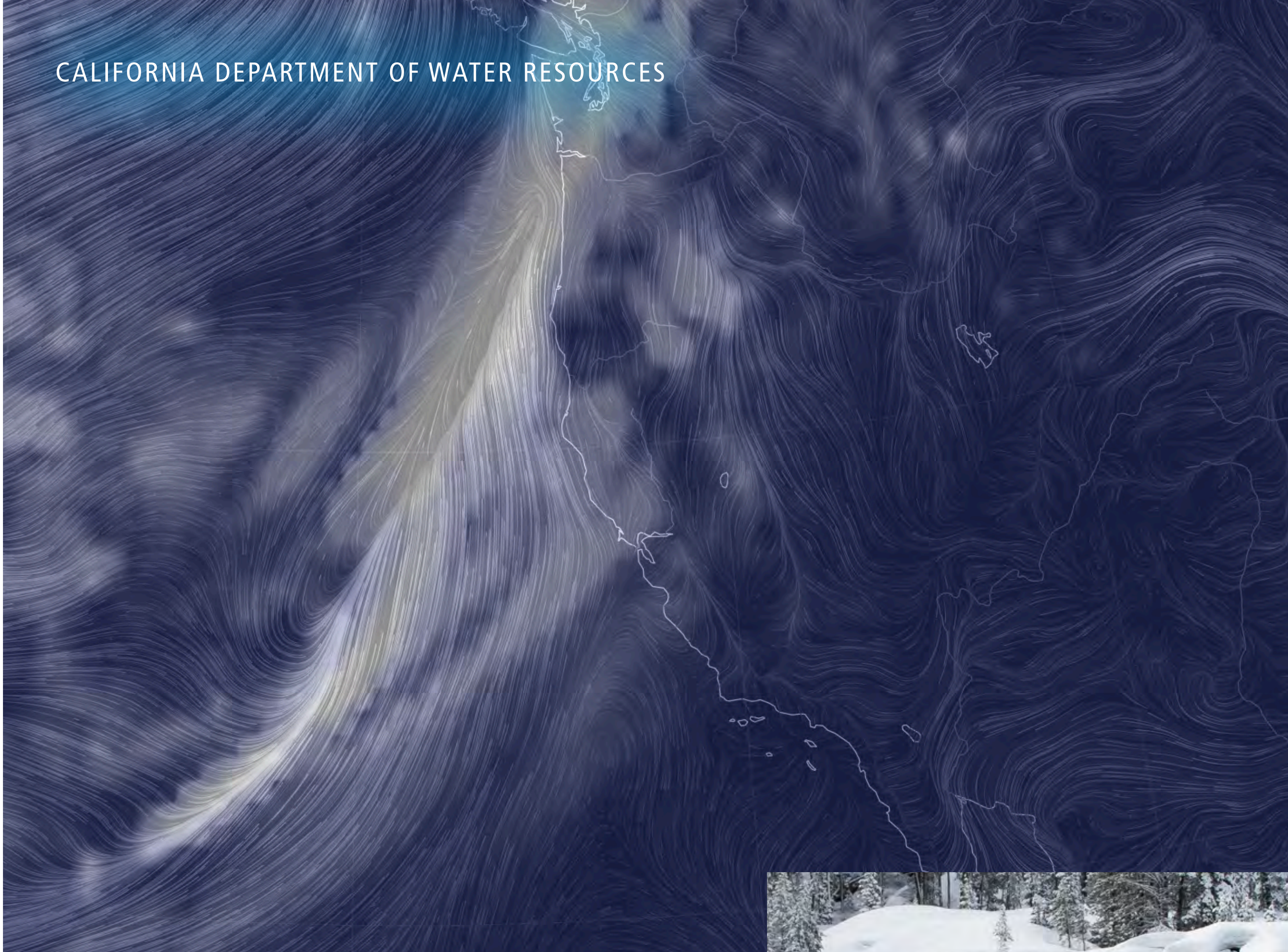
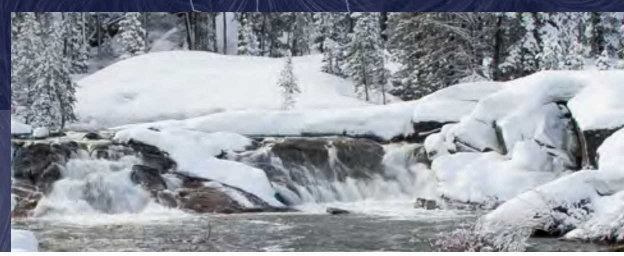
CALIFORNIA DEPARTMENT OF WATER RESOURCES





Hydroclimate Report Water Year 2016

Office of the State Climatologist

Executive Summary

Water year 2016 ended up being different than expected, from a climate standpoint. Water year 2015 marked the 4th year of drought in California, ending with record high temperatures, record low precipitation, and a record low snowpack. Forecasts were for a strong, wet El Nino during water year 2016, with the potential to rival large flood producing events of 1983 and 1998, higher than average sea levels, increased wave action and potential damage along the coast, warmer than average temperatures, and above-average precipitation producing storms. As a result of the cooling of the tropical Pacific sea surface temperatures, and the decay of El Nino, only some of the anticipated impacts were realized, above-average precipitation and greater than average snowpack did not come to pass.

While statewide air temperatures averaged lower than the record setting 2015 water year they were still well above the long-term record, ranking water year 2016 warmest 117 of 121 since 1895. Precipitation was above normal in the Northern Sierra with the majority of precipitation falling in January and March. Precipitation in the Southern Sierra was on average with the long-term trend. Differences in Northern and Southern Sierra precipitation were due to the majority of Atmospheric River landfalls occurring in the north including the two strongest occurring in the first two weeks of March while only two Atmospheric Rivers made landfall south of Monterey Bay.

Statewide snowpack was 15 percent below average and impacted the April-July snowmelt with streamflow on the Sacramento and San Joaquin Rivers by 32 percent and 22 percent below average respectively. Water year type was classified as “Below Normal” for the Sacramento River system and “Dry” for the San Joaquin. Overall, water year 2016 was an improvement to the previous four years of drought conditions with enough precipitation to offset some of the large deficits in water storage reservoirs.

Sea surface temperature anomalies depicting El Niño conditions in the equatorial Pacific on January 16, 2016.

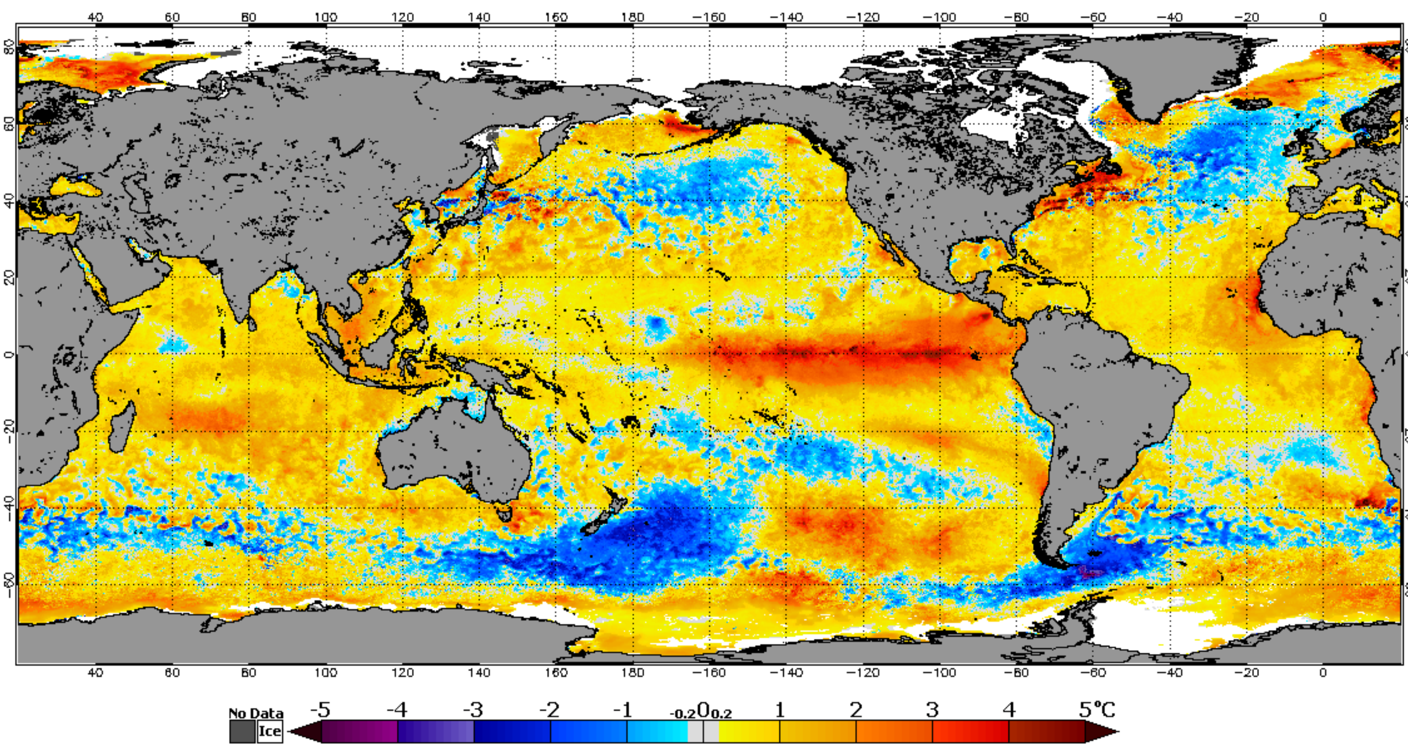


Image: NOAA

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The State Climatologist Office would like to thank Peter Coombe, Elissa Lynn, and Kevin He for their contributions to the annual Hydroclimate Reports.

Front and back cover earth images courtesy of earth.nullschool.net

Introduction

The Hydroclimate Report Water Year 2016 updates the 2015 report with data from Water Year 2016. This report includes key indicators for hydrology and climate in California and is updated annually with the newest available data to track important trends, provide a compilation of indicators, and provide graphical visualization of data trends that are of interest to water managers, the media, State government, and the research community.

As the Hydroclimate Report is a living document reflective of current needs, new data sources, and analysis strategies are updated to provide the best scientific information available. This year's report has added some new indicator metrics that are important indicators of climate trends. These additions include Atmospheric River (AR) climatology and Water Year Type.

Key indicators included in this Hydroclimate Report are listed in Table 1. Hydroclimate is defined in this report as natural hydrologic processes such as streamflow, snowpack, sea level, and precipitation; which are directly and indirectly linked to climate features, such as temperature trends and the nature of annual storms that bring precipitation, providing a primary source of freshwater.

The hydrology and climate of California impact the California Department of Water Resources' (DWR) mission to manage the water resources of California in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments. DWR has a long history of tracking variables that may be of use in assessing climate change impacts on water resources.

With the concern about climate change and hydrologic change indicated by modeling simulations and measured data, DWR recognizes the need to plan for the future and to track continuing data trends. Indications of an uncertain climate future means the State will have to plan, manage, and adapt differently than in the past. Going forward, additional new data or analysis methods may result in additional indicator metrics warranting inclusion in future reports. By tracking change through a collection of indicators on an annual basis, it is hoped that transitions of important thresholds can be better anticipated, enabling the continued refinement of adaptation strategies.

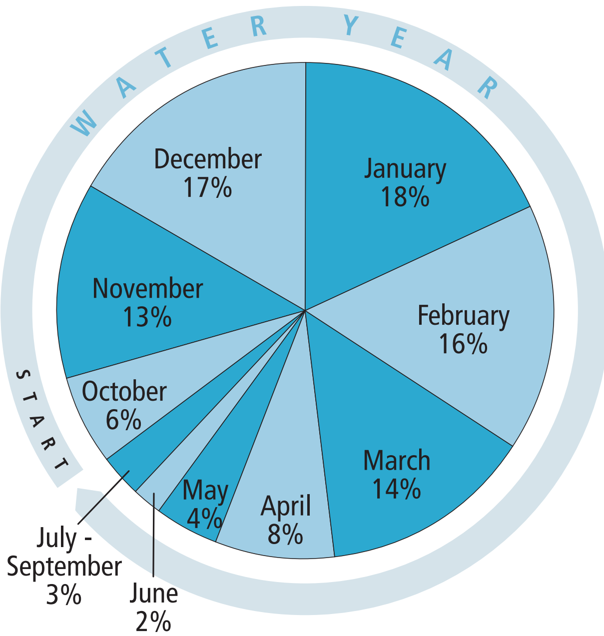
Key Hydroclimate Indicators

Indicators	Spatial Resolution	Temporal Resolution	Period of Record	Data Source
Temperature (Air)	WRCC Climate Regions	Monthly Mean	1895-present	WRCC
Temperature (Air)	NOAA Climate Divisions	Annual Calendar Year	1895-present	NOAA
Precipitation	WRCC Climate Regions	Monthly	1895-present	WRCC
Precipitation	Northern Sierra 8-Station	Annual Cumulative	1921-present	DWR
Precipitation	San Joaquin 5-Station	Annual Cumulative	1913-present	DWR
Atmospheric Rivers	Statewide	Annual Cumulative	2016-present	Scripps
Water Year Type / Streamflow (Unimpaired)	Sacramento River Basin	April-July	1906-present	DWR
Water Year Type / Streamflow (Unimpaired)	San Joaquin River Basin	April-July	1901-present	DWR
Snowpack (Snow Water Equivalent)	Statewide	April 1st	1950-present	Cooperative Snow Survey
Snowpack (Snow Water Equivalent)	Northern Sierra	April 1st	1950-present	Cooperative Snow Survey
Snowpack (Snow Water Equivalent)	Southern Sierra	April 1st	1950-present	Cooperative Snow Survey
Rain/Snow (Percent As Rain)	Selected Sierra Watersheds	Annual Cumulative	1949-present	DWR/WRCC
Sea Level	Crescent City Tide Gauge	Monthly Mean	1933-present	NOAA
Sea Level	San Francisco Tide Gauge	Monthly Mean	1855-present	NOAA
Sea Level	La Jolla Tide Gauge	Monthly Mean	1924-present	NOAA

What Is A Water Year?

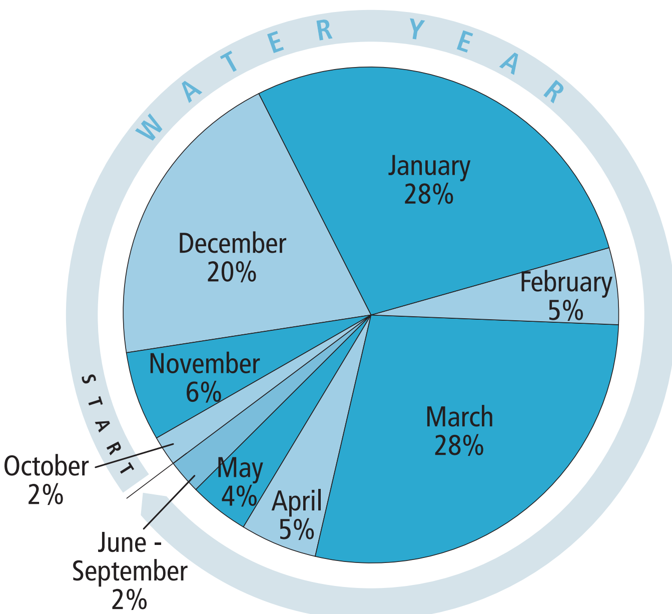
Northern Sierra 8-Station Precipitation Index **(see map page 11 for locations)**

Long Term Water Year Average by Month



The chart above depicts typical precipitation by month and percent of total that California receives throughout each water year. Precipitation generally arrives at the start of the water year in October and continues to increase through the winter months. The months of December, January, and February provide half of our expected annual precipitation. This is also the main development period of California's snowpack.

Water Year 2016 by Month



This chart represents monthly precipitation as percent of the total 2016 water year precipitation.

Hydrologic data such as precipitation and streamflow data are key indicators for the Hydroclimate Report. These data are typically represented as being within the water year. A water year (also discharge year or flow year) is a term commonly used in hydrology to describe a time period of 12 months during which precipitation totals are measured. Its beginning differs from the calendar year because precipitation in California starts to arrive at the start of the wet season in October and continues to the end of the dry season the following September. On a calendar year time scale, the October to December precipitation would not be accounted for, including snowpack that doesn't melt and run off until the following spring and summer. DWR defines a water year in California to include the period from Oct 1 to Sept 30. The 2016 water year covers the period from October 1, 2015 to September 30, 2016.

A comparison of the pie charts on the left between the long term average and water year 2016, shows that in 2016 the highest percentage of the total water year precipitation occurred in December, January, and March. On average, the month of February typically accounts for 16 percent of the annual precipitation; however, in 2016 February was lower than the long term average at only 5 percent. The water year ended with an exceptionally dry period in the Northern Sierra 8-Station region (see map, page 11) with no precipitation being recorded for the months of July, August, and September. This was the first time in the record since 1921 that the 8-Station index received no measurable precipitation for those three months which usually account for 3 percent of the annual precipitation.

California Hydroclimate Water Year 2016 “At A Glance”

Sea level (100 year trend)

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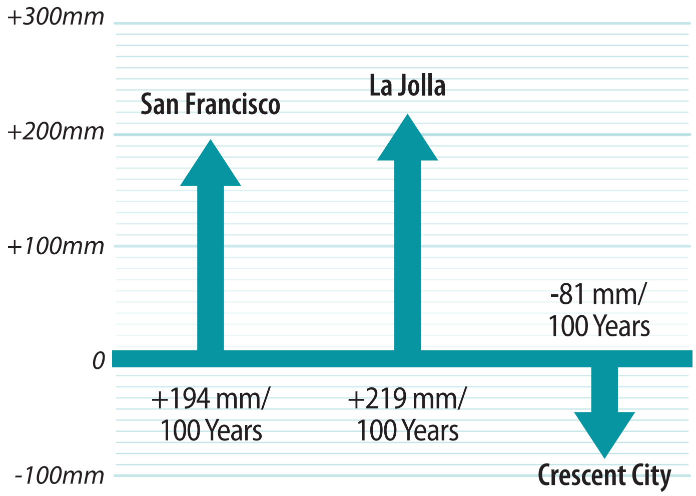

Temperature (Statewide)*

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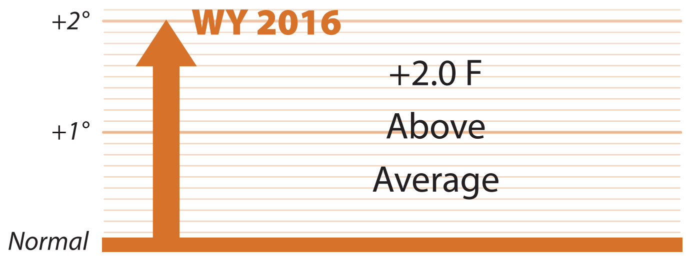

*Normal average air temperature represents 1949-2005 base period.

Precipitation (Northern Sierra)*

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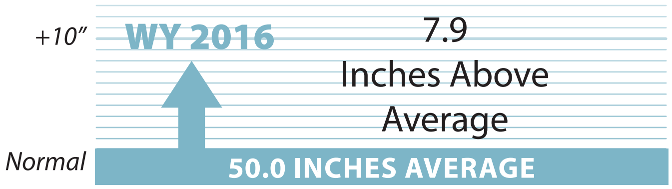

*Normal average precipitation represents 1961-2010 base period.

Precipitation (Southern Sierra)*

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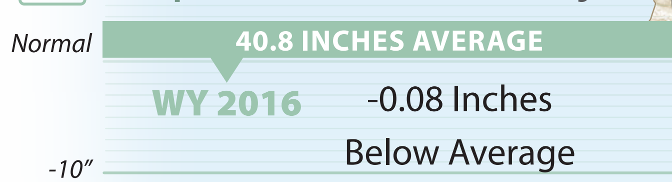


*Normal average precipitation represents 1961-2010 base period.

Streamflow, April-July (Sacramento River)* *Page 20*

*Normal average streamflow represents 1966-2015 base period.

Snowpack (Statewide)* *Page 14*

*Normal average snowpack represents 1961-2010 base period.

Streamflow, April-July (San Joaquin River)* *Page 20*

*Normal average streamflow represents 1966-2015 base period.

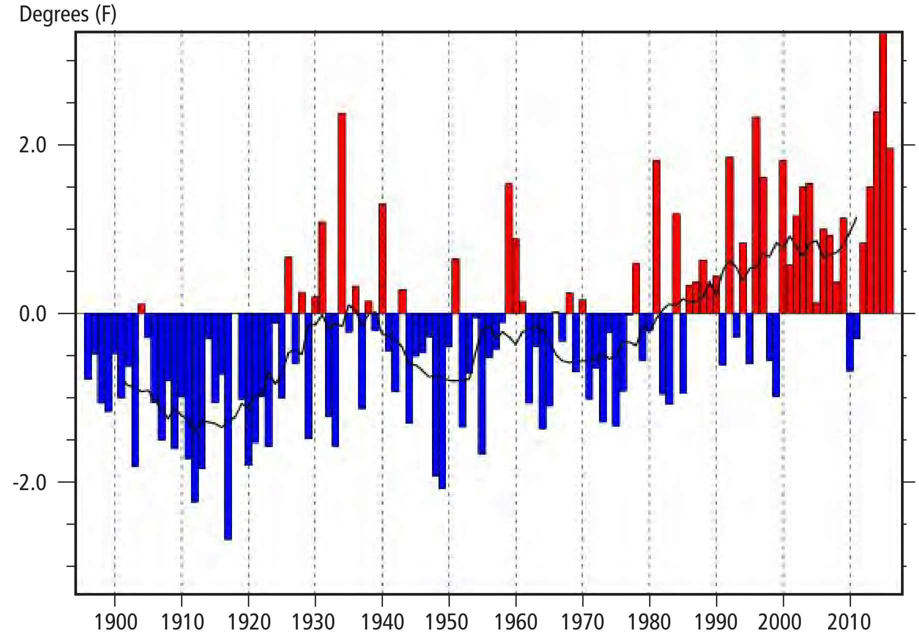
Annual Air Temperatures

According to the Intergovernmental Panel on Climate Change (IPCC) the warming of the climate system is unequivocal. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The atmosphere and ocean have warmed, and each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere (IPCC, 2014).

California's temperature record reflects global temperature trends. According to an ongoing temperature analysis conducted by scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased by about 1.4 °F since 1880, and two-thirds of the warming has occurred since 1975 (Hansen et al., 2010). According to the Western Region Climate Center (WRCC), California has experienced an increase of (1.3 to 2.2 °F) in mean temperature in the past century. Both minimum and maximum annual temperatures have increased, but the minimum temperatures (+1.8 to 2.7 °F) have increased more than maximums (+0.7 to 1.9 °F) (WRCC, 2017).

Water year 2016 temperature measurements using WRCC and National Oceanic and Atmospheric Administration (NOAA) datasets demonstrate a continuing warming trend. Statewide average temperatures were ranked at 117 warmest out of 121 years of record dating back to 1895.

California statewide mean temperature departure, October through September



Black line denotes 11-year running mean

Departures from 1949-2005 base period:

Linear trend 1895-present	+1.76 ± 0.48°F/100 yr		
Linear trend 1949-present	+3.00 ± 1.16°F/100 yr		
Linear trend 1975-present	+4.25 ± 2.60°F/100 yr		
Warmest year	59.4°F (+3.3°F in 2015	Mean	56.1°F
Coldest year	53.4°F (-2.7°F) in 1917	STDEV	0.98°F
October-September 2016	58.0°F (+2.0°F)	Rank	117 of 121

Western Regional Climate Center (WRCC) California Climate Tracker

- Spatial resolution: 11 climate regions
- Temporal resolution: Monthly Mean

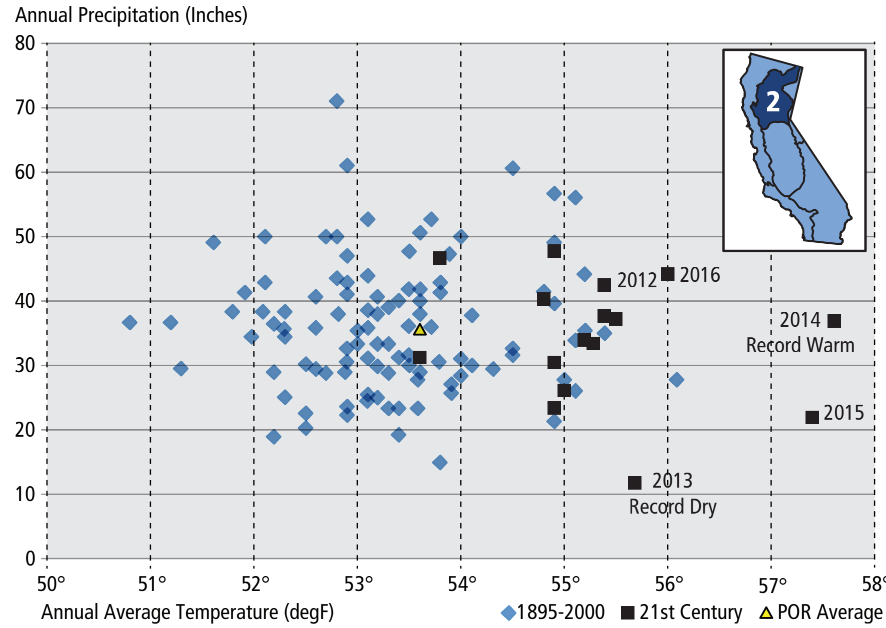
Graph shows "departures" for average (mean) and maximum temperatures each year from a long-term average (the years 1949 to 2005) i.e., the difference between each year's value and the long-term average.

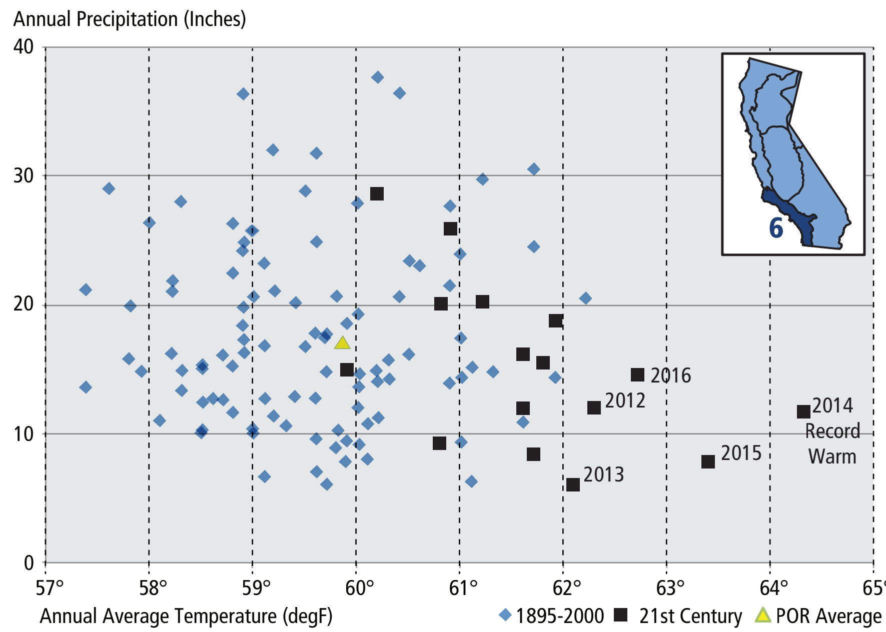
The NOAA Climate Divisional Dataset is a long-term temporally and spatially complete dataset used to generate historical climate analyses (1895-2016) for the contiguous United States. This data set is based on a calendar year instead of the hydrologic water year. There are 344 climate divisions in the US and this report's focus is on two climate divisions within California: Climate Division 2 (Sacramento Drainage) and Climate Division 6 (South Coast Drainage). For each climate division, monthly station temperature and precipitation values are computed from daily observations. Plots of annual precipitation versus annual average temperature are shown, using the annual average values from 1895-2016.

Within Climate Division 2 (Sacramento Drainage), the long-term record depicts a dramatic shift in annual average temperature. The data points from the 21st century are shown as boxes indicating an overall shift in climate compared to the historical record. The past three years are depicted as outliers, being some of the warmest and driest years on record.

Data from Climate Division 6 (South Coast Drainage) depicts even more annual precipitation variation from 5 to 40 inches per calendar year. The past 15 years since the turn of the century are also extremely warm and dry, indicating a change in climate. The past three years are depicted as being some of the warmest and driest years on record, with the warmest on record occurring in 2015 and second warmest in 2016.

NOAA California Climate Divisions: #2 Sacramento Drainage; #6 South Coast Drainage





The Sacramento and South Coast Drainage Climate Division data plots show 2014 and 2015 as the warmest years on record. 2016 was the fourth warmest on record for the Sacramento Climate Division and third warmest for the South Coast. The combination of warmer temperatures and lower rainfall in the 21st Century are depicted as being outliers on the scatterplot graphs.

NOAA Climate Division Calendar Year Data

- Spatial resolution: NOAA California Climate Divisions
- Temporal resolution: Annual Mean

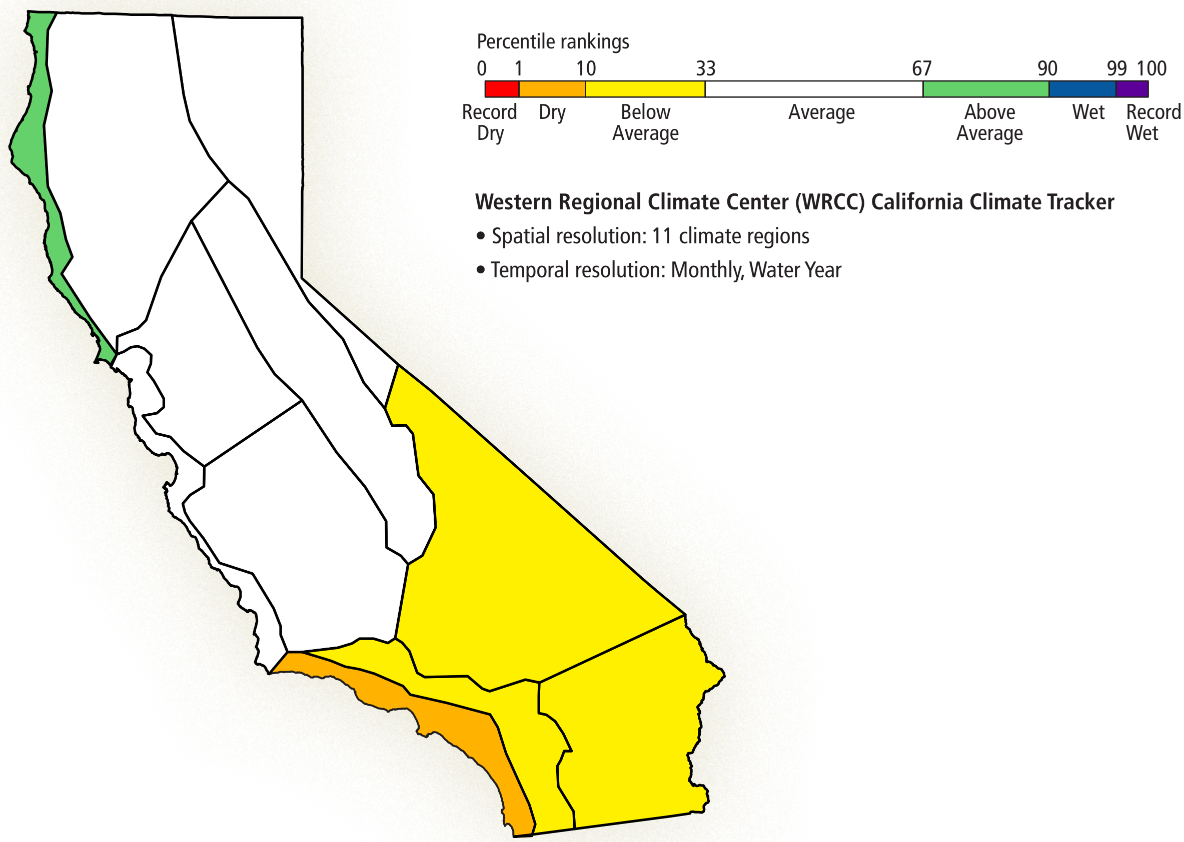
Annual Precipitation

Annual precipitation data from California shows significant year-to-year variation. This inter-annual variability makes trend analysis difficult for this indicator. An analysis of precipitation records since the 1890's shows no statistically significant trend in precipitation throughout California. Although the overall precipitation trend is generally flat over the past 120 years, the precipitation record indicates significant decadal variability giving rise to dry and wet periods. A decadal fluctuation signal has become apparent in northern California where winter precipitation varies with a period of 14 to 15 years. This decadal signal has increased in intensity over the twentieth century resulting in more distinct dry and wet periods (Ault and St. George 2010). There is no known physical process driving this observed precipitation variability and remains an area for future research.

Water Year 2016 Precipitation

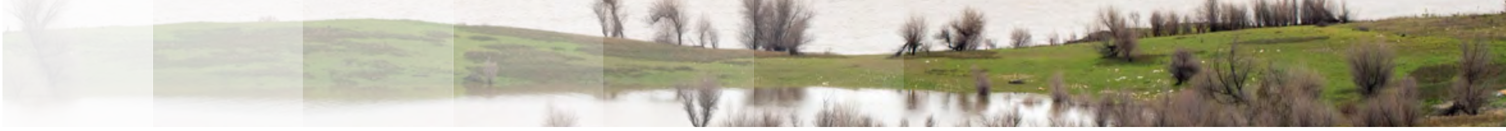
Statewide precipitation trends were analyzed by the WRCC using a data set that includes precipitation values across California. A total of 195 stations across the state are included in this analysis. Cooperative Observer Network (COOP), station data along with the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database are considered in this analysis dating back to January of 1895. PRISM analyses depict an average precipitation water year in 2016 for much of the Central Valley and northeastern part of the State. The southeast experienced below average precipitation, while the Northwest coast was the only region with above average precipitation.

California Climate Regions Precipitation Rankings, Water Year 2016



Western Regional Climate Center (WRCC) California Climate Tracker

- Spatial resolution: 11 climate regions
- Temporal resolution: Monthly, Water Year

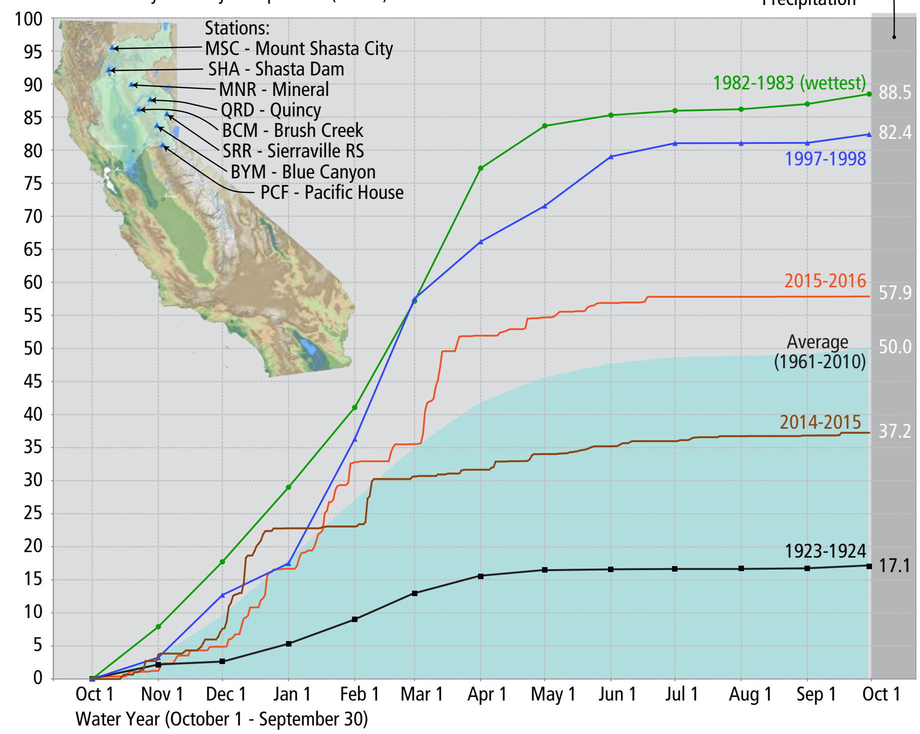


DWR Aggregate Precipitation Station Indices

Regional precipitation trends are tracked by DWR at key locations critical to water supply in the state.

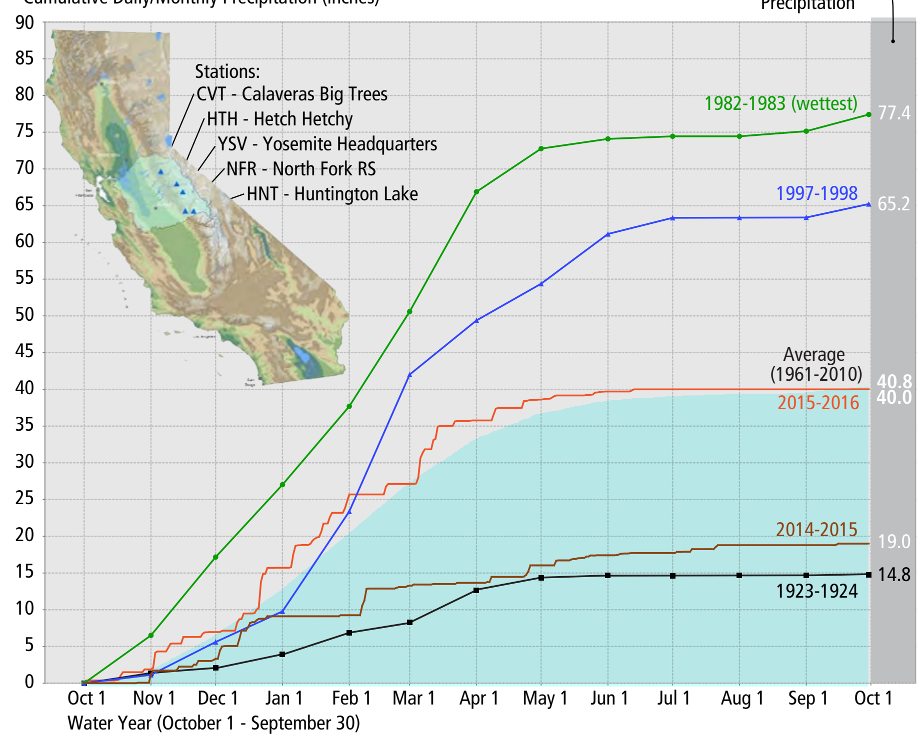
These precipitation station indices are located in the Northern and Southern Sierra and correspond well to the water year type on the Sacramento and San Joaquin River systems.

Northern Sierra Precipitation: 8-Station Index
Cumulative Daily/Monthly Precipitation (inches)



For water year 2016, the Northern Sierra Precipitation 8-Station Index shows total water year precipitation at 57.9 inches, higher than the long-term average of 50.0 inches. Accumulated precipitation in March played a role in bringing the index to above the average, and helped to replenish much needed water, especially for reservoirs in Northern California.

San Joaquin Precipitation: 5-Station Index
Cumulative Daily/Monthly Precipitation (inches)



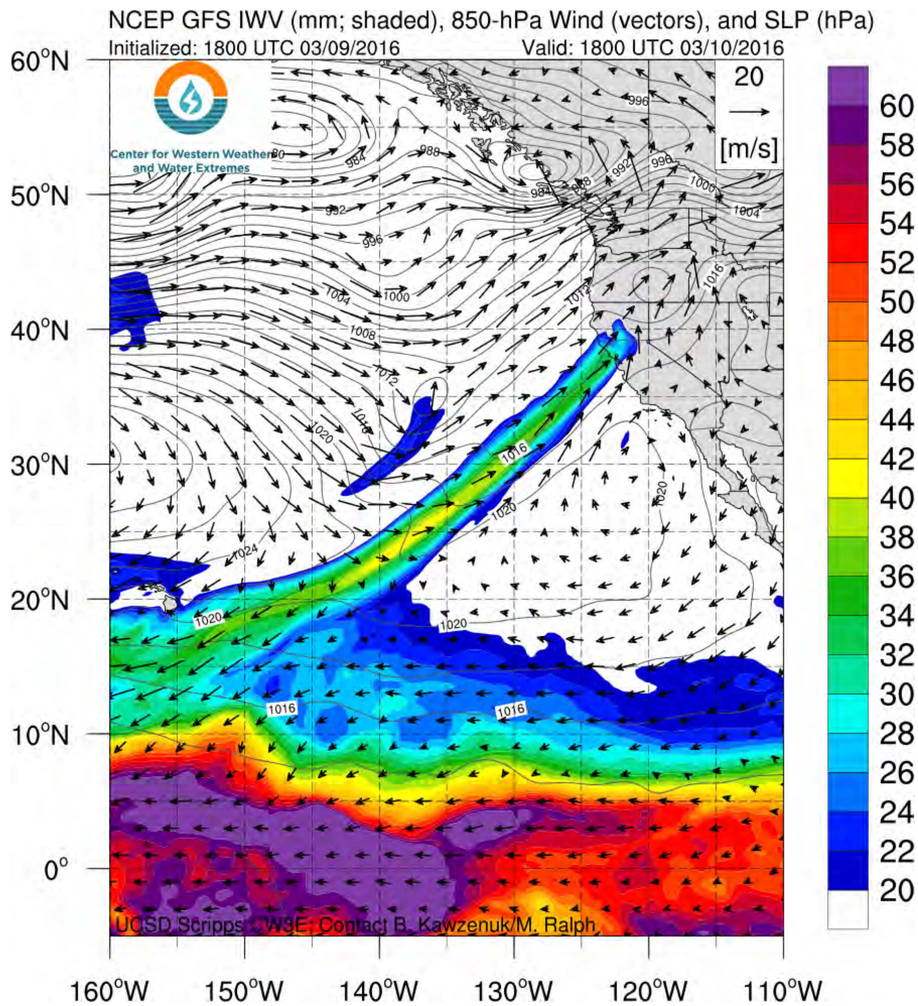
The San Joaquin Precipitation 5-Station Index, which is representative of the Southern Sierra, received less precipitation than the Northern Sierra. Water year 2016 had a total water year precipitation of 40.0 inches; almost equal to the average of 40.8 inches, significantly above the 19.0 inches that was received in the water year of 2015. These average precipitation values did little to relieve the drought and water deficits in Central California.

Atmospheric Rivers

A limited number of precipitation producing storms move over California every water year. Attention has recently turned to storms associated with atmospheric rivers (ARs) due to their impact on water supply and flooding. ARs are long (approximately 1000 miles), narrow (less than 100 miles wide) bands of intense water vapor concentrated in the lower atmosphere that can be entrained into the leading edge of winter storms that make landfall over California and the west coast of the United States. Typically, only a few strong AR storms impact California during the winter months, and on average, AR storms provide 30 to 50 percent of California's annual precipitation and 40 percent of Sierra snowpack. With warmer air, and changing ocean conditions, AR episodes have the potential to increase in duration and intensity yielding increases in precipitation from the largest storms (Dettinger, 2016).

Recent research into the characteristics of ARs at the Center for Western Weather and Water Extremes (CW3E) has yielded a categorization, the Ralph/CW3E AR Strength Scale, based on the amount of integrated vapor transport (IVT). IVT is a combination of the amount of water vapor in the atmosphere above a given point and the horizontal winds that move the water vapor. IVT has shown early promise for AR characterization as well as predictability in weather forecast models (Lavers et al., 2016). The Ralph/CW3E AR Strength Scale includes four categories: weak, moderate, strong, and extreme. The categories are evenly divided in increments of 250 flux units of IVT

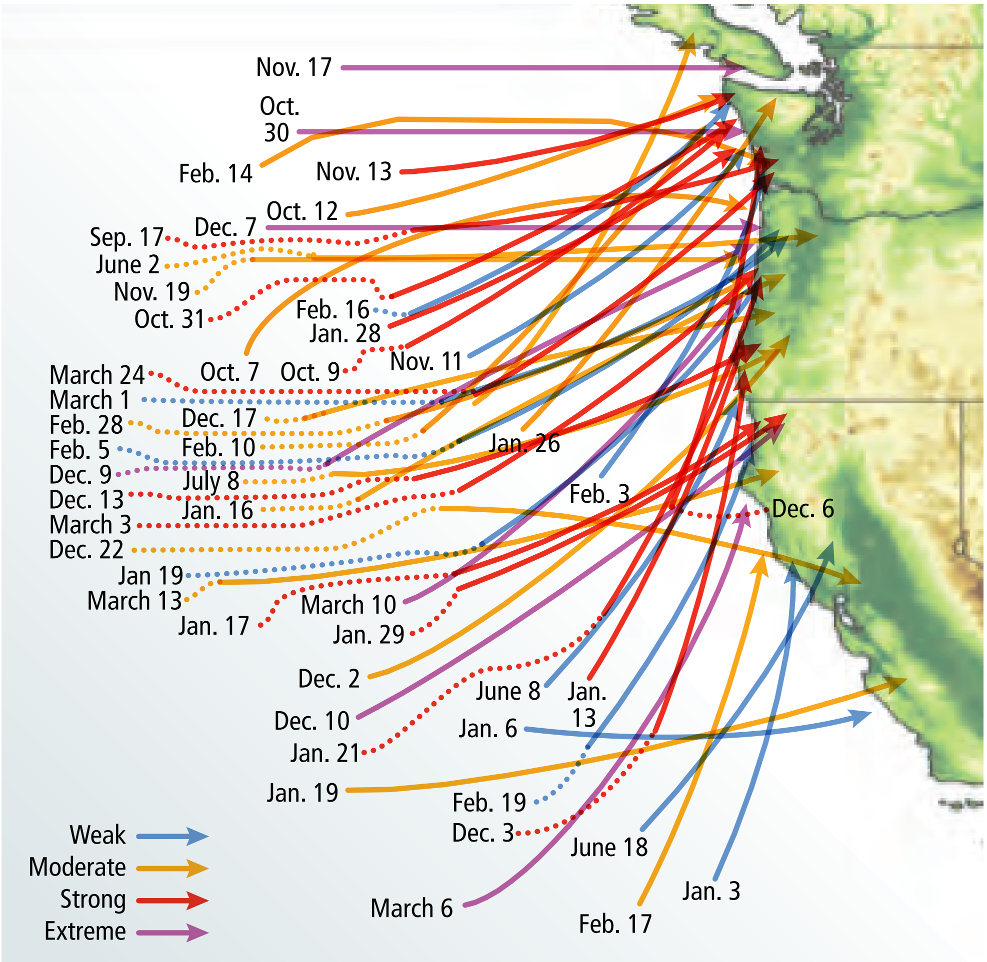
Depiction of atmospheric river making landfall over northern California on March 10th 2016. Image: Center for Western Weather and Water Extremes



with extreme being stronger than 1000 flux units.

The figure (top left, page 13) shows a characterization of the 49 ARs that made landfall along the U.S. West Coast in water year 2016 as well as the location of maximum intensity of the AR when it hit the coast. Most of the landfalls were north of California. While most of the ARs were oriented from the southwest (as shown by the arrows on the graphic), a few were from the west and a couple out of the northwest. Only 2 ARs made landfall south of Monterey Bay and none below the California Bight which is notably different from expectations associated with the strong El Niño conditions that were in place in the tropical Pacific. Of the 7 extreme ARs, only 2 made landfall in California with the most southerly landfall of

Distribution of landfalling Atmospheric Rivers on the U.S. West Coast during water year 2016.



Ralph/CW3E AR Strength Scale

- Weak: IVT=250–500 kg m^{-1} s^{-1}
- Moderate: IVT=500–750 kg m^{-1} s^{-1}
- Strong: IVT=750–1000 kg m^{-1} s^{-1}
- Extreme: IVT>1000 kg m^{-1} s^{-1}

an extreme AR happening on March 6. Of the top 10 ARs that impacted the northern Sierra 8-Station Index, 3 occurred in the first two weeks of March including the strongest, second strongest and fifth strongest. These 3 ARs clustered together generated 25% of the seasonal precipitation accumulation on the 8-Station Index (see page 11), 20% of the northern region snow water equivalent, and produced notable runoff into Oroville and Shasta reservoirs greatly offsetting the deficits accrued by the drought. In the following years, more information on ARs will be included in the hydroclimate report including information on AR climatology as it is developed.

Atmospheric River strength by month and 2016 water year totals.

AR Strength	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	WY Total
Weak	0	1	0	3	4	1	0	0	2	0	0	0	11
Moderate	2	2	3	3	4	1	0	0	0	1	0	0	16
Strong	2	1	3	5	0	2	0	0	1	0	0	1	15
Extreme	1	1	3	0	0	2	0	0	0	0	0	0	7
Total	5	5	9	11	8	6	0	0	3	1	0	1	49

Snowpack

Snowpack is an essential water supply feature in California and historically provides approximately 15 million acre-feet of water accounting for one-third of the State's annual water supply. Numerous studies have reported declines in Western US snowpack in recent years and have been attributed to warming temperatures associated with climate change.

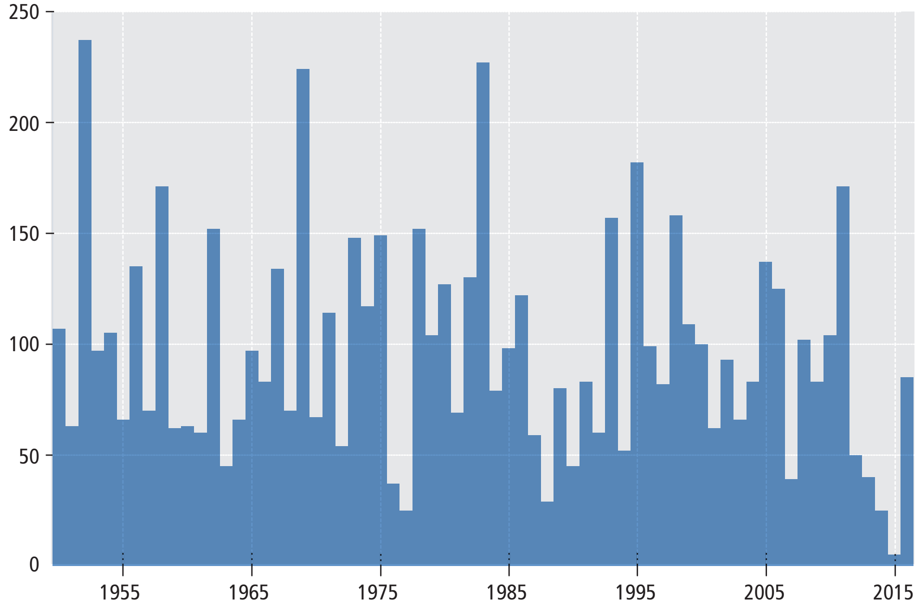
The California Cooperative Snow Surveys program has been actively collecting data since the 1930's and presently has approximately 130 snow sensor sites from Northern and Southern Sierra locations. A consistent long-term historical record lends this data set to making a good indicator in of snowpack in California.

The California Environmental Protection Agency (EPA) Indicators of Climate Change in California (2013) report used a subset of the snowpack monitoring locations; 13 stations from Northern Sierra and 13 stations from Southern Sierra which were identified by Scripps Institution of Oceanography researchers for their completeness and to represent their respective regions.

The Hydroclimate Report will continue to track statewide snowpack trends and the Northern and Southern Sierra 13 station indicators with updated graphs each water year. Values presented are the April 1st Snow Water Equivalent (SWE), or snow-water content, as this is historically the date when the maximum snow accumulation has occurred at monitoring locations throughout the Sierra.

Statewide snow water equivalent (April 1)

Percent of average



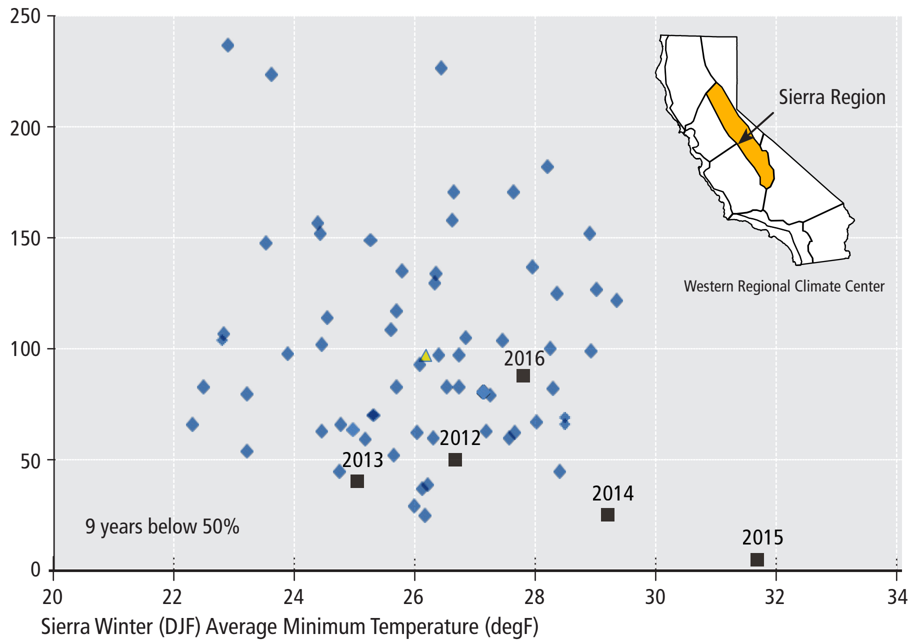
Water year 2016 statewide snowpack water content was 85 percent of the long-term average. This was a considerable improvement compared to the 2015 April 1st snow survey the California Cooperative Snow Surveys Program found water content at only 5 percent of average.

California Cooperative Snow Surveys - Snowpack

- Spatial resolution: Statewide, Northern Sierra, Southern Sierra
- Temporal resolution: Monthly Winter Season, April 1st SWE

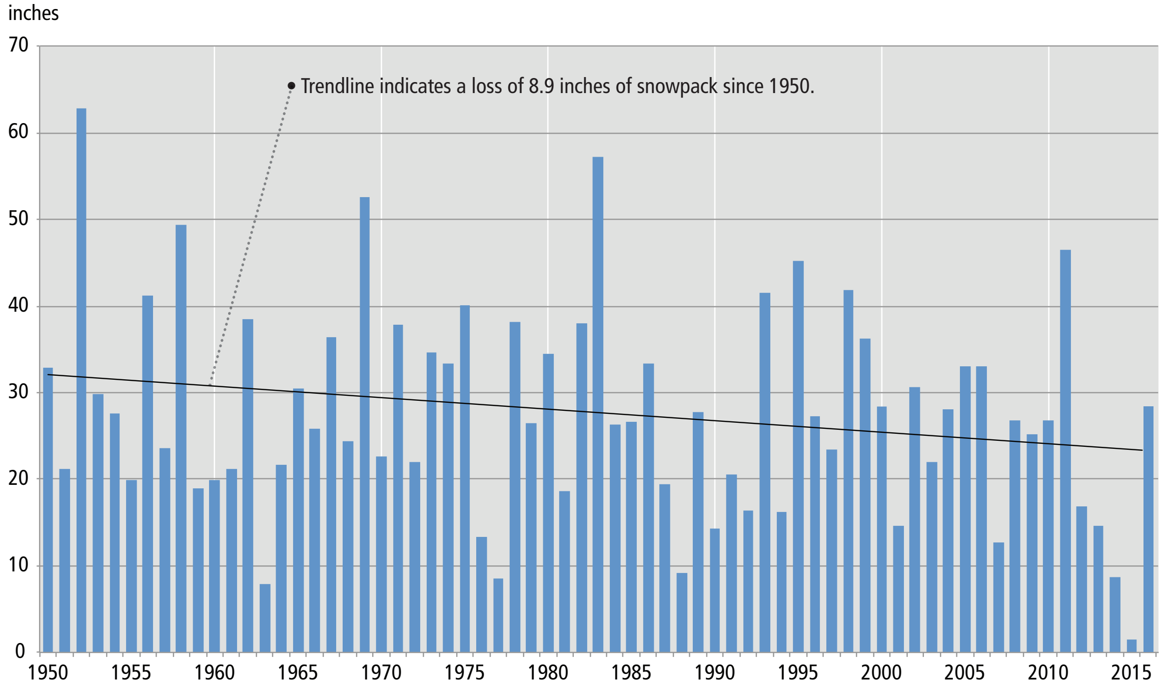
Sierra snowpack vs Winter Temperature, 1950-2015

April 1 Snowpack Percent Above Average - from California Cooperative Snow Surveys

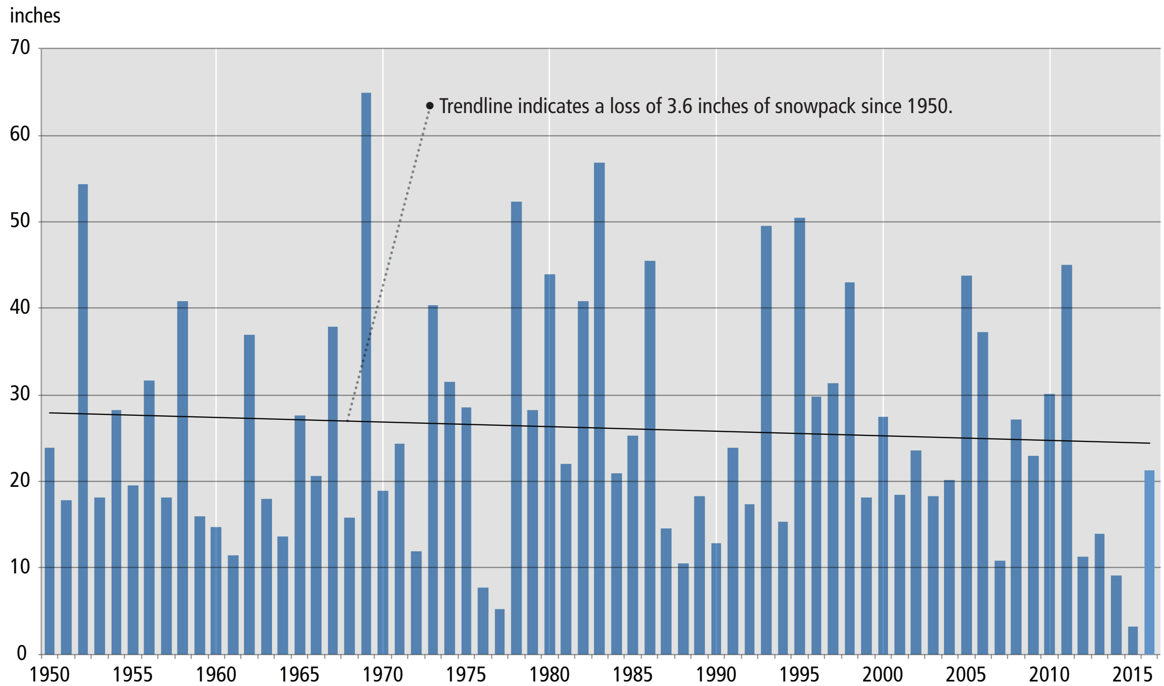


A scatterplot of April 1st snowpack vs. Sierra minimum air temperatures shows the past five years labeled as boxes.

April 1 Snow-Water Content, 13 Northern Sierra Nevada Snow Courses



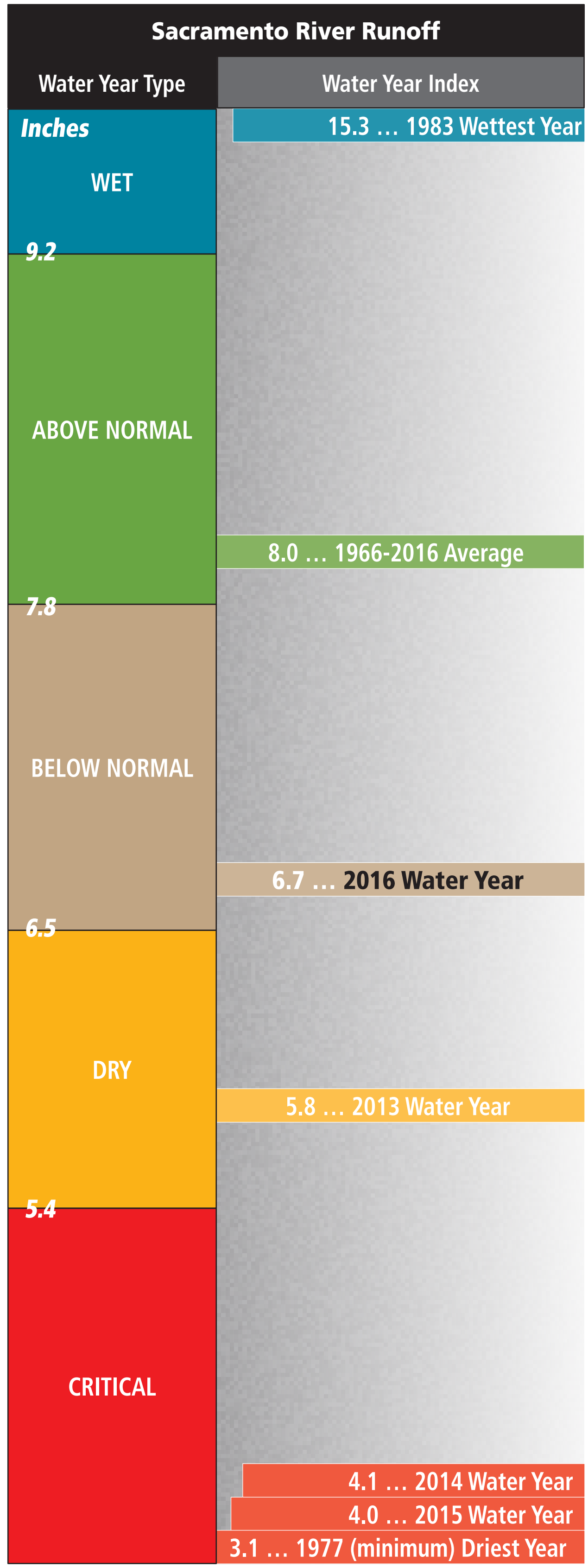
April 1 Snow-Water Content, 13 Southern Sierra Nevada Snow Courses



Water year 2016 shows an improvement compared to the past four years in both the Northern and Southern Sierra 13 station snow courses. While not a record breaking year, both regions came close to matching the long-term average. The lower elevation Northern Sierra 13 station group has a greater downward trend since 1950 as compared to the higher elevation Southern Sierra 13 station group. Up until 2011, Roos and Sahota (2012) had found that snowpack in the Southern Sierra 13 station group had increased, however that trend has reversed in the past 5 years. In the coming years, this trend comparison will need to be watched closely as higher elevations of the Southern Sierra 13 station group are considered to be less affected by rising snow lines.

Water Year Type

California's water supply is defined by geographic and seasonal variability which are influenced by inter-annual climatic variability with year to year changes in precipitation and runoff. Runoff from the Sacramento and San Joaquin River basins provide much of the State's surface water supply and are classified into a water year type using an index system. Each water year, both river basins are classified in to one of five water year types; a "wet" year classification, two "normal" classifications (above and below normal), and two "dry" classifications (dry and critical). This water year classification system provides a means to assess the amount of water available from the basins and can be used as an indicator of long-term water supply trends. These water year type classifications or "indices" were developed by DWR for the State Water Resources Control Board (SWRCB) for the Sacramento and San Joaquin River hydrologic basins as part of SWRCB's Bay-Delta regulatory activities and are important for water planning and management through each water year.

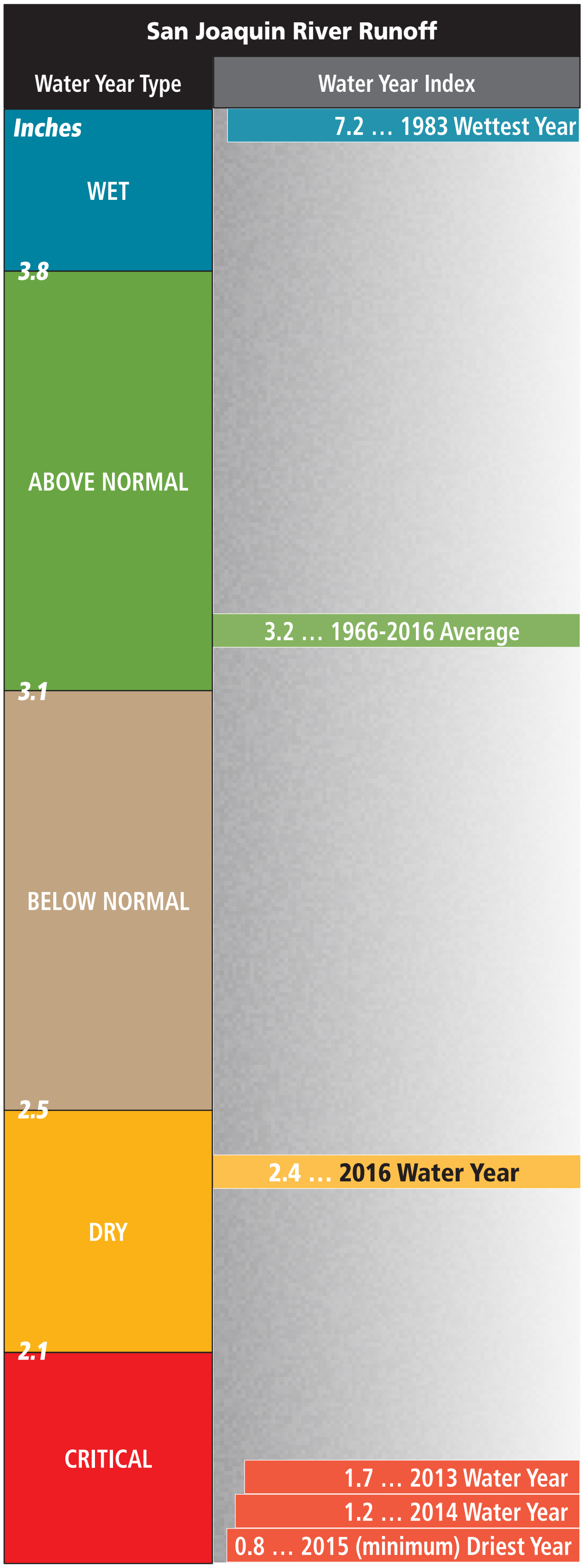


The Sacramento Valley 40-30-30 Index based on flow in million acre feet for water year 2016 was 84 percent of average with an index value of 6.7 classified as a "below normal" water year type.

The water year classification system Sacramento and San Joaquin River basins was designed based on historical hydrology and the assumption of a stationary climate. With climate change and changing hydroclimatic conditions there is debate whether this stationary approach to the water year indices will be adequate to make water management decisions in the future. A recent modelling study by Null and Viers (2013) analyzed the context of climate change with the current water year classification system and found a significant shift in the indices due to warmer air temperatures, earlier snowmelt runoff resulting in changes to streamflow timing. With changing in climatic conditions, a more adaptive approach may be needed for water supply indices for the water year classification system to better represent current climate trends.

For more information on water year type classification, see appendix (pg. 27-28).

The San Joaquin Valley 60-20-20 Index based on flow in million acre feet for water year 2016 was 73 percent of average with an index value of 2.4 classified as a "dry" water year type. This was an improvement over the 2015 water year index value which was 0.8 or 25 percent of average which was the lowest index value on record.

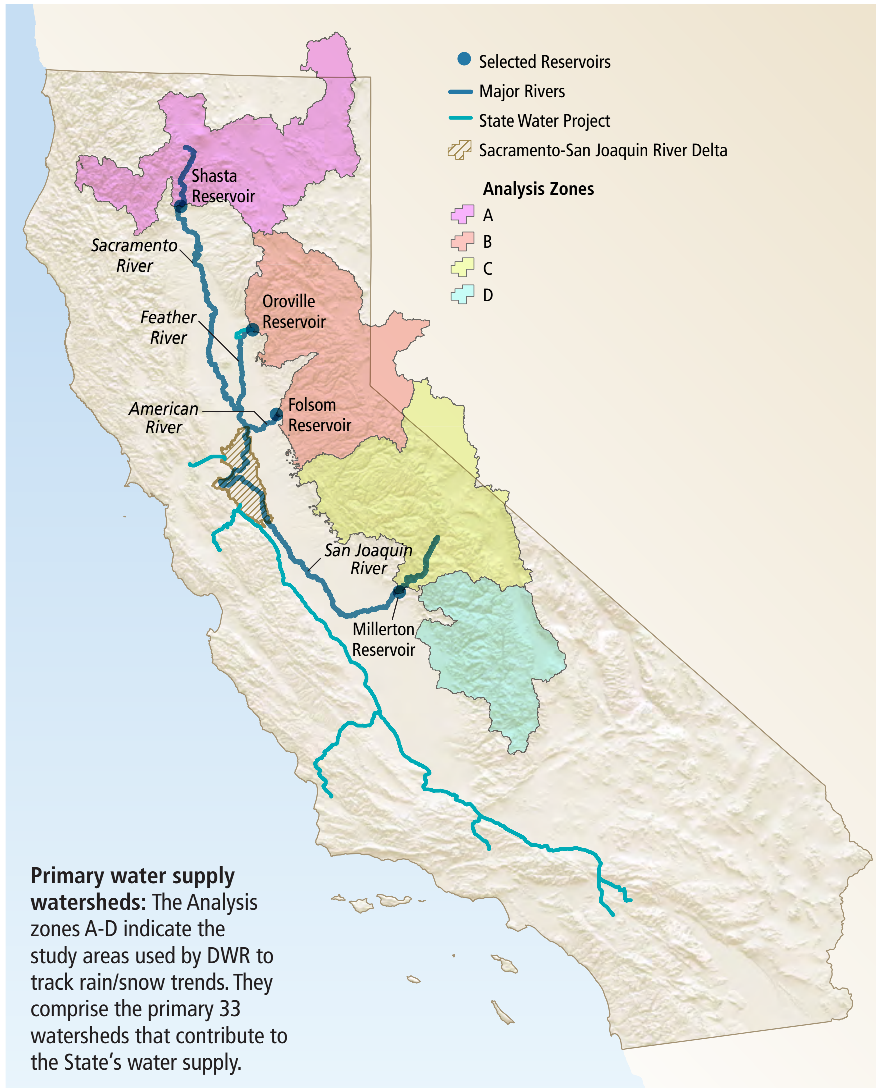


Rain/Snow Trends

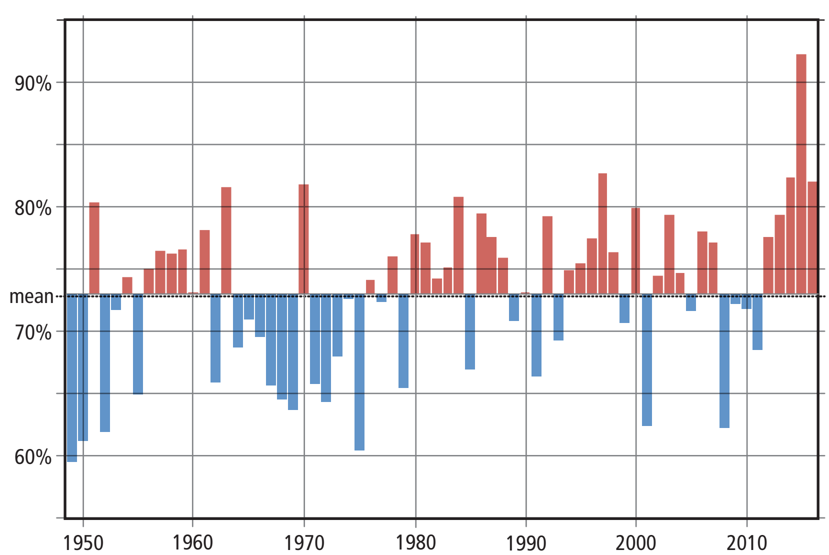
In recent decades, there has been a trend towards a a higher percentage of rain vs. snow in the total precipitation volume. The implication on water management stems from California's reliance on the winter snowpack and its spring ablation to facilitate the winter influx of water into the State, in order to meet high water demand in the warm, dry summers. Federally-driven reservoir operations criteria are built on the historical record of timing of the snowfall accumulation and melting of the seasonal snowpack. A change in the ratio of rain/snow to total precipitation in the winter and spring can have significant impacts on the ability to balance the multiple water management objectives through reservoir operations.

DWR has developed a methodology that uses readily available research data sets to produce gridded estimates of historical rainfall as a fraction of total precipitation for areas comprising the major water-supply watersheds of California (DWR, 2014). Statistically significant increases in the ratio of liquid (rain) to the total precipitation are seen for large areas in the northern part of the State and northern Sierra, the State's primary water supply watersheds (above right). No statistically significant trends were seen for regions in the central and southern portions of the Sierra, which are higher in elevation.

The figure at the bottom of page 18 illustrates the percentage of precipitation falling as rain versus snow during the entire water year for all zones comprising the main water supply watersheds. The data show



Primary water supply watersheds: The Analysis zones A-D indicate the study areas used by DWR to track rain/snow trends. They comprise the primary 33 watersheds that contribute to the State's water supply.

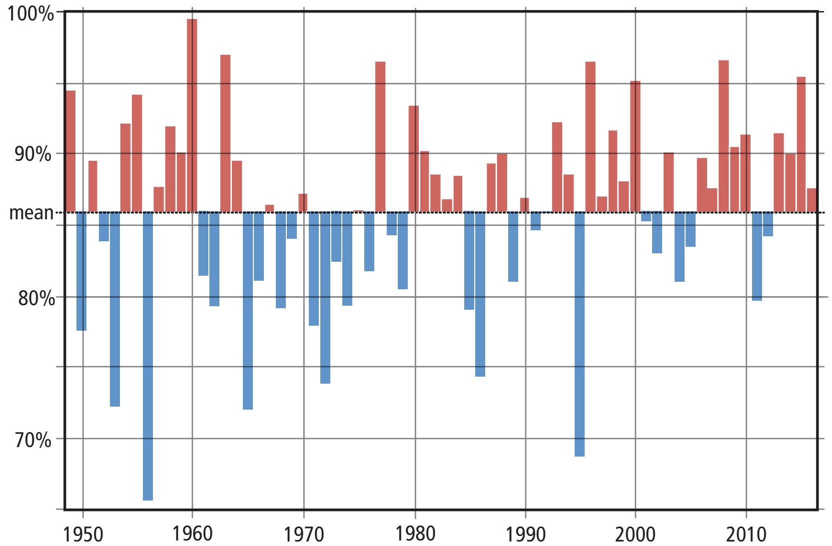


Water Year percentage of rain for the analysis period WY 1949-2016
- Mean for 1st half of record: 71
- Mean for 2nd half of record: 75
- Mean for entire dataset: 73

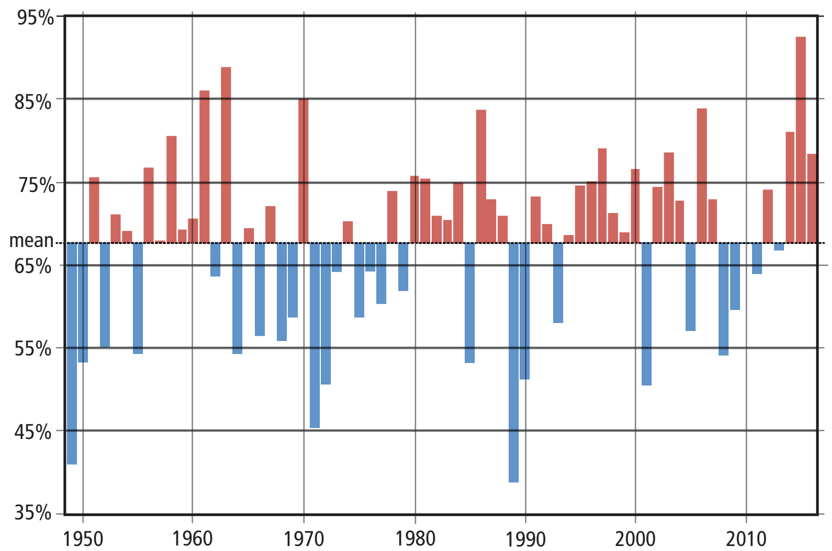
substantial inter-annual variability due to climate signals that occur on annual and decadal scales as variations from the analysis period mean. Years with red bars have a higher percentage of rain than the mean, and years with blue bars have a lower percentage of rain than the mean. For the entire water year, the second half of the record has a 4 percent higher mean percent than the first half. In water year 2016 this indicator shows percentage of precipitation falling as rain was 82 percent, well above the period of record average of 73 percent. A sharp increase in rain percentage is noticeable during the recent drought years. Not only was it dry, but a higher proportion of what fell came down as rain, rather than snow, compared to the earlier part of the record.

The figures to the right break down the trends in rain percentage by season. They show an increase from the first half of the record to the second half; 2 percent higher rain percentage during fall (Sep-Oct-Nov); 3 percent during winter (Dec-Jan-Feb); and 10 percent during spring (Mar-Apr-May).

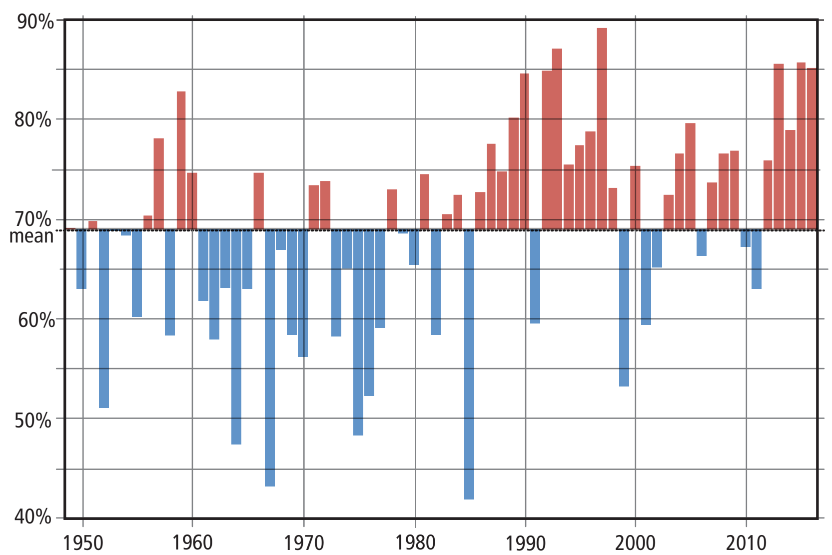
Spring is a critical time in water management as winter storms are winding down and snowmelt is beginning. Reservoir management has used April 1 as a historical mean point of this transition. With a 10 percent rise in rain during the spring in this transition period, it may be more challenging to balance the immediate flood control needs with future water supply requiring more active management of water resource systems. Forecasts during this time period become more important for informing those actions.



Fall (Sep-Oct-Nov) percentage of rain for the analysis period WY 1949-2016
- Mean for 1st half of record: 85
- Mean for 2nd half of record: 87
- Mean for entire dataset: 86



Winter (Dec-Jan-Feb) percentage of rain for the analysis period WY 1949-2016
- Mean for 1st half of record: 66
- Mean for 2nd half of record: 69
- Mean for entire dataset: 68



Spring (Mar-Apr-May) percentage of rain for the analysis period WY 1949-2016
- Mean for 1st half of record: 64
- Mean for 2nd half of record: 74
- Mean for entire dataset: 69

Unimpaired Streamflow: Sacramento and San Joaquin River Systems

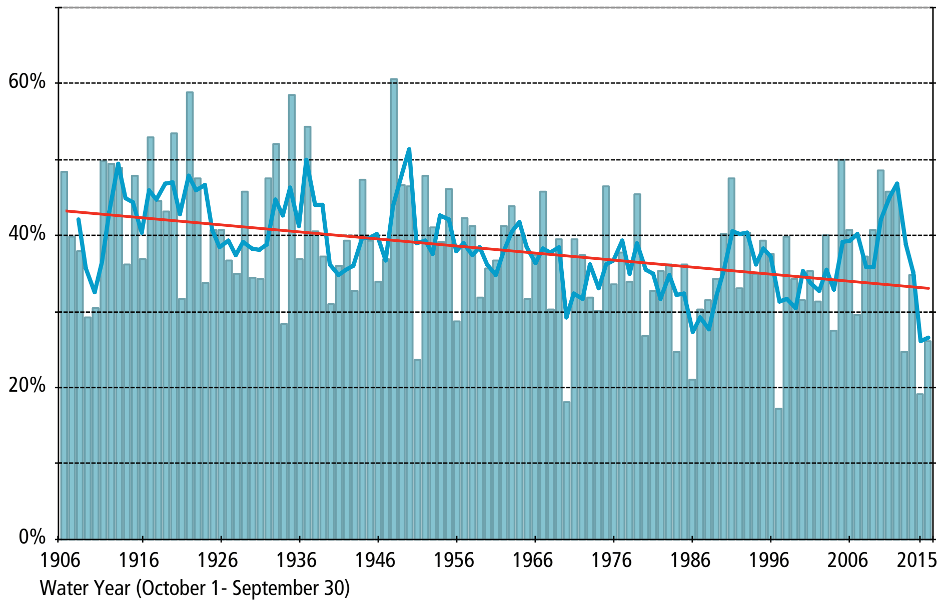
With increasing temperatures and corresponding loss of snowpack, how can a comparison be made representing spring snowmelt? Since the main watersheds in California have been altered by water development projects such as dams and diversions, historical natural hydrology flows would be difficult to compare. To overcome this, natural or "unimpaired" flows are calculated to indicate flow change in each water year from 1906 in the Sacramento River and 1901 in the San Joaquin River systems.

A method to quantify loss of snow pack and corresponding flow during the spring months was developed by DWR Chief Hydrologist Maury Roos in 1987. Instead of comparing seasonal snowmelt amounts, unimpaired flow occurring during the April through July snowmelt season is analyzed. Through this analysis, a distinct trend in flow loss is apparent. Currently, data indicate a 9 percentage point decline per century on the Sacramento and 6 percentage point decline on the San Joaquin River systems.

Following an exceptionally dry water year in 2015 and corresponding lack of snow, in water year 2016 this indicator has shown some improvement for April through July flows. However, in the long term record, the percent of water year runoff during the April to July shows a declining trend.

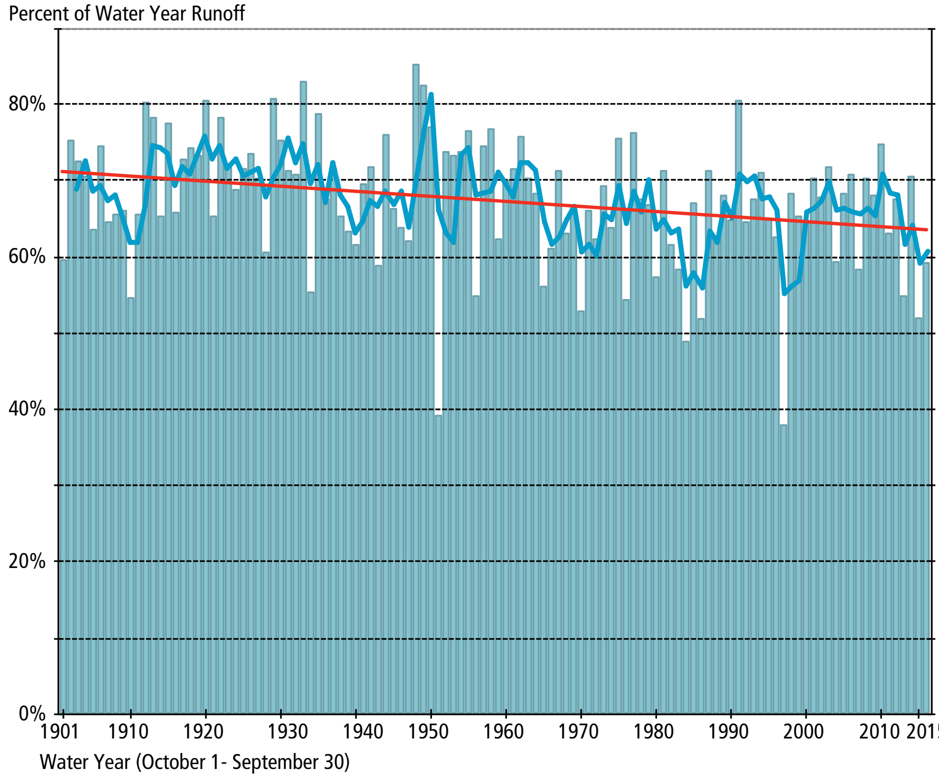
Sacramento River Runoff, April - July Runoff in percent of Water Year Runoff
— Linear Regression (least squares) line showing historical trend — 3-year running average

Percent of Water Year Runoff



San Joaquin River Runoff, April - July Runoff in Percent of Water Year Runoff
— Linear Regression (least squares) line showing historical trend — 3-year running average

Percent of Water Year Runoff

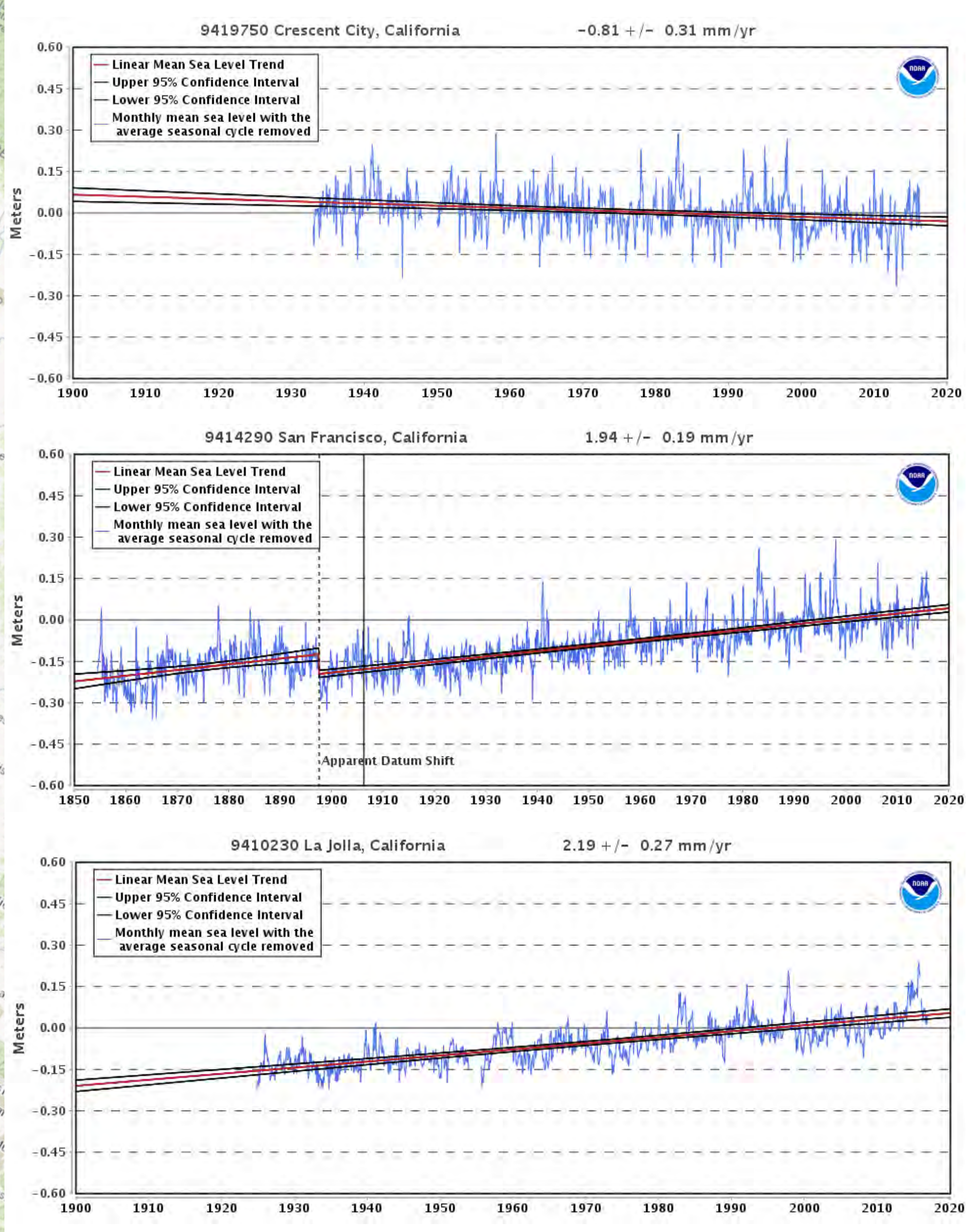


Sea Level

Mean sea level at three key coastal tide gauges are used as an indicator of change over time. During the last century, sea level at the Golden Gate tide gauge in San Francisco has shown a 7 inch increase, similar to global measurements. Sea level at the La Jolla tide gauge in Southern California has increased 8 inches and has decreased by 3 inches in Northern California at the tide gauge at Crescent City.

While the long-term trends over the past century are gradual, there are annual and seasonal differences that are more dramatic, including higher sea levels related to climatic phenomenon such as the El Nino conditions in the Pacific Ocean during water year 2016. A tidal fluctuation that is experienced along the California coast on certain days of the year are referred to as "King Tides". These exceptionally high tides are predictable in nature as they are seasonal and related to Earth's alignment to the pull of gravity from the moon. In November and December of 2015 sea levels in Southern California were up to 6 inches above normal. The exceptionally high King Tides experienced in water year 2016 were influenced by El Niño conditions in the Pacific where warmer, expanded ocean water raises overall sea level and raising the tides. In November 2015, some of the highest King Tides on record occurred, causing minor nuisance flooding along the low-lying areas of San Diego.

Mean sea level, as measured at three key coastal guages



Notable Climate Events and Weather Extremes

Water year 2016 started with seasonal temperatures and moisture streaming in from the Pacific. Some snow was reported at the higher elevations of the Southern Sierra. On October 15th, a cutoff low interacting with a surge of Pacific moisture led to intense convective events north of the Los Angeles Basin and the Southern Sierra. The heavy rain on the steep slopes with little vegetation led to mudflows that closed Interstate 5 and Highway 58. Record high temperatures were recorded in many locations for Halloween. Precipitation in October was below average in 6 of the 10 hydrologic regions.

Nearly 200 vehicles were buried in a mudflow as much as 6 feet high after an intense 1000-year rainfall event caused a massive debris flow blocking a section of California Highway 58 east of Tehachapi. Image copyright 2017 California Department of Transportation, all rights reserved.

The first storms of November arrived in the first week with the highest amounts of precipitation in the northern part of the State. Precipitation that fell as snow melted away within a few days. After the warm weather to start the month, the second week brought cooler than average temperatures. The cooler temperatures resulted in more snow falling in the mountain regions. The colder temperatures and precipitation continued in weeks three and four with storms interspersed by a few days of dry weather. The month closed out with freezing temperatures in the Central Valley and heavy rain on the North Coast, however, precipitation in November was below average in 8 of the 10 hydrologic regions.

December started off colder than average. The first storms of the month arrived in the first week with the northern parts of the state receiving the bulk of the precipitation. Precipitation that fell as snow was heavy in places with upwards of 3 feet in some locations. Persistent low pressure along the west coast led to some locally heavy rains in the northwestern region of the State. Precipitation did make it to the rest of the state over the course of the month with cooler temperatures also in play. Precipitation in December was above average across the State.

The first storms of 2016 arrived in the first week of January with precipitation reaching most of the State. San Diego saw heavy precipitation from an atmospheric river event. Temperatures warmed in the second week and heavy rain fell in places along the coast and the west slope of the Sierras. The best snowpack accumulation continued to be in the northern part of the State. Precipitation was confined to the northern part of the State for the rest of the month with continued near or above average temperatures. Precipitation in January was above average statewide.

February started off cooler than average and dry. Precipitation finally showed up in the third week of the month with some good snow accumulation in the Sierra. Warmer temperatures that started in week 2 persisted to the end of the month and the only other precipitation was limited to the northern parts of the State. Precipitation in February was below average statewide.

March started warm and dry, but by the end of the first week, a significant atmospheric river pushed through the State dropping significant rain and snow. The wet weather continued in the second week with a second notable storm towards the end of the week. In the first 14 days of the month, the northern Sierra 8-station index recorded 28% of its water year to date total of precipitation. The northern region snow water equivalent gained 24% of its water year total and Shasta and Oroville reservoirs combined gained over 1.5 million acre-feet. After these events, things dried out with the exception of a small event in the fourth week. Precipitation in March was above average in the north and below average in the south.

The Lower Lake Clementine Dam on the North Fork American River in Placer County in Northern California. Photo taken March 31, 2016.

April started out warmer than average with scattered showers over the coastal regions and the Sierra. Precipitation developed into widespread rainfall by the end of the second week. In week three temperatures were again above average and precipitation was limited to the northern part of the State. Atmospheric moisture remained to close out the month with coastal fog and some radiational fog present. Precipitation in April was below average across the state with the exception of the Lahontan Regions and Colorado River Desert.

Table 2. Monthly temperature and precipitation anomalies for water year 2015 as computed by the California Climate Tracker of Western Region Climate Center.

Month	Temperature Anomaly (degrees Fahrenheit)	Precipitation Anomaly (percent of average)
October	4.9	64%
November	-2.0	65%
December	-1.3	111%
January	1.7	147%
February	5.3	26%
March	3.3	161%
April	3.9	92%
May	1.0	83%
June	4.1	51%
July	1.0	7%
August	1.3	1%
September	0.3	12%

May started out with fairly constant temperatures due to a moist air mass over the State. This moist air led to mornings with radiation fog and scattered showers over most of the State. Temperatures cooled towards then end of second week as Pacific air surged inland. Precipitation continued as scattered showers with the heaviest rain in the northern Sierra Nevada Mountains. In week three temperatures jumped as a ridge developed over the State leading to dry conditions. Coastal areas were cooler due to the presence of the marine layer. Spotty showers returned in the following week as the ridge broke down with cooler temperatures prevailing. Temperatures warmed to close out the month leading to some thunderstorms over the Sierra Nevada. Precipitation in May was below average across the state with the exception of the South Coast, North Lahontan Region and Tulare Lakebed Region.

June started warm and dry with cooler areas near the coast and higher elevations. The high pressure ridging broke down in the third week leading to cooler conditions and some thunderstorm activity in the Sierra Nevada. Onshore flow persisted through the end of the month with cooler temperatures near the coast but hot temperatures in the inland deserts. Precipitation in June was below average across the state with the exception of the South Lahontan Region and Tulare Lakebed Region.

July started hot and dry with isolated thunderstorms at higher elevations. This pattern continued through the second week of the month with a few showers on the North Coast. Cooler Pacific air made entry into coastal areas of the State in the third week leading to locally cooler conditions. Hot, dry weather persisted through the end of the month with a few isolated thunderstorms in the mountains. Precipitation in July was below average across the state.

August started hot and dry across the state with scattered thunderstorms in the Sierra Nevada Mountains and southeast deserts. Week two saw no precipitation with cooler temperatures in the early part of the week. By the weekend, triple digit temperatures were common in the valley and in some mountain locations. The heat continued into week three where thunderstorms again dropped

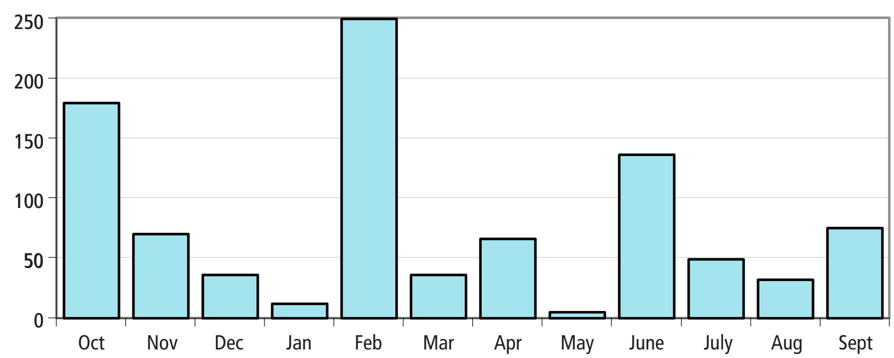
rain in the desert and Sierra regions. The month closed out with a cooling trend and continued scattered showers. Precipitation in August was below average across the state.

September started with a cooling trend across the state with dry conditions. Week two saw no precipitation with warming temperatures topping triple digits in some locations. Some scattered showers including some snow at the higher elevations showed up in week three, but warming conditions in the latter part of the week saw any accumulation melt out. The month closed out with a tropical moisture surge into the southeastern deserts from the remains of Hurricane Paine while a Pacific low pressure system brought cooler weather and some showers into the northern part of the state including the Sierra Nevada Mountains. Precipitation in September was below average across the state with the exception of the Colorado River Desert Region.

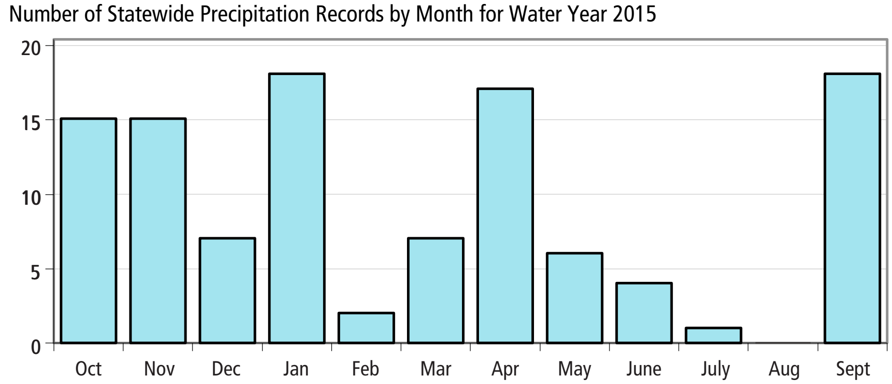
Daily temperature or precipitation records were set on 171 days of the 2016 water year. The month with the most days with records set was November with 20 days while the month with the fewest days was May with 5 days. For the water year, there were 945 temperature records set and 110 precipitation records set. The largest monthly total for temperature records was in February with 249 records. The largest monthly total for precipitation records was in January with 18 records set. A plot of the monthly distribution of temperature and precipitation records is shown (right).

A view of Lake Oroville's Bidwell Bar Bridge with 96 percent of total capacity, or 117 percent of historical capacity, on May 11th, 2016 in Oroville, Calif.

Number of Statewide Temperature Records by Month for Water Year 2016



Number of Statewide Precipitation Records by Month for Water Year 2015



Glossary

• **Anomaly:** The difference of a value over a specified period from the long-term average value (e.g. 1949-2005) over the same period.

• **Average Maximum Temperature:** The average of all daily maximum temperatures over a given time period.

• **Average Mean Temperature:** The mean value of the average maximum temperature and the average minimum temperature over a given time period.

• **Average Minimum Temperature:** The average of all daily minimum temperatures over a given time period.

• **Calendar Year (to date):** The interval between January and December (or to present month), inclusive.

• **Climate:** The average weather or the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands or millions of years.

• **Climate change:** A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties (often by using statistical tests), and that persists for an extended period, typically decades or longer.

• **Climate model:** A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.

• **Climate variability:** Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events.

• **COOP station:** Cooperative Observer Network (COOP), managed by the National Weather Service, consists of up to 12,000 weather stations across the United States that report daily measurements of precipitation and/or temperature.

• **Inhomogeneities:** Variations in data that are not attributed to climate variations. Non-climatic influences on the dataset can include abrupt changes due to changes in instrumentation or station location, as well as gradual changes due to growth of nearby vegetation or urban centers.

• **Linear Trend:** A simple method that fits a line (linear trend) to observations of a given variable over some time period. Beside each linear trend given on this set of pages is a 95% confidence interval that provides a measure as to how likely a trend is significant. For example, a trend of +2°F/100 years with an uncertainty interval of + or - 1°F/100 years says that with 95% confidence there is a positive linear trend, with a range between +1° and +3°F/100 years. On the other hand, a linear trend of + 2°F/100 years with an uncertainty interval of +/- 5°F/100 years does not provide conclusive evidence of a linear trend, as the range is between -3° to + 7°F/100 years. Confidence Intervals are calculated according to Santer et al 2000.

• **PRISM:** Parameter-elevation Relationships on Independent Slopes Model. A model that incorporates point measurements and topographic database to create a high resolution gridded climate database. More information on PRISM is available from Oregon Climate Service.

• **Percentile Ranking:** The ranking of a variable (e.g., temperature) over a given time period versus comparable time periods overall years of record, normalized to a 0 (coldest) to 100 (warmest) scale.

• **Precipitation:** The accumulation of water (in liquid form) that is deposited to the surface over a given time period.

• **Streamflow:** The amount of water flowing in a river.

• **Water Year (to date):** The interval between October and September (or to present month). For example the water year 2007 refers to the interval between October 2006 and September 2007.

Appendix

Temperature and Precipitation

WRCC California Climate Tracker

http://www.wrcc.dri.edu/monitor/cal-mon/background_brief.html

Monthly station data, taken from cooperative observers (COOP), along with gridded data from the PRISM database, are used to assess climate across the state. The primary variables that are considered in this process are monthly average mean temperatures and monthly precipitation totals. COOP stations across the state that reported over 75% of observations over the time period 1949-2005, and continued to report in 2006. A total of 195 stations across the state are included in this analysis. We consider COOP station data along with the PRISM database dating back to January of 1895. Temperature data from the COOP stations have been adjusted for inhomogeneities, a procedure used to "correct" for non-climate shifts in temperature. No effort is made to adjust for urbanization or land-use changes. Inhomogeneity detection includes the entire period of record; however the dataset contains larger uncertainties prior to 1918 due to the limited number of stations reporting statewide.

NOAA U.S. Climate Divisional Dataset

https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php

For many years the Climate Divisional Dataset was the only long-term temporally and spatially complete dataset from which to generate historical climate analyses (1895-2013) for the contiguous United States (CONUS). It was originally developed for climate-division, statewide, regional, national, and population-weighted monitoring of drought, temperature, precipitation, and heating/cooling degree day values. Since the dataset was at the divisional spatial scale, it naturally lent itself to agricultural and hydrological applications.

There are 344 climate divisions in the CONUS. For each climate division, monthly station temperature and precipitation values are computed from the daily observations. The divisional values are weighted by area to compute statewide values and the statewide values are weighted by area to compute regional values. (Karl and Koss, 1984).

Precipitation: DWR 8 Station and 5 Station Indices

Department of Water Resources hydrologists use two mountain precipitation indexes to track daily accumulation of rain and snow during the winter rainy season for the major Central Valley basins. The first is the Northern Sierra 8 station average, a group of 8 precipitation stations extending from Mount Shasta in the north to near Lake Tahoe in the south, which corresponds quite well to the water year runoff of the Sacramento River system (the Sacramento four river index). A southern group of 5 Sierra stations comprise the 5 station index which correspond fairly well to water year runoff for the San Joaquin River (the San Joaquin four river index).

The 8 station precipitation index includes: Mt Shasta City, Shasta Dam, Mineral, Quincy, Brush Creek, Sierraville, Blue Canyon, Pacific House.

http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=8SI

The 5 station precipitation index includes: Calaveras Big Trees, Hetch Hetchy, Yosemite, North Fork RS, Huntington Lake

http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=5SI

Atmospheric Rivers

http://cw3e.ucsd.edu/

The Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, UCSD has developed a method in order to characterize atmospheric river (AR) events that make landfall along the US west coast. ARs are Identified using 6 hourly GFS Analysis derived integrated water vapor data. Arrows are drawn on the map where integrated vapor transport (IVT) within identified ARs was strongest over the US West Coast (Arrows do not identify all locations each AR impacted). Given the spatial scale of a landfalling AR, the landfall latitude is an approximation. Intensity is determined for each AR using the Ralph/CW3E AR strength scale using IVT.

Snowpack

Bulletin 120 and Water Supply Index forecasts

Water Supply Index (WSI) and Bulletin 120 (B120) forecasts are posted at:

WSI: http://cdec.water.ca.gov/cgi-progs/iodir/wsi

B120: http://cdec.water.ca.gov/cgi-progs/iodir?s=b120

Contrasting Snowpack Trends In The Sierra Nevada Of California (Roos and Sahota, 2012)

http://www.westernsnowconference.org/sites/westernsnowconference.org/PDFs/2012Roos.pdf

Originally a group of 13 northern courses and 13 southern Sierra courses were chosen by Scripps researchers for use by the California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, for inclusion in a roughly 180 page 2009 report “Indicators of Climate Change in California” (CA EPA, 2009). The report has a large number of indicators for measured changes in economic factors, greenhouse gases, climate and temperature, physical systems, and biological systems with time. Over 30 indicators were discussed; the list included Sierra river runoff trends, the snowpack record, and two charts showing snow water content trends from1950 through 2008 for a group of northern Sierra Nevada snow courses and a group of southern Sierra Nevada snow courses.

Water Year Type: Unimpaired Flow (Runoff)

http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

Unimpaired runoff represents the natural water production of a river basin, unaltered by upstream diversions, storage, export of water to or import of water from other basins. Sacramento River Runoff is the sum (in maf) of Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake. The water year sum is also known as the Sacramento River Index, and was previously referred to as the “4 River Index” or “4 Basin Index”. It was previously used to determine year type classifications under State Water Resources Control Board (SWRCB) Decision 1485.

Sacramento Valley Water Year Index = 0.4 * Current Apr-Jul Runoff Forecast (in maf) + 0.3 * Current Oct-Mar Runoff in (maf) + 0.3 * Previous Water Year’s Index- (if the Previous Water Year’s Index exceeds 10.0, then 10.0 is used). This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the Sacramento Valley water year type as implemented in SWRCB D-1641. Year types are set by first of month forecasts beginning in February. Final determination is based on the May 1 50% exceedence forecast.

Sacramento Valley Water Year Hydrologic Classification:

Year Type:	**Water Year Index:**
Wet	Equal to or greater than 9.2
Above Normal	Greater than 7.8, and less than 9.2
Below Normal	Greater than 6.5, and equal to or less than 7.8
Dry	Greater than 5.4, and equal to or less than 6.5
Critical	Equal to or less than 5.4

San Joaquin River Runoff is the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake (in maf). San Joaquin Valley Water Year Index = 0.6 * Current Apr-Jul Runoff Forecast (in maf) + 0.2 * Current Oct-Mar Runoff in (maf) + 0.2 * Previous Water Year’s Index(if the Previous Water Year’s Index exceeds 4.5, then 4.5 is used). This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the San Joaquin Valley water year type as implemented in SWRCB D-1641. Year types are set by first of month forecasts beginning in February. Final determination for San Joaquin River flow objectives is based on the May 1 75% exceedence forecast.

San Joaquin Valley Water Year Hydrologic Classification:

Year Type:	**Water Year Index:**
Wet	Equal to or greater than 3.8
Above Normal	Greater than 3.1, and less than 3.8
Below Normal	Greater than 2.5, and equal to or less than 3.1
Dry	Greater than 2.1, and equal to or less than 2.5
Critical	Equal to or less than 2.1

Eight River Index = Sacramento River Runoff + San Joaquin River Runoff. This Index is used from December through May to set flow objectives as implemented in SWRCB Decision 1641.

The current water year indices based on forecast runoff are posted at:

http://cdec.water.ca.gov/water_supply.html

And published in DWR Bulletin 120:

http://cdec.water.ca.gov/snow/bulletin120

These indices have been used operationally since 1995, and are defined in SWRCB

Decision 1641: http://www.waterrights.ca.gov/baydelta/d1641.htm

This report is updated each fall once the data is available.

Snowpack and Snowmelt Changes- Maury Roos Chief Hydrologist, California Department of Water Resources (1/03/2012).

http://www.water.ca.gov/climatechange/blog/

Sea Level Trends

http://tidesandcurrents.noaa.gov/sltrends/sltrends.html

http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9419750

http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9414290

http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9410230

The Center for Operational Oceanographic Products and Services has been measuring sea level for over 150 years, with tide stations of the National Water Level Observation Network operating on all U.S. coasts. Changes in Mean Sea Level (MSL), either a sea level rise or sea level fall, have been computed at 142 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month to remove the effect of higher frequency phenomena in order to compute an accurate linear sea level trend. The trend analysis has also been extended to 240 global tide stations using data from the Permanent Service for Mean Sea Level (PSMSL). This work is funded in partnership with the NOAA OAR Climate Observation Division.

The mean sea level (MSL) trends measured by tide gauges that are presented on this web site are local relative MSL trends as opposed to the global sea level trend. Tide gauge measurements are made with respect to a local fixed reference level on land; therefore, if there is some long-term vertical land motion occurring at that location, the relative MSL trend measured there is a combination of the global sea level rate and the local vertical land motion. The global sea level trend has been recorded by satellite altimeters since 1992 and the latest calculation of the trend can be obtained from NOAA's Laboratory for Satellite Altimetry, along with maps of the regional variation in the trend. The University of Colorado's Sea Level Research Group compares global sea level rates calculated by different research organizations and provides detailed explanations about the issues involved.

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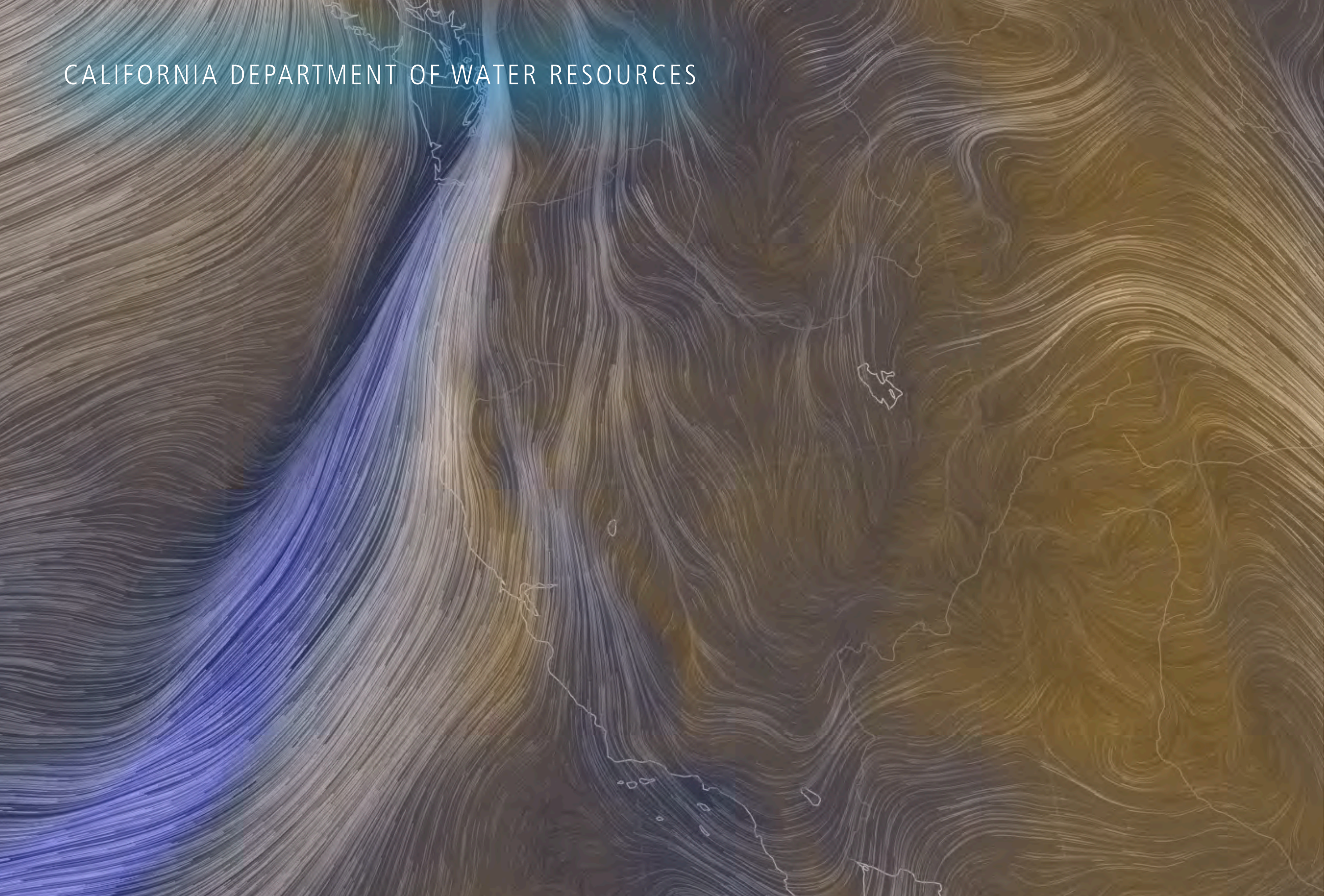
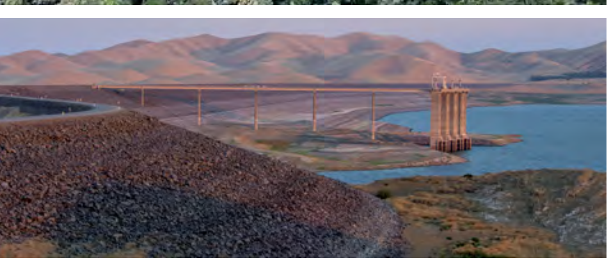
Photo of Nina Oakley, who is an Assistant Research Climatologist with Western Regional Climate Center and the Desert Research Institute. Nina is releasing a radiosonde at UC Davis' Bodega Marine Lab in Bodega Bay, California, during a strong atmospheric river on February 9, 2017, to observe a vertical profile of the atmosphere's moisture content, temperature, pressure, and winds from the surface to an altitude of approximately 20 km.

CALIFORNIA DEPARTMENT OF WATER RESOURCES





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