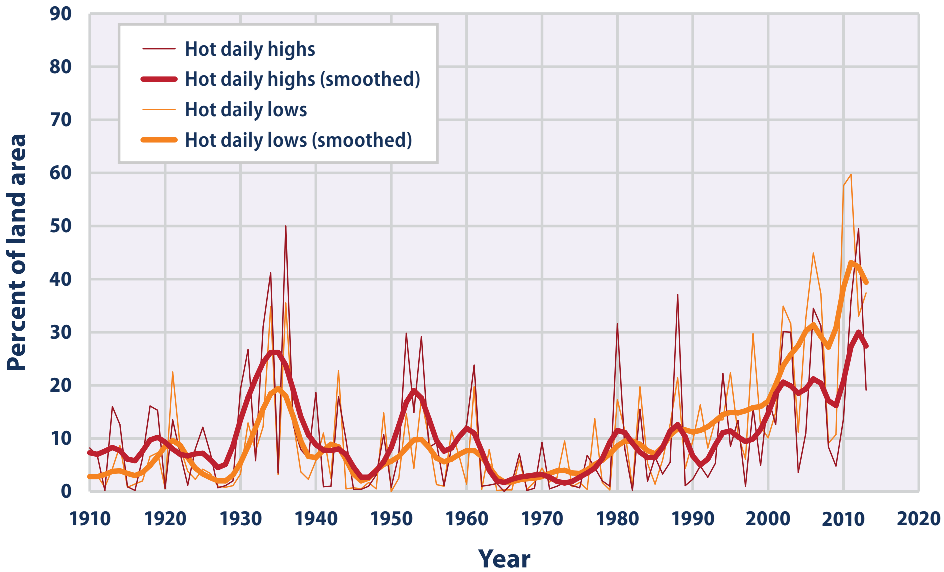
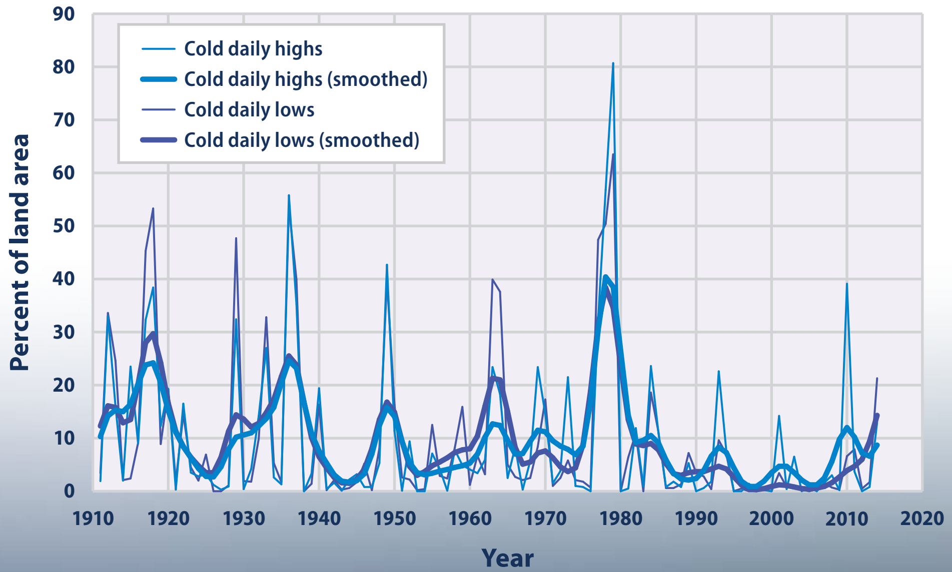
Figure 2. Area of the Contiguous 48 States with Unusually Hot Summer Temperatures, 1910–2013



This graph shows the percentage of the land area of the contiguous 48 states with unusually hot daily high and low temperatures during the months of June, July, and August. The thin lines represent individual years, while the thick lines show a nine-year weighted average. Red lines represent daily highs, while orange lines represent daily lows. The term "unusual" in this case is based on the long-term average conditions at each location.

Data source: NOAA, 2014[9]

Figure 3. Area of the Contiguous 48 States with Unusually Cold Winter Temperatures, 1911–2014



This graph shows the percentage of the land area of the contiguous 48 states with unusually cold daily high and low temperatures during the months of December, January, and February. The thin lines represent individual years, while the thick lines show a nine-year weighted average. Blue lines represent daily highs, while purple lines represent daily lows. The term "unusual" in this case is based on the long-term average conditions at each location.

Data source: NOAA, 2014[10]

High and Low Temperatures
Continued

KEY POINTS

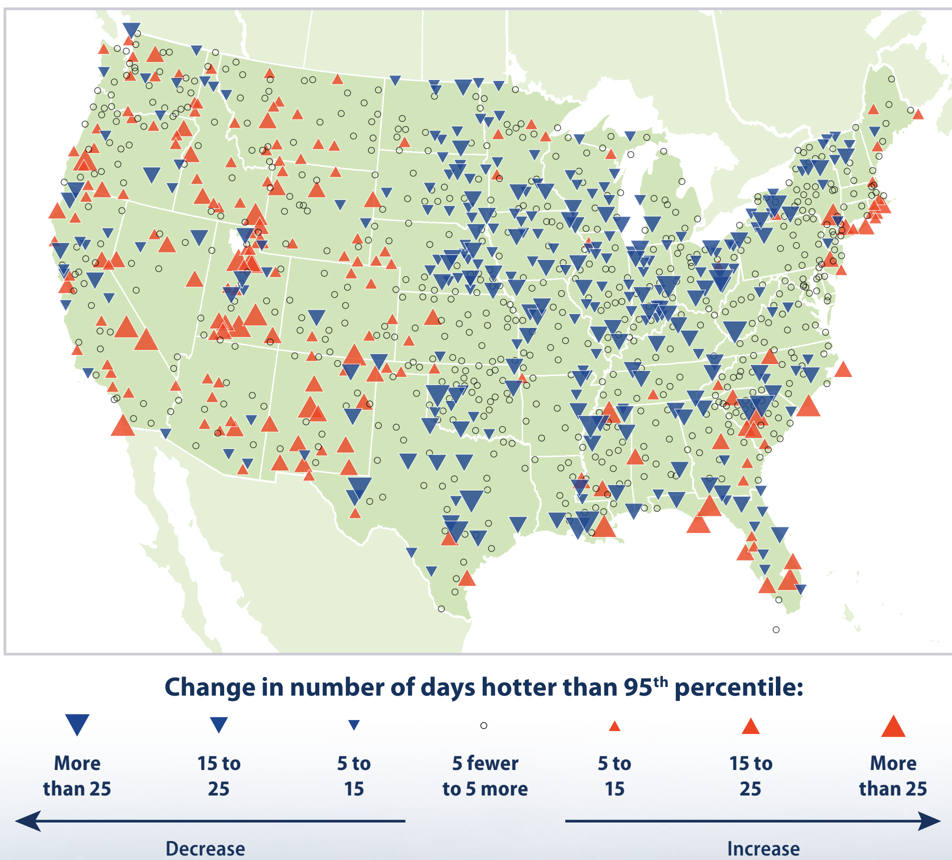
- The two maps show where changes in the number of days with unusually hot (above the 95^{th} percentile) and cold (below the 5^{th} percentile) days have occurred since 1948. Unusually high temperatures have increased in the western United States and in several areas along the Gulf and Atlantic coasts, but decreased in much of the middle of the country (see Figure 4). The number of unusually cold days has generally decreased throughout the country (see Figure 5).
- If the climate were completely stable, one might expect to see highs and lows each accounting for about 50 percent of the records set. However, since the 1970s, record-setting daily high temperatures have become more common than record lows across the United States (see Figure 6). The most recent decade had twice as many record highs as record lows.

(Continued from previous page)

Figures 4 and 5 show how trends in unusually hot and cold daily temperatures throughout the year vary by location. These maps cover 1,119 weather stations that have operated since 1948. Figure 4 was created by reviewing all daily maximum temperatures from 1948 to 2013 and identifying the 95^{th} percentile temperature (a temperature that one would only expect to exceed in five days out of every 100) at each station. Next, for each year, the total number of days with maximum temperatures higher than the 95^{th} percentile (that is, unusually hot days) was determined. The map shows how the total number of unusually hot days per year at each station has changed over time. Figure 5 is similar except that it looks at unusually cold days, based on the 5^{th} percentile of daily minimum temperatures.

Many people are familiar with record daily high and low temperatures, which are frequently mentioned in weather reports. Figure 6 depicts trends in these records by comparing the number of record-setting highs with the number of record-setting lows by decade. These data come from a set of weather stations that have collected data consistently since 1950.

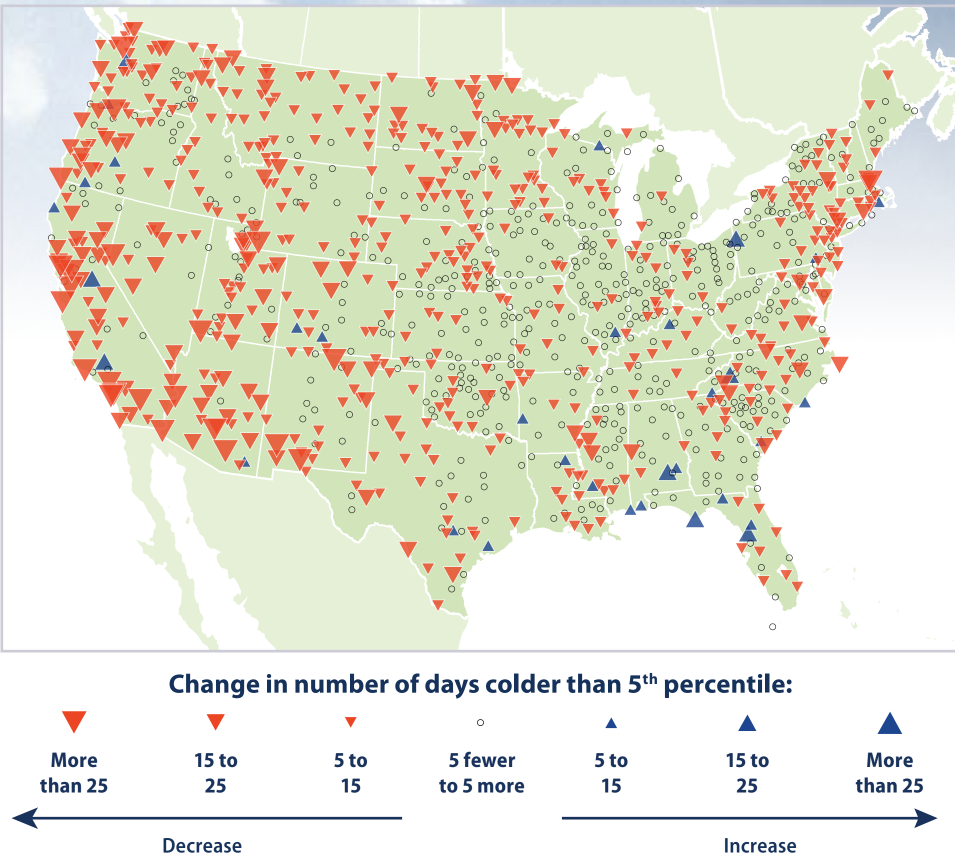
Figure 4. Change in Unusually Hot Temperatures in the Contiguous 48 States, 1948–2013



This map shows trends in unusually hot temperatures at individual weather stations that have operated consistently since 1948. In this case, the term "unusually hot" refers to a daily maximum temperature that is hotter than the 95^{th} percentile temperature during the 1948–2013 period. Thus, the maximum temperature on a particular day at a particular station would be considered "unusually hot" if it falls within the warmest 5 percent of measurements at that station during the 1948–2013 period. The map shows changes in the total number of days per year that were hotter than the 95^{th} percentile. Red upward-pointing symbols show where these unusually hot days are becoming more common. Blue downward-pointing symbols show where unusually hot days are becoming less common.

Data source: NOAA, 2014[11]

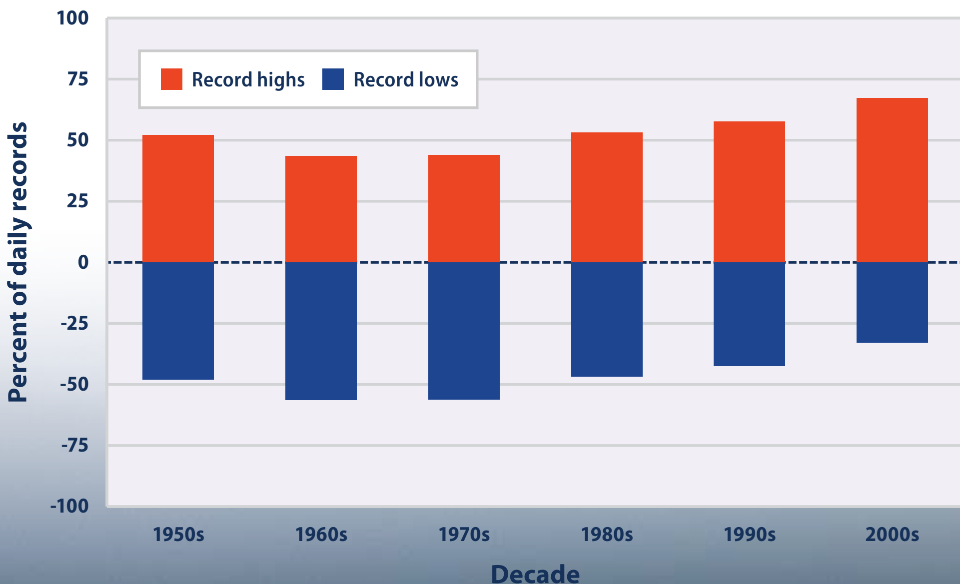
Figure 5. Change in Unusually Cold Temperatures in the Contiguous 48 States, 1948–2013



This map shows trends in unusually cold temperatures at individual weather stations that have operated consistently since 1948. In this case, the term "unusually cold" refers to a daily minimum temperature that is colder than the 5th percentile temperature during the 1948–2013 period. Thus, the minimum temperature on a particular day at a particular station would be considered "unusually cold" if it falls within the coldest 5 percent of measurements at that station during the 1948–2013 period. The map shows changes in the total number of days per year that were colder than the 5th percentile. Blue upward-pointing symbols show where these unusually cold days are becoming more common. Red downward-pointing symbols show where unusually cold days are becoming less common.

Data source: NOAA, 2014[12]

Figure 6. Record Daily High and Low Temperatures in the Contiguous 48 States, 1950–2009



This figure shows the percentage of daily temperature records set at weather stations across the contiguous 48 states by decade. Record highs (red) are compared with record lows (blue).

Data source: Meehl et al., 2009[13]

INDICATOR NOTES

Temperature data are less certain for the early part of the 20th century because fewer stations were operating at that time. In addition, measuring devices and methods have changed over time, and some stations have moved. The data have been adjusted to the extent possible to account for some of these influences and biases, however, and these uncertainties are not sufficient to change the fundamental trends shown in the figures.

DATA SOURCES

The data for this indicator are based on measurements from weather stations managed by the National Oceanic and Atmospheric Administration. Figure 1 uses data from the National Weather Service Cooperative Observer Network. Figures 2 and 3 come from the U.S. Climate Extremes Index, which is based on a smaller group of long-term weather stations that are tracked by the National Climatic Data Center and referred to as the U.S. Historical Climatology Network. Figures 4 and 5 use data from a somewhat larger set of stations tracked by the National Climatic Data Center, known as the Global Historical Climatology Network. Figure 6 uses National Weather Service data processed by Meehl et al. (2009).[14] All of these weather station records are available online at: www.ncdc.noaa.gov, and information about the Climate Extremes Index can be found at: www.ncdc.noaa.gov/extremes/cei.

U.S. and Global Precipitation

This indicator describes trends in average precipitation for the United States and the world.

KEY POINTS

- On average, total annual precipitation has increased over land areas in the United States and worldwide (see Figures 1 and 2). Since 1901, global precipitation has increased at an average rate of 0.2 percent per decade, while precipitation in the contiguous 48 states has increased at a rate of 0.5 percent per decade.
- Some parts of the United States have experienced greater increases in precipitation than others. A few areas such as Hawaii and parts of the Southwest have seen a decrease in precipitation (see Figure 3).

Precipitation can have wide-ranging effects on human well-being and ecosystems. Rainfall, snowfall, and the timing of snowmelt can all affect the amount of water available for drinking, irrigation, and industry, and can also determine what types of animals and plants (including crops) can survive in a particular place. Changes in precipitation can disrupt a wide range of natural processes, particularly if these changes occur more quickly than plant and animal species can adapt.

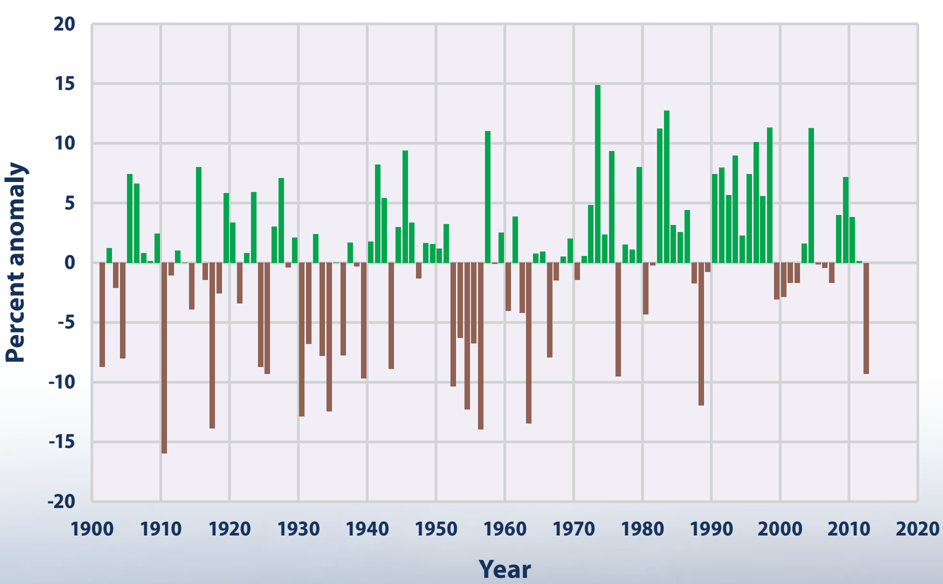
As average temperatures at the Earth's surface rise (see the U.S. and Global Temperature indicator on p. 28), more evaporation occurs, which, in turn, increases overall precipitation. Therefore, a warming climate is expected to increase precipitation in many areas. However, just as precipitation patterns vary across the world, so will the precipitation effects of climate change. By shifting the wind patterns and ocean currents that drive the world's climate system, climate change will also cause some areas to experience decreased precipitation. In addition, higher temperatures lead to more evaporation, so increased precipitation will not necessarily increase the amount of water available for drinking, irrigation, and industry (see the Drought indicator on p. 38).

ABOUT THE INDICATOR

This indicator examines U.S. and global precipitation patterns from 1901 to the present, based on rainfall and snowfall measurements from land-based weather stations worldwide.

This indicator shows annual anomalies, or differences, compared with the average precipitation from 1901 to 2000. These anomalies are presented in terms of percent change compared with the baseline. Annual anomalies are calculated for each weather station. Anomalies for broader regions have been determined by dividing the country (or the world) into a grid, averaging the data for all weather stations within each cell of the grid, and then averaging the grid cells together (for Figures 1 and 2) or displaying them on a map (Figure 3). This method ensures that the results are not biased toward regions that happen to have many stations close together.

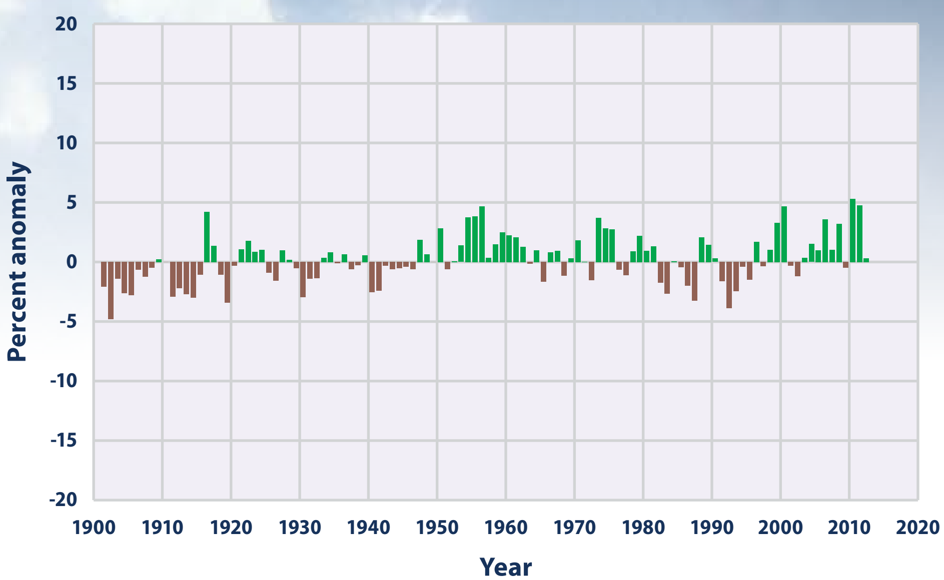
Figure 1. Precipitation in the Contiguous 48 States, 1901–2012



This figure shows how the total annual amount of precipitation in the contiguous 48 states has changed since 1901. This graph uses the 1901–2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time.

Data source: NOAA, 2013[15]

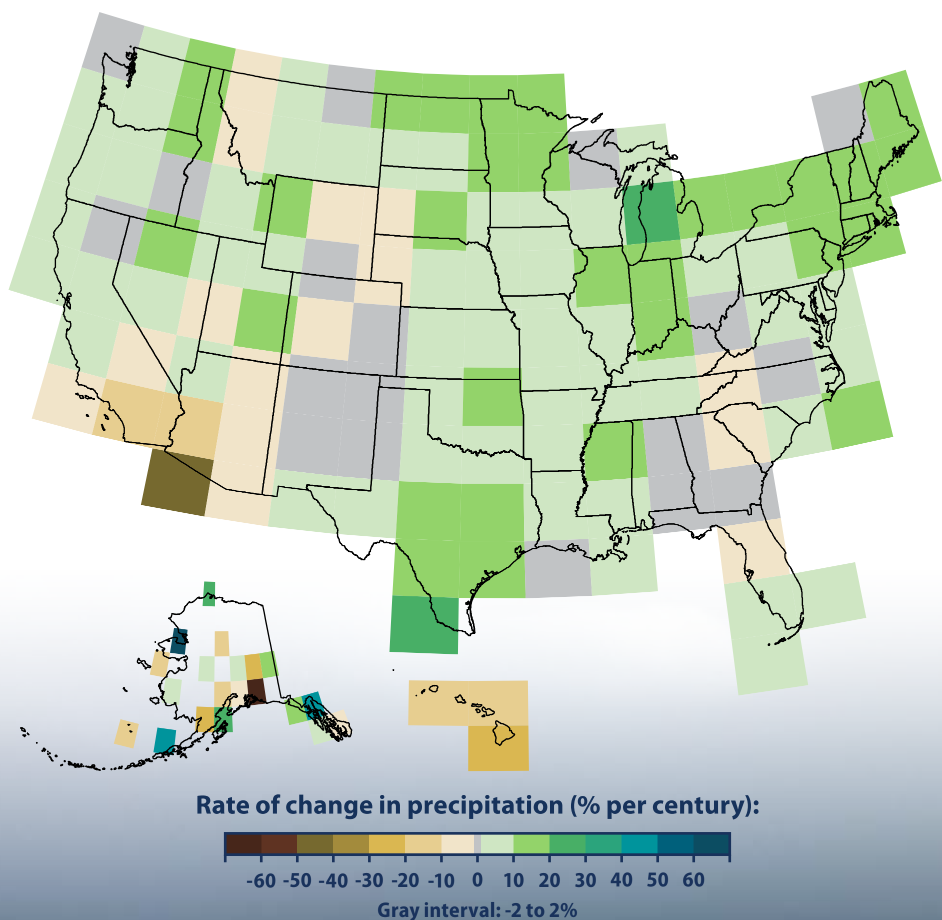
Figure 2. Precipitation Worldwide, 1901–2012



This figure shows how the total annual amount of precipitation over land worldwide has changed since 1901. This graph uses the 1901–2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time.

Data source: NOAA, 2013[16]

Figure 3. Rate of Precipitation Change in the United States, 1901–2012



This figure shows the rate of change in total annual precipitation in different parts of the United States since the early 20th century (since 1901 for the contiguous 48 states, 1905 for Hawaii, and 1918 for Alaska).

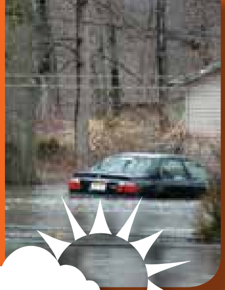
Data source: NOAA, 2013[17]

INDICATOR NOTES

Data from the early 20th century are somewhat less precise because there were fewer stations collecting measurements at the time. To ensure that overall trends are reliable, the data have been adjusted where possible to account for any biases that might be introduced by factors such as station moves or changes in measurement instruments.

DATA SOURCES

The data for this indicator were provided by the National Oceanic and Atmospheric Administration's National Climatic Data Center, which maintains a large collection of climate data online at: www.ncdc.noaa.gov/oa/ncdc.html. The precipitation anomalies shown here were calculated based on monthly values from a network of long-term monitoring stations.



Heavy Precipitation

This indicator tracks the frequency of heavy precipitation events in the United States.

KEY POINTS

- In recent years, a larger percentage of precipitation has come in the form of intense single-day events. Nine of the top 10 years for extreme one-day precipitation events have occurred since 1990 (see Figure 1).
- The prevalence of extreme single-day precipitation events remained fairly steady between 1910 and the 1980s, but has risen substantially since then. Over the entire period from 1910 to 2013, the portion of the country experiencing extreme single-day precipitation events increased at a rate of about half a percentage point per decade (see Figure 1).
- The percentage of land area experiencing much greater than normal yearly precipitation totals increased between 1895 and 2013. However, there has been much year-to-year variability. In some years there were no abnormally wet areas, while a few others had abnormally high precipitation totals over 10 percent or more of the contiguous 48 states' land area (see Figure 2). For example, 1941 was extremely wet in the West, while 1982 was very wet nationwide.[18]
- Figures 1 and 2 are both consistent with other studies that have found an increase in heavy precipitation over timeframes ranging from single days to 90-day periods to whole years.[19] For more information on trends in overall precipitation levels, see the U.S. and Global Precipitation indicator (p. 34).

Heavy precipitation refers to instances during which the amount of precipitation experienced in a location substantially exceeds what is normal. What constitutes a period of heavy precipitation varies according to location and season.

Climate change can affect the intensity and frequency of precipitation. Warmer oceans increase the amount of water that evaporates into the air. When more moisture-laden air moves over land or converges into a storm system, it can produce more intense precipitation—for example, heavier rain and snow storms.[20] The potential impacts of heavy precipitation include crop damage, soil erosion, and an increase in flood risk due to heavy rains. In addition, runoff from precipitation can impair water quality as pollutants deposited on land wash into water bodies.

Heavy precipitation does not necessarily mean the total amount of precipitation at a location has increased—just that precipitation is occurring in more intense events. However, changes in the intensity of precipitation, when combined with changes in the interval between precipitation events, can also lead to changes in overall precipitation totals.

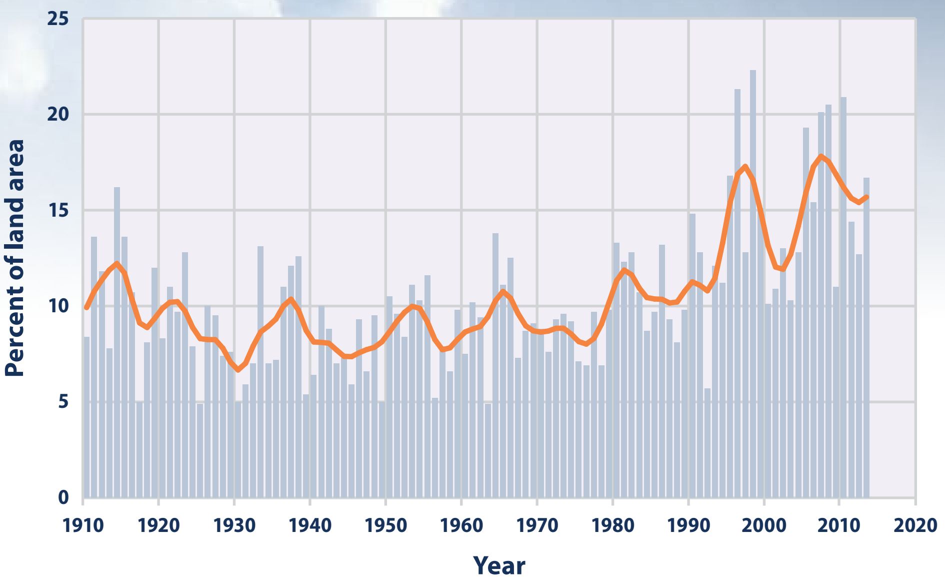
ABOUT THE INDICATOR

Heavy precipitation events can be measured by tracking their frequency, examining their return period (the chance that the event will be equaled or exceeded in a given year), or directly measuring the amount of precipitation in a certain period (for example, inches of rain falling in a 24-hour period).

One way to track heavy precipitation is by calculating what percentage of a particular location's total precipitation in a given year has come in the form of extreme one-day events—or, in other words, what percentage of precipitation is arriving in short, intense bursts. Figure 1 of this indicator looks at the prevalence of extreme single-day precipitation events over time.

For added insight, this indicator also tracks the occurrence of unusually high total yearly precipitation. It does so by looking at the Standardized Precipitation Index (SPI), which compares actual yearly precipitation totals with the range of precipitation totals that one would typically expect at a specific location, based on historical data. If a location experiences less precipitation than normal during a particular period, it will receive a negative SPI score, while a period with more precipitation than normal will receive a positive score. The more precipitation (compared with normal), the higher the SPI score. The SPI is a useful way to look at precipitation totals because it allows comparison of different locations and different seasons on a standard scale. Figure 2 shows what percentage of the total area of the contiguous 48 states had an annual SPI score of 2.0 or above (well above normal) in any given year.

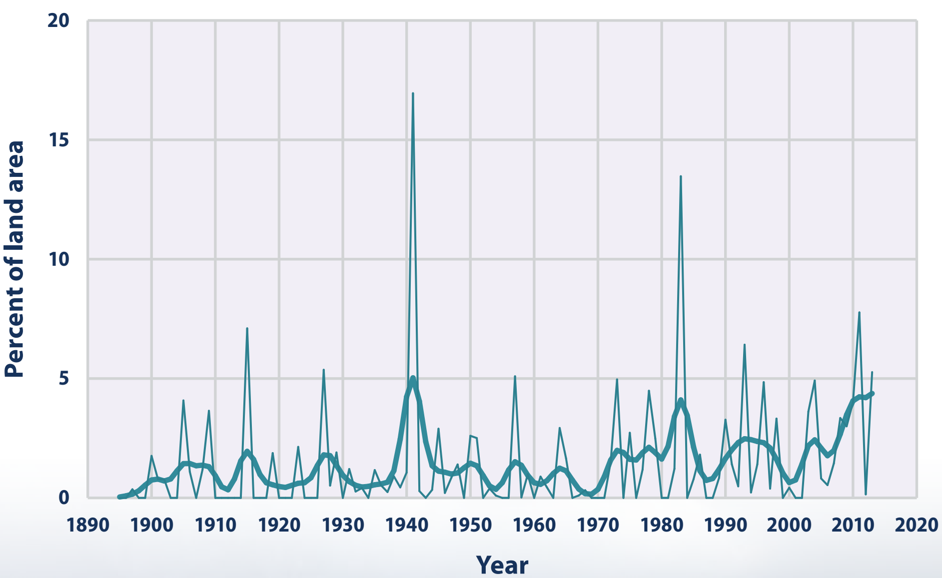
Figure 1. Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2013



This figure shows the percentage of the land area of the contiguous 48 states where a much greater than normal portion of total annual precipitation has come from extreme single-day precipitation events. The bars represent individual years, while the line is a nine-year weighted average.

Data source: NOAA, 2014[21]

Figure 2. Unusually High Annual Precipitation in the Contiguous 48 States, 1895–2013



This figure shows the percentage of the land area of the contiguous 48 states that experienced much greater than normal precipitation in any given year, which means it scored 2.0 or above on the annual Standardized Precipitation Index. The thicker line shows a nine-year weighted average that smoothes out some of the year-to-year fluctuations.

Data source: NOAA, 2014[22]

INDICATOR NOTES

Weather monitoring stations tend to be closer together in the eastern and central states than in the western states. In areas with fewer monitoring stations, heavy precipitation indicators are less likely to reflect local conditions accurately.

DATA SOURCES

The data used for this indicator come from a large national network of weather stations and were provided by the National Oceanic and Atmospheric Administration's National Climatic Data Center. Figure 1 is based on Step #4 of the National Oceanic and Atmospheric Administration's U.S. Climate Extremes Index; for data and a description of the index, see: www.ncdc.noaa.gov/extremes/cei. Figure 2 is based on the U.S. SPI, which is shown in a variety of maps available online at: www.ncdc.noaa.gov/oa/climate/research/prelim/drought/spi.html. The data used to construct these maps are available from the National Oceanic and Atmospheric Administration at: ftp://ftp.ncdc.noaa.gov/pub/data/cirs.

Drought

This indicator measures drought conditions of U.S. lands.

KEY POINTS

- Average drought conditions across the nation have varied since records began in 1895. The 1930s and 1950s saw the most widespread droughts, while the last 50 years have generally been wetter than average (see Figure 1).
- Over the period from 2000 through 2013, roughly 20 to 70 percent of the U.S. land area experienced conditions that were at least abnormally dry at any given time (see Figure 2). The years 2002–2003 and 2012–2013 had a relatively large area with at least abnormally dry conditions, while 2001, 2005, and 2009–2011 had substantially less area experiencing drought.
- Both drought figures indicate that in 2012, the United States experienced the driest conditions in more than a decade. During the latter half of 2012, more than half of the U.S. land area was covered by moderate or greater drought (see Figure 2). In several states, 2012 was among the driest years on record.[23] See Temperature and Drought in the Southwest (p. 40) for a closer look at trends in one of the hardest-hit regions.

There are many definitions and types of drought. Meteorologists generally define drought as a prolonged period of dry weather caused by a lack of precipitation that results in a serious water shortage for some activity, population, or ecological system. Drought can also be thought of as an extended imbalance between precipitation and evaporation.

As average temperatures have risen because of climate change, the Earth's water cycle has sped up through an increase in the rate of evaporation. An increase in evaporation makes more water available in the air for precipitation, but contributes to drying over some land areas, leaving less moisture in the soil. Thus, as the climate continues to change, many areas are likely to experience increased precipitation (see the U.S. and Global Precipitation indicator on p. 34) and increased risk of flooding (see the Heavy Precipitation indicator on p. 36), while areas located far from storm tracks are likely to experience less precipitation and increased risk of drought. As a result, since the 1950s, some regions of the world have experienced longer and more intense droughts, particularly in southern Europe and West Africa, while other regions have seen droughts become less frequent, less intense, or shorter (for example, in central North America).[24]

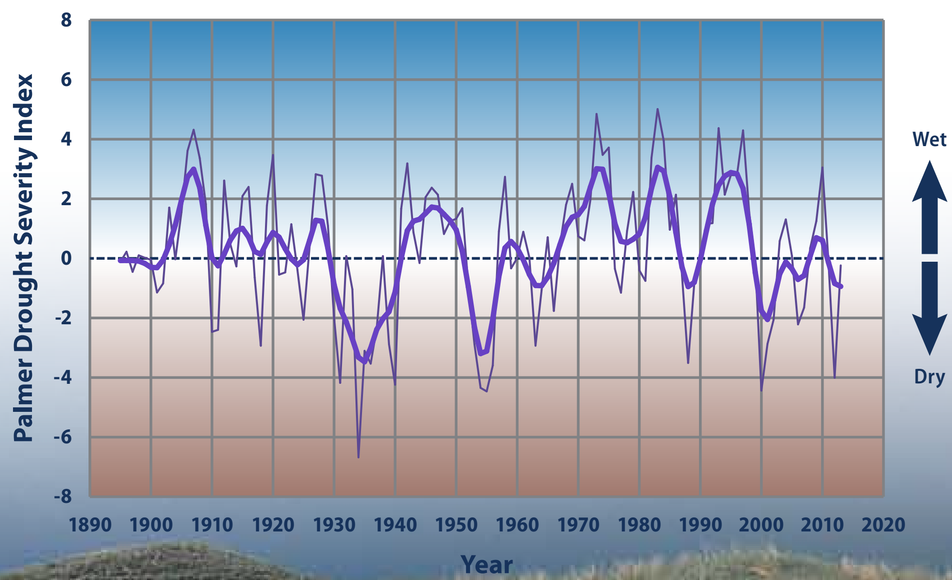
Drought conditions can negatively affect agriculture, water supplies, energy production, and many other aspects of society. The impacts vary depending on the type, location, intensity, and duration of the drought. For example, effects on agriculture can range from slowed plant growth to severe crop losses, while water supply impacts can range from lowered reservoir levels and dried-up streams to major water shortages. Lower streamflow and groundwater levels can also harm plants and animals, and dried-out vegetation increases the risk of wildfires.

ABOUT THE INDICATOR

During the 20th century, many indices were created to measure drought severity by looking at precipitation, soil moisture, stream flow, vegetation health, and other variables.[25] Figure 1 shows annual values of the most widely used index, the Palmer Drought Severity Index, which is calculated from precipitation and temperature measurements at weather stations. An index value of zero represents the average moisture conditions observed between 1931 and 1990 at a given location. A positive value means conditions are wetter than average, while a negative value is drier than average. Index values from locations across the contiguous 48 states have been averaged together to produce the national values shown in Figure 1.

For a more detailed perspective on recent trends, Figure 2 shows a newer index called the Drought Monitor, which is based on several indices (including Palmer), along with additional factors such as snow water content, groundwater levels, reservoir storage, pasture/range conditions, and other impacts. The Drought Monitor uses codes from D0 to D4 (see table below Figure 2) to classify drought severity. This part of the indicator covers all 50 states and Puerto Rico.

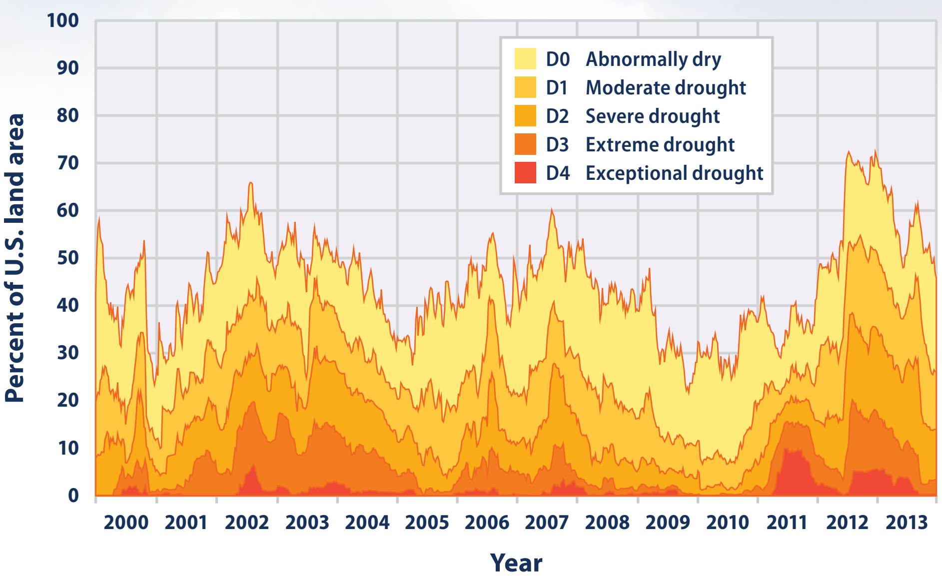
Figure 1. Average Drought Conditions in the Contiguous 48 States, 1895–2013



This chart shows annual values of the Palmer Drought Severity Index, averaged over the entire area of the contiguous 48 states. Positive values represent wetter-than-average conditions, while negative values represent drier-than-average conditions. A value between -2 and -3 indicates moderate drought, -3 to -4 is severe drought, and -4 or below indicates extreme drought. The thicker line is a nine-year weighted average.

Data source: NOAA, 2014[26]

Figure 2. U.S. Lands Under Drought Conditions, 2000–2013



This chart shows the percentage of U.S. lands classified under drought conditions from 2000 through 2013. This figure uses the U.S. Drought Monitor classification system, which is described in the table below. The data cover all 50 states plus Puerto Rico.

Data source: National Drought Mitigation Center, 2014[27]

Categories of Drought Severity

Category	Description	Possible Impacts
D0	Abnormally dry	Going into drought: short-term dryness slowing planting or growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered.
D1	Moderate drought	Some damage to crops or pastures; streams, reservoirs, or wells low; some water shortages developing or imminent; voluntary water use restrictions requested.
D2	Severe drought	Crop or pasture losses likely; water shortages common; water restrictions imposed.
D3	Extreme drought	Major crop/pasture losses; widespread water shortages or restrictions.
D4	Exceptional drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells, creating water emergencies.

Experts update the U.S. Drought Monitor weekly and produce maps that illustrate current conditions as well as short- and long-term trends. Major participants include the National Oceanic and Atmospheric Administration, the U.S. Department of Agriculture, and the National Drought Mitigation Center. For a map of current drought conditions, visit the Drought Monitor website at: http://droughtmonitor.unl.edu.

INDICATOR NOTES

Because this indicator focuses on national trends, it does not show how drought conditions vary by region. For example, even if half of the country suffered from severe drought, Figure 1 could show an average index value close to zero if the rest of the country was wetter than average. Thus, Figure 1 might understate the degree to which droughts are becoming more severe in some areas while other places receive more rain as a result of climate change.

The U.S. Drought Monitor (Figure 2) offers a closer look at the percentage of the country that is affected by drought. However, this index is relatively new and thus too short-lived to be used for assessing long-term climate trends or exploring how recent observations compare with historical patterns. With several decades of data collection, future versions of this indicator should be able to paint a more complete picture of trends over time.

Overall, this indicator gives a broad overview of drought conditions in the United States. It is not intended to replace local or state information that might describe conditions more precisely for a particular region.

DATA SOURCES

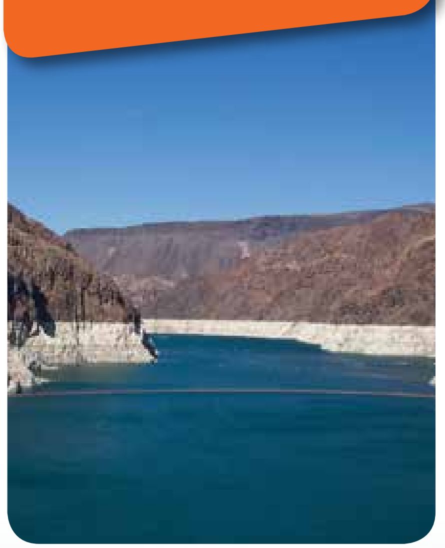
Data for Figure 1 were obtained from the National Oceanic and Atmospheric Administration's National Climatic Data Center, which maintains a large collection of climate data online at: www.ncdc.noaa.gov/oa/ncdc.html. Data for Figure 2 were provided by the National Drought Mitigation Center. Historical data in table form are available at: http://droughtmonitor.unl.edu/MapsAndData.aspx.

A Closer Look

Temperature and Drought in the Southwest

KEY POINTS

- Every part of the Southwest experienced higher average temperatures between 2000 and 2013 than the long-term average (1895–2013). Some areas were nearly 2°F warmer than average (see Figure 1).
- Large portions of the Southwest have experienced drought conditions since weekly Drought Monitor records began in 2000. For extended periods from 2002 to 2005 and from 2012 through 2013, nearly the entire region was abnormally dry or even drier (see Figure 2).
- Based on the long-term Palmer Index, drought conditions in the Southwest have varied since 1895. The early 1900s and the 1950s experienced considerable drought, the 1980s were relatively wet, and the last decade has seen the most persistent droughts on record (see Figure 3).



The American Southwest might evoke images of a hot, dry landscape—a land of rock, canyons, and deserts baked by the sun. Indeed, much of this region has low annual rainfall and seasonally high temperatures that contribute to its characteristic desert climate. Yet this landscape actually supports a vast array of plants and animals, along with millions of people who call the Southwest home. All of these plants, animals, and people need water to survive.

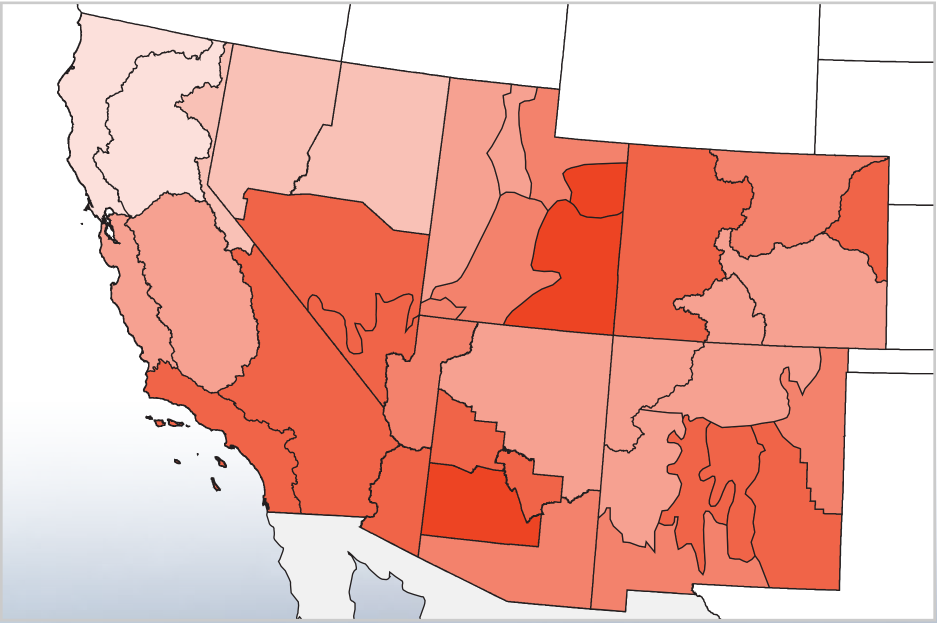
Water is already scarce in the Southwest, so every drop is a precious resource. People in the Southwest are particularly dependent on surface water supplies like Lake Mead, which are vulnerable to evaporation. Thus, even a small increase in temperature (which drives evaporation) or a decrease in precipitation in this already arid region can seriously threaten natural systems and society. Droughts also contribute to increased pest outbreaks and wildfires, both of which damage local economies.[28]

While two indicators in this report present information about unusually high or low temperatures and drought on a national scale (see the High and Low Temperatures indicator on p. 30 and the Drought indicator on p. 38), this feature highlights the Southwest because of its particular sensitivity to temperature and drought. It focuses on six states that are commonly thought of as "southwestern" and characterized at least in part by arid landscapes and scarce water supplies: Arizona, California, Colorado, Nevada, New Mexico, and Utah. Temperature and drought data come from a network of thousands of weather stations overseen by the National Weather Service.

The map in Figure 1 shows how average annual temperatures in the Southwest from 2000 to 2013 differed from the average over the entire period since widespread temperature records became available (1895–2013).

Figures 2 and 3 show two ways of measuring drought in the Southwest: the Drought Monitor and the Palmer Drought Severity Index. The Palmer Index is calculated from precipitation and temperature measurements at weather stations, and has been used widely for many years. The Drought Monitor is a more recent and more detailed index based on several other indices (including Palmer), along with additional factors such as snow water content, groundwater levels, reservoir storage, pasture/range conditions, and other impacts. See the Drought indicator (p. 38) for more information about these indices.

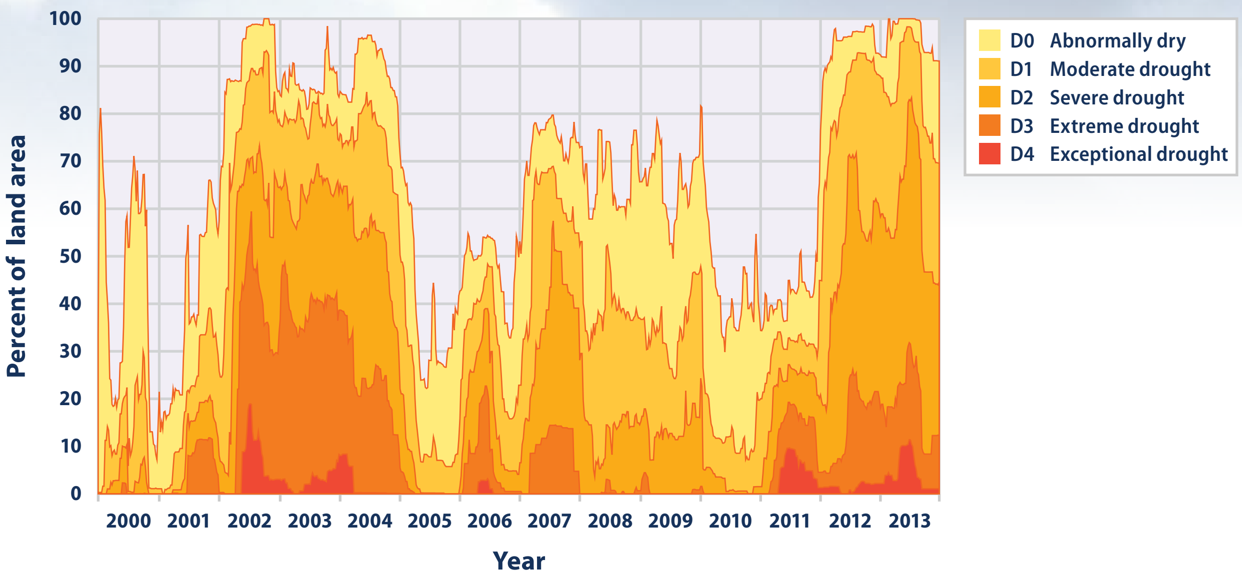
Figure 1. Average Temperatures in the Southwestern United States, 2000–2013 Versus Long-Term Average



This map shows how the average air temperature from 2000 to 2013 has differed from the long-term average (1895–2013). To provide more detailed information, each state has been divided into climate divisions, which are zones that share similar climate features.

Data source: NOAA, 2014[29]

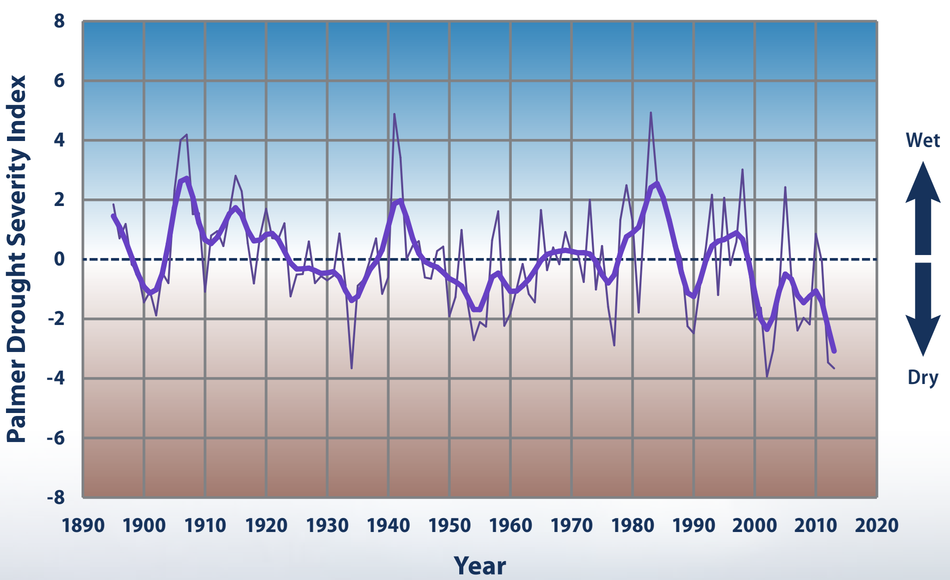
Figure 2. Southwestern U.S. Lands Under Drought Conditions, 2000–2013



This chart shows the percentage of land area in six southwestern states classified under drought conditions from 2000 through 2013. This figure uses the U.S. Drought Monitor classification system, which is described in the table in the Drought indicator on p. 39.

Data source: National Drought Mitigation Center, 2014[30]

Figure 3. Drought Severity in the Southwestern United States, 1895–2013



This chart shows annual values of the Palmer Drought Severity Index, averaged over six states in the Southwest. Positive values represent wetter-than-average conditions, while negative values represent drier-than-average conditions. A value between -2 and -3 indicates moderate drought, -3 to -4 is severe drought, and -4 or below indicates extreme drought. The thicker line is a nine-year weighted average.

Data source: NOAA, 2014[31]

NOTES

Natural variability, changes in irrigation practices, and other diversions of water for human use can influence certain drought-related measurements. Soil moisture, ground water, and streamflow are part of Drought Monitor calculations (Figure 2), and they are all sensitive to human activities.

DATA SOURCES

Data for Figures 1 and 3 were obtained from the National Oceanic and Atmospheric Administration's National Climatic Data Center, which maintains a large collection of climate data online at: www.ncdc.noaa.gov/oa/ncdc.html. Data for Figure 2 were provided by the National Drought Mitigation Center. Historical data in table form are available at: http://droughtmonitor.unl.edu/MapsAndData.aspx.

Tropical Cyclone Activity

This indicator examines the frequency, intensity, and duration of hurricanes and other tropical storms in the Atlantic Ocean, Caribbean, and Gulf of Mexico.

KEY POINTS

- Since 1878, about six to seven hurricanes have formed in the North Atlantic every year. Roughly two per year make landfall in the United States. The total number of hurricanes (particularly after being adjusted for improvements in observation methods) and the number reaching the United States do not indicate a clear overall trend since 1878 (see Figure 1).
- According to the total annual ACE Index, cyclone intensity has risen noticeably over the past 20 years, and six of the 10 most active years since 1950 have occurred since the mid-1990s (see Figure 2). Relatively high levels of cyclone activity were also seen during the 1950s and 1960s.
- The PDI (see Figure 3) shows fluctuating cyclone intensity for most of the mid- to late 20th century, followed by a noticeable increase since 1995 (similar to the ACE Index). These trends are associated with variations in sea surface temperature in the tropical Atlantic (see Figure 2).
- Despite the apparent increases in tropical cyclone activity in Figures 2 and 3, changes in observation methods over time make it difficult to know whether tropical storm activity has actually shown a long-term increase.[32]

Hurricanes, tropical storms, and other intense rotating storms fall into a general category called cyclones. There are two main types of cyclones: tropical and extratropical (those that form outside the tropics). Tropical cyclones get their energy from warm tropical oceans. Extratropical cyclones get their energy from the jet stream and from temperature differences between cold, dry air masses from higher latitudes and warm, moist air masses from lower latitudes.

This indicator focuses on tropical cyclones in the Atlantic Ocean, Caribbean, and Gulf of Mexico. Tropical cyclones are most common during the "hurricane season," which runs from June through November. The effects of tropical cyclones are numerous and well known. At sea, storms disrupt and endanger shipping traffic. When cyclones encounter land, their intense rains and high winds can cause severe property damage, loss of life, soil erosion, and flooding. The associated storm surge—the large volume of ocean water pushed toward shore by the cyclone's strong winds—can cause severe flooding and destruction.

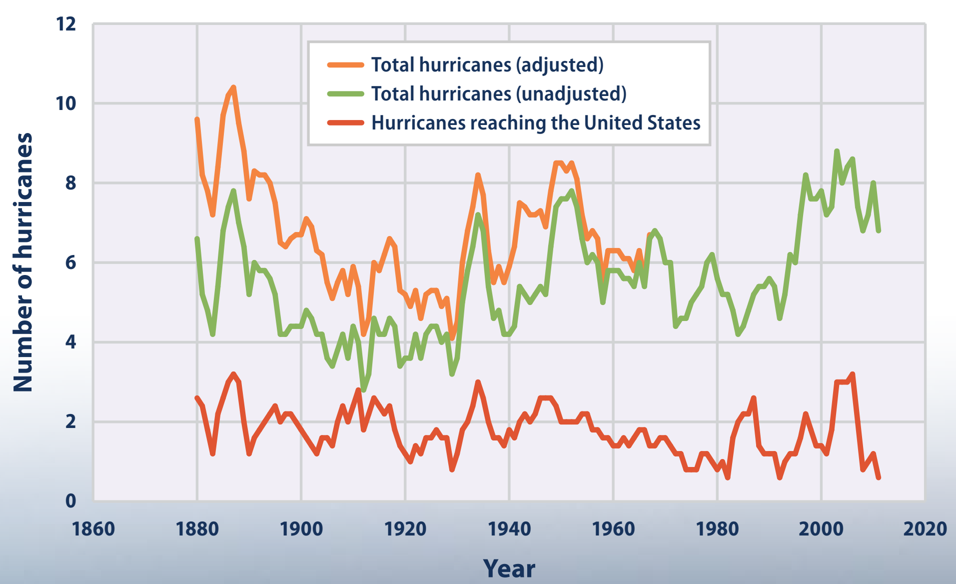
Climate change is expected to affect tropical cyclones by increasing sea surface temperatures, a key factor that influences cyclone formation and behavior. The U.S. Global Change Research Program and the Intergovernmental Panel on Climate Change project that, more likely than not, tropical cyclones will become more intense over the 21st century, with higher wind speeds and heavier rains.[33,34]

ABOUT THE INDICATOR

Records of tropical cyclones in the Atlantic Ocean have been collected since the 1800s. The most reliable long-term records focus on hurricanes, which are the strongest category of tropical cyclones in the Atlantic, with wind speeds of at least 74 miles per hour. This indicator uses historical data from the National Oceanic and Atmospheric Administration to track the number of hurricanes per year in the North Atlantic (north of the equator) and the number reaching the United States since 1878. Some hurricanes over the ocean might have been missed before the start of aircraft and satellite observation, so scientists have used other evidence, such as ship traffic records, to estimate the actual number of hurricanes that might have formed in earlier years.

This indicator also looks at the Accumulated Cyclone Energy (ACE) Index and the Power Dissipation Index (PDI), which are two ways of monitoring the frequency, strength, and duration of tropical cyclones based on wind speed measurements.

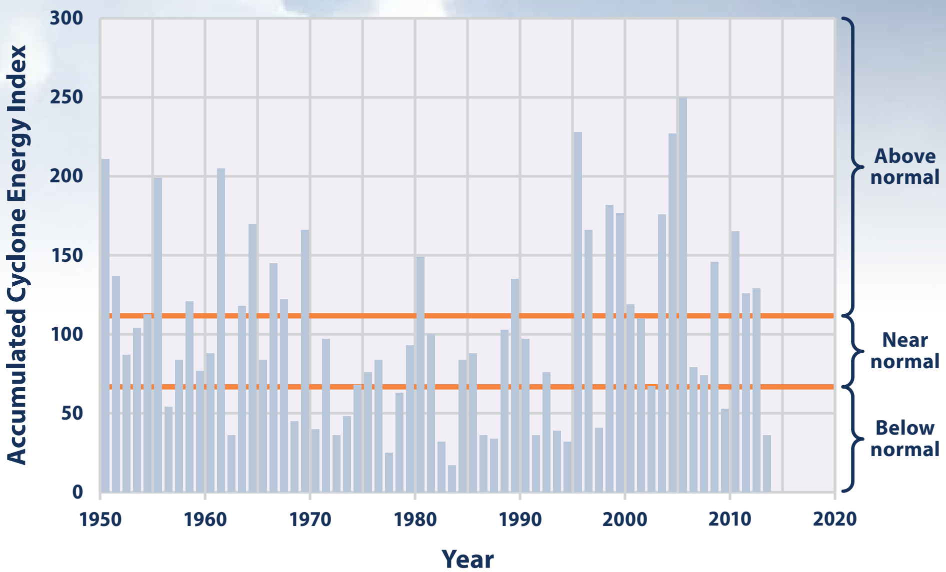
Figure 1. Number of Hurricanes in the North Atlantic, 1878–2013



This graph shows the number of hurricanes that formed in the North Atlantic Ocean each year from 1878 to 2013, along with the number that made landfall in the United States. The orange curve shows how the total count in the green curve can be adjusted to attempt to account for the lack of aircraft and satellite observations in early years. All three curves have been smoothed using a five-year average, plotted at the middle year. The most recent average (2009–2013) is plotted at 2011.

Data source: Knutson, 2014[35]

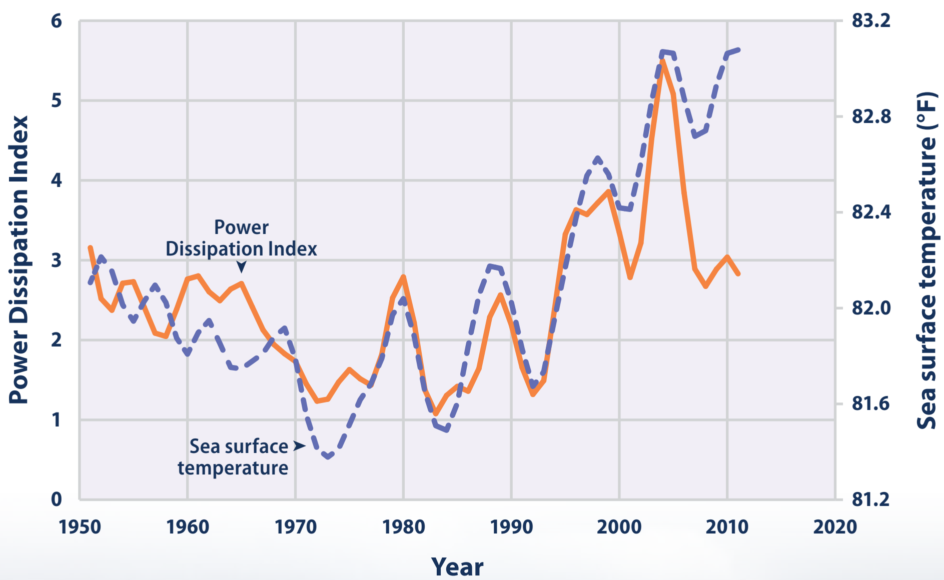
Figure 2. North Atlantic Tropical Cyclone Activity According to the Accumulated Cyclone Energy Index, 1950–2013



This figure shows total annual Accumulated Cyclone Energy (ACE) Index values, which account for cyclone strength, duration, and frequency, from 1950 through 2013. The National Oceanic and Atmospheric Administration has defined "near normal," "above normal," and "below normal" ranges based on the distribution of ACE Index values over the 30 years from 1981 to 2010.

Data source: NOAA, 2014[36]

Figure 3. North Atlantic Tropical Cyclone Activity According to the Power Dissipation Index, 1949–2013



This figure presents annual values of the Power Dissipation Index (PDI), which accounts for cyclone strength, duration, and frequency. Tropical North Atlantic sea surface temperature trends are provided for reference. Note that sea surface temperature is measured in different units, but the values have been plotted alongside the PDI to show how they compare. The lines have been smoothed using a five-year weighted average, plotted at the middle year. The most recent average (2009–2013) is plotted at 2011.

Data source: Emanuel, 2014[37]

Every cyclone has an ACE Index value, which is a number based on the maximum wind speed measured at six-hour intervals over the entire time that the cyclone is classified as at least a tropical storm (wind speed of at least 39 miles per hour). Therefore, a storm's ACE Index value accounts for both strength and duration. The National Oceanic and Atmospheric Administration calculates the total ACE Index value for an entire hurricane season by adding the values for all named storms, including subtropical storms, tropical storms, and hurricanes. The resulting annual total accounts for cyclone strength, duration, and frequency. For this indicator, the index has been converted to a scale where 100 equals the median value (the midpoint) over a base period from 1981 to 2010. The thresholds in Figure 2 define whether the ACE Index for a given year is close to normal, significantly above normal, or significantly below.

Like the ACE Index, the PDI is based on measurements of wind speed, but it uses a different calculation method that places more emphasis on storm intensity. This indicator shows the annual PDI value, which represents the sum of PDI values for all named storms during the year.

INDICATOR NOTES

Over time, data collection methods have changed as technology has improved. For example, wind speed collection methods have evolved substantially over the past 60 years, while aircraft reconnaissance began in 1944 and satellite tracking around 1966. Figure 1 shows how older hurricane counts have been adjusted to attempt to account for the lack of aircraft and satellite observations. Changes in data gathering technologies could substantially influence the overall patterns in Figures 2 and 3. The effects of these changes on data consistency over the life of the indicator would benefit from additional research.

While Figures 2 and 3 cover several different aspects of tropical cyclones, there are other important factors not covered here, including the size of each storm, the amount of rain, and the height of the storm surge.

DATA SOURCES

Hurricane counts are reported on several National Oceanic and Atmospheric Administration websites and were compiled using methods described in Knutson et al. (2010).[38] The ACE Index data (Figure 2) came from the National Oceanic and Atmospheric Administration's Climate Prediction Center, and are available online at: www.cpc.noaa.gov/products/outlooks/background_information.shtml. Values for the PDI have been calculated by Kerry Emanuel at the Massachusetts Institute of Technology. Both indices are based on wind speed measurements compiled by the National Oceanic and Atmospheric Administration.