

# California DWR–CW3E Research and Operations Partnership: Highlights of a Family of Nine Atmospheric Rivers

California has the most variable precipitation of any state, driven by the presence or absence of atmospheric rivers (ARs). ARs provide 50% of California’s water supply but also cause 90% of its floods. Projections show ARs becoming more extreme and contributing a larger share of California’s annual precipitation, with long periods of dry conditions punctuated by stronger and wetter ARs.

A rapid transition from dry to wet occurred when a family of nine ARs hit the California coast over three weeks starting on December 27, 2022. These storms were driven by the alignment of the jet stream over the North Pacific and featured the longest period of continuous AR days since 1950. They caused enormous impacts statewide.

## Impacts

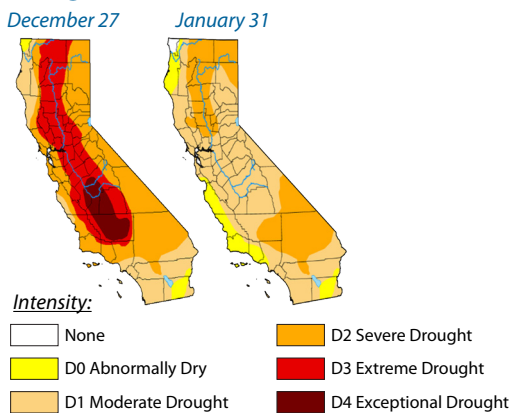
- **Record flooding:** At eight locations
- **Average precipitation:** >11 inches, about half of the state’s annual average in 3 weeks
- **Maximum precipitation:** Several high-elevation sites approached 50 inches
- **Snowpack:** Increased from 43% to 124% of April 1 peak snowpack
- **Reservoir refill:** Most large reservoirs >50% full
- **Severe drought:** Cut from 81% to 33%
- **NWS storm reports:** >2,000; 75% associated with flooding or heavy rain
- **Rescues:** Early forecasts helped position equipment to save lives

## AR Family Timing, Location, and Strength



An AR family occurs when a series of ARs strike in quick succession. This map shows the location and maximum strength of the nine ARs according to the AR scale, as they made landfall in California.<sup>2</sup>

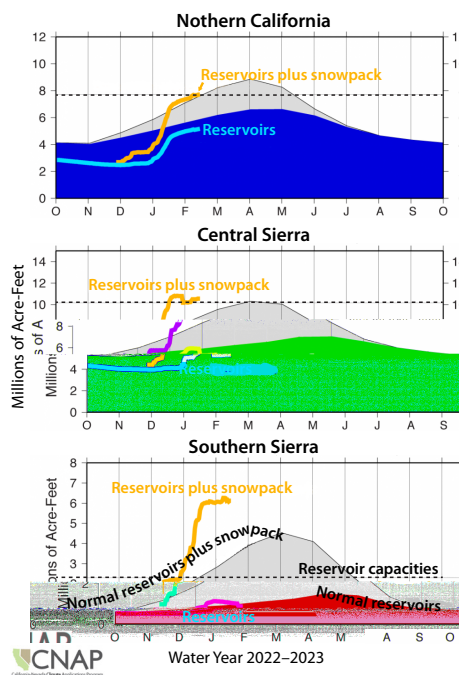
## Drought Before and After ARs



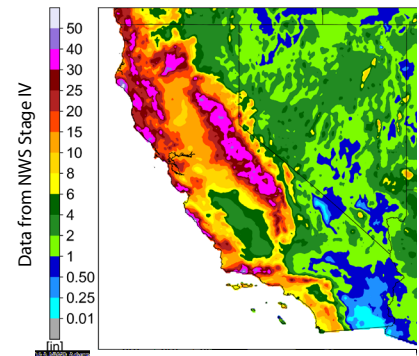
USDA NDMC NOAA droughtmonitor.unl.edu

Drought severity according to the U.S. Drought Monitor.

## Water Storage: Reservoir + Snowpack



## Total Precipitation from Nine ARs

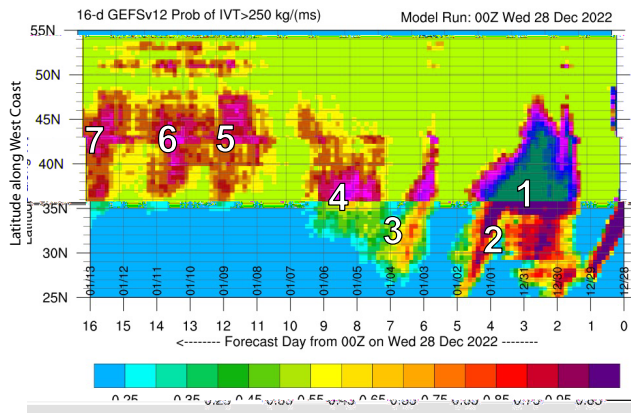
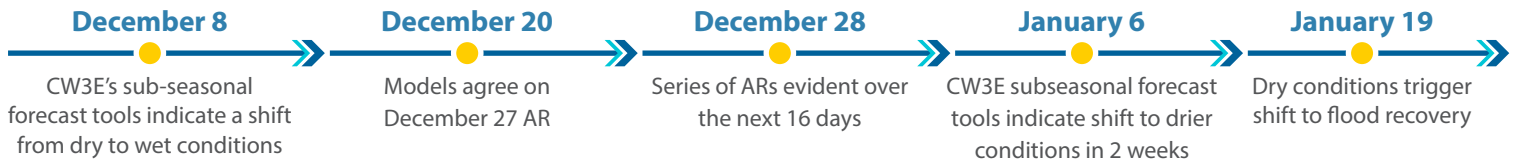


Total precipitation from the AR family topped 40 inches. Some areas received more than 100% of normal water year precipitation.

Total water storage, a combination of snowpack and reservoirs compared with the 2000–2015 normal. The ARs increased reservoir levels and snowpack in all regions, with the largest increase in the Southern Sierra region.

1. Fish et al., J. Hydrometeor., 2019.  
2. Ralph et al., BAMS, 2019.

## Were These ARs Forecasted? Yes!



The AR landfall tool shows the probability of AR conditions with warmer colors indicating higher probabilities. This example shows the extended period of AR conditions forecasted on December 28.

## Investments in the AR Program Make a Difference

- The AR Reconnaissance program has improved AR lead time forecasts by 1-2 days.
- The January 14 AR forecast was spot on, with over 90% probability of an AR 3 and the AR duration within 12 hours.
- Forecast Informed Reservoir Operations (FIRO) at Lake Mendocino allowed higher post-storm storage to enhance water supply reliability as a hedge against the possibility of a dry year.
- CW3E's experimental weather forecasting model, West-WRF, enhanced prediction of extreme precipitation using innovative modeling and machine learning methods. DWR is testing West-WRF forecast data for use in operations.
- AR Reconnaissance improved predictors of AR strength, by up to 50%. Getting these factors right leads to better forecasts.

"CW3E's tools provide great insight into meteorological conditions for reservoir management, particularly during large AR events. This was especially true during the recent family of ARs. The ongoing development and integration of CW3E decision support products aid in situational awareness and improve forecast skill. These advances directly support Yuba Water by being better able to manage for both droughts and floods."

– **John James**  
Yuba Water Agency



NOAA and Air Force Hurricane Hunters fly from the Gulf of Mexico to Hawaii and California to monitor the AR season, which now extends from November through March. Air Force C130s in California are shown here.

## What's Next?

- Each AR has distinct characteristics that determine the landfall location, timing, and strength, which impact the associated precipitation. CW3E's West-WRF model will continue to improve forecasting by integrating enhanced scientific understanding and applying novel technological advancements, including supercomputing and machine learning.
- Analyzing the transition from dry to wet at the onset of this AR family will improve subseasonal (2-4 week) forecasts.
- The AR Reconnaissance season will begin earlier and needs to ensure coverage during extreme ARs, such as this AR family that occurred over the holiday season.
- CW3E and DWR are exploring integration of AR forecast tools into emergency operations to better support water management and flood hazard mitigation.
- 73 California reservoirs are being screened for FIRO suitability to improve resilience to drought and floods. Improving forecast skill will enable greater adoption of FIRO.

## AR Program Partners



For more information visit <https://cw3e.ucsd.edu/>