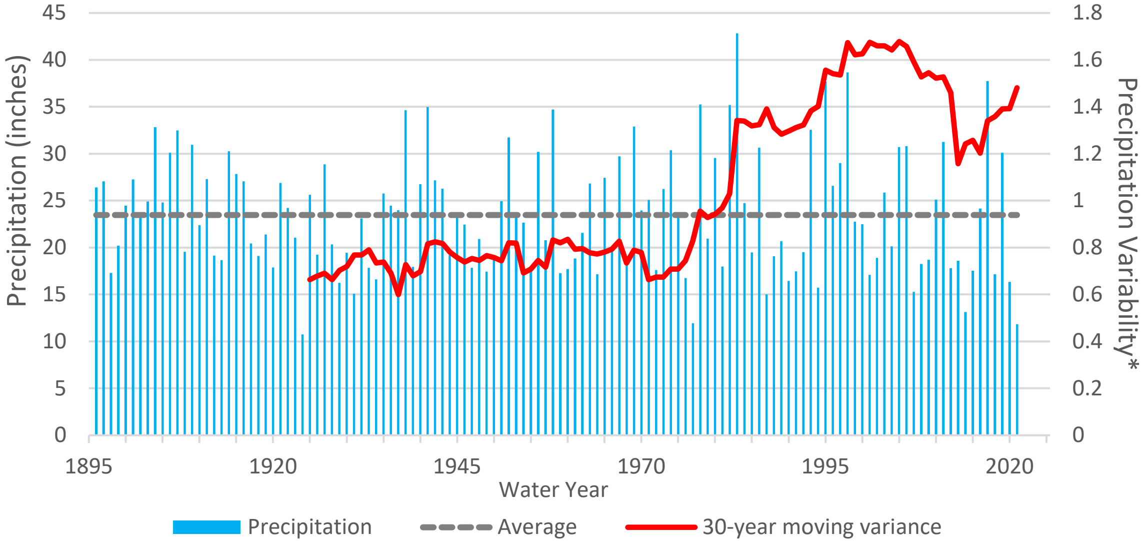
# PRECIPITATION

*While the amount of annual precipitation over time shows no statewide trend, year-to-year variability has increased since the 1980s. In recent years, the fraction of precipitation that falls as rain instead of snow has increased in the Sierra Nevada and Southern Cascades, reducing the water stored in the snowpack that provides most of California's water supply.*

**Figure 1. Statewide annual precipitation (1895-2021)**



Source: WRCC, 2022

**Precipitation variability*: *the value shown for each year beginning in 1925 is the ratio of the variance for the 30-year period ending in that year to the variance over the entire period (1895-2021). A ratio above 1 means precipitation was more variable; below one, less variable.*

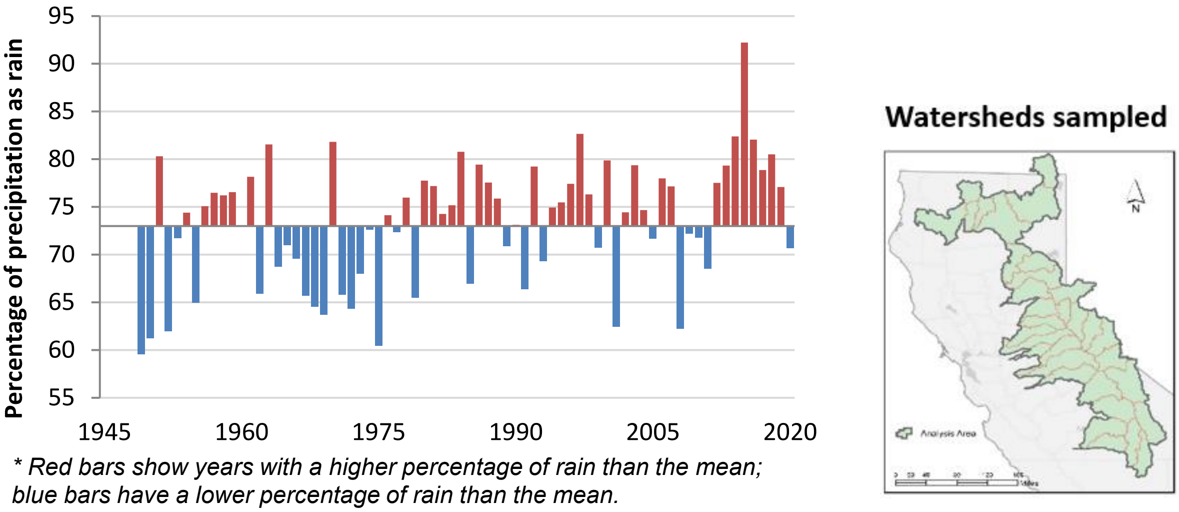
## *What does the indicator show?*

California experiences high year-to-year variability in precipitation: some years are very wet, while others are very dry. Since the early 1980s, precipitation over the state has become more variable (Figure 1, red line). The same is true across the state's climate regions (see appendix; also He and Guatam, 2016). The past decade included the third wettest year on record (2017) and the second driest (2021). In 2017 California emerged from a severe and prolonged drought. From October 2018 to September 2019, California transitioned from a very dry fall into a very wet winter. The water year 2021 was the second driest on record, following 1924.

Precipitation totals are tracked by "water year," from the beginning of the rainy season in October through the following September, the end of the dry season. This is more useful than a calendar year in California due to its typically dry summer and wet winter ("Mediterranean") climate. On average, 75 percent of the state's annual precipitation occurs from November through March, with 50 percent occurring from December through February.

No clear trend is evident in the amount of total annual precipitation (Figure 1, blue bars). Statewide precipitation is the area-weighted average of regional precipitation values. In other words, the regional precipitation values — computed as an area-weighted average of precipitation at the climate stations in the region — are weighted by the area covered by each region, and an average is calculated as the statewide value. Since records began in 1895, statewide annual precipitation has ranged from a low of 10.75 inches in 1924 to a high of 42.82 inches in 1983. The water years spanning 2012 to 2015 set a record for the driest consecutive four-year period of statewide precipitation. The average annual precipitation varies greatly among California's eleven climate regions (as defined by the Western Regional Climate Center): from 4.7 inches in the Sonora Desert to 67.8 inches in the North Coast.

**Figure 2. Rain as a percentage of total precipitation* (1949-2020)**



** Red bars show years with a higher percentage of rain than the mean; blue bars have a lower percentage of rain than the mean.*

Source: DWR, 2021a

Figure 2 shows the percentage of yearly precipitation falling as rain over the 33 watersheds that provide most of the state's water supply. Each value shown represents the difference between that year's percentage of rain compared to the average of 73 percent (mean, black line) for the entire period (1949 to 2020). Red bars show years with more rain than average (and thus less snow), and blue bars show years with less rain than average. Despite high year-to-year variability, recent years clearly show a trend toward more precipitation falling as rain. The percentage of precipitation falling as rain for 8 of the last 10 years was higher than average. The 2015 water year, which had the lowest snowpack on record, also had the highest percentage of rain, at about 92 percent.

### *Why is this indicator important?*

Precipitation, in the form of rain and snow, provides most of California's supply of water. The fraction of precipitation falling as rain significantly affects how much water is stored as snow. During warmer months, the state relies on Sierra Nevada snowmelt to meet a large fraction of its water demand (see *Snow-water content* and *Snowmelt runoff* indicators). Tracking changes in the amount and physical state of precipitation, and in the patterns of storm events gives critical information for balancing the multiple water management objectives of reservoir operations, including storage and flood protection. Historical trends help inform short- and long-term water management planning and provide the basis for future projections (Siirila-Woodburn et al. 2021; Sterle et al., 2019).

Changes in the timing of precipitation are also important to track. A comparison of historical and current precipitation (1960–1989 vs 1990–2019) averaged over the entire state shows a change in the monthly distribution of precipitation (Luković et al., 2021). This study found a progressively delayed and shorter, sharper rainy season in California. This is consistent with climate change projections (Oakley et al. 2019; Polade et al. 2014, Swain et al., 2018).

Along with providing water to people in California, precipitation also nourishes the natural environment. Changes to precipitation or water availability can manifest in ecosystems in various ways. During the 2012-2016 drought, five consecutive dry winters resulted in severe ecological impacts, including massive tree mortality, catastrophic wildfires, and steep drops in winter-run Chinook salmon fry survival and in the number of adult Coho salmon returning to spawn (DWR, 2021b).

As dry and wet extremes continue to occur more often, shifts between droughts and floods will become more frequent. Shifts between extreme dry years to extreme wet years are anticipated to happen more often in southern California (Swain et al., 2018). California’s recent rapid shift from severe drought (2012-2016) to heavy precipitation and flooding (2016-2017 winter) exemplifies what so-called precipitation “whiplash” looks like and what its impacts can be: hundreds of roads and other infrastructure throughout California were damaged by floods and mass movements such as landslides. Heavy runoff in the Feather River watershed contributed to the failure of the Oroville Dam spillway, forcing the evacuation of almost a quarter of a million people (Swain et al., 2018). A wet-to-dry whiplash promotes the growth of vegetation that later dries and serve as fuel for fires (Williams et al., 2019). Altogether, projections of climate change suggest that California will spend most of the year in a perennial drought, interrupted periodically by large storms that produce heavy precipitation (Allen and Luptowitz, 2017; Gershunov et al., 2019; Huang et al, 2020; Pottinger, 2020).

**Figure 3. Heavy rainfall triggered over 500 landslides at the Tuolumne River canyon in 2018**

Source: Collins,et al. 2020;
Photo credit: Wayne Hadley
(used with permission)

Floods, landslides, and even avalanches following heavy rainfall threaten human life and property (Collins et al., 2020; Hatchett et al., 2017 and 2020). Fast-moving, highly destructive debris flows triggered by intense rain can happen after a wildfire due to vegetation loss and soil exposure (USGS, 2021). An example of the devastating nature of post-debris flows occurred January 2018, when high intensity rainfall in southern California over an area recently burned by the Thomas Fire triggered landslides that killed 23 people, destroyed over 130 homes, severely damaged infrastructure in Montecito and Carpinteria, and caused the closure of Highway 101 for 13 days (Lukashov et al., 2019). Figure 3 shows shallow landslide and debris flow scars caused by another storm on March 22, 2018, at the Tuolumne River Canyon (near the town of Groveland, in the Sierra Nevada foothills). This storm created a flash flood that caused infrastructure damage in the tens of millions of dollars, led to more than 500 landslides, and moved more sediment in one day than the Tuolumne River would normally transport in a year (Collins et al., 2020).

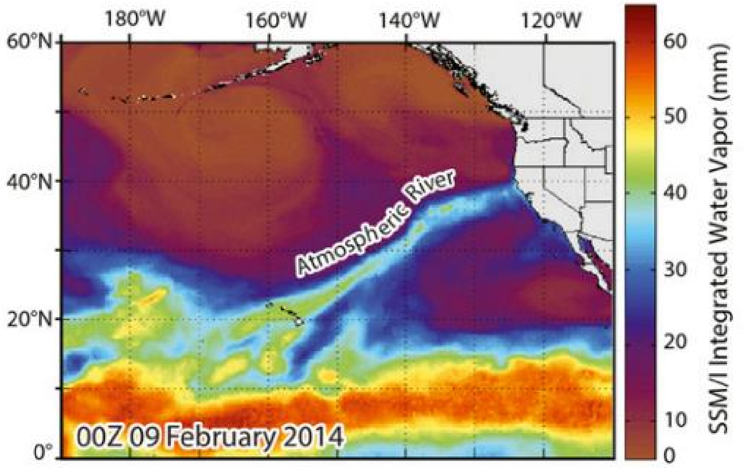
The chances of an extreme 200-year flood event, last seen in the extraordinary “Great Flood” of 1861-1862, is more likely than not to occur within the next 40 years, and multiple occurrences are plausible by 2100 on a business-as-usual greenhouse gas emissions trajectory (Swain et al., 2018). During the Great Flood, flood waters remained throughout the state for months, transforming the land and making roads impassable (Jones, 2019). A storm of this magnitude today would probably lead to considerable loss of life and economic damages approaching a trillion dollars (Swain et al., 2018; USGS, 2011).

### *What factors influence this indicator?*

High year-to-year variability in precipitation is a natural part of California’s climate: the western United States has experienced great swings between wet and dry for thousands of years (Ibarra et al., 2018; Sterle et al. 2019). During the summer, California experiences a deep “seasonal drought” as atmospheric moisture gets diverted away from the state by dense blobs of air parked over the north Pacific Ocean (also known as a “high pressure zone”). In the southeastern desert regions, however, some monsoonal activity in the summertime may bring thunderstorm precipitation (Corbosiero et al., 2009; WRCC, 2021). Precipitation deficits during the recent drought have been associated with a prominent region of high pressure nicknamed the "ridiculously resilient ridge" that diverted storm tracks northward during California's rainy season from 2012 to 2015 (Swain, 2015). During winter, the Pacific high pressure zone retreats southward, and much of California's annual precipitation falls during a few large "atmospheric river" storms (Lamjiri et al., 2018; WRCC, 2021).

Atmospheric rivers are long, narrow bands of water vapor, greater than 1,000 miles long and typically about 250 to 370 miles wide (Figure 4). A natural part of the global water cycle, they transport most of the water vapor outside of the tropics. Some atmospheric rivers originate from the Pacific Ocean near Hawaii and make landfall in California, where they can release water vapor in the form of heavy rain or snow (NASA, 2021; NOAA, 2017).

**Figure 4. Satellite-derived image of an atmospheric river**



Source: Hatchett et al., 2017

*An atmospheric river along the western United States identified using satellite-derived integrated water vapor or the amount of water vapor in the atmosphere (shown according to the color scale on the right).*

Precipitation from atmospheric rivers supplies 30 to 50 percent of California's annual precipitation and about 40 percent of the Sierra Nevada snowpack (Dettinger, 2013; Guan et al., 2010). On average, rainfall from atmospheric rivers makes up 79 percent, 76 percent, and 68 percent of all extreme-rainfall accumulations in the North Coast, northern Sierra, and Transverse Ranges of southern California, respectively (Lamjiri et al., 2018). Windward slopes of hills or mountains provide the ideal location for atmospheric rivers to produce heavy precipitation in California through a phenomenon called orographic forcing: when air gets pushed up the slope of a mountain range, the water vapor cools and condenses if the air is moist enough, forming clouds and causing heavy precipitation to fall (Ralph, 2020). Precipitation from atmospheric rivers in western North America will become more frequent, heavy, and extreme (Gershunov et al., 2019; Hagos et al., 2016; Polade et al., 2017). Although climate change will enhance the amount of precipitation delivered by landfalling atmospheric rivers along the West Coast, the overall frequency of precipitation will decrease as fewer storms not caused by atmospheric rivers are projected (Gershunov et al, 2019).

Most of the water vapor that provides the state's precipitation comes from the Pacific Ocean. Much of the variability in the state's precipitation is related to El Niño and La Niña in the tropical Pacific, which are the warm and cool phases of a recurring climate pattern called the El Niño-Southern Oscillation, or ENSO. The warm phase of

ENSO, El Niño, happens in years when warm surface waters in the ocean intensify a current of strong, high-altitude winds called the Pacific jet stream and shift it south. This causes wet winters in the southern part of the United States (including southern California) and warmer and drier conditions in the northern United States. During the cool phase of ENSO, La Niña, unusually cool surface water conditions in the ocean displace the jet stream northward, leading to drought in the southern United States and heavy rain in the Pacific Northwest. Climate change may make extreme El Niño and La Niña events become more frequent and stronger by the end of the century (NOAA, 2020).

Regarding physical state, precipitation falls as rain or snow depending on the temperature of the air and the ground, the local geography, and the characteristics of the storm itself. Warming temperatures and their influence on a rising snowline (the altitude above which snow remains on the ground) make winter precipitation more likely to fall as rain instead of snow and run off into the ocean instead of being stored in reservoirs (Gonzales et al, 2019; Hatchett et al, 2017; Huang et al, 2020, Lynn et al, 2020). This higher runoff poses a greater flood risk (Huang et al, 2020).

Modeling simulations show that greenhouse gases including carbon dioxide and methane, as well as solar forcing, can increase California wintertime precipitation. Precipitation also changes in response to aerosols: sulfate aerosol increases California wintertime precipitation, whereas black carbon reduces it. California precipitation is more sensitive to aerosols, especially regional emissions from Europe and Asia, than to greenhouse gases (Allen et al., 2020).

A climate change signal can be found in extreme precipitation events globally over the past several decades (Dong et al., 2020). Observed increases in precipitation extremes in California are consistent with projected impacts of climate change in the state (Swain et al., 2018). At the national level, projections suggest that climate change will increase the size and frequency of very heavy and rare rainfall events across the United States (Swain et al., 2020).

## *Technical Considerations*

### Data characteristics

Data for Figure 1 come from the California Climate Tracker, an operational database tracker for weather and climate monitoring information. This indicator tracks precipitation amount in a “water year” defined as October 1 to September 30. This operational product, the California Climate Tracker, is updated periodically online at the Western Regional Climate Center. Data, including historical data, is continuously monitored and updated. The data provided here is the dataset available as of April 7, 2021, from WRCC with the most up-to-date values for modeled historical data.

Precipitation data for nearly 200 climate stations in the NOAA Cooperative Network (COOP) within California were obtained from the Western Regional Climate Center database archive of quality-controlled data from the National Climatic Data Center. For this study, COOP data from 1948-2020 were utilized. Gridded climate data from Parameter-elevation Regressions on Independent Slopes Model (Daly et al., 1997) were acquired from the PRISM group at Oregon State University for the period 1895-2021. PRISM provides complete spatial coverage of the state, where the station data serve to fill in recent data, until PRISM is processed each month. Because climate stations are not evenly spaced, the PRISM data are used to provide even and complete coverage across the state. These are combined to create a time series of annual statewide precipitation dating back to 1895.

Time series datasets prior to 1981 were modeled using climatologically aided interpolation that used the long-term average pattern (i.e., the 30-year normals) as first-guess of the spatial pattern of climatic conditions for a given month or day. Data are based on monthly modeling (PRISM, 2021).

The methodology for determining the rain/snow trends presented in Figure 2 combined fine-scale gridded precipitation data with coarse-scale freezing level and precipitation data from an atmospheric reanalysis. Snowfall was estimated as a fraction of total precipitation at a high spatial resolution, with output from WRCC's North American Freezing Level Tracker (NAFLT). For more information about the methods used, see Lynn et al. (2020).

Strengths and limitations of the data

The datasets used in this work were 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 data offer complete coverage across the state for every month of the record. Limitations include the bias of station data toward populated areas and the limited ability of quality control processes in remote or high terrain areas. The results cited here offer a hybrid using both gridded and station data, considered more robust than either data set used independently (Abatzoglou et al., 2009).

A major advantage of the rain/snow approach used by Lynn et al. (2020) is that the NAFLT can be periodically updated as higher resolution gridded data products become available. This type of analysis can play an important role in developing and implementing adaptive strategies for water management. However, the methodology used interpolations based on observational data which are sparse in mountainous regions. It also might not fully reflect snow line variability in complex terrains.

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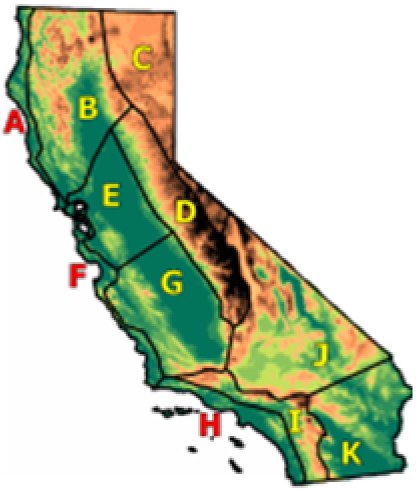
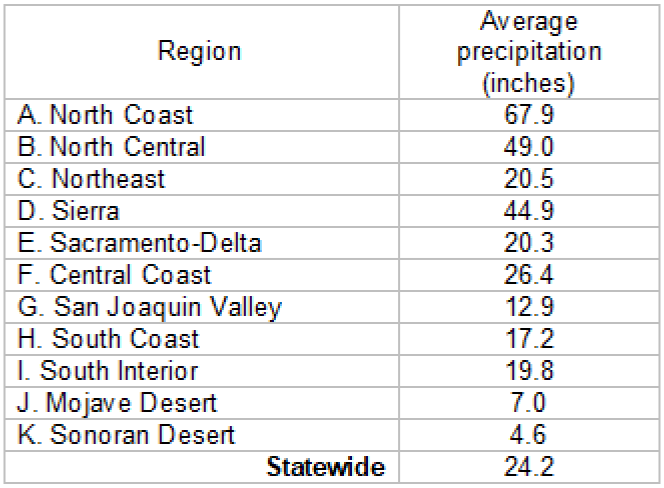
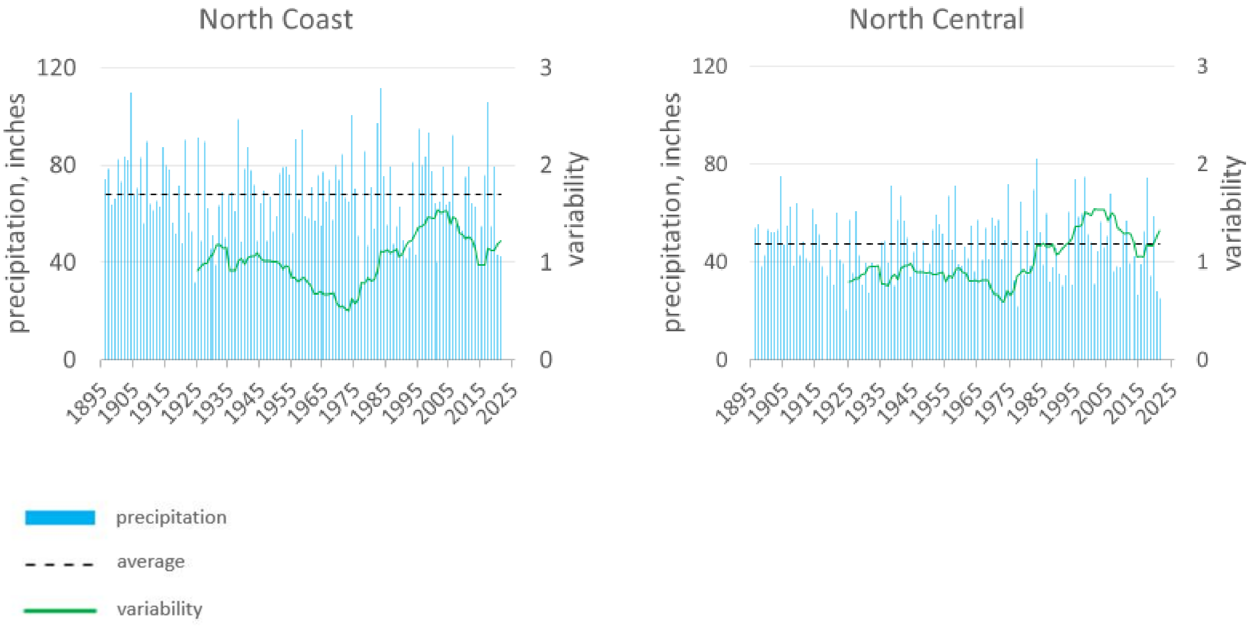
## *APPENDIX. Regional precipitation trends in California's climate regions (as defined by the Western Regional Climate Center)*

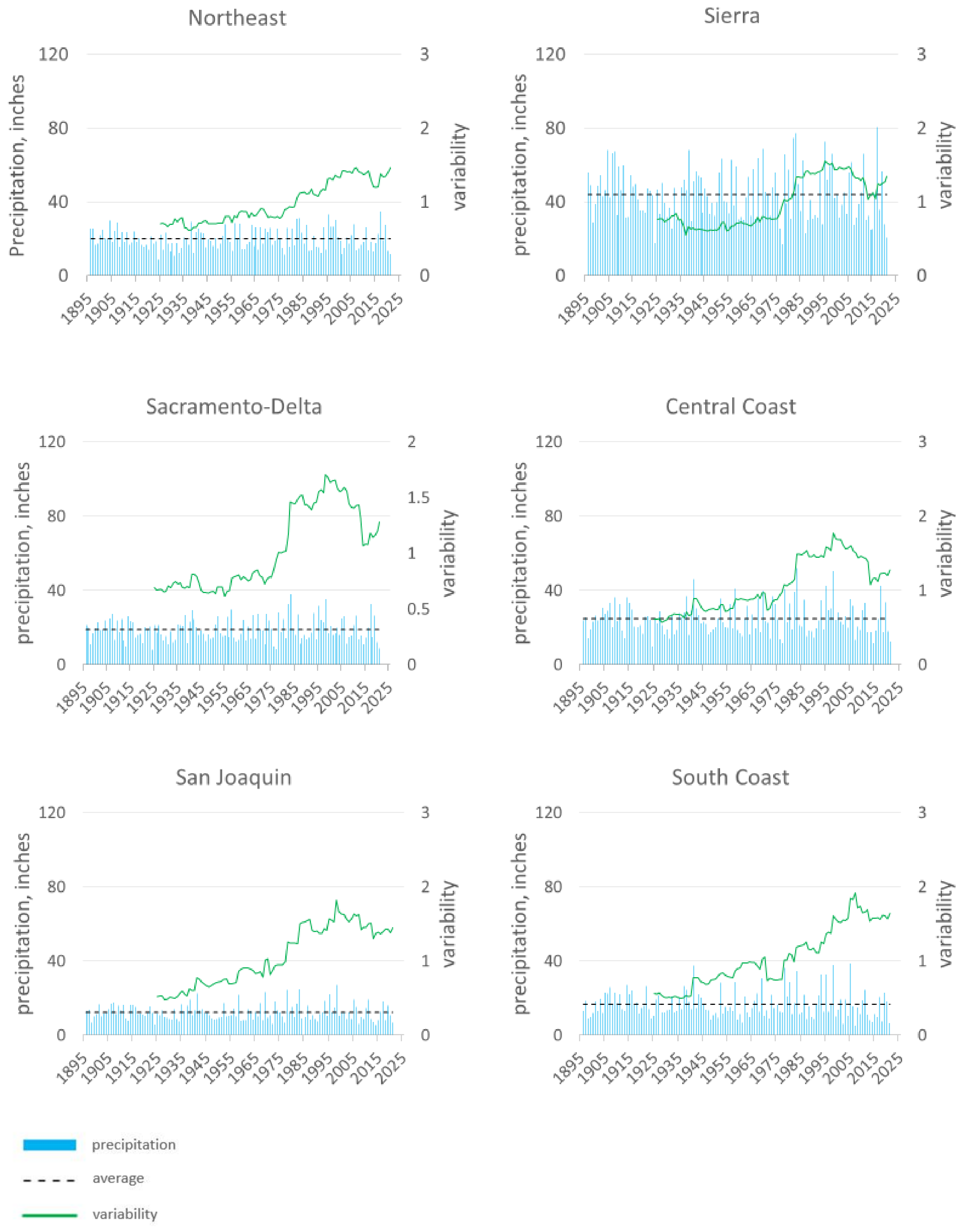




| Region | Average precipitation (inches) |
|---|---|
| A. North Coast | 67.9 |
| B. North Central | 49.0 |
| C. Northeast | 20.5 |
| D. Sierra | 44.9 |
| E. Sacramento-Delta | 20.3 |
| F. Central Coast | 26.4 |
| G. San Joaquin Valley | 12.9 |
| H. South Coast | 17.2 |
| I. South Interior | 19.8 |
| J. Mojave Desert | 7.0 |
| K. Sonoran Desert | 4.6 |
| **Statewide** | 24.2 |

Source: WRCC, 2021




Northeast
Sierra
Sacramento-Delta
Central Coast
San Joaquin
South Coast
precipitation, inches
variability
0
40
80
120
0
0.5
1
1.5
2
3
1895
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1945
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1965
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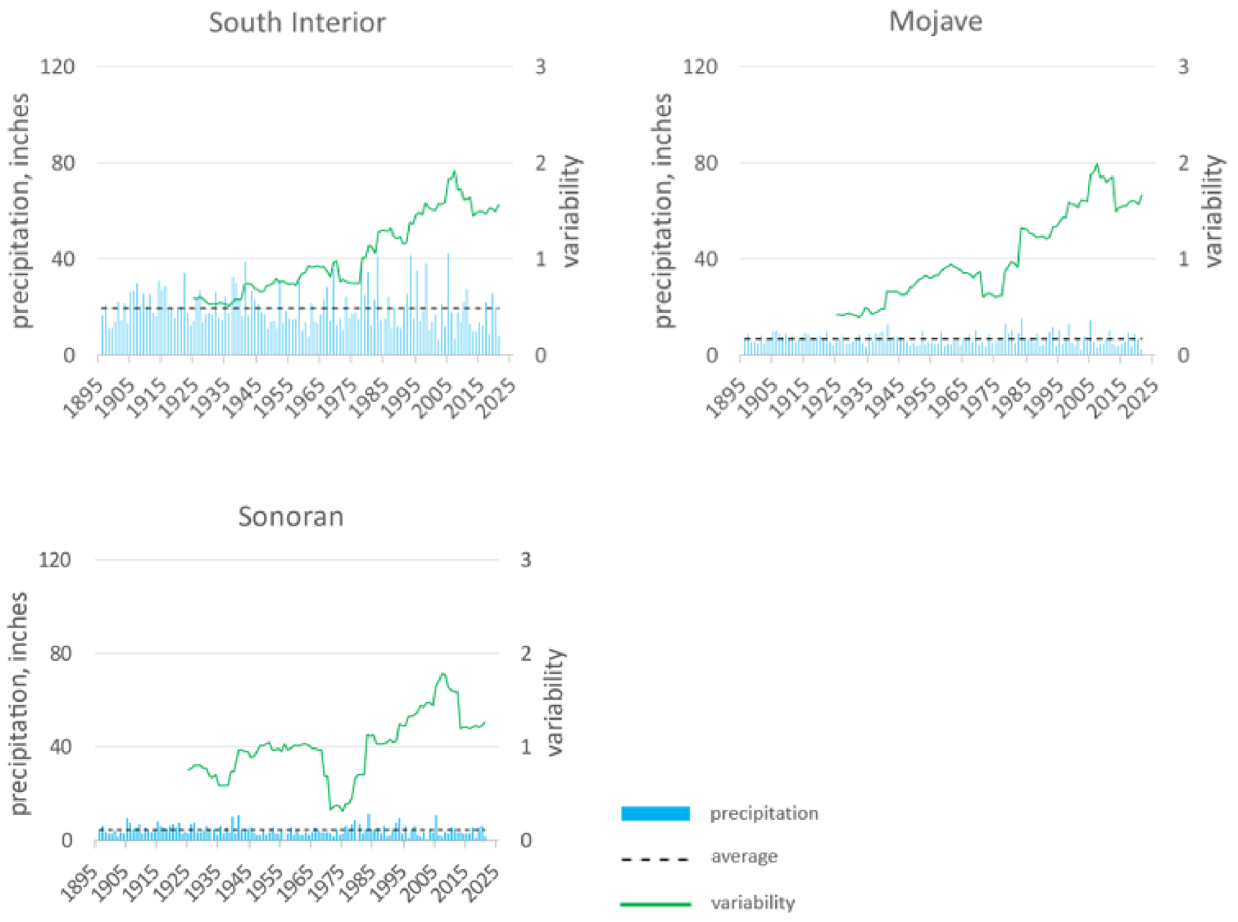
2025
precipitation
average
variability


South Interior
Mojave
Sonoran
precipitation, inches
variability
120
80
40
0
3
2
1
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1895
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1965
1975
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1995
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2015
2025
precipitation
average
variability