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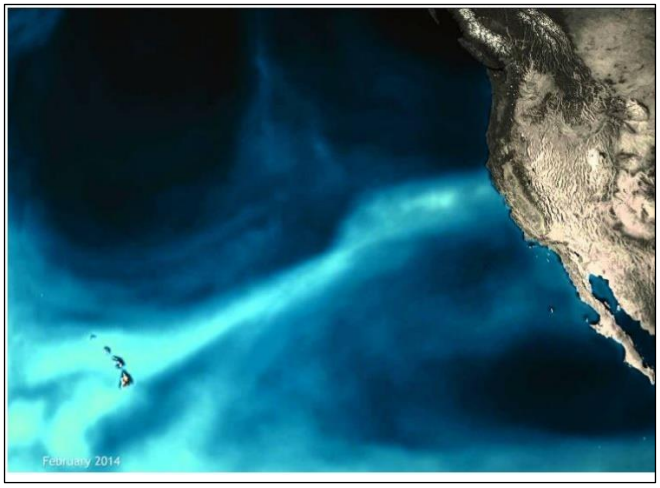
Atmospheric Rivers: Background and Forecasting

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 of 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.

Federal support for AR research and the use of AR forecasting may be an issue in congressional authorizations and appropriations across 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. It also includes those federal agencies operating water resource projects for flood risk reduction and/or water supply purposes, such as the U.S. Army Corps of Engineers (USACE).

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

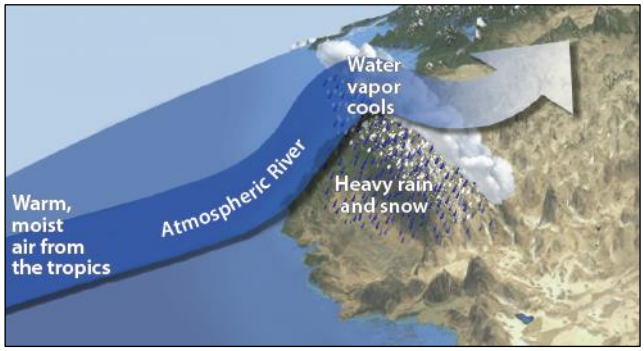


Source: NOAA, "Atmospheric Rivers."

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 also can help improve or "bust" drought conditions.

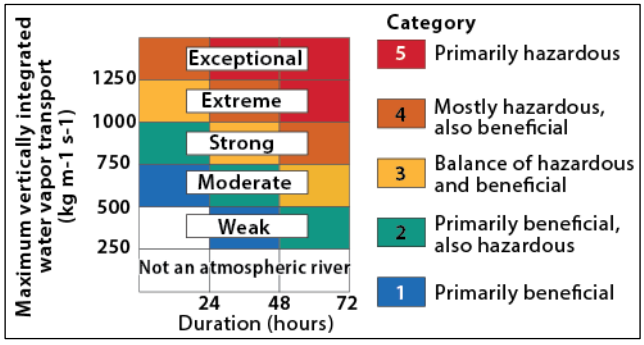
Figure 2. Example of Atmospheric River Formation



Source: CRS, adapted from NOAA, "What Are Atmospheric Rivers?"

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 2024 water year U.S. West Coast 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."

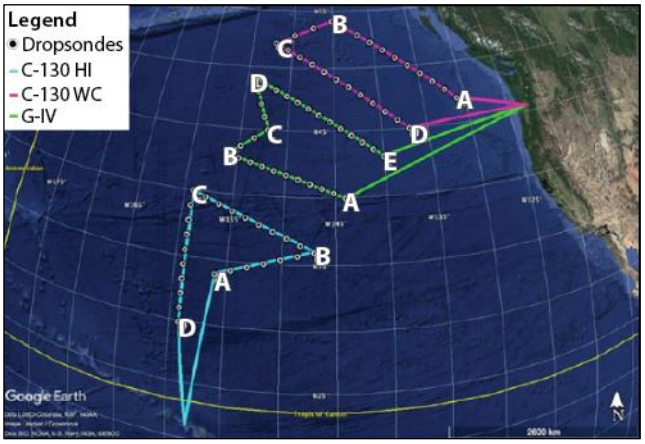
Notes: This rating scale uses 250 kg $m^{-1}s^{-1}$ (i.e., 250 kilograms of water vapor per meter per second) intervals to categorize ARs by their transport of water vapor and duration as measured in hours.

Detection and Forecasting

NOAA, USGS, and other partners employ a range of methods to observe and forecast ARs and their short- and

long-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, federal and nonfederal partners established an AR Reconnaissance (AR Recon) partnership to coordinate and share U.S. AR observations of certain regions in and along the Pacific Ocean, Gulf of America, and Western Atlantic Ocean. 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 2024, Fig. E-9.

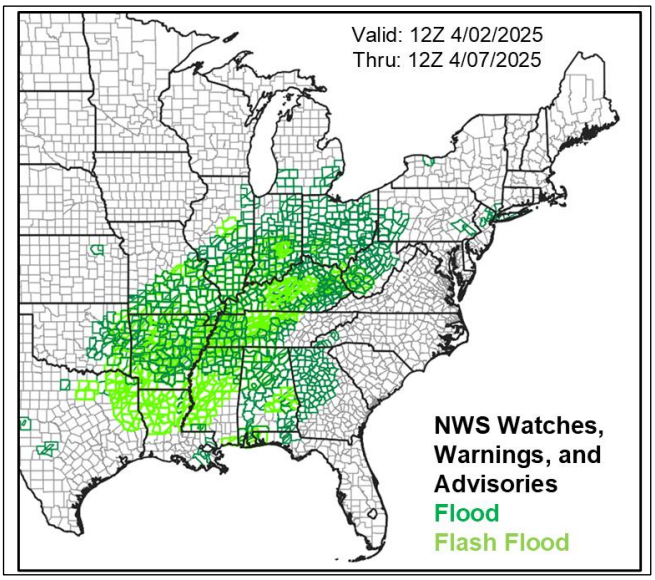
Notes: *Dropsondes* are weather reconnaissance devices that measure conditions as the devices fall from an aircraft at altitude over water. C-130 and G-IV are the types of aircraft used. For a summary of AR Recon flights and dropsondes, see Center for Western Weather and Water Extremes, "Atmospheric 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 (e.g., **Figure 5**), thunderstorms, and tornadoes. Data from these observations also serve to improve forecasting efforts.

Emergency managers and infrastructure operators also may use information about ARs. For example, managers may use AR forecasts, along with other information, to inform decisions on 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 Lake Mendocino, Prado Dam, and New Bullards Bar and Oroville Dams in California to increase nonfederal downstream efforts to capture the released stormwater for groundwater recharge.

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. In a warming climate, ARs may be associated with greater overall precipitation globally; however, how ARs will change precipitation in specific regions is still unclear. An improved understanding and more accurate forecasting of ARs may align emergency management and FIRO more precisely with potential regional changes on both U.S. coasts.

Figure 5. Floods and Flash Flood Watches, Warnings, and Advisories Related to ARs of April 1-7, 2025



Source: CRS, adapted from CW3E, "CW3E Event Summary: 1-7 April 2025 East Coast ARs."

Notes: Almost 5,000 flood and flash flood watches, warnings, and advisories were issued by NWS weather forecast offices over the Ohio and Mississippi River Basins during this timeframe.

Congressional Considerations

In recent years, Congress has supported AR-related activities through appropriations for NOAA to observe and predict ARs (e.g., 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 (e.g., P.L. 116-260, §157, Division AA, and P.L. 117-263, §8303, Title LXXXI, Division H), among other ways.

In the 119th Congress, some Members of Congress have introduced AR-related bills or AR provisions within broader bills (e.g., H.R. 2250/S. 1626; H.R. 3816; H.R. 4302; H.R. 5089; and S. 322). Examples of topics addressed in the bills or provisions include improving AR forecasting, modeling, reconnaissance, and communication, among other actions. Another bill (S. 324) would direct federal agencies to incorporate assessments of the impacts of ARs in a national landslide strategy. The 119th Congress may consider assessing federal efforts to advance the understanding and forecasting of ARs and their impacts, including effects on emergency management and preparedness, flood risk, and water supplies.

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