ATMOSPHERIC RIVERS & CALIFORNIA

Water Education Foundation’s 36th Annual Water Summit
October 30, 2019

Marty Ralph, CW3E Director
Rob Hartman, RKHCS
CALIFORNIA HAS GREATEST VARIABILITY OF ANNUAL PRECIPITATION IN THE U.S.

Coefficient of variation for annual Precipitation, 1950-2008

A FEW LARGE STORMS (OR THEIR ABSENCE) account for a disproportionate amount of CA’s precipitation variability

85% of interannual variability results from how wet the 5% wettest days are each year.

These days are mostly atmospheric river events.

ATMOSPHERIC RIVERS (ARs)

ARs ARE IMPORTANT FOR WATER SUPPLY.

Gershunov et al., 2017, GRL.
Flooding on California’s Russian River: Role of atmospheric rivers


ARs CAN CAUSE FLOODS

Atmospheric Rivers Drive Flood Damages in the Western US

ATMOSPHERIC RIVER FORECAST CHALLENGES

Russian River at Guernville, February 22-27, 2019 Forecasts

Forecast changed by 20 feet in the four days before AR landfall.
At 4-7 days lead time, AR position error is between 190-370 miles (300-600 km).

Mesoscale (100-1000 km) interactions can make forecasts difficult.

Nardi et al., 2018, Monthly Weather Review

Low pressure system interacts with AR causing AR to stall.

CW3E Post Event Summary: 25-27 Feb 2019
AR Reconnaissance

AR Recon, in its third year, supports improved prediction of landfalling atmospheric rivers on the US west coast, which is a type of storm that is key to the region’s precipitation, flooding and water supply. This campaign has been conducted with participation of experts on midlatitude dynamics, atmospheric rivers, airborne reconnaissance, and numerical modeling, who have come together from various organizations.
CW3E has developed West-WRF to:
1. Serve as a testbed for understanding physical processes and their relationship to forecast error.
2. Improve the accuracy of extreme event forecasts. In the western US, these events pose unique challenges (see table)

Project Sponsors & Partners: USACE, NSF XSEDE, SDSC, CA DWR, NCAR

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Primary NWP Shortcoming</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR Landfall Characteristics</td>
<td>Location and strength of water vapor flux</td>
<td>Wick et al. (2013)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ralph et al. (2017)</td>
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<tr>
<td>Extreme Precipitation Skill</td>
<td>Over prediction of light rain,</td>
<td>Ralph et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Under prediction of extreme amounts</td>
<td>Ralph and Dettinger (2012)</td>
</tr>
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<td></td>
<td></td>
<td>Sukovich et al. (2014)</td>
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<tr>
<td>Snow level</td>
<td>Low precision, Biases near terrain</td>
<td>White et al., (2010)</td>
</tr>
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<td></td>
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<td>Neiman et al. (2014)</td>
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<tr>
<td></td>
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<td>Minder and Kingsmill (2013)</td>
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</tbody>
</table>
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Forecasts of Opportunity

MJO Phase 8 forecasts (red) have lower false alarm rates at week-2 lead than ave

DeFlorio et al., 2019

Experimental AR Week 3 Forecasts

Increase AR activity

DeFlorio et al., 2019
MACHINE LEARNING TO IMPROVE AR FORECASTS

Chapman et al., 2019, *GRL*.

Improvements through 7 days of lead time
- RMSE reduced 9-17%
- Correlation increased 0.5-12%

GFS (4-day lead) of IVT Forecast (% improvement of RMSE)
AR FORECASTING TOOLS: LANDFALL TOOL

GFS Ensemble Probability of IVT > 250 kg/(ms)  
Model Run: 00Z Mon 2 Apr 2018

Forecast Day from 00Z on Mon 2 Apr 2018

https://cw3e.ucsd.edu/iwv-and-ivt-forecasts/
AR FORECASTING TOOLS: PLUME DIAGRAMS

https://cw3e.ucsd.edu/iwv-and-ivt-forecasts/
In WYs 2018 & 2019 CW3E posted 68 news items on ARs.

AR OUTLOOKS, UPDATES & SUMMARIES (CW3E.UCSD.EDU)

AR Updates and Outlooks provide forecast information of a forecasted AR.

AR Summaries provide information the meteorology and impacts of AR events.
A Scale to Characterize the Strength and Impacts of Atmospheric Rivers

F. Martin Ralph (SIO/CW3E), J. J. Rutz (NWS), J. M. Cordeira (Plymouth State), M. Dettinger (USGS), M. Anderson (CA DWR), D. Reynolds (CfRES), L. Schick (USACE), C. Smallcomb (NWS); Bull. Amer. Meteor. Soc. (Feb. 2019); DOI/10.1175/BAMS-D-18-0023.1

The AR level of an AR Event* is based on its Duration** and max Intensity (IVT)***

<table>
<thead>
<tr>
<th>Cat</th>
<th>Name</th>
<th>AR Intensity</th>
<th>Maximum IVT (kg m&lt;sup&gt;-1&lt;/sup&gt;s&lt;sup&gt;-1&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Primarily hazardous</td>
<td>Exceptional</td>
<td>1250</td>
</tr>
<tr>
<td>4</td>
<td>Mostly hazardous, also beneficial</td>
<td>Extreme</td>
<td>1150</td>
</tr>
<tr>
<td>3</td>
<td>Balance of beneficial and hazardous</td>
<td>Strong</td>
<td>1050</td>
</tr>
<tr>
<td>2</td>
<td>Mostly beneficial, also hazardous</td>
<td>Moderate</td>
<td>950</td>
</tr>
<tr>
<td>1</td>
<td>Primarily beneficial</td>
<td>Weak</td>
<td>800</td>
</tr>
<tr>
<td>0</td>
<td>Not an AR</td>
<td></td>
<td>250</td>
</tr>
</tbody>
</table>

**How long IVT > 250 at that location. If duration is < 24 h, reduce AR by 1, if longer than 48 h, add 1.

***This is the max IVT at the location of interest during the AR.

### Determining AR Intensity and AR Category

**Step 1:** Pick a location
**Step 2:** Determine a time period when IVT > 250 (using 3 hourly data) at that location, either in the past or as a forecast. The period when IVT continuously exceeds 250 determines the start and end times of the AR, and thus also the AR Duration for the AR event at that location.

**Step 3:** Determine AR Intensity
- Determine max IVT during the AR at that location
- This sets the AR Intensity and preliminary AR CAT

**Step 4:** Determine final value of AR level to assign
- If the AR Duration is > 48 h, then promote by 1 level
- If the AR Duration is < 24 h, then demote by 1 level

- An “AR Event” refers to the existence of AR conditions at a specific location for a specific period of time.

IMPACTS

- AR 5 – Primarily hazardous
- AR 4 – Mostly hazardous, also beneficial
- AR 3 – Balance of beneficial and hazardous
- AR 2 – Mostly beneficial, also hazardous
- AR 1 – Primarily beneficial

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The Oroville Event

On the Web: CW3E.UCSD.EDU
On Twitter: @CW3E_Scripps
Atmospheric Rivers Highlighted in the U.S. Fourth National Climate Assessment, released on 3 November 2017

1. Tropical Cyclones (Hurricanes and Typhoons)
2. Severe Convective Storms (Thunderstorms)
3. Winter storms
4. Atmospheric Rivers (NEW in 4th Assessment)

5. The frequency and severity of landfalling “atmospheric rivers” on the U.S. West Coast (narrow streams of moisture that account for 30%-40% of the typical snowpack and annual precipitation in the region and are associated with severe flooding events) will increase as a result of increasing evaporation and resulting higher atmospheric water vapor that occurs with increasing temperature. (Medium confidence)
Precipitation Regime change in Western North America: The role of Atmospheric Rivers

WHAT IS FORECAST INFORMED RESERVOIR OPERATIONS (FIRO)?

FIRO is a proposed management strategy that uses data from watershed monitoring and modern weather and water forecasting to help water managers selectively retain or release water from reservoirs in a manner that reflects current and forecasted conditions.
WHY FORECAST INFORMED RESERVOIR OPERATIONS (FIRO)?

"MAKING THE MOST OF A LIMITED RESOURCE"

- Many dams authorized and constructed with multiple purposes
  - Flood control, water supply, recreation, navigation, etc.
  - Management strategies are often in conflict
- Standard reservoir operating procedures generally don’t include the leveraging of forecast information
  - Engineered when forecast skill was very limited (40+ years ago)
- Pressure on water resources is increasing
  - Growing population and demand
  - Resiliency to climate change and climate variability
  - Encroachment of natural flood plains
- Good dam sites have largely been constructed...
Can we save some of this water? To prevent low storage?

Different storage outcomes

About the same total rainfall WY2012 ≈ WY2013

Timing very different

Lake Mendocino Storage Water Years 2012 & 2013
CURRENT USACE / CW3E FIRO PROJECTS

Russian River
Lake Mendocino
2014

Santa Ana River
Prado Dam
2017

Yuba-Feather
Oroville and New Bullards Bar
2019
1. Partner with local sponsoring agency
   • Lake Mendocino – Sonoma Water
   • Prado Dam – Orange County Water District
   • Yuba-Feather System – Yuba Water Agency and CA State Water Project
2. Form a Steering Committee with a support team
3. Initiate research investigations
4. Develop Workplan for the Viability Assessment
5. Conduct the Viability Assessment
6. Pursue an update to the Water Control Manual
Recognizes, develops, and supports relationships
VIABILITY ASSESSMENT COMPONENTS

Scientific Research & Development
- Hydrology & WR Engineering
- Weather Forecasting
- S2S
- AR Detection / Awareness
- Observations & Monitoring

Interim Operations
- Technical Studies
- Decision Support System
- Major Deviations (testing)
- Evaluation of Water Control Plan Alternatives

Request Water Control Manual Update
FIRO MODEL FOR ADAPTIVE WATER CONTROL MANUALS

Flood Risk Management Objectives

Improved Water Supply Reliability
Environmental Conditions
Societal Benefits

Met/Exceeded

Ongoing Research and Development

Changes in baseline conditions (e.g. climate change or regulations)

Weather and Water Forecasts

Formulation and Evaluation of Revised Management Alternative

Observations

Adaptive Water Control Plan

WCM
Thank You