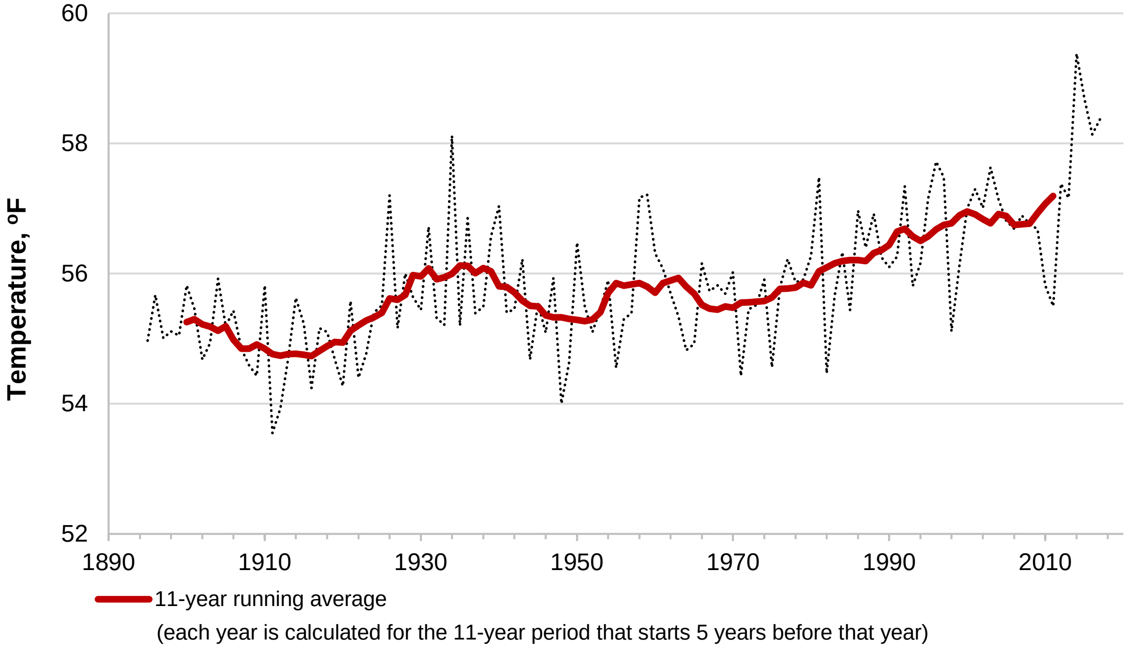
ANNUAL AIR TEMPERATURE

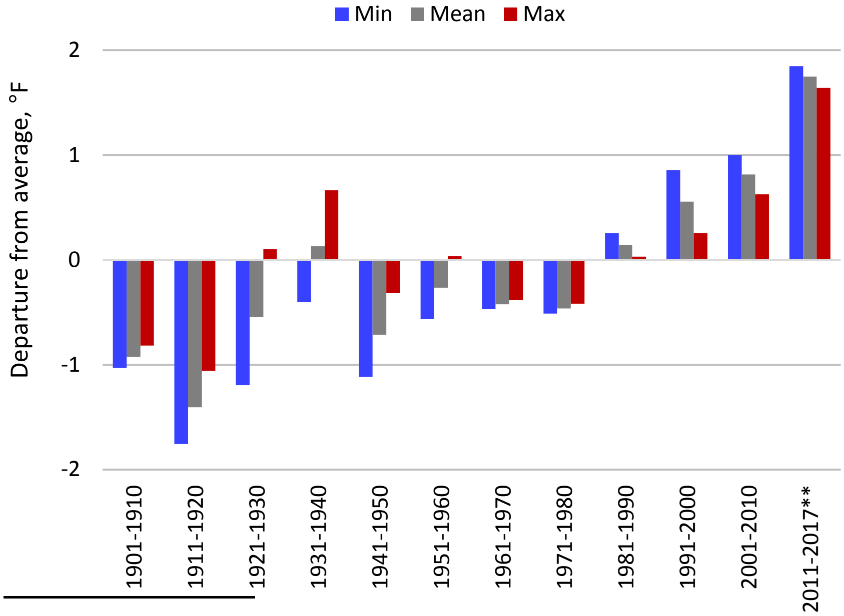
Air temperatures have increased over the past century.

Figure 1. Statewide annual average temperatures



Source: WRCC, 2018

Figure 2. Statewide Temperatures, Decadal Averages (relative to long-term average*)



** 1949-2005 base period*

***Note: Partial decade*

Source: WRCC, 2018

Temperature Departures: Definition of terms used

Average is the long-term average temperature based on data from 1949 to 2005.

Departure is the difference between the long-term average and the value for the period of interest. Positive values are above the long-term average (which is set at zero) and negative values are below the long-term average.

Maximum and minimum temperature is an average of the maximum or minimum temperature values for a given length of time.

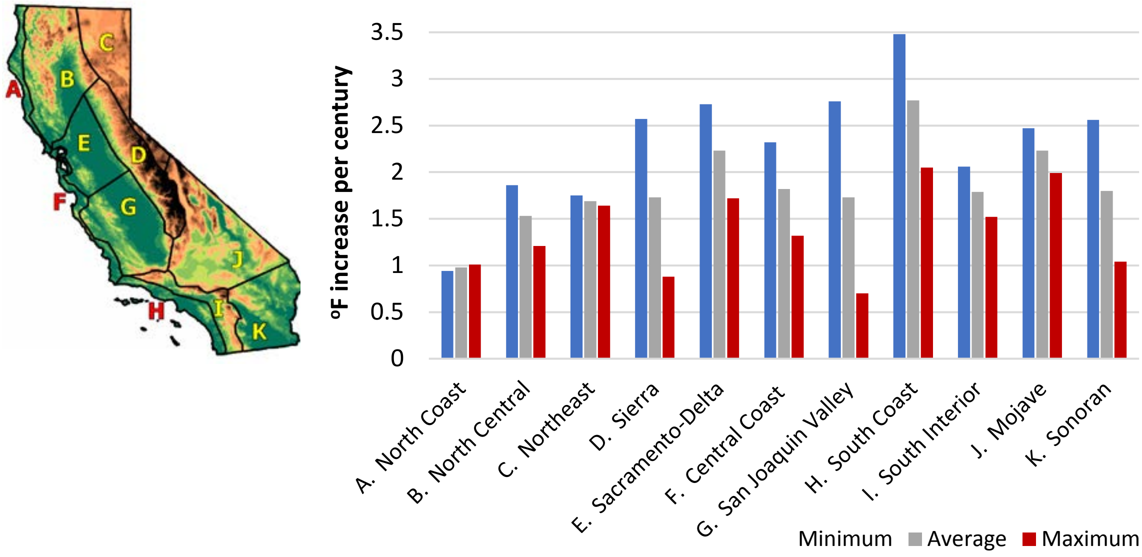
Mean temperature is the average of the maximum and minimum temperatures, or the sum of maximum + minimum, divided by 2.

What does the indicator show?

Statewide air temperatures have been recorded since 1895 and have shown a warming trend consistent to that found globally (IPCC, 2013). Figure 1 shows annual mean temperatures averaged over the state. Since 1895, annual mean temperatures have increased by about 2.2 degrees Fahrenheit (^{o}F) (or about 1.8 ^{o}F per century, which is a common way of measuring long-term temperature changes). The last four years were notably warm, with 2014 being the warmest on record, followed by 2015, 2017 and 2016. These warm years coincided with some of the driest years in the instrumental record leading to exacerbated drought conditions due to increased land surface temperatures, evapotranspiration, and evaporative demand.

Figure 2 shows “departures” by decade from a long-term average (base period of 1949 to 2005) for minimum, average (mean) and maximum temperatures — i.e., the difference between each decade’s value and the long-term average. Minimum, average and maximum temperatures have been increasing overall, particularly since the 1980s. Minimum temperatures (that reflect overnight low temperatures) have increased the fastest. Minimum temperatures rose by 2.8 ^{o}F since 1895 (at a rate of 2.3 ^{o}F per century). Maximum temperatures rose by 1.6 ^{o}F since 1895 (at 1.3 °F per century). The increasing trend in mean California temperature is driven more by nighttime processes than by daytime processes.

Figure 3. Regional temperature trends (1895 to 2017)



Source: WRCC, 2018

All of California’s 11 climate regions show warming trends over the last century, although at varying rates (see Figure 3). The greatest increase is observed in the South Coast region. Minimum temperatures showed the greatest rate of increase in all the regions, except the North Coast. Minimum temperatures rose up to four times faster than maximum temperatures in the San Joaquin Valley, and three times faster in the Sierra Region. Graphs showing annual minimum, average and maximum temperatures from 1895 to 2017 for the North Coast, Sierra, San Joaquin Valley, and South Coast regions are presented under “What factors influence this indicator?” (see “Regional Annual (Jan-Dec) Temperature Departures”).

Why is this indicator important?

Temperature is a basic physical factor that affects many natural processes and human activities. Warmer air temperatures alter precipitation and runoff patterns, affecting the availability of freshwater supplies. Increased temperature leads to a wide range of impacts on ecosystems — including changes in species’ geographic distribution, in the timing of life cycle events, and in their abundance — as well as human health and well-being. In addition, warming temperatures affect energy needed for cooling and heating, which in turn influences the types of energy generation, infrastructure, and management policies needed to meet these demands. Temperature changes can also increase the risk of severe weather events such as heat waves and intense storms. Understanding observed temperature trends is important for refining future climate projections for climate sensitive sectors and natural resources within the state (Cordero et al., 2011).

What factors influence this indicator?

Globally, the increase in the concentration of carbon dioxide and other greenhouse gases in the Earth’s atmosphere since the Industrial Revolution in the mid-1700s has been a principal factor causing warming (IPCC, 2013). Emissions of these greenhouse gases are intensifying the natural greenhouse effect, causing surface temperatures to rise. Greenhouse gases absorb heat radiated from the Earth’s surface and lower atmosphere, and radiate much of the energy back toward the surface.

Temperatures are influenced by local topography, proximity to the ocean, and global and regional atmospheric and oceanic circulations. Climate patterns can vary widely from year to year and from decade to decade, in accordance with large-scale circulation changes around the Earth. The Pacific Ocean has a major effect on California temperatures all year along the coast, especially summer, and farther inland in winter. In addition to topography, local influences on temperature include changes in land surface and land use. For example, urbanization of rural areas is generally known to have a warming effect, due in large part to the heat absorbing concrete and asphalt in building materials and roadways. Expansion of irrigation has been shown to have a cooling effect on summertime temperatures (Bonfils and Lobell, 2007).

There are unequal warming trends in each season, and spring is of particular interest due to its apparent larger warming trend. Abatzoglou and Redmond (2007) found that the difference between spring and autumn temperature trends observed in western North America is most likely due to global atmospheric circulation changes over the last several decades that exacerbate regional warming in the spring, and counteract warming in autumn (hence producing cooling).

Statewide seasonal temperature trends are listed in Table 1. The values are linear trends reported by the California Climate Tracker (WRCC, 2018). The greatest increases in maximum and mean temperatures occurred in the spring, while increases in minimum temperatures were greatest in the summer and in the fall. Trends since 1975 are greater than trends since 1895, except for maximum temperatures in the winter.

Table 1. Statewide trends by season

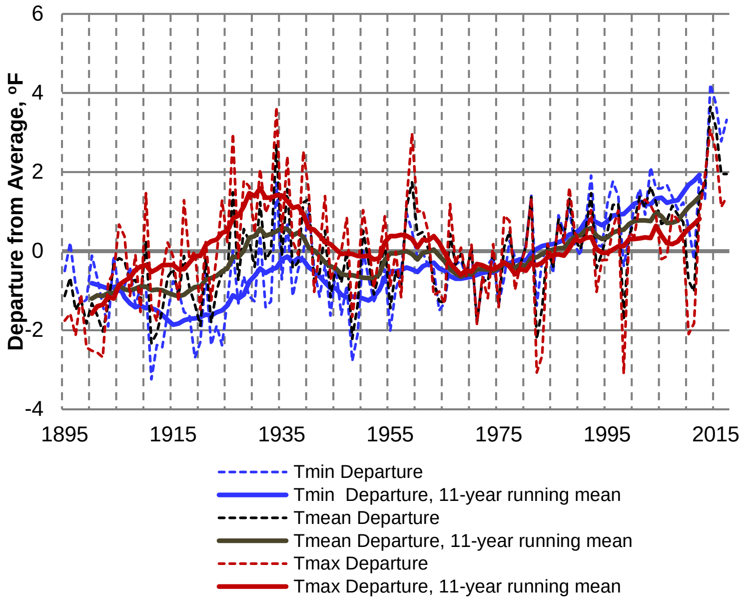
Season	Trend, °F/100 years					
	1895 to Present			1975 to Present		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Fall (Sep-Nov)	2.74	1.94	1.15	6.96	5.78	4.61
Winter (Dec-Feb)	1.57	1.44	1.31	1.93	1.27	0.61
Spring (Mar-May)	2.08	2.00	1.92	4.86	5.82	6.77
Summer (Jun-Aug)	2.76	1.82	0.88	5.93	5.46	5.00
Annual (Jan-Dec)	2.30	1.82	1.34	5.23	4.84	4.45

Source: WRCC, 2018

Regional Annual (Jan-Dec) Temperature Departures (based on 1949-2005 averages)

To illustrate the varied nature of temperature trends in different regions of the state, data are presented for four of the 11 California climate regions. The South Coast showed the greatest warming of all regions, the San Joaquin Valley and the Sierra regions showed the largest and second largest difference between the increase in minimum temperatures compared to maximum temperatures, and the North Coast showed fairly equal trends in minimum, average, and maximum temperatures (see Figure 3). In the graphs that follow, the red line is the maximum temperature; the blue line is the minimum temperature; and the black line is mean temperature. Thin lines are values for annual departures from the long term (1949 to 2005) average. Bold lines are the 11-year running mean, where the value shown for each year is calculated for the 11-year period that starts five years before that year.

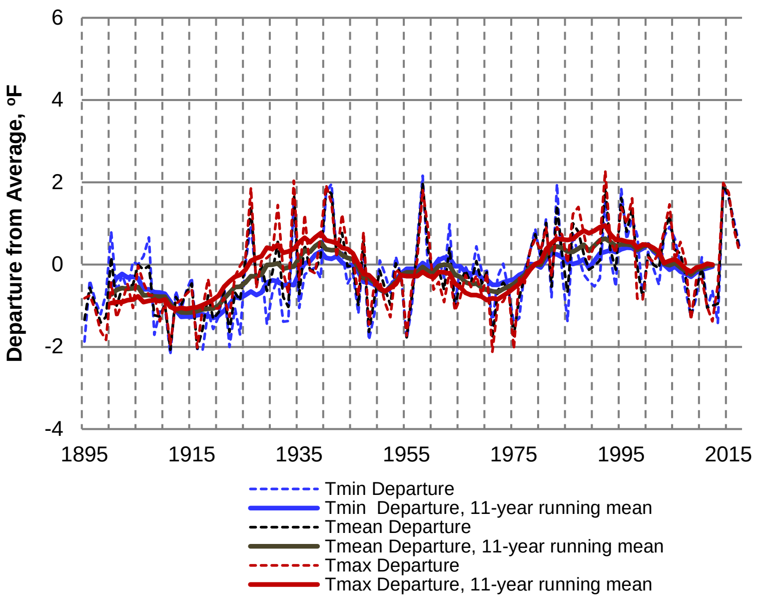
Figure 4. Sierra Region



Source: WRCC, 2018

The Sierra Region contains the natural winter snowpack storage for the state’s water supply. It stretches from the Feather River in the north to the Kern River in the south, ranging from about 2,000 feet to above 14,000 feet in elevation. Minimum temperatures in this region have increased about three times faster than maximum temperatures. The rise in spring season minimum temperatures and decrease in the number of days with temperatures below freezing have impacted snowpack and snowmelt. Snow cover is a factor affecting temperature in this region: the disappearance of snow cover exposes surfaces that absorb solar energy, resulting in further warming (a phenomenon known as “snow albedo feedback”) (Walton et al., 2017).

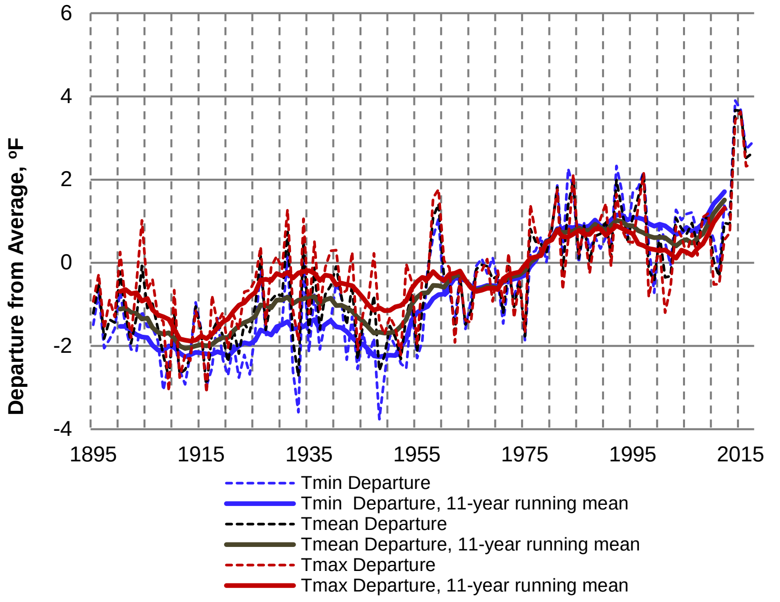
Figure 5. North Coast Region



Source: WRCC, 2018

The North Coast region is a narrow coastal strip from the Oregon border to just south of Point Reyes. The region shows less of an increase in minimum and average temperatures than the rest of the state. Further, the overall trends for minimum, mean and maximum temperatures are similar. These trends may reflect the moderating influence of maritime air on temperatures (Abatzoglou et al., 2009).

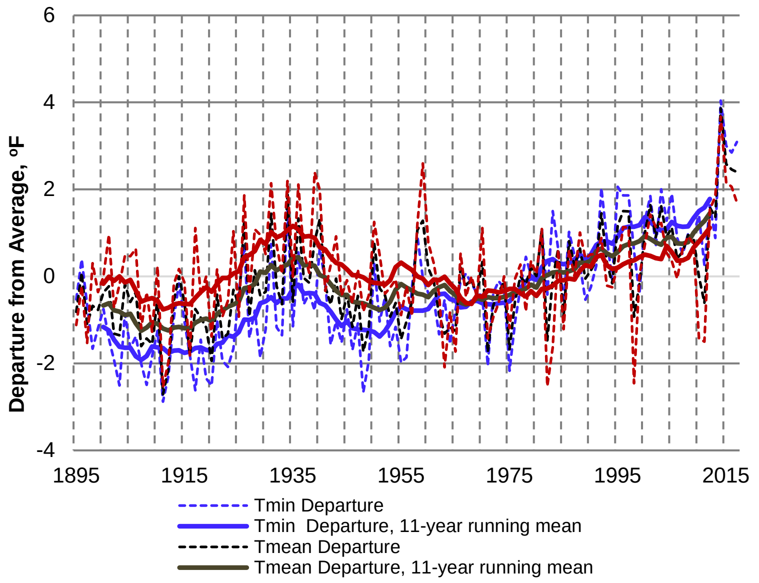
Figure 6. South Coast Region



Source: WRCC, 2018

The South Coast region encompasses a narrow band along the coast from Point Conception to the Mexican border, including the Los Angeles Basin and San Diego. It has experienced the greatest warming among the regions since1895. Although the region experiences the moderating influence of maritime air, rapid urbanization may have contributed to its relatively steep overall warming trend (LaDochy et al., 2007). More recently, increased sea breeze activity due to the gradient created by inland warming is thought to have created a cooling effect in the summer (Lebassi et al., 2009).

Figure 7. San Joaquin Valley Region



Source: WRCC, 2018

Minimum temperatures in the San Joaquin Valley region have been rising about four times faster than maximum temperatures. Studies in this region suggest that urbanization has primarily increased minimum temperatures (LaDochy et al., 2007), while irrigation has both decreased maximum temperatures and increased minimum temperatures (e.g., Bonfils and Lobell, 2007; Kueppers et al., 2007).

Technical Considerations

Data Characteristics

Two data sources are used to create a single value for each temperature variable each month: (1) data for nearly 200 climate stations in the NOAA Cooperative Network within California (from the Western Regional Climate Center database archive of quality controlled data from the National Climatic Data Center); and (2) gridded climate data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al., 1997) acquired from the PRISM group at Oregon State University. PRISM provides complete spatial coverage of the state. Because climate stations are not evenly spaced, the PRISM data are used to provide even and complete coverage across the state. This operational product, the California Climate Tracker, is updated monthly online at the Western Regional Climate Center at http://www.wrcc.dri.edu/monitor/cal-mon/index.html. Software and analyses were produced by Dr. John Abatzoglou (Abatzoglou et al., 2009).

Strengths and Limitations of the Data

The datasets used are subjected to their own separate quality control procedures, to account for potentially incorrect data reported by the observer, missing data, and to remove inconsistencies such as station relocation or instrument change.

The PRISM dataset offers complete coverage across the state for every month of the record. Limitations include the bias of station data toward populated areas, and limited ability of quality control processes in remote or high terrain areas. The results cited here offer a hybrid using both gridded (full coverage) and station data, which is suggested to be more robust than either dataset used independently (Abatzoglou et al., 2009).

For more information, contact:

Dan McEvoy and Nina Oakley
Western Regional Climate Center
Division of Atmospheric Science
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512-1095
(775) 674-7010
Daniel.McEvoy@dri.edu
Nina.Oakley@dri.edu

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