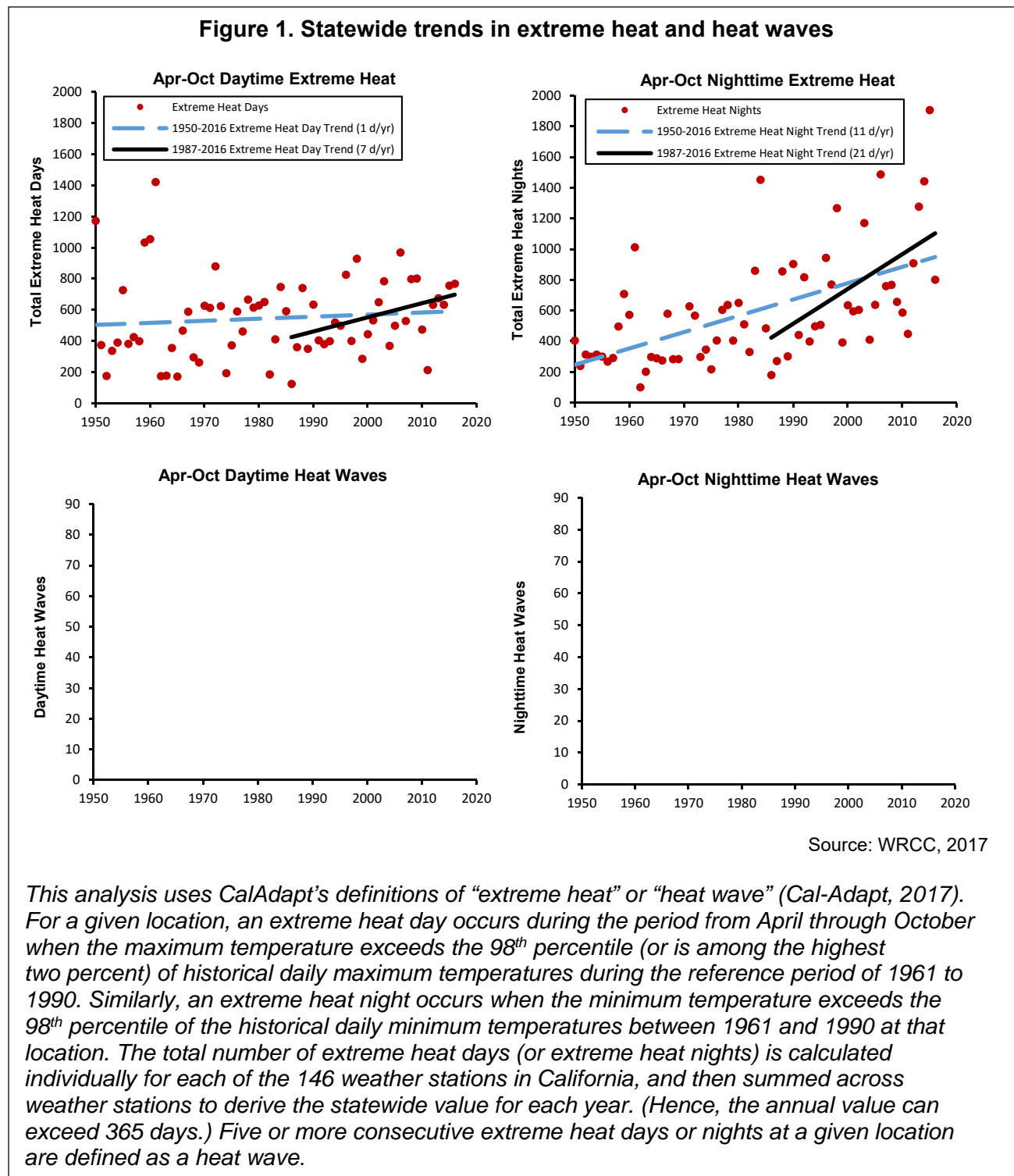


## EXTREME HEAT EVENTS

Extreme heat days and nights have become more frequent since 1950. Heat waves have been variable each year, but nighttime heat waves have shown a marked increase since the mid-1970s.



### What does the indicator show?

The two top graphs in Figure 1 show statewide trends in the number of extreme heat days and nights from April through October. The dashed blue lines show the linear trend for the period from 1950 to 2016. The solid line shows the trend for the last 30 years (1987-2016). Since 1950, the number of extreme heat days has increased slightly statewide, at a rate of about one day per year. In contrast, the rate of increase in the occurrence of extreme heat nights for the same period is over 10 times higher, at 11 days per year. For both extreme heat days and nights, the rate of change has been greater over the most recent 30 years. From 1987 to 2016, extreme heat days and nights increased by 7 and 21 days per year, respectively.

Statewide heat waves are shown in the two bottom graphs in Figure 1. The number of daytime heat waves shows considerable year-to-year variability, without a clear trend. Nighttime heat waves, which occurred infrequently until the mid-1970s, have increased in frequency over the past 40 years.

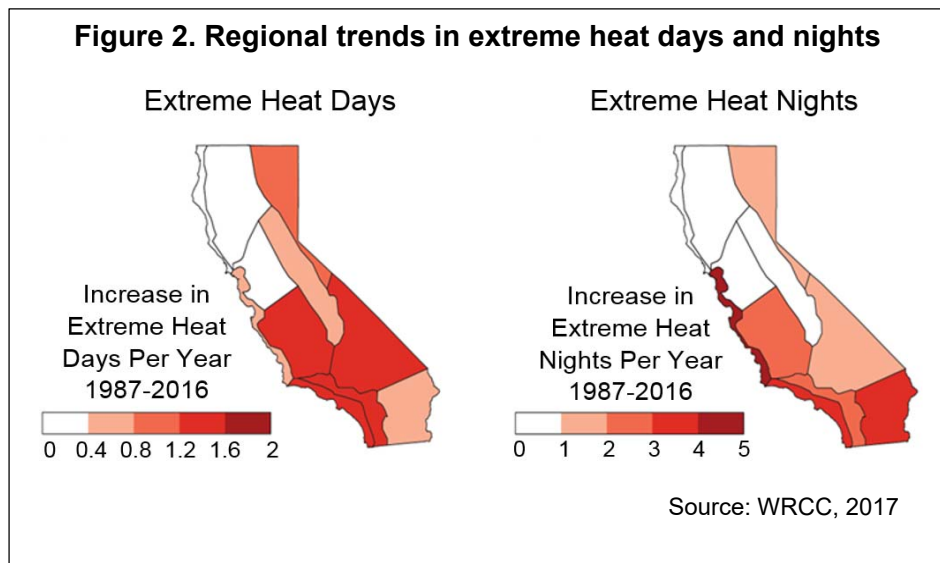
Regional trends in the number of extreme heat days and nights over the 30-year period from 1987 to 2016 are illustrated in the maps in Figure 2. For most regions, the rate of increase in the number of extreme heat nights was twice that of the rate of increase in extreme heat days. The greatest

increase in the total number of daytime and nighttime extreme heat events occurred in Southern California. Nighttime heat increased the most in the Central Coast region.

### Why is this indicator important?

Periods of extremely high temperatures have significant public health, ecological, and economic impacts. Among these are heat-related illnesses and deaths, livestock deaths, increased water demand, increased air pollution, and strains on the power supply. Heat causes the most weather-related deaths in the United States (NOAA, 2017).

Heat events are projected to become more frequent and last longer (USGCRP, 2016). Taking action to mitigate the impacts of extreme heat is critical, particularly given the largely preventable adverse effects on public health. Anticipating the effects of



unusually high temperatures on wildfires, agriculture, and energy demand will also help inform planning and resource allocation.

A recent study found a changing pattern of heat waves in California. Since the 1980s, heat waves have become more humid, in part due to ocean warming (Gershunov et al., 2009). Humidity prevents surfaces from cooling down at night, leading to higher nighttime temperatures. Warmer nighttime temperatures have a significant biological impact. People, animals, and plants that are adapted to California's traditionally dry daytime heat and nighttime cooling are unable to recover from extreme heat, especially when humidity is high at night. The increase in nighttime heat waves presents an additional risk factor for vulnerable populations.

### ***What factors influence the indicators?***

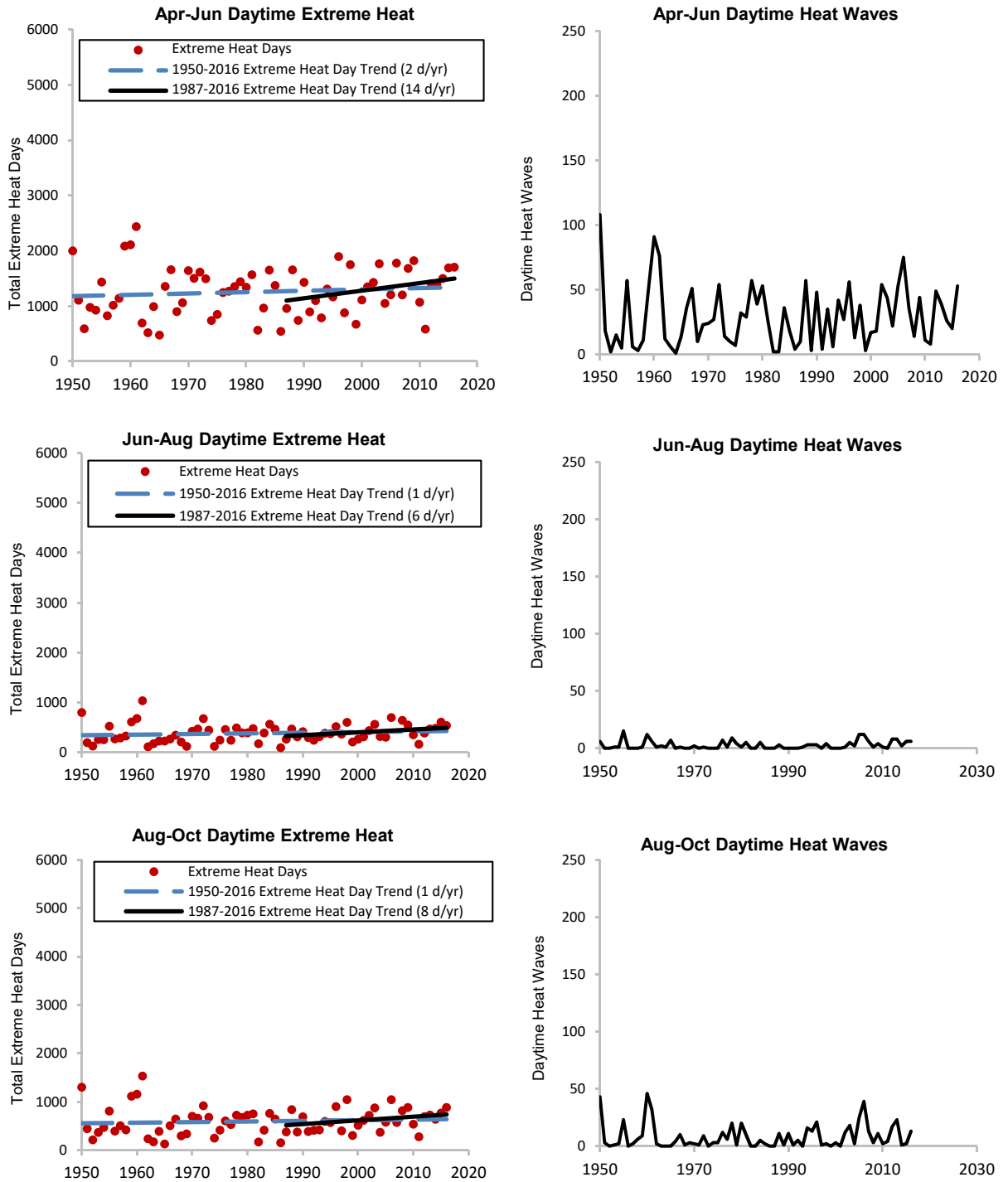
Air temperature varies according to the time of day, the season of the year, and geographic location. Temperatures in urban areas can also be affected by the urban heat island effect due to land surface modification and other human activities. However, rural locations see comparable increases in extreme heat days and nights and all regions of California are affected by regional climate change. This suggests that urbanization and land use does not explain the changes observed in California. The asymmetric increase in nighttime California heat wave activity and extreme heat nights compared to daytime heat extremes is consistent with impacts expected under global climate change.

As noted above, heat waves are becoming more humid. Although concern over greenhouse gas emissions tends to focus on carbon dioxide, water vapor is the most abundant greenhouse gas in the atmosphere, and the largest contributor to warming (Myhre et al, 2013). Human activities have little direct influence on the amount of atmospheric water vapor (Forster et al., 2007). As air temperatures rise due to anthropogenic emissions of other greenhouse gases, the water vapor content of the atmosphere increases. Water vapor absorbs outgoing longwave terrestrial radiation and re-radiates energy back to the surface, thus impeding radiative cooling. Therefore, there is less nighttime respite from heat when specific humidity is high. Moreover, humid heat waves tend to last longer due to the stronger coupling of maximum and minimum temperatures during humid heat waves (Gershunov et al., 2009).

The influence of the time of year (or season) is evident in the extreme heat trends presented in the graphs (Figures 3 and 4) and Table 1. The period from April to June showed the greatest increase in the number of extreme heat days and nights (see Figure 3, 4 and 5). This suggests that these months are warming at a faster rate than other months of the year. Further, the increase in extreme heat occurred at a faster rate during the past 30 years (1987-2016) than the past 67 years (1950-2016), suggesting that warming has increased during the recent decades.



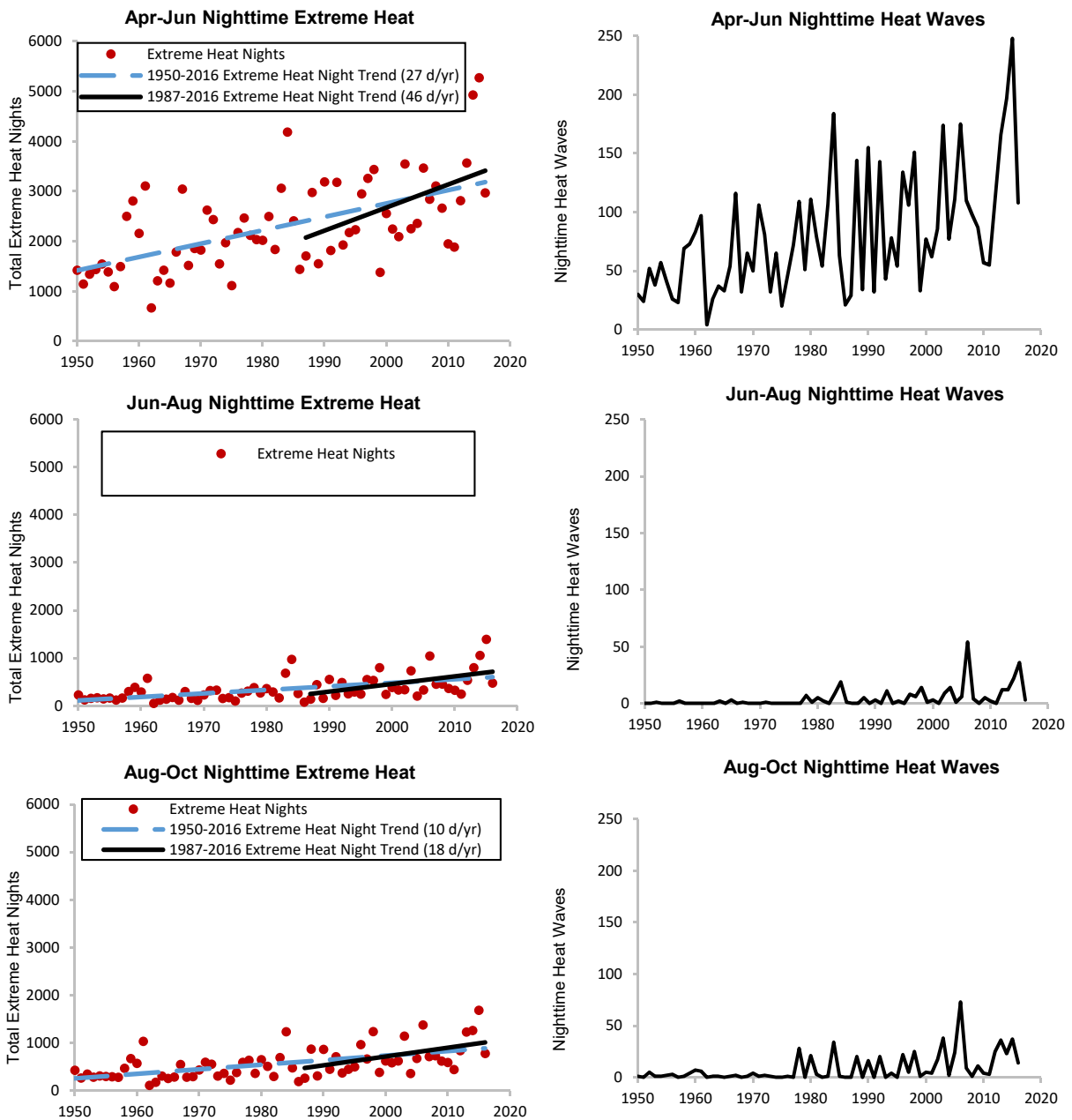
**Figure 3. Statewide trends in daytime heat waves and extreme heat days**



Source: WRCC, 2017



**Figure 4. Statewide trends in nighttime heat waves and extreme heat nights**

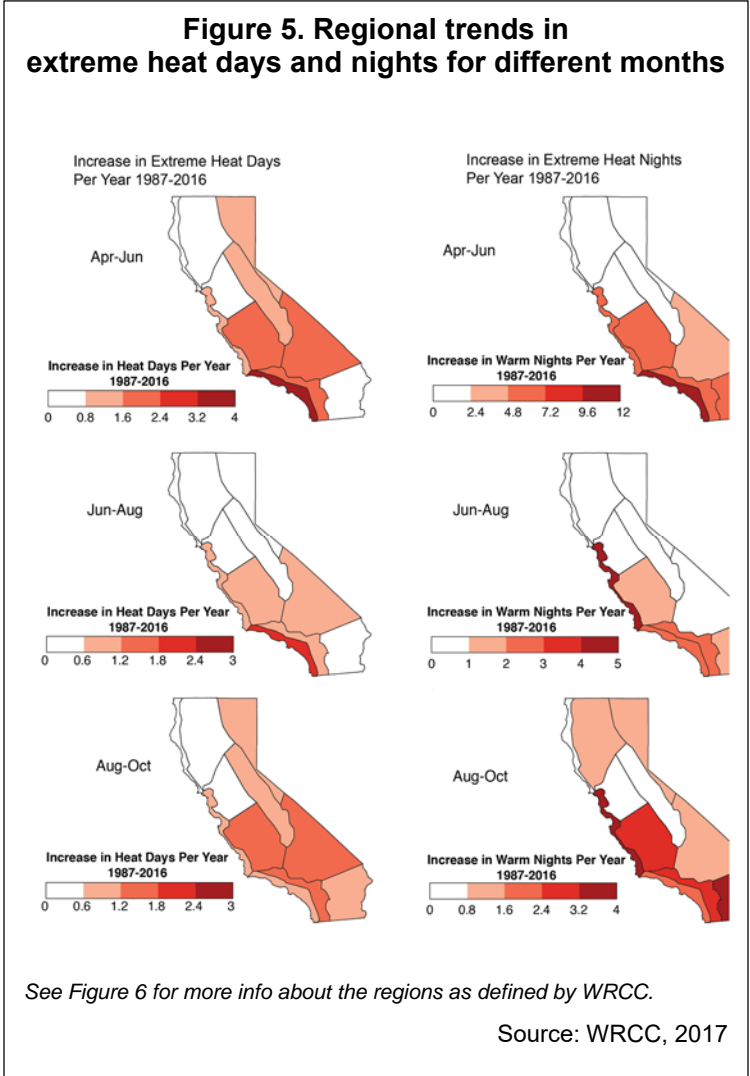


Source: WRCC, 2017



<b>Table 1. Summary of extreme heat trends</b>				
Rate of increase in the number of extreme heat days or nights per year for different periods during the warm months at 146 CA weather stations				
Period	Daytime extreme heat trend (days/year)		Nighttime extreme heat trend (days/year)	
	1950-2016	1987-2016	1950-2016	1987-2016
April-October	1	7	11	21
April-June	2	14	27	46
June-August	1	6	7	16
August-October	1	8	10	18

Nighttime trends are at least two times greater than daytime trends in extreme heat. The greatest increases are found in Southern California. The South Coast has experienced the greatest increases in both daytime and nighttime heat extremes during late spring (April-June). Note that the spring season nighttime extreme heat increases are on the order of two to four times greater than other seasons. Summer (June-August) increases in nighttime heat extremes are most pronounced along the Central Coast followed by the South Coast and South Interior regions. Early fall (August-October) increases in nighttime extreme heat is more widespread throughout southern California with the Central Coast and Mojave Desert regions experiencing the greatest increases, followed by the South Interior and San Joaquin Valley regions.

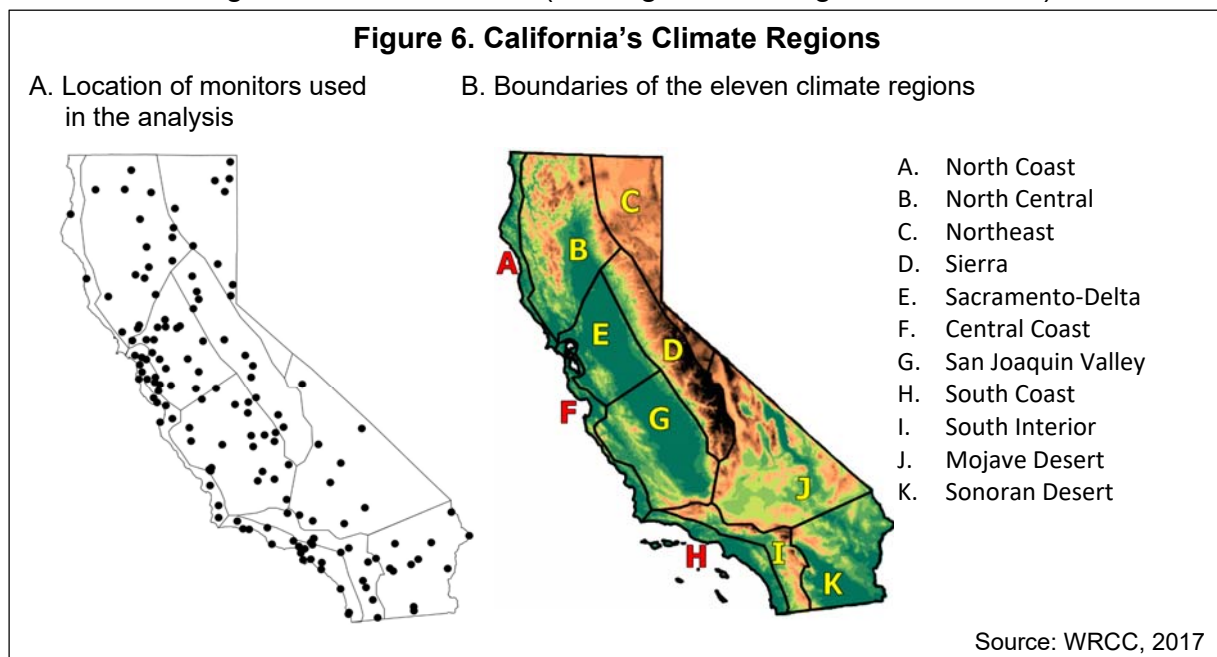


## Technical Considerations

### Data Characteristics

This indicator uses station data from the National Weather Service (NWS) cooperative observation network acquired from the Applied Climate Information System (via <https://wrcc.dri.edu/csc/scenic/>). The vast majority of the observers are trained volunteers, and the network also includes the NWS principal climatological stations. The observing equipment used at all of the stations, whether at volunteer sites or federal installations, are calibrated and maintained by NWS field representatives, Cooperative Program Managers, and Hydro-Meteorological Technicians. Only stations with at least 90 percent complete records were used in the analysis for a total of 146 stations. These stations are shown in Figure 6.

Regional trends are presented according to California's climate regions, as defined by the Western Regional Climate Center (see Figure 6 for region boundaries).



### Strengths and Limitations of the Data

The station data have received a high measure of quality control through computer and manual edits, and are subjected to internal consistency checks, compared against climatological limits, checked serially, and evaluated against surrounding stations. Station coverage is not uniformly distributed geographically and coverage can be quite sparse in mountainous areas such as the Sierra Nevada and Klamath Mountain regions, therefore there is a bias towards populated areas and lower elevations. Recorded temperatures in urban areas can also be affected by the urban heat island effect due to land surface modification and other human activities. The majority of California's population resides in urban areas, implying that the heat impacts from urban-induced warming on health are non-negligible. The statewide and climate region-based estimates should be interpreted as maximum estimates of changes in heat extremes due to the contribution of urban warming. Quantification of the specific



magnitudes of station-based urban heat contributions and its influence on regional and statewide trends in heat extremes are beyond the scope of the present study but are the subject of ongoing research. The stations used in this analysis have undergone a homogenization technique applied by the National Center for Environmental Information to reduce urban heat-related biases (Hausfather et al., 2013).

**For more information, contact:**



Western Regional  
Climate Center

Benjamin Hatchett, Ph.D.  
Desert Research Institute  
Western Regional Climate Center  
2215 Raggio Parkway  
Reno, Nevada, 89512  
[Benjamin.Hatchett@dri.edu](mailto:Benjamin.Hatchett@dri.edu)  
(775) 674-7111

**References:**

CCSP (2008). *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems. Final Report, Synthesis and Assessment Product 4.6. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.* U.S. Climate Change Science Program. Available at <http://www.climatechange.gov/Library/sap/sap4-6/final-report>

Gershunov A, Cayan DR and Iacobellis SF (2009). The Great 2006 Heat Wave over California and Nevada: Signal of an Increasing Trend. *Journal of Climate* **22**(23): 6181–6203.

Guirguis KJ and Avissar R (2008). A precipitation climatology and dataset intercomparison for the western United States. *Journal of Hydrometeorology* **9**(5): 825-841.

Hausfather, Z, Menne MJ, Williams CN, Masters T, Broberg R and Jones D (2013). Quantifying the effect of urbanization on U.S. Historical Climatology Network temperature records. *Journal of Geophysical Research: Atmospheres* **118**: 481-494.

Forster P, Ramaswamy V, Artaxo P, Bernsten T, Betts R, et al. (2007). Changes in Atmospheric Constituents and in Radiative Forcing. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Solomon S, Qin D, Manning M, Chen Z, Marquis M, et al. [Eds.]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available at [http://www.ipcc.ch/publications\\_and\\_data/ar4/wg1/en/ch2.html](http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2.html)

Maurer EP, Wood AW, Adam JC, Lettenmaier DP and Nijssen B (2002). A long-term hydrologically based dataset of land surface fluxes and states for the conterminous United States. *Journal of Climate* **15**(22): 3237-3251. data updated to 2010 at: [http://www.engr.scu.edu/~emaurer/gridded\\_obs/index\\_gridded\\_obs.html](http://www.engr.scu.edu/~emaurer/gridded_obs/index_gridded_obs.html)

Myhre G, Shindell D, Bréon F-M, Collins W, Fuglestedt J, et al. (2013). Anthropogenic and Natural Radiative Forcing. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, et al. [Eds.]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available at [https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_Chapter08\\_FINAL.pdf](https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf)

NOAA (2017). National Weather Service: 77-Year List of Severe Weather-Related Fatalities (1940-2016). Retrieved July 10, 2017, from <http://www.nws.noaa.gov/om/hazstats.shtml>.





Richman MB and Lamb PJ (1985). Climatic Pattern Analysis of Three- and Seven-Day Summer Rainfall in the Central United States: Some Methodological Considerations and a Regionalization. *Journal of Climate and Applied Meteorology* **24**(12): 1325-1343.

USGCRP (2016). *Chapter 2: Temperature-Related Death and Illness. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. US Global Change Research Program. Available at <https://health2016.globalchange.gov/temperature-related-death-and-illness>

WRCC (2017). Western Regional Climate Center. National Weather Service Cooperative Observation Network, accessed 10 March 2017 via the Applied Climate Information System. Data analyzed by Ben Hatchett, Desert Research Institute.

