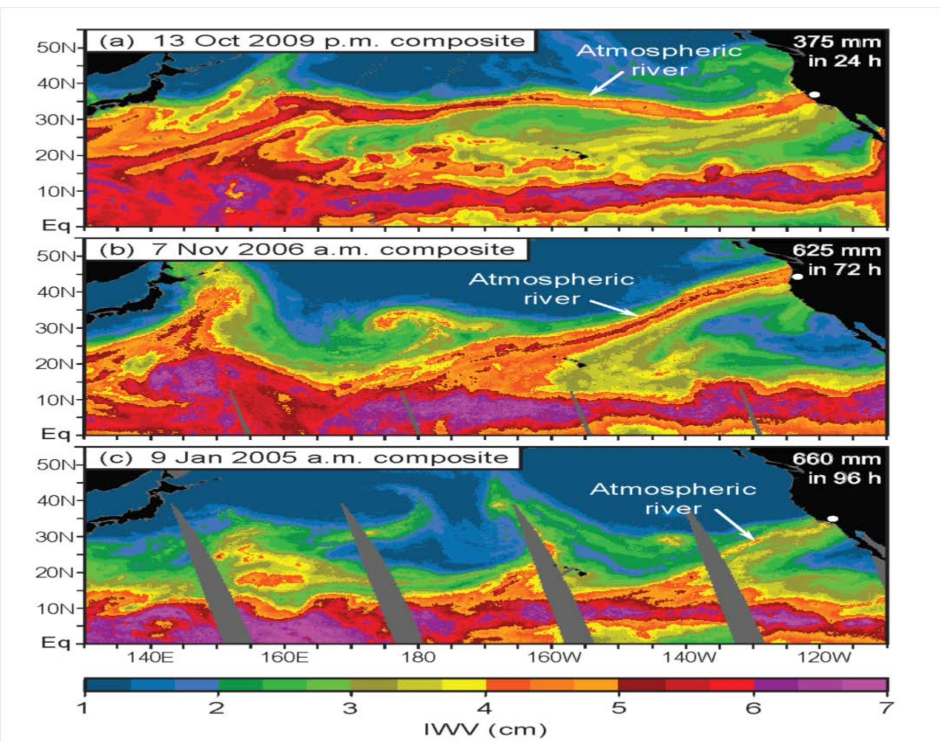
ATMOSPHERIC RIVERS

Source: FEMA; Credit: Mark Wolfe.

Atmospheric Rivers

Introduction



Atmospheric Rivers (AR) are relatively narrow regions in the atmosphere that are responsible for most of the horizontal transport of water vapor outside of the tropics. Examples of strong ARs are shown to the right using satellite data.

Examples (right) of AR events that produced extreme precipitation on the US West Coast, and exhibited spatial continuity with the tropical water vapor reservoir as seen in SSM/I satellite observations of IWV. (From Ralph et al. 2011, Mon. Wea. Rev.)

The color scale used in these images represents the total amount of water vapor between the ocean surface and space. The data are from passive microwave sensors onboard polar orbiting satellites, which measure vertically integrated water vapor (IWV), i.e., the total amount of vapor in the atmosphere from the surface to space (g/cm2).

ARs move with the weather and are present somewhere on the earth at any given time. In the strongest cases ARs can create major flooding when they make landfall. On average ARs are 400-600 kilometers wide. For comparison, a strong AR transports an amount of water vapor roughly equivalent to 10-20 times the average flow of liquid water at the mouth of the Mississippi River.

While ARs come in many shapes and sizes, those that contain the largest amounts of water vapor, the strongest winds, and stall over watersheds vulnerable to flooding, can create extreme rainfall and floods. These events can disrupt travel, induce mud slides, and cause catastrophic damage to life and property. A well-known example of a type of strong AR that can hit the U.S. west coast is the "Pineapple Express," due to their apparent ability to bring moisture from the tropics near Hawaii to the U.S. west coast.

Learn about a scenario for an Atmsopheric River Storm prepared by the U.S. Geological Survey. Not all ARs cause damage – most are weak, and simply provide beneficial rain or snow that is crucial to water supply. In short, ARs are a primary feature in the entire global water cycle, and are tied closely to both water supply and flood risks, particularly in the Western U.S. The improved understanding of ARs and their importance has emerged from roughly a decade of scientific studies that have made use of new satellite, radar, aircraft and other observations and major numerical weather model improvements.

What are they, in more scientific terms?

ARs are the water-vapor rich part of the broader warm conveyor belt (e.g., Browning, 1990; Carlson, 1991), that is found in extratropical cyclones ("storms"). They result from the action of winds associated with the storm drawing together moisture into a narrow region just ahead of the cold front where low-level winds can sometimes exceed hurricane strength.

The term AR was coined in a seminal scientific paper published in 1998 by researchers Zhu and Newell at MIT (Zhu and Newell 1998). Because they found that most of the water vapor was transported in relatively narrow regions of the atmosphere (90% of the transport occurred typically in four to five long, narrow regions roughly 400 km wide), the term atmospheric river was used.

A number of formal scientific papers have since been published building on this concept (see the publication list), and forecasters and climate researchers are beginning to apply the ideas and methods to their fields. The satellite images at right show strong ARs as seen by satellite.
The advent of these specialized satellite observations have revealed ARs over the oceans and have revolutionized understanding of the global importance of ARs (more traditional satellite data available in the past could not clearly detect AR conditions). The interpretation of these satellite images, which represent only water vapor, not winds, was confirmed using NOAA research aircraft data over the Eastern Pacific Ocean and wind profilers along the coast (Ralph et al. 2004). The event shown in the image was documented by Ralph et al. (2006), which concluded this AR produced roughly 10 inches of rain in two days and caused a flood on the Russian River of northern California.
It was also shown that all floods on the Russian River in the seven year period of study were associated with AR conditions. As of late 2010 there have been a number of papers published on major west coast storms where the presence and importance of AR conditions have been documented. These are provided in an informal list of the "Top Ten ARs" of the last several years on the U.S. West Coast.

It is now recognized that the well-known "Pineapple express," storms (a term that has been used on the U.S. West Coast for many years) correspond to a subset of ARs, i.e., those that have a connection to the tropics near Hawaii. In some of the most extreme ARs, the water vapor transport is enhanced by the fact that they entrain (draw in) water vapor directly from the tropics (e.g., Bao et al 2006, Ralph et al. 2011).

Can we forecast atmospheric rivers?

- National Weather Service forecasters located along the west coast are now familiar with the concept of atmospheric rivers and can identify these phenomena in current numerical forecast models. This provides them the capability to give advanced warning of potential heavy rain sometime 5 to 7 days in advance. They have also learned to monitor polar orbiter microwave satellite imagery that provides advanced warning of the presence and movement of these phenomena in the Pacific. During the last two winters, with the development of atmospheric river observatories, forecasters have been able to monitor the strength and location of these rivers as they make landfall and thus improve short-term rainfall forecasts for flash flooding. There are still challenges to predicting rainfall totals in these events as models still struggle with the details of the duration and timing of AR's as they make landfall.

Why are ARs capable of producing extreme rainfall on the U.S. West Coast?

AR conditions are conducive to creating heavy orographic precipitation (Ralph et al., 2005; MWR) because:

- they are rich in water vapor,
- they are associated with strong winds that force the water vapor up mountain sides,
- the atmospheric conditions do not inhibit upward motions (because the atmospheric static stability is nearly neutral up to about three km MSL, on average)
- once the air moves upward, the water vapor condenses and can form precipitation

What is the role of atmospheric rivers in creating floods?

- Research has shown there were 42 ARs that impacted CA during the winters from 1997 to 2006, and the resulting seven floods that occurred on the Russian River watershed northwest of San Francisco during this period were all associated with AR conditions.
- A major flood in California, known as the "New years Day Flood" in 1997 cause over $1 Billion in damages and had a well-defined AR.
- Less formally, ARs are known to result in an order of magnitude larger post-storm stream flow "bumps" (increases) than other California storms, in the Merced and American Rivers.
- The Pacific Northwest also regularly experiences this type of storm. Case in point is the landfalling AR of early November 2006 that produced heavy rainfall and devastating flooding and debris flows with region-wide damage exceeding $50 million.
- The "Top-Ten AR" list highlights additional high-impact AR events.

How are science and applications of ARs being addressed?

- Research experiments (CalJet and PacJet) performed by NOAA in the 1998, 2001, and 2002 were conducted to better understand landfalling Pacific winter storms.
- CalJet/PacJet led to the development of the NOAA Hydrometeorology Testbed (HMT; hmt.noaa.gov). HMT's aim is to accelerate the development and prototyping of advanced

hydrometeorological observations, models, and physical process understanding, and to foster infusion of these advances into forecasting operations of the NWS, and to support the broader user community's needs for 21st Century precipitation information.

- Within HMT, scientists have developed and prototyped an atmospheric river observatory (ARO) designed to further our understanding of the impact of ARs on enhancing precipitation in the coastal mountains and the high Sierra of California.
- Studies of the potential impacts of climate change on AR characteristics is the focus on an ongoing project –CalWater that is partnering with HMT, the California Energy Commission, Scripps Institution of Oceanography, USGS and others, to explore the potential implications for flood risk and water supply.
- Under the USGS-led Multihazards project, ARs have become the focus of an emergency preparedness scenario for California that is intended to help the region prepare for a potentially catastrophic series of ARs. The scenario is named "ARkStorm" and has developed an informational video for use with the public (http://urbanearth.gps.caltech.edu/winter-storm/).

What are the benefits of studying atmospheric rivers?

- The community of flood control, water supply and reservoir operators of the West Coast states see ARs as a key phenomenon to understand, monitor and predict as they work to mitigate the risks of major flood events, while maintaining adequate water supply. The frequency and strength of AR events in a given region over the course of a typical west-coast wet season greatly influences the fate of droughts, floods, and many key human endeavors and ecosystems. Better coupling of climate forecasts with seasonal weather forecasts of ARs can improve water management decisions. Long-term monitoring using satellite measurements, offshore aircraft reconnaissance, and land-based atmospheric river observatories, combined with better numerical modeling, scientific progress, and the development of AR-based smart decision aids for resource managers, will enable society to be more resilient to storms and droughts, while protecting our critical ecosystems.

Source : http://www.eoearth.org/view/article/51cbf0c17896bb431f6a2f0f/?topic=51cbfc78f702fc2ba8129ea9