Observations and predictions of atmospheric rivers: Current capabilities and future challenges associated with extreme precipitation

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Flooding in Western Washington: The Connection to Atmospheric Rivers

by Paul J. Neiman, Lawrence J. Schick, F. Martin Ralph, Mimi Hughes, and Gary A. Wick

*J. Hydrometeorology* (2011)

Of 48 annual peak daily flows on 4 watersheds, 46 were associated with the land-fall of atmospheric river conditions.

The orientation of an atmospheric river strongly influences which specific watersheds receive the most precipitation and highest stream flow.

Atmospheric river conditions can penetrate inland through gaps in complex terrain and impact watersheds farther inland.
Physical Processes Associated with Heavy Flooding Rainfall in Nashville, Tennessee, and Vicinity during 1–2 May 2010: The Role of an Atmospheric River and Mesoscale Convective Systems

Ben Moore, Paul Neiman, Marty Ralph, Faye Barthold


Up to 493 mm rainfall in 2 days caused major flooding.
Winter Floods in Britain are Connected to Atmospheric Rivers

David Lavers, R. Allan, E. Wood, G. Villarini, D. Brayshaw, and A. Wade,
Geophysical Research Letters (2011)
Global distribution of ARs in 2 winters
Geographic locations of AR studies

Formal publications diagnosing AR conditions as key to extreme precipitation and/or flooding
Atmospheric River Observatory

Altitude MSL (km)

0
1
2
3

Atmospheric River

"Controlling layer" (upslope winds)

Surface friction and barrier jet

Ocean

GPS-satellite

Wind profiler beam with 100-m vertical resolution

0-50 km between wind profiler/GPS-met site and S-PROF precipitation profiler

Plan view

Rain shadow

Mountains

AR

PROF

S-PROF data up to 10 km MSL

Orographic cloud and precipitation

Wind profiler (915 or 449 MHz)

10-m surface meteorology tower

GPS-met receiver

S-PROF precipitation profiler; surface met; disdrometer

Snow level

Wind direction in AR

400 km wide

ARO

Heavy rain

Dividing streamline

Heavy rain

Rain shadow

Mountains

0
1
2
3

Atmos. Riv.
An AR-focused long-term observing network is being installed in CA as part of a 5-year project between CA-DWR, NOAA and Scripps Inst. of Oceanography
- Installed 2008-2012
- 93 field sites

California has begun implementation of key land-based sensors
Predictive capability added to ARO at request of NWS

The left side of the figure represents forecasts of AR conditions from a specialized numerical model.

Note that time increases from right to left in this display, which is a meteorological style.
• 12 COSMIC soundings used to construct X-section along NW-SE through the AR
• All soundings (save #12) were acquired in the 3.5-h period 0354 – 0732Z 7-Nov-06
• Even the fastest dropsonde aircraft cannot cover this distance in the allotted time

Cross-section through an Atmospheric River using COSMIC data
Neiman, Ralph, Wick, Kuo, Wee, Ma, Taylor, Dettinger (2008, MWR)
Winter Storms and Pacific Atmospheric Rivers (WISPAR)

J. R. Spackman\textsuperscript{1,2}, G. A. Wick\textsuperscript{1}, M. L. Black\textsuperscript{3}, F. M. Ralph\textsuperscript{1}, Y. Song\textsuperscript{4}, Y. Zhu\textsuperscript{4}, P. J. Neiman\textsuperscript{1}, J. Intrieri\textsuperscript{1}, T. Hock\textsuperscript{5}, B. H. Lambrigtsen\textsuperscript{6}, R. E. Hood\textsuperscript{7}

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\textsuperscript{5}National Center for Atmospheric Research
\textsuperscript{6}NASA Jet Propulsion Laboratory
\textsuperscript{7}NOAA Unmanned Aircraft Systems Program
GH AR Flight, 11-12 Feb 2011, IVT

403 km wide

186x10^6 kg/s flux
SSM/I Observed

GFS Model Analysis

GFS 1-day forecast

GFS 2-day forecast

GFS 5-day forecast

GFS 7-day forecast

“AR Detection Tool” example from 14 March 2012

Satellite observations + GFS Model analysis

GFS Model Forecasts all valid at the same time, but from different lead times

Observed

March 14, 2012 Descending Passes
SSMIS Integrated Water Vapor (Wentz algorithm)

Russian River - Sonoma County Water Agency
1-day GFS Forecast

20120313 024 Hour Forecast
GFS Modeled Water Vapor

Russian River - Sonoma County Water Agency
2-day GFS Forecast

Russian River - Sonoma County Water Agency
5-day GFS Forecast

20120309 120 Hour Forecast

GFS Modeled Water Vapor

Russian River - Sonoma County Water Agency
7-day GFS Forecast

20120307 168 Hour Forecast
GFS Modeled Water Vapor

Russian River - Sonoma County Water Agency
NOAA/HMT Contributed new AR-related methods as part of a broad multi-agency rapid response
This rapid response effort led to many lasting lessons, including demonstration of use of ARO data by the US Army Corps of Engineers (USACE)

- USACE was considering taking over operation of a dam in Washington State during a recent storm.

- Using the HMT ARO at the coast and NWS forecasts, USACE saw the back edge of the AR was coming ashore and thus heavy rain was about to end, so they did not take over operation from the local water agency.

Forecasting Atmospheric Rivers

HMT Findings used in NWS Training

- Improved situational awareness
- Advance lead time that a “big event” may be coming, a few days ahead
- Details on locations, timing and strength improve as event nears, but precipitation amounts are generally underpredicted
Thank You

• Atmospheric Rivers Information Page (includes a detailed publication list)
  – www.esrl.noaa.gov/psd/atmrivers/

• CalWater web page
  – www.esrl.noaa.gov/psd/calwater/

• HMT web page
  – hmt.noaa.gov

• Marty.Ralph@noaa.gov
Assessment of Extreme Quantitative Precipitation Forecasts (QPFs) and Development of Regional Extreme Event Thresholds Using Data from HMT-2006 and COOP Observers

F. M. Ralph, E. Sukovich, D. Reynolds, M. Dettinger, S. Weagle, W. Clark, and P. J. Neiman
Journal of Hydrometeorology (December 2010)

Of the 20 dates with >3 inches of precipitation in 1 day, 18 were associated with ARs.

The Forecasting Challenge

41 West Coast sites were used

Forecasting large precipitation amounts is difficult

On average forecasts are 50% less than observations
Atmospheric River Retrospective Forecast Experiment (ARRFEX)

• 8 past AR events were used to perform an experiment where forecasters from several NWS offices predicted QPF and evaluated new tools and products.

• Forecast offices represented included:
  – NCEP/HPC
  – NWRFC
  – WFOs

• Co-led by HPC and ESRL/PSD within NOAA/HMT

• Conducted in September 2012
Key Features Associated with Atmospheric Rivers and Orographic Precipitation

Physical conditions required for extreme precipitation

- Wind in the controlling layer near 1 km MSL: speed $> 12.5$ m/s, and preferred direction
- Water vapor content: vertically integrated water vapor (IWV) $> 2$ cm
- Snow level: Above top of watershed
Planetary- and synoptic-scale conditions in the March 2005 case

(a) Planetary-scale conditions including tropical and midlatitude waves; 24-26 Mar 2005

BWP propagation

Atmospheric river

A Anticyclone
C Cyclone
K Kelvin wave
MJO Madden-Julian Oscillation
Research has identified Atmospheric Rivers as the primary meteorological cause of extreme precipitation & flooding on the U.S. West Coast. 

Central CA

> 15 inches rain

Vertically integrated water vapor, g/cm²

Discharge at Nacimiento River (USGS 11148900) ▲

Daily Streamflow Ranking for 14 Oct 2009 Relative to Historic Records at Each Site

California's storms are as big as any in the country, primarily due to Atmospheric River events.

Atmospheric Rivers, Floods and the Water Resources of California
by Mike Dettinger, Marty Ralph, Tapash Das, Paul Neiman, Dan Cayan
*Water, 2011*

25-35% of annual precipitation in the Pacific Northwest fell in association with atmospheric river events.

35-45% of annual precipitation in California fell in association with atmospheric river events.
Extreme Snowfall Events Linked to Atmospheric Rivers and Surface Air Temperature via Satellite Measurements

Bin Guan, Noah P. Molotch, Duane E. Waliser, Eric J. Fetzer, and Paul J. Neiman


- On average 6-7 AR events provided 30-40% of total seasonal SWE accumulation in most years, dominated by 1-2 extreme events in some cases.

- ARs generated ~4 times as much daily SWE accumulation compared to non-AR events for 2004-10.
- Colder (warmer) surface air temperature was observed for high (low)-impact ARs.
Phasing of tropical and extratropical conditions leading to entrainment of tropical water vapor into the AR

The frontal wave increased the duration of AR conditions where the extreme precipitation occurred

(b) Synoptic-scale conditions including baroclinic wave packet; 24-26 Mar 2005

(c) Mesoscale conditions including frontal wave; 26-27 Mar 2005
Flooding on California’s Russian River: Role of atmospheric rivers

Ralph, F.M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, D. R. Cayan, A. White


- SSM/I satellite image shows atmospheric river
- Stream gauge data show regional extent of high stream flow
  Covering roughly 500 km of coast

This paper showed that flooding on the Russian River is associated with atmospheric rivers (all 7 floods over 8 years).

If a strong AR stalls for 12-36 hours, it can create flooding.