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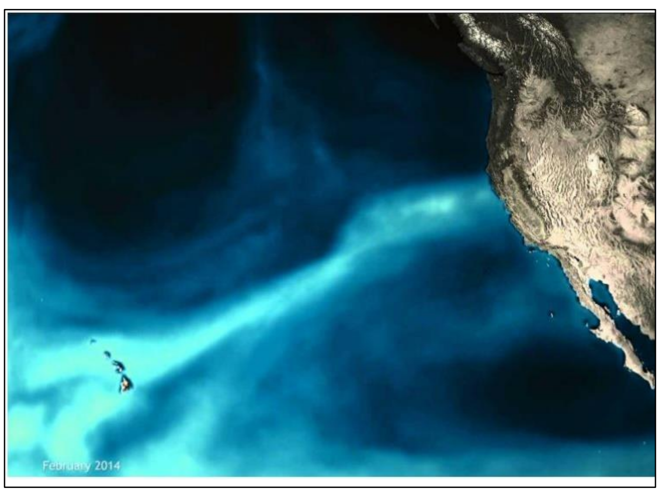
# Atmospheric Rivers: Background and Forecasting

An atmospheric river (AR) consists of a long band of water vapor moving through the atmosphere, typically resulting in heavy precipitation over land (**Figure 1**). Improved AR observations and understanding (especially for large ARs) may facilitate flood preparedness and response and water supply management. This is especially true in some snowpack-dominated watersheds. ARs significantly influence U.S. West Coast water conditions, producing on average 30%-50% of the region's annual precipitation (and sometimes more). According to scientists, 67 ARs made landfall over the U.S. West Coast in the 2024 water year (October 1, 2023, through September 30, 2024). ARs may have implications for other U.S. regions, as well. For instance, ARs from the Gulf of Mexico contributed to central U.S. flooding in 1983 and 2008 and southern U.S. flooding in 2016.

The level of federal support for AR research and the use of AR forecasting may be an issue in congressional authorizations and appropriations for various agencies. These include the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS), which conduct and support AR science and forecasting, and the U.S. Army Corps of Engineers (USACE), which manages flood risks associated with various federal water resource projects.

**Figure 1. Atmospheric River Extending from Hawaii to the U.S. West Coast, 2014**

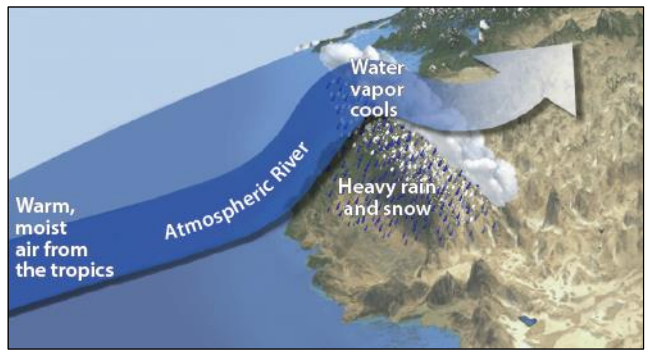



**Source:** NOAA, "Atmospheric Rivers."

**Notes:** The light blue area denotes a plume of water vapor. An AR originating in the tropics near Hawaii that brings water vapor to the U.S. West Coast is sometimes called a *Pineapple Express.*

ARs typically form in tropical regions when winds over the ocean draw water vapor into narrow bands. AR interactions with land features, such as mountain ranges (**Figure 2**), or certain atmospheric conditions cause the water vapor to move upward in the atmosphere and then fall as heavy rain or snowfall. When ARs slow down over a particular area or occur in rapid succession, the resultant precipitation can lead to flooding, mudslides, landslides, and debris flows, especially in areas impacted by wildfires in recent years. In some cases, ARs can help improve or "bust" drought conditions.

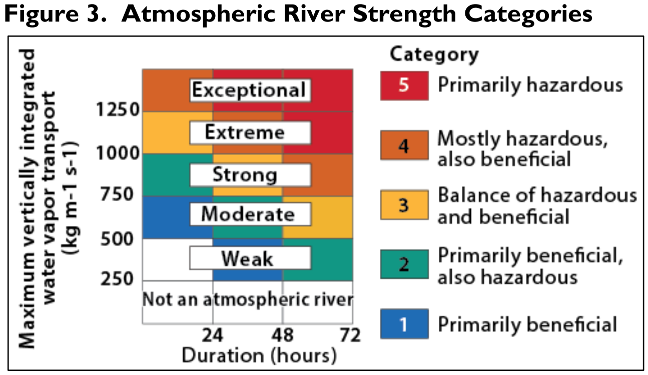
**Figure 2. Example of Atmospheric River Formation**




**Source:** CRS adapted from NOAA, "What Is an Atmospheric River?"

According to some estimates, multiple ARs are in motion around the Earth at any given time, with 90% of the planet's atmospheric water vapor concentrated in four to five ARs. Scientists have begun categorizing ARs based on their maximum water vapor transported over a certain space and time (**Figure 3**; e.g., the U.S. West Coast 2024 water year ARs ranged from weak to extreme).

**Figure 3. Atmospheric River Strength Categories**



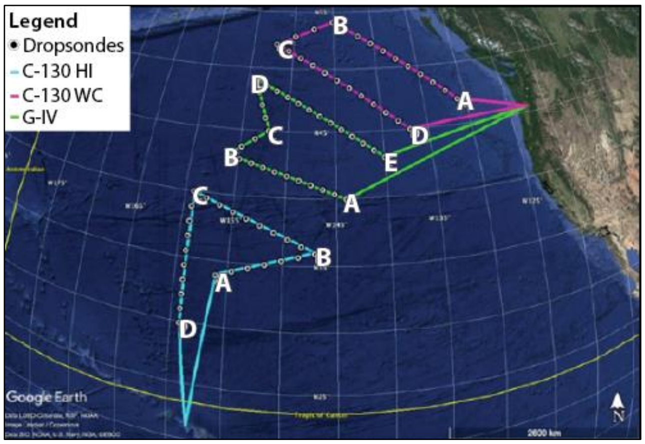

**Source:** CRS adapted from USGS, "Rivers in the Sky: 6 Facts You Should Know About Atmospheric Rivers."

**Notes**: This rating scale, adapted from a 2019 article, uses 250 kg $m^{-1}s^{-1}$ (i.e., 250 kilograms of water vapor per meter per second) intervals to categorize ARs by their transport of water vapor and duration as measured in hours.

## Detection and Forecasting

NOAA, USGS, and other partners employ a range of methods to observe and forecast ARs and their short- and longer-term impacts, including on snowpack, rivers and streams, and subsequent vegetation growth. Observations (e.g., wind, temperature, water vapor content) come from satellites, radar, and aircraft- or ocean-based missions (e.g., **Figure 4**). For example, scientists working on improving prediction of land-falling ARs in the western United States have established an AR Reconnaissance (AR Recon) partnership; AR Recon activities include coordinating and sharing U.S. AR observations on the U.S. West Coast and more recently in the Gulf of Mexico and Southeastern United States. A limited number of land-based AR monitoring stations also are deployed to collect data not well captured by other observing systems.

**Figure 4. Planned AR Recon Flight Patterns Deploying Dropsondes on February 6, 2020**




**Source:** CRS adapted from Interagency Council for Advancing Meteorological Services, *National Winter Season Operations Plan*, December 2023, Fig. E-9.

**Notes:** *Dropsondes* are weather reconnaissance devices that measure conditions as the devices fall from an aircraft at altitude over water. C-130 and G-IV are the types of aircraft to be used. For a summary of AR Recon flights and dropsondes, see Center for Western Weather and Water Extremes, "Atmospheric River Reconnaissance."

NOAA and others use these observations in forecasting models. NOAA's National Weather Service uses the model outputs to issue outlooks and warnings for AR-related weather events, such as rain, snow, wind, high surf, flooding, thunderstorms, and tornadoes (e.g., **Figure 5**). These observations also serve as data to improve forecasting efforts.

Emergency managers and infrastructure operators also may use AR information. For example, managers may use AR forecasts, along with other information, to inform when to release water from reservoirs—known as Forecast Informed Reservoir Operations (FIRO)—to reduce flood risk and enhance water supplies. For example, USACE is using FIRO to alter its releases of stormwater stored at Prado Dam in California to increase nonfederal downstream efforts to capture the released stormwater for groundwater recharge.

**Figure 5. Top 10 Wind Gusts in Central California from February 4, 2024**

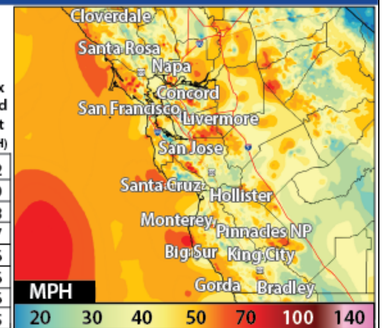
(due to atmospheric river February 3-5, 2024)

**Top Ten Wind Gusts from Sunday**

An Atmospheric River brought gusty winds to the Bay Area and Central Coast. Strongest winds were in the Coastal Mountains.

Notable Speeds

| Location | County | Max Wind Gust (MPH) |
|---|---|---|
| Pablo Point | Marin | 102 |
| Rd. to Ranches | Marin | 99 |
| Loma Prieta | Santa Clara | 98 |
| Knpt Towers | Santa Clara | 97 |
| Pine Mt. Fire Rd. | Marin | 96 |
| Soda Springs Rd. | Santa Clara | 96 |
| Gunsight Fire Rd. | Marin | 96 |
| Cobb Ridge W. | Marin | 95 |
| Point Reyes | Marin | 89 |
| Lucas Valley | Marin | 89 |




**Source:** CRS adapted from NOAA, National Weather Service, San Francisco Bay Area, CA, Weather Forecast Office, "Atmospheric River Impacts California."

As understanding of ARs improves, scientists are exploring how ARs may change with a warming climate. Some research (as noted by USGS and NOAA) suggests a warmer climate may alter U.S. West Coast ARs' frequency, intensity, and location. Although globally ARs in a warming climate may be associated with more precipitation, the effects on precipitation may not be uniform along the U.S. West Coast. The potential for changes to AR-related rain and snowfall may further encourage improved understanding and forecasting of ARs in both watersheds that receive significant AR precipitation and areas that receive ARs less frequently.

## Additional Considerations

In recent years, Congress has supported AR-related activities through appropriations for NOAA to observe and predict ARs (S.Rept. 118-62, referred to within the explanatory statement accompanying P.L. 118-42) and authorization for USACE to expand its understanding of the impacts of ARs and FIRO efforts to other river basins (P.L. 116-260, §157, Division AA; P.L. 117-263, §8303, Title LXXXI, Division H), among other ways. Some Members of Congress introduced several bills (e.g., H.R. 3966, H.R. 6093, S. 2203, S. 5361) in the 118th Congress regarding ARs, including efforts to improve AR forecasting, codify AR Recon, and advance AR hazard communication, among other actions. Another bill would have directed federal agencies to incorporate assessments of the impacts of ARs in a national landslide strategy (S. 3788). The 119th Congress may consider assessing federal efforts to advance the understanding and forecasting of ARs and their impacts, including on emergency management and preparedness, flood risk, and water supplies.

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