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# Atmospheric Rivers: Harbors for Extreme Winter Precipitation

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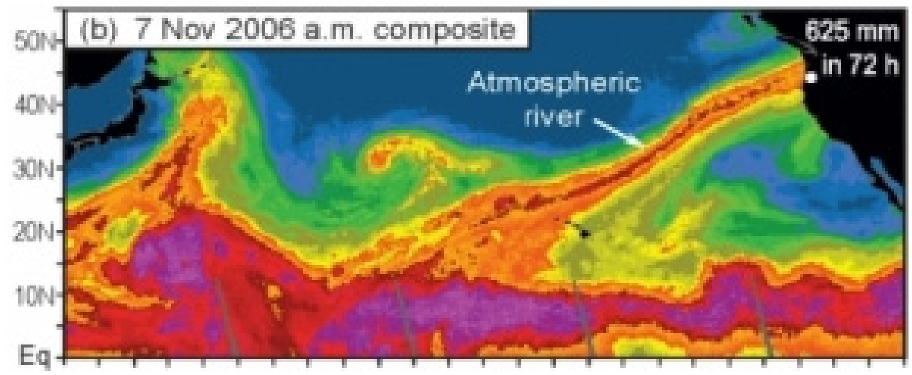


*Figure 1. Satellite image of an atmospheric river striking the Pacific Northwest on November 7, 2006. This event produced about 25 inches of rain in three days. Warm colors in the image represent moist air and cool colors denote dry air. The horizontal band of red and purple at the bottom of the image is the Intertropical Convergence Zone (ITCZ), a normally moist area that some of the strongest ARs can tap into, as happened in this case. (Source: Marty Ralph, NOAA ESRL)*

Fierce winds loaded with moisture blasted into the Southwest and Intermountain region on December 18, 2010, dumping record-setting rain and snow from Southern California to southern Colorado. Fourteen inches of rain drenched St. George, Utah over six days, and seven feet of snow fell in Utah's Wasatch Mountains during the same period. Across southwestern Colorado, over five inches of water equivalent was added to the snowpack.

Behind this wet weather was a phenomenon called atmospheric rivers (ARs), a term first coined in 1998. ARs often deliver extreme precipitation, mostly to the West Coast, but sometimes inland as well, prompting researchers to probe how they form and the effects they have in a changing climate.

ARs have caused nearly all of the largest floods on record in California, accounting for most of the $400 million the state spends each year to repair flood damage. The high price tag, not to mention the lives they disrupt, makes assessing potential changes in AR intensity and frequency critical to informing long-term planning, including water infrastructure upgrades such as levees and culverts. Initial research suggests that global warming may boost AR intensity and slightly increase the number of times ARs occur.

**The Nuts and Bolts of ARs**

Atmospheric rivers are relatively thin ribbons of strong winds near the Earth's surface that funnel moist air over long stretches of ocean. They are common in the Pacific, where research has been focused, but they occur globally. At any given time, approximately three to five ARs are occurring in each hemisphere.

ARs are the movers and shakers in the global hydrologic cycle, transporting about 90 percent of the water vapor that moves poleward from the tropics. They are products of an unevenly heated Earth and form during winter, when the temperature difference between the tropics and the poles is greatest.

In an attempt to equilibrate this temperature difference, the climate system forms extratropical cyclones that spin off the westerly jet stream. When these storms form in the North Pacific Ocean, their counterclockwise motion pulls warm, dank air from the lower latitudes and hurls it north toward the U.S. West Coast (Figure 1).

"The biggest AR events happen when cyclones form that allow tapping [of] tropical moisture," said Marty Ralph, chief of the Water Cycle Branch of the NOAA Earth System Research Laboratory (ESRL) Physical Science Division (PSD) in Boulder.

“Pineapple Express” storms are a form of ARs that draw moisture directly from the tropics, although not all ARs follow this pattern. ARs tend to strike the northern West Coast of the U.S. earlier in the winter and progress south. Alaska often is hit in early fall, with storms pounding the Pacific Northwest in early winter. January through March is the peak season for ARs that drench Southern California.

The most intense ARs can transport an amount of water vapor equal to the flow of 15 Mississippi Rivers measured at the river’s mouth, according to NOAA. Most of the water vapor remains entrained in the air until it flows over land, where mountains force it upwards. The vapor cools as it rises and is wrung from the air like a sponge. “The perfect storm for heavy rain is to have moisture-laden, low-level winds hit mountains,” Ralph said.

The mountains along the West Coast often act as a protective shield for inland states like Arizona, Utah, and Colorado. “If you look at the big picture, ARs often don’t pass the coastal mountains,” said Mike Dettinger, research hydrologist at the U.S. Geological Survey at the Scripps Institution of Oceanography in southern California.

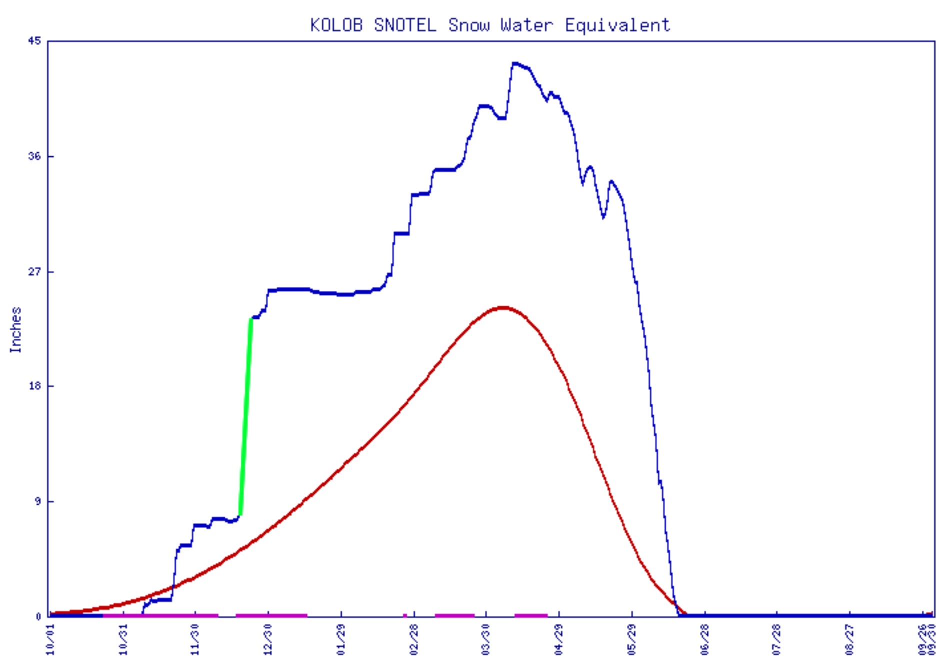


*Figure 2. Snow-water equivalent (SWE) as measured at the Kolob SNOTEL site in southwestern Utah, over the 2011 water year (blue) compared with the average water year (red). Highlighted in green is the 16 inches of SWE—about two-thirds of average seasonal peak SWE—that accumulated over four days during the December 2010 atmospheric river (AR) event. (Source: Utah Snow Survey, NRCS)*

However, some atmospheric rivers do reach as far as Utah and Colorado, such as the December 2010 event mentioned earlier (Figure 2). The storms that reach the Southwest and our region seem to have the right orientation to slip past mountain ranges that otherwise would sap the moisture from the air.

**Future ARs**

Knowledge gained about ARs in the past decade has paved the way for scientists to investigate their fate in a warming world. Understanding how climate variability and human-caused change may alter ARs, as well as the record-breaking floods they spur, can help regions prepare for and adapt to potential changes.

“Flooding is likely to be an acute symptom of climate change in the future,” Dettinger said. “People have built on floodplains, and I don’t think we’re well prepared for increased floods in the future.”

Dettinger is leading the charge on trying to understand how global warming will alter ARs. He published one of the first climate change impacts studies focused on AR events in the June 2011 issue of *Journal of the American Water Resources Association*.

“Generally speaking, what makes AR events strong and dangerous is how much water vapor they transport and how fast it moves,” he said.

To assess how the intensity and character of ARs will change in the future, Dettinger analyzed seven global climate models (GCMs) used in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC). The models were driven by a high greenhouse gas (GHG) emission scenario, known as the A2 trajectory. That scenario leads to projections of a roughly 7°F global temperature change by 2100, which is considered dangerously high by many scientists and policy experts. It is nonetheless plausible given current emissions, which presently outpace this scenario.

Results from Dettinger's study suggested counteracting changes: while modeled ARs will carry more water vapor, the winds will slacken, with the increases in moisture more significantly influencing the character of ARs.

"The upshot is that in all seven models increased water vapor wins out over decreasing winds, so overall the number of ARs increase by about 20 percent," Dettinger said. "Arguably more ominous is that although the average increase in number of events is moderate, there is a tendency to see an increase in the frequency of years with a lot of ARs and a decrease in the years with few events."

His analysis also found the most intense AR storms become stronger in a warmer world. The physical explanation for this is warmer air temperatures hold more moisture, and the models suggest the air within the ARs will warm by about 3°F by the end of the 21st century. In addition to increasing the moisture content, warmer temperatures also elevate snowlines in the mountains. This subjects more area to rain instead of snow, and, all else being equal, causes larger floods. The season in which ARs occur also lengthens in four of the seven models. This would likely force decision makers to alter some resource management strategies.

"Flood managers expect to see bigger storms, but a lot of how they manage water presupposes that big storms will be over by March, [which may not occur]," Dettinger said.

He cautions his results are a first crack at assessing future changes in ARs and their attendant impacts. "I hope my analysis encourages others to dive into the issue and take a deeper look. I think I have the story right, but I'm absolutely convinced there's more work to be done before we have a lot of confidence [in future changes to ARs]," Dettinger said.

Analysis of more GHG emission scenarios, including lower emission scenarios, will help refine estimates, as will improvements in models.

What we know is although ARs predominantly strike the West Coast, a few stream into the Southwest and the Intermountain West. Continued global warming might increase the incidence of extreme winter precipitation events like the one that occurred in December 2010.

**Resources**

For more information on ARs, visit the NOAA ESRL Atmospheric River Information Page at http://www.esrl.noaa.gov/psd/atmrivers/