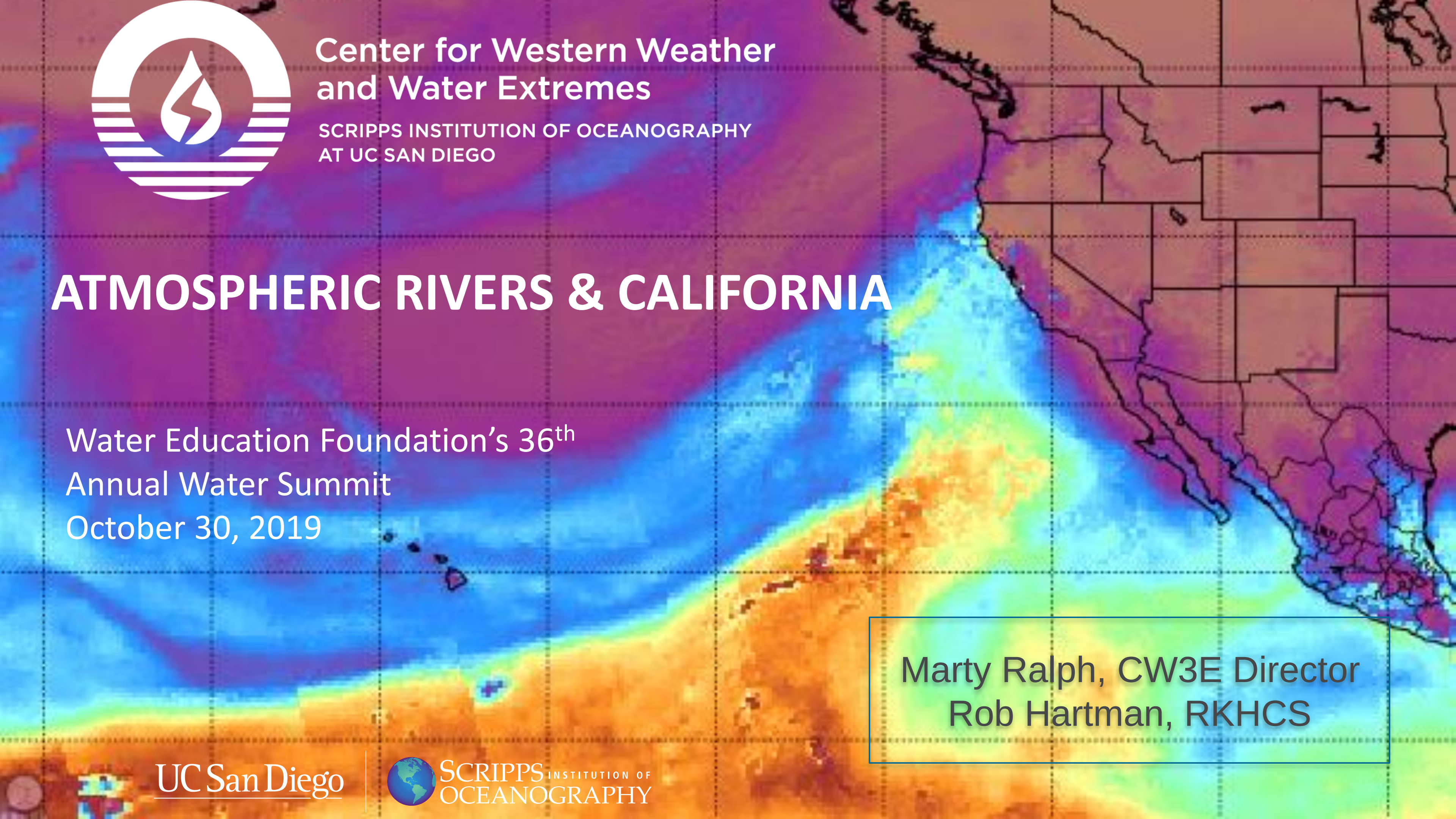


Center for Western Weather and Water Extremes

SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

ATMOSPHERIC RIVERS & CALIFORNIA

Water Education Foundation's 36th Annual Water Summit

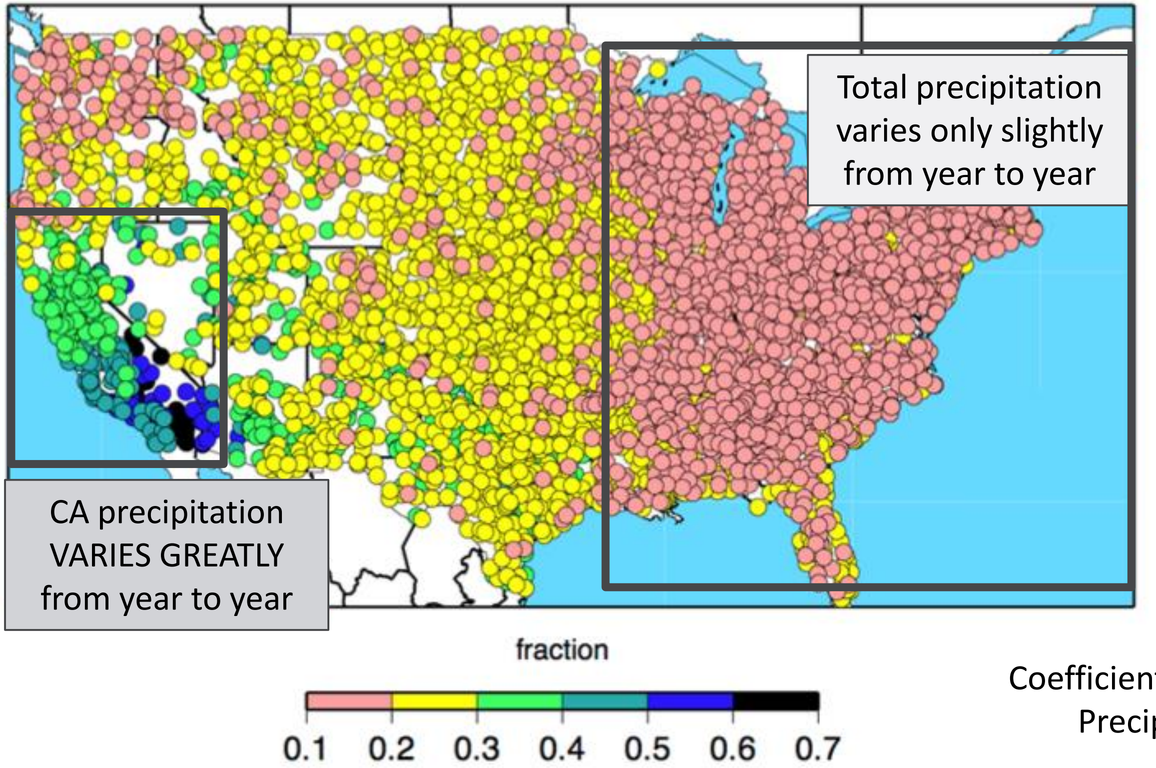
October 30, 2019

Marty Ralph, CW3E Director

Rob Hartman, RKHCS

UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

CALIFORNIA HAS GREATEST VARIABILITY OF ANNUAL PRECIPITATION IN THE U.S.



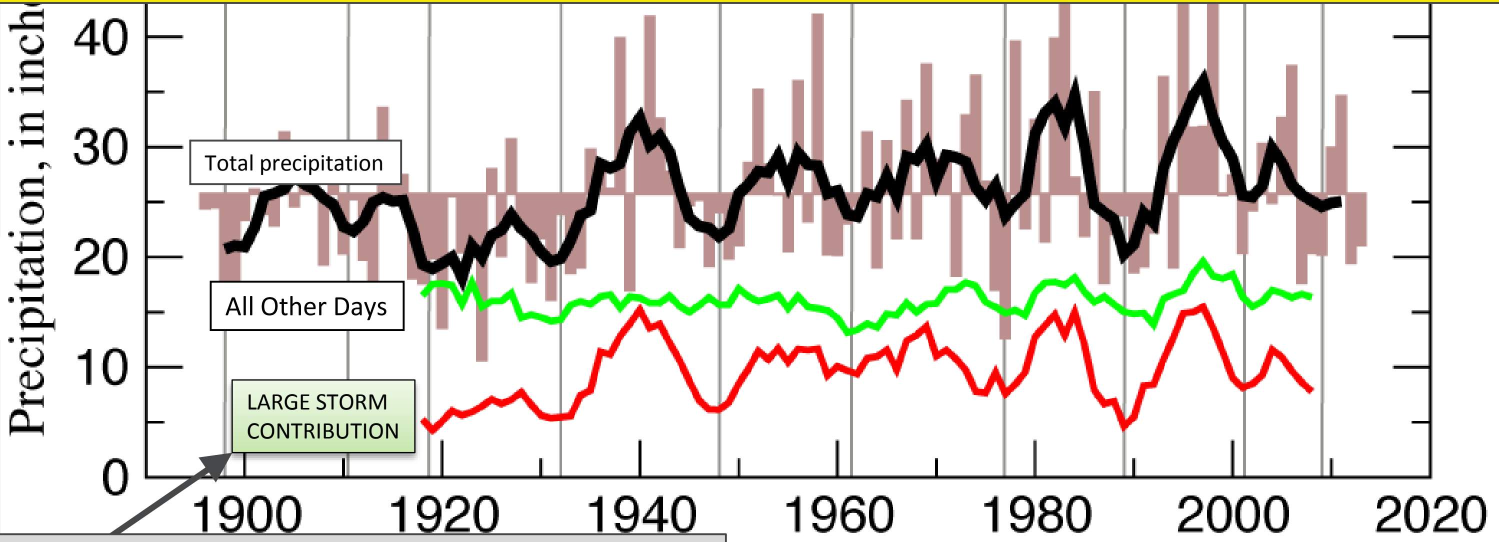
Coefficient of variation for annual Precipitation, 1950-2008

Dettinger, M.D., Ralph, F.M., Das, T., Neiman, P.J., and Cayan, D., 2011: **Atmospheric rivers, floods, and the water resources of California**. *Water*, **3**, 455-478.

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

a) Water-Year Precipitation, Delta Catchment

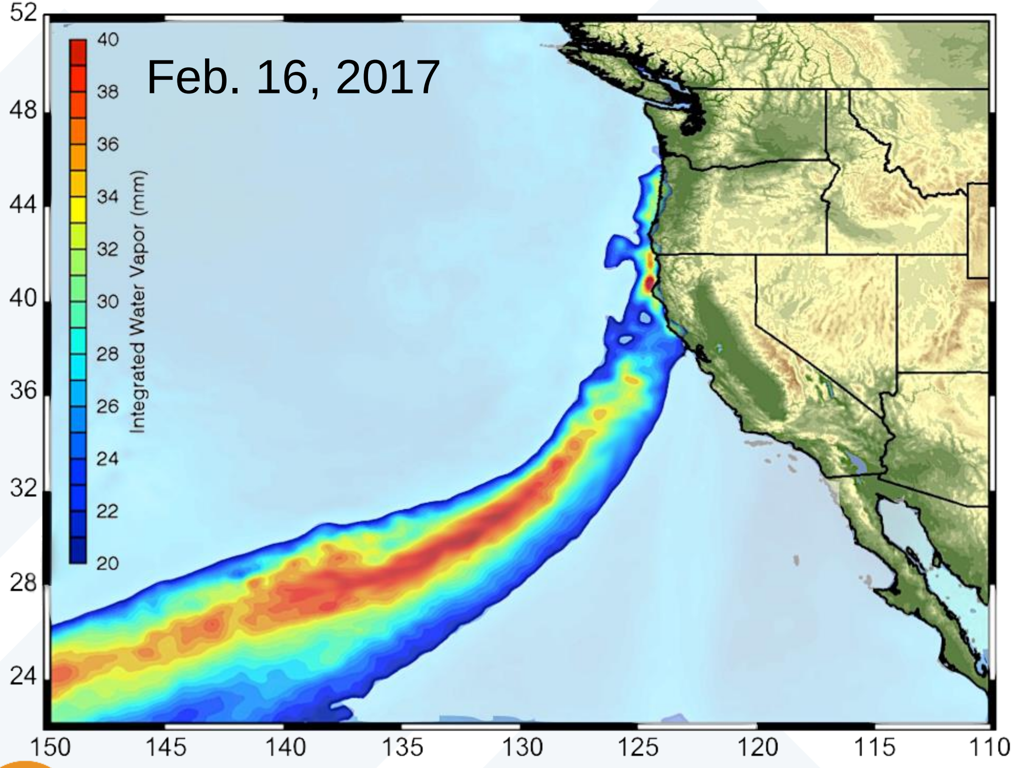
WHETHER A YEAR WILL BE WET OR DRY IN CALIFORNIA IS MOSTLY DETERMINED BY THE NUMBER AND STRENGTH OF ATMOSPHERIC RIVERS STRIKING THE STATE.



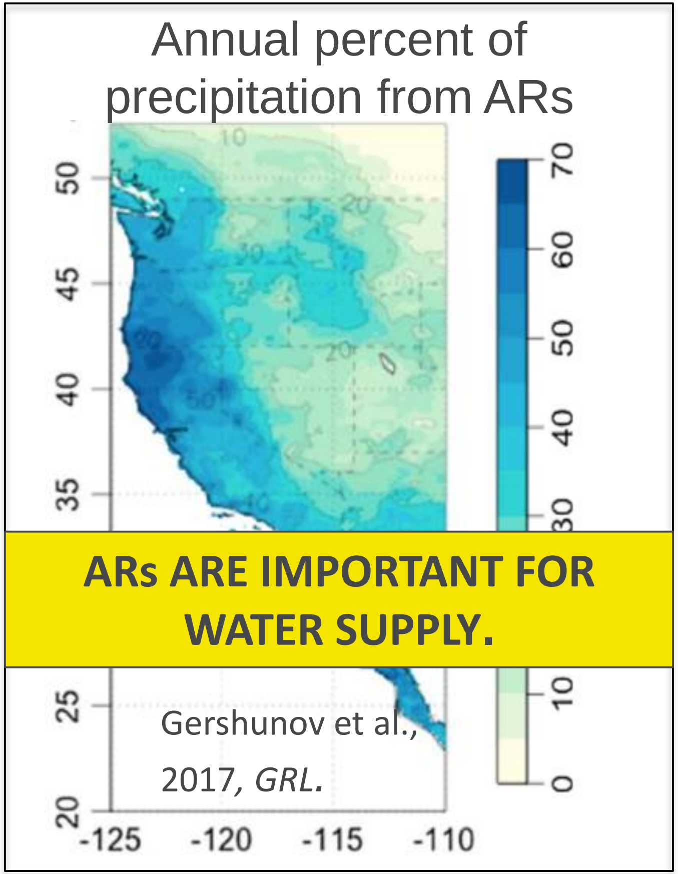
- 85% of interannual variability results from how wet the 5% wettest days are each year.
- These days are mostly atmospheric river events.

Dettinger and Cayan, **Drought and the Delta—A Matter of Extremes,** *San Francisco Estuary and Watershed Science, 2014.*

ATMOSPHERIC RIVERS (ARs)

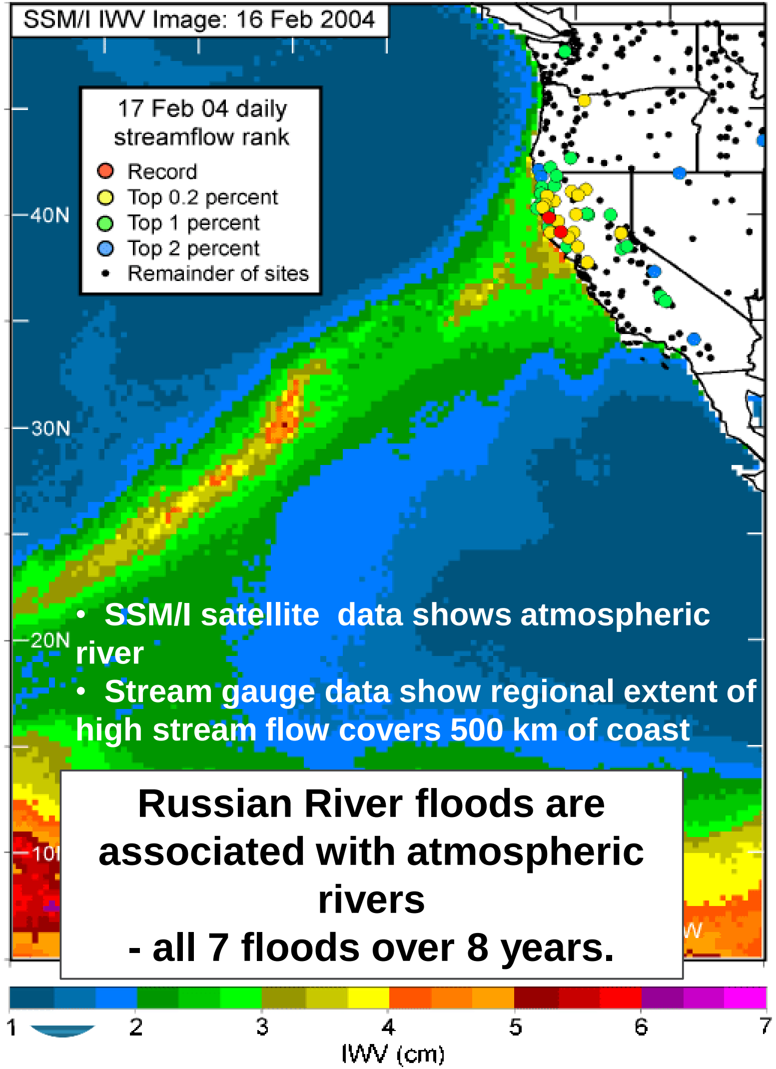


F. Cannon



Gershunov et al., 2017, *GRL.*

ARs ARE IMPORTANT FOR WATER SUPPLY.



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

Russian River floods are associated with atmospheric rivers
- all 7 floods over 8 years.

Flooding on California's Russian River: Role of atmospheric rivers

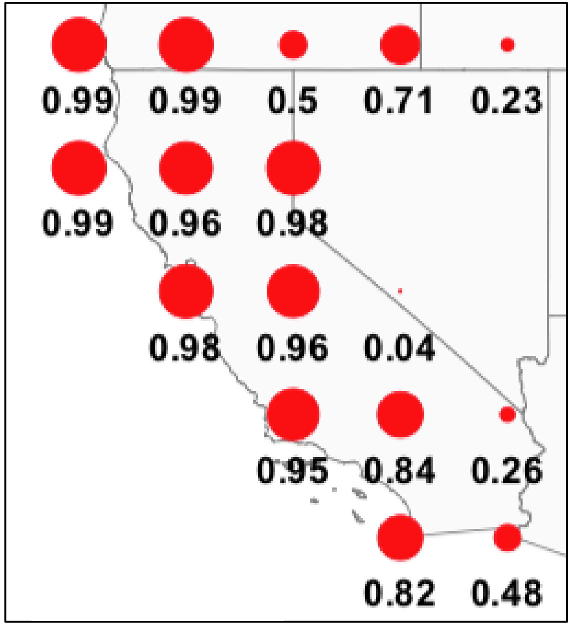
Ralph, F.M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, D. R. Cayan, A. White (*Geophys. Res. Lett., 2006)*

ARs CAN CAUSE FLOODS

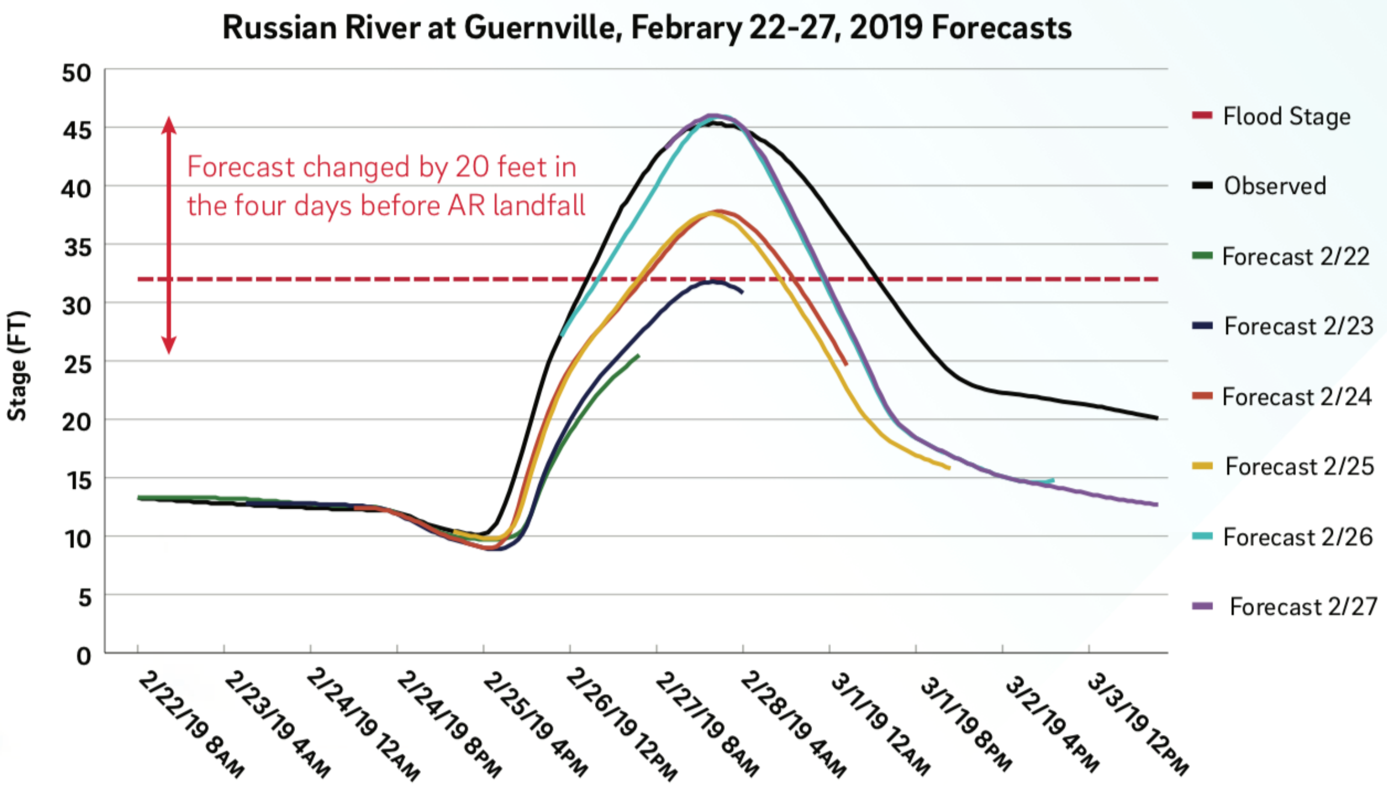
Atmospheric Rivers Drive Flood Damages in the Western US

Corringham, Thomas W., F. Martin Ralph, Alexander Gershunov, Daniel R. Cayan, and Cary A. Talbot, (Sci. Adv., in press, 2019).

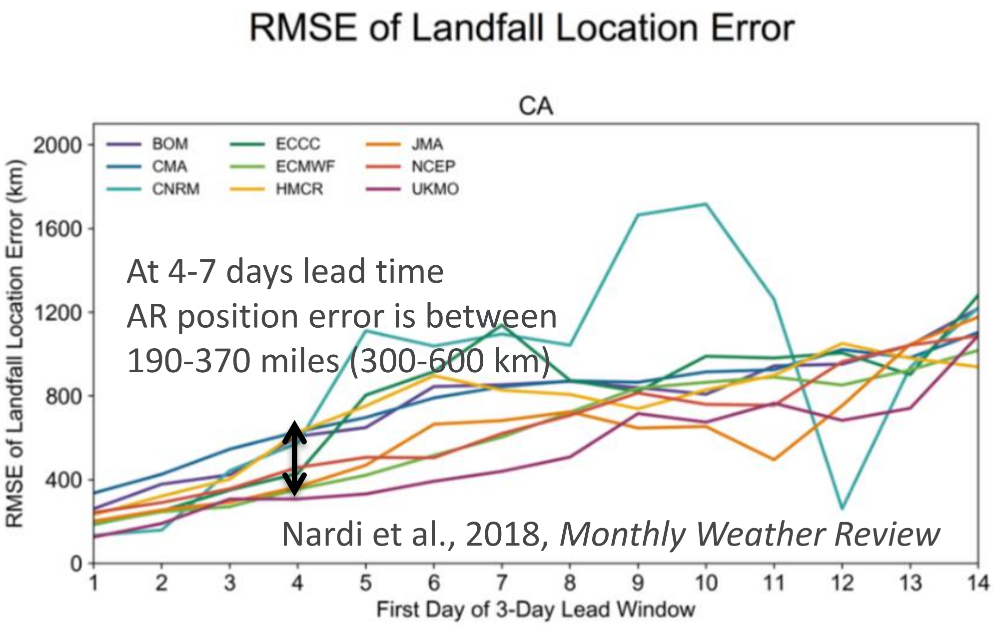
Insured Losses due to ARs



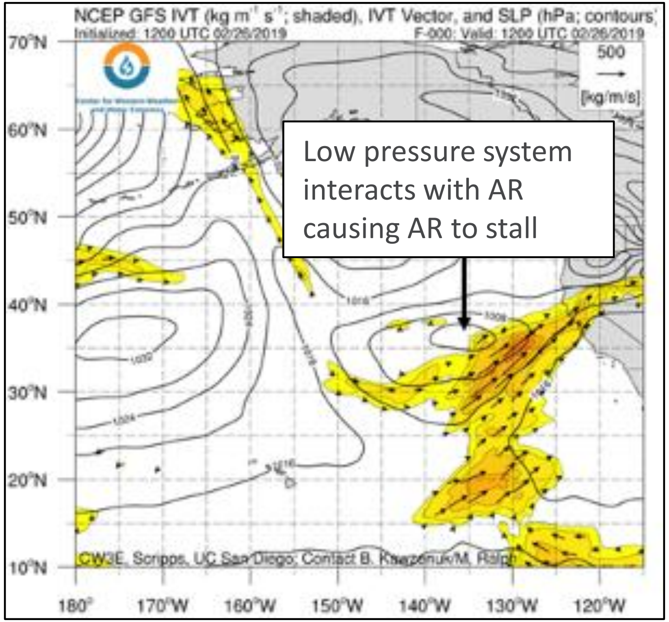
ATMOSPHERIC RIVER FORECAST CHALLENGES



ATMOSPHERIC RIVER FORECAST CHALLENGES

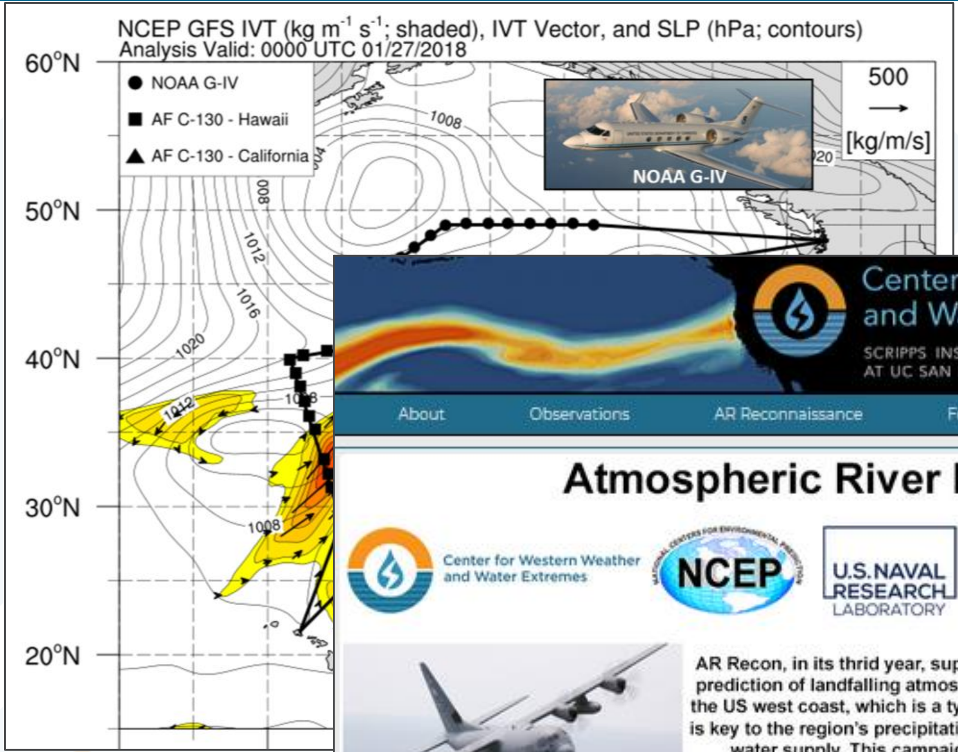


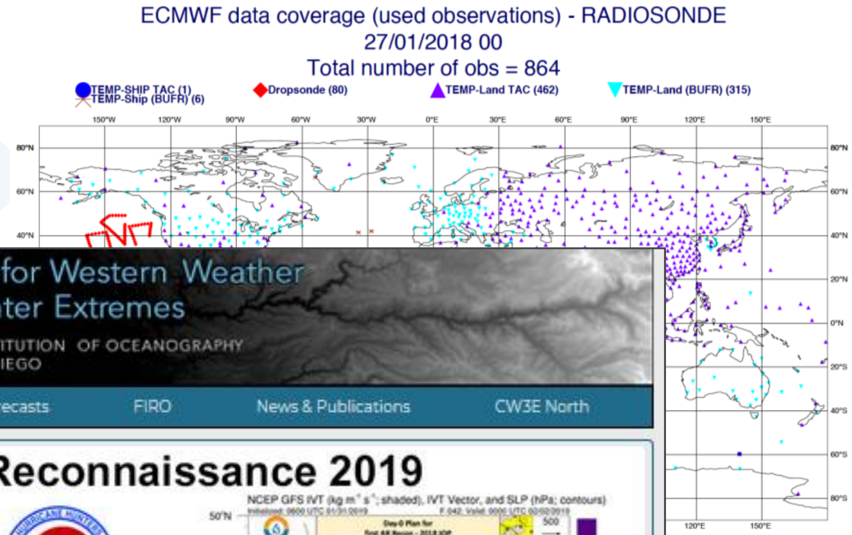
Mesoscale (100-1000 km) interactions can make forecasts difficult



CW3E Post Event Summary: 25- 27 Feb 2019

AR RECONNAISSANCE



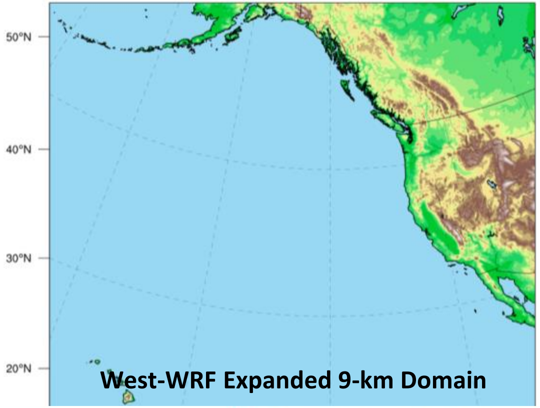


WEST-WRF: REGIONAL WEATHER FORECAST MODEL

CW3E has developed West-WRF to:

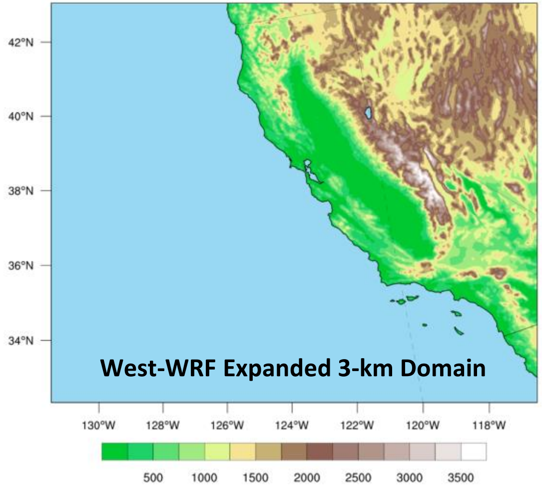
1. Serve as a testbed for understanding physical processes and their relationship to forecast error.
2. Improve the accuracy of extreme event forecasts. In the western US, these events pose unique challenges (see table)

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



Unique Forecast Challenges Posed by Western Extreme Events

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



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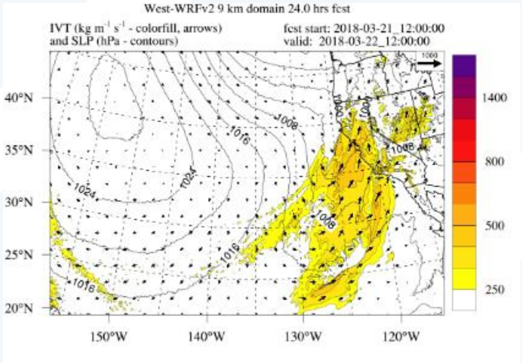
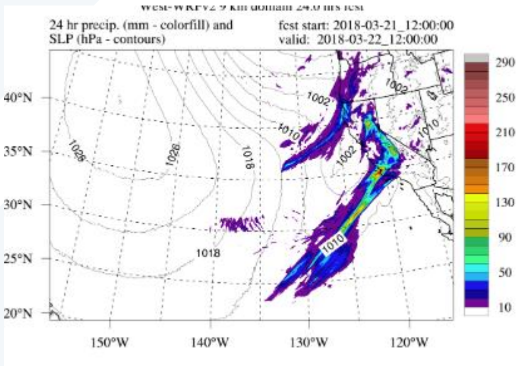
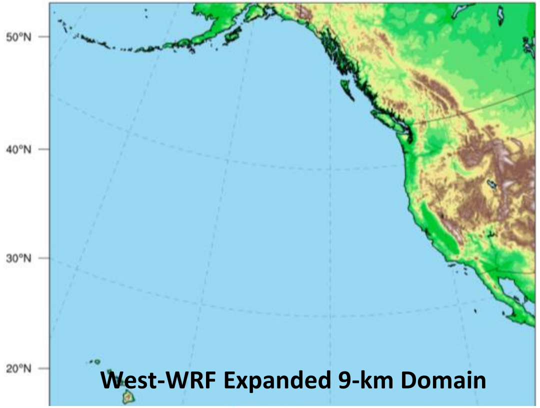
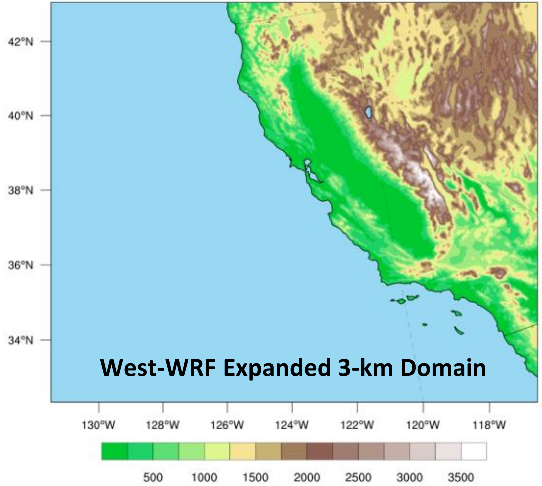
Project Sponsors & Partners: USACE, NSF XSEDE, SDSC, CA DWR, NCAR

WEST-WRF FORECASTS AVIALBLE AT CW3E.UCSD.EDU DEC-MAR



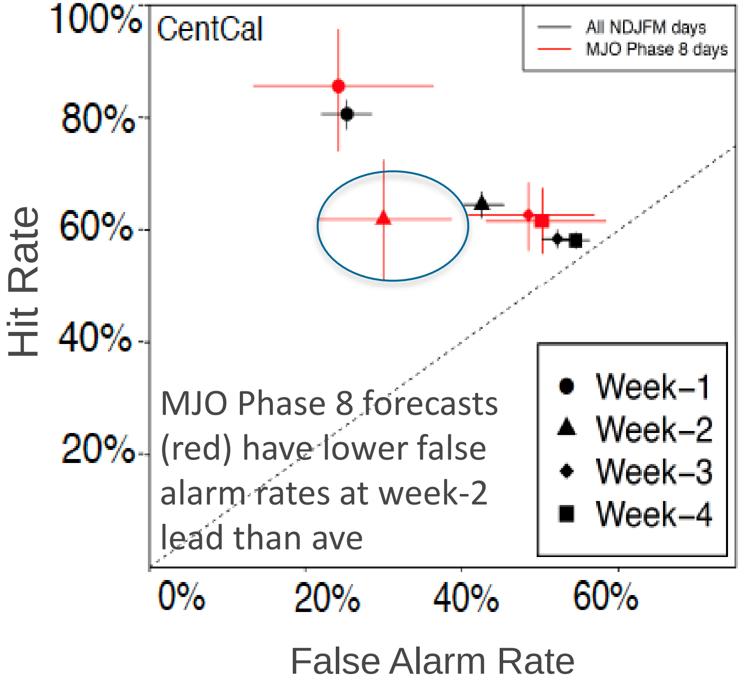






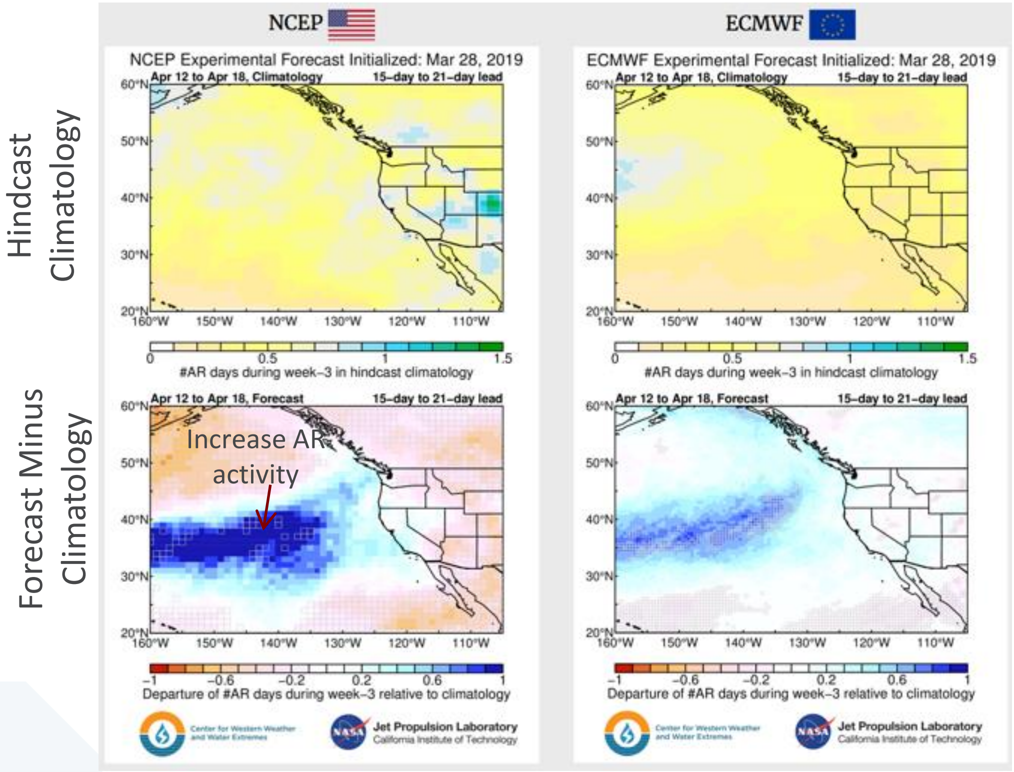
SUBSEASONAL AR FORECASTS

Forecasts of Opportunity



DeFlorio et al., 2019

Experimental AR Week 3 Forecasts

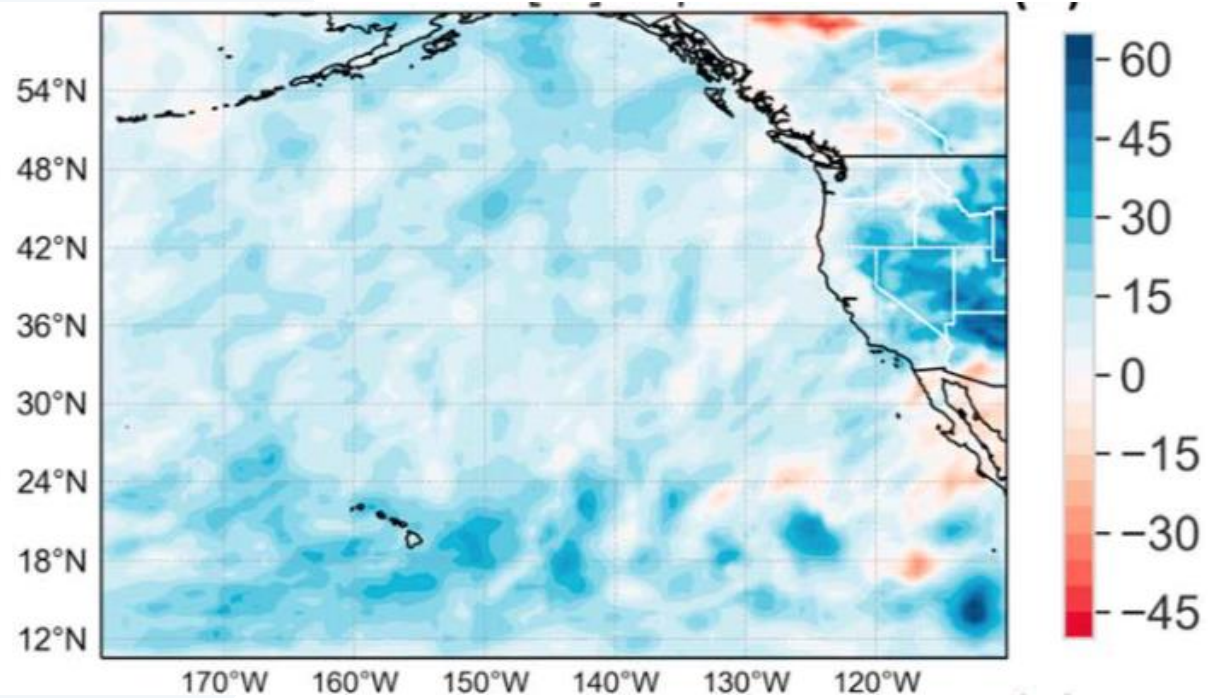


MACHINE LEARNING TO IMPROVE AR FORECASTS

Improvements through 7 days of lead time

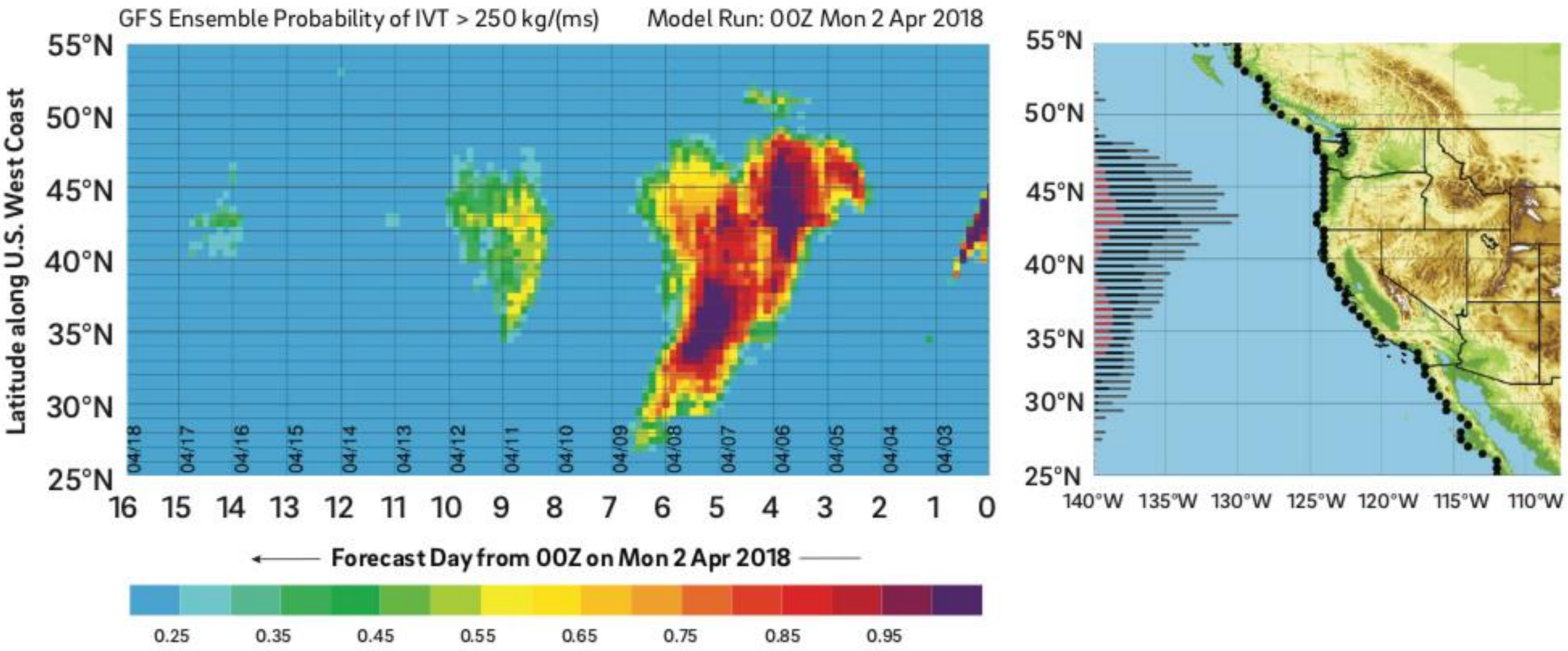
- RMSE reduced 9-17%
- Correlation increased 0.5-12%

GFS (4-day lead) of IVT Forecast
(% improvement of RMSE)



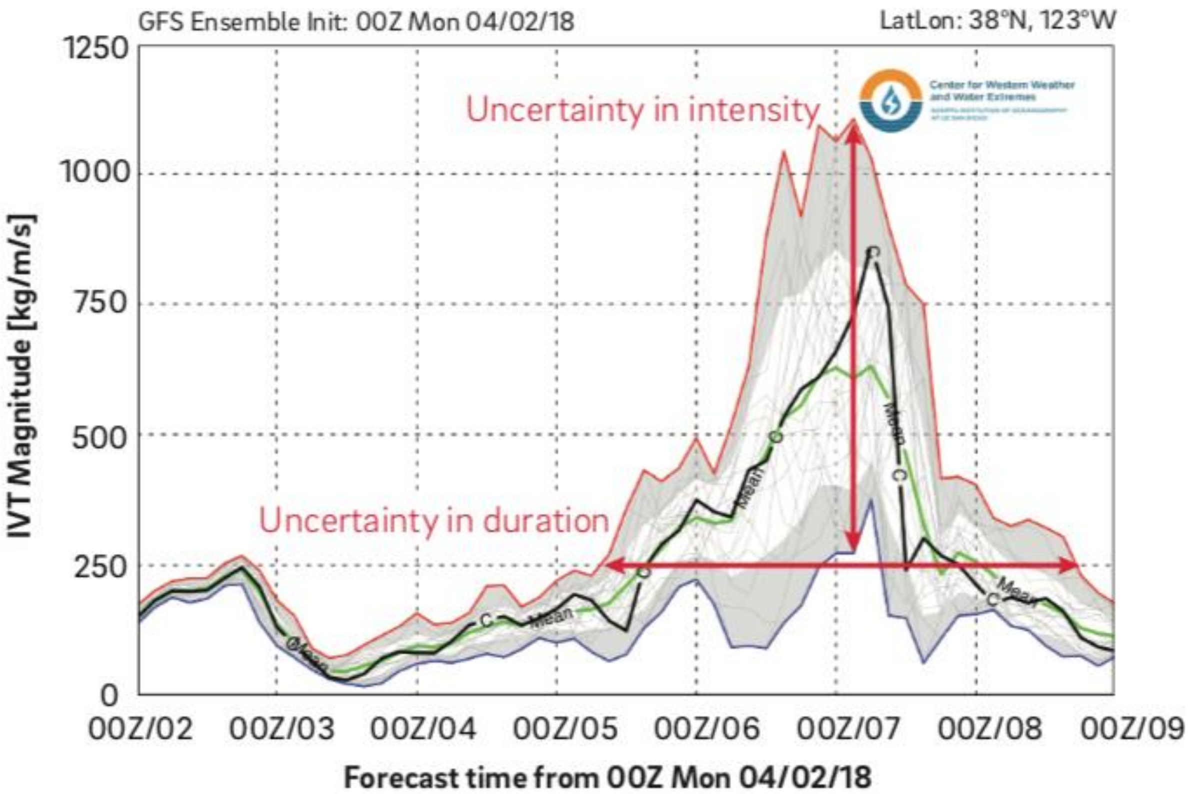
Chapman et al., 2019, *GRL*.

AR FORECASTING TOOLS: LANDFALL TOOL



https://cw3e.ucsd.edu/iwv-and-ivt-forecasts/

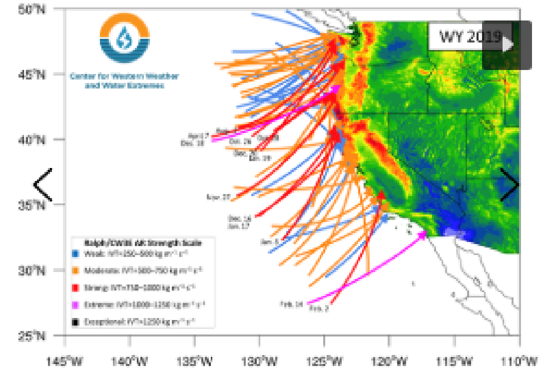
AR FORECASTING TOOLS: PLUME DIAGRAMS



https://cw3e.ucsd.edu/iwv-and-ivt-forecasts/

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

CW3E News



Distribution of Landfalling Atmospheric Rivers over the U.S. West Coast During Water Year 2019: End of Water Year Summary

In WYs 2018 & 2019 CW3E

CW3E AR Update: 25 February Outlook

February 25, 2019

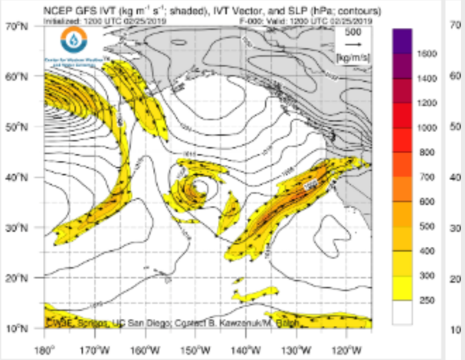
Click here for a pdf of this information.

Two ARs to bring heavy precipitation to CA over the next se

- The AR currently making landfall over northern CA is exp precipitation over northern CA over the next three days.
- This **Category 3 AR** is forecast to produce up to 15 inches 10+ inches over portions of coastal CA.
- A second AR is predicted to make landfall over Southern a
- The AR on 2 March is currently predicted to be weaker and of shorter duration than the first AR, but could still produce an additional 3-5 inches of precipitation over central CA.

Click IVT or IWV image to see loo

Valid 1200 UTC 25 February -



AR Updates and Outlooks provide Forecast Information of a forecasted AR

AR Summaries provide information the meteorology and impacts of AR events

AR Event Summary: 13-14 February 2019

The high precipitation accumulations and high winds produced by this event led to numerous impacts across the state of California

Flooding associated with the Holy Fire burn area in Riverside led to several evacuations and damage/destruction to several homes (as reported by CalFire)

Numerous roadways throughout the state were closed due to flooding, snow, high winds, and damage
- I-80 over Donner Summit due to snow and high winds
- I-5 northbound in Colusa County due to flooding
- HWY 50 in Sierra due to avalanche mitigation
- HWY 243 in Lake Fulmore due to collapsed roadway
- Visit CalTrans for a more thorough list of roadway impacts

The saturated soils in many areas across the state and intense rainfall created conditions conducive to slope failure
- A shallow landslide that mobilized into a debris flow in Sausalito (Marin County) destroyed three homes

A Scale to Characterize the Strength and Impacts of Atmospheric Rivers

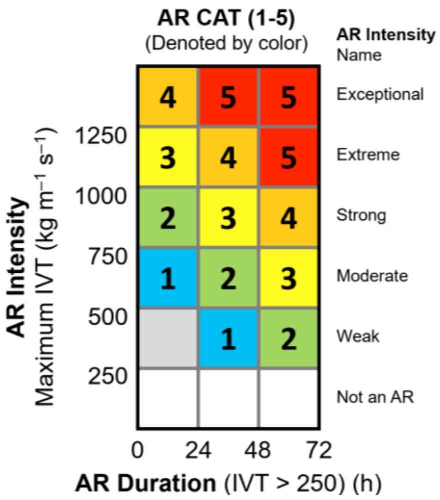
F. Martin Ralph (SIO/CW3E), J. J. Rutz (NWS), J. M. Cordeira (Plymouth State), M. Dettinger (USGS), M. Anderson (CA DWR), D. Reynolds (CIRES), L. Schick (USACE), C. Smallcomb (NWS); *Bull. Amer. Meteor. Soc. (Feb. 2019); DOI/10.1175/BAMS-D-18-0023.1*

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

** An "AR Event" refers to the existence of AR conditions at a specific location for a specific period of time.*
*** 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.*

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



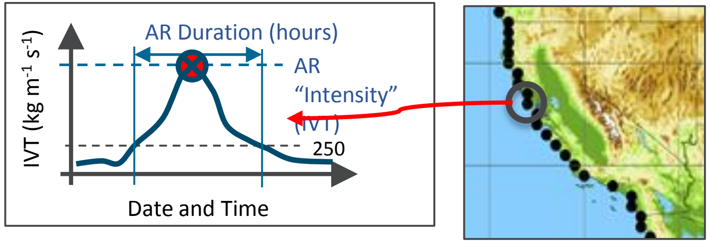
__**Determining AR Intensity and AR Category**__

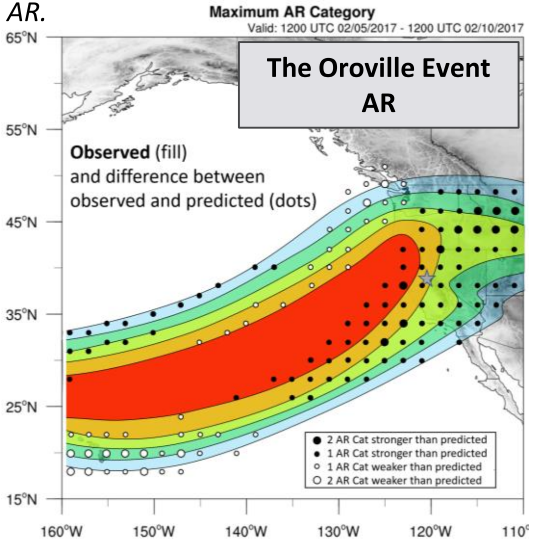
Step 1: Pick a location

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

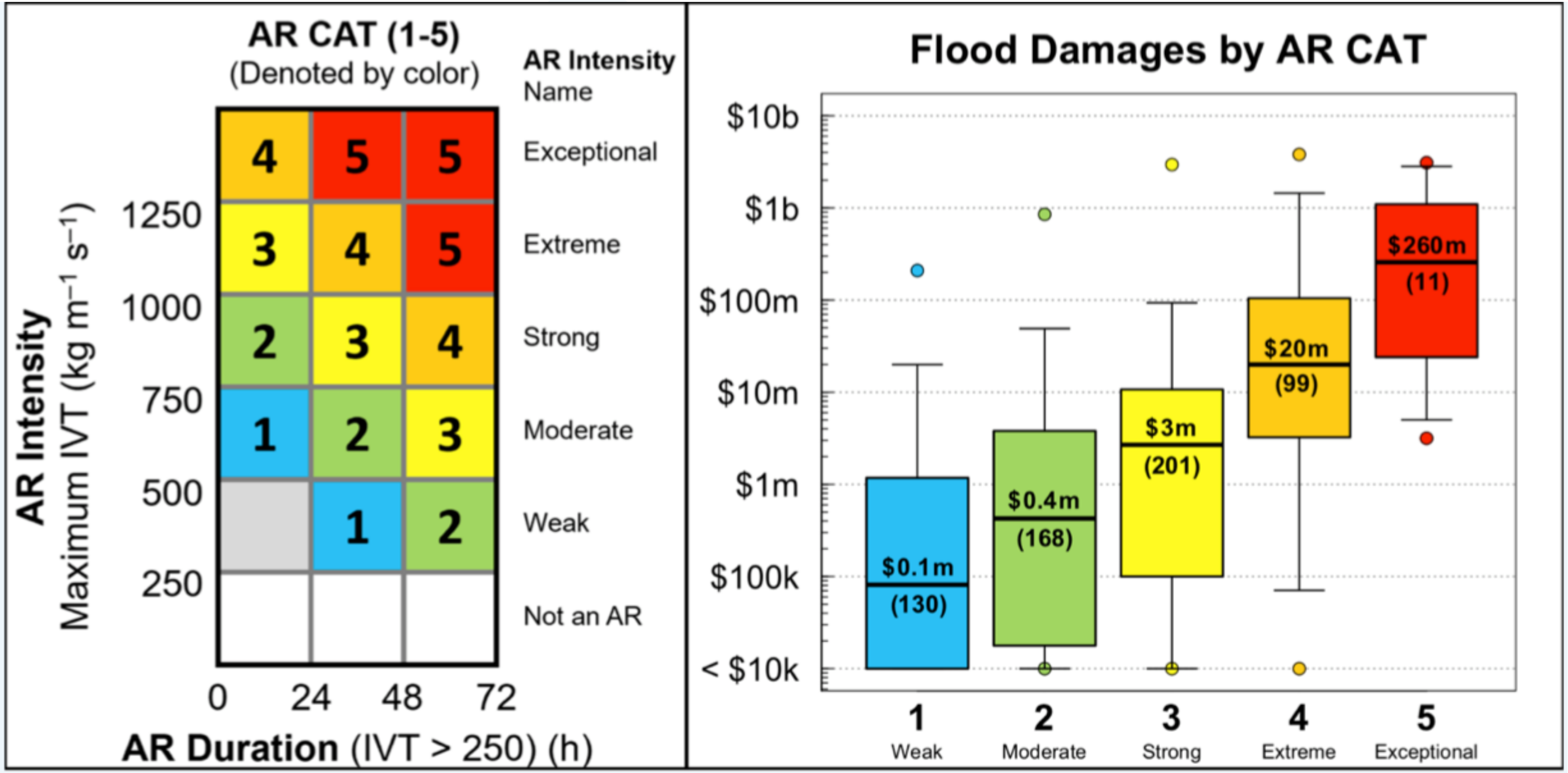




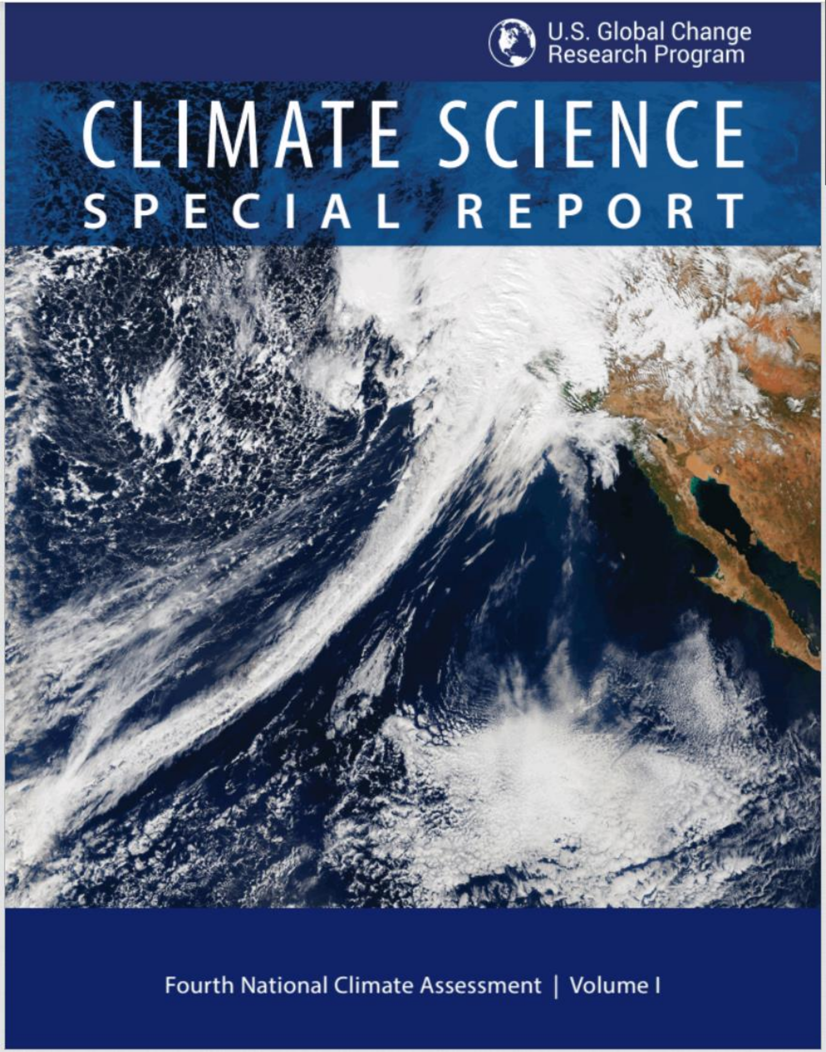
On the Web: CW3E.UCSD.EDU
On Twitter: @CW3E_Scripps

Center for Western Weather and Water Extremes

AR SCALE & FLOOD LOSSES



Corringham, Thomas W., F. Martin Ralph, Alexander Gershunov, Daniel R. Cayan, and Cary A. Talbot, 2019: Atmospheric Rivers Drive Flood Damages in the Western United States. Sci. Adv., in press.



Atmospheric Rivers Highlighted in the U.S. Fourth National Climate Assessment, released on 3 November 2017

9 Extreme Storms

KEY FINDINGS

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*)

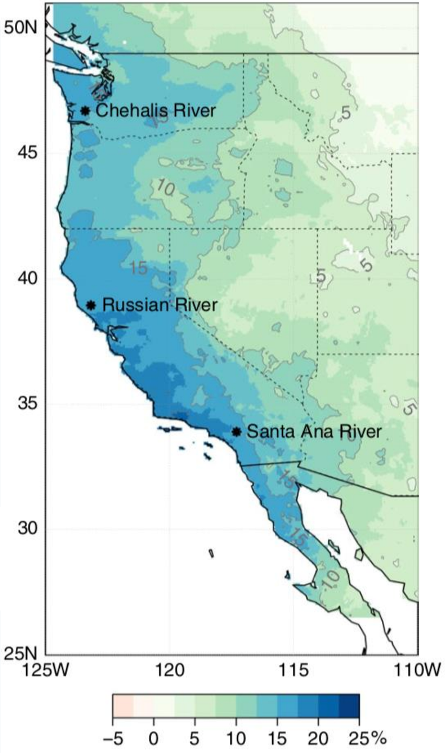
1. Tropical Cyclones (Hurricanes and Typhoons)
2. Severe Convective Storms (Thunderstorms)
3. Winter storms
4. **Atmospheric Rivers (NEW in 4th Assessment)**

Image Credit

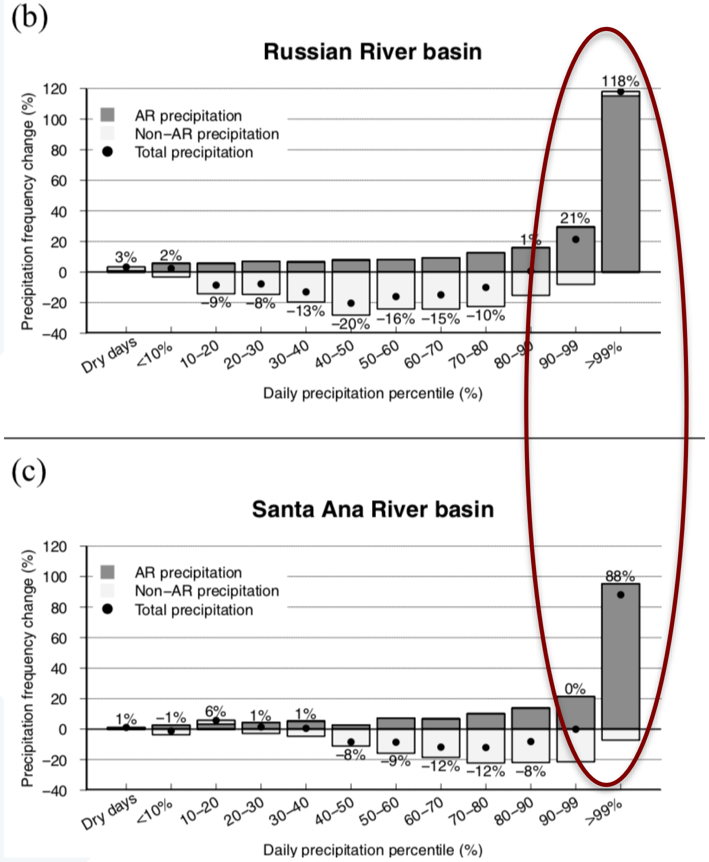
Front Cover: Atmospheric rivers are relatively long, narrow regions in the atmosphere – like rivers in the sky – that transport most of the water vapor outside of the tropics. When an atmospheric river makes landfall, extreme precipitation and flooding can often result. The cover features a natural-color image of conditions over the northeastern Pacific on 20 February 2017, helping California and the American West emerge from a 5-year drought in stunning fashion. Some parts of California received nearly twice as much rain in a single deluge as normally falls in the preceding 5 months (October–February). The visualization was generated by Jesse Allen (NASA Earth Observatory) using data from the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite.

ATMOSPHERIC RIVERS AND CLIMATE CHANGE

% change in the contribution of ARs to total precipitation



Precipitation Regime change in Western North America: The role of Atmospheric Rivers
A. Gershunov, T. Shulgina, R. Clemesha, K. Guirguis, D. Pierce, M. Dettinger, D. Lavers, D. Cayan, S. Polade, J. Kalansky, F. M. Ralph, (Scientific Reports 2019)



MOST EXTREME EVENTS ARE GOING TO OCCUR MORE OFTEN AND ARE CAUSED BY ARs

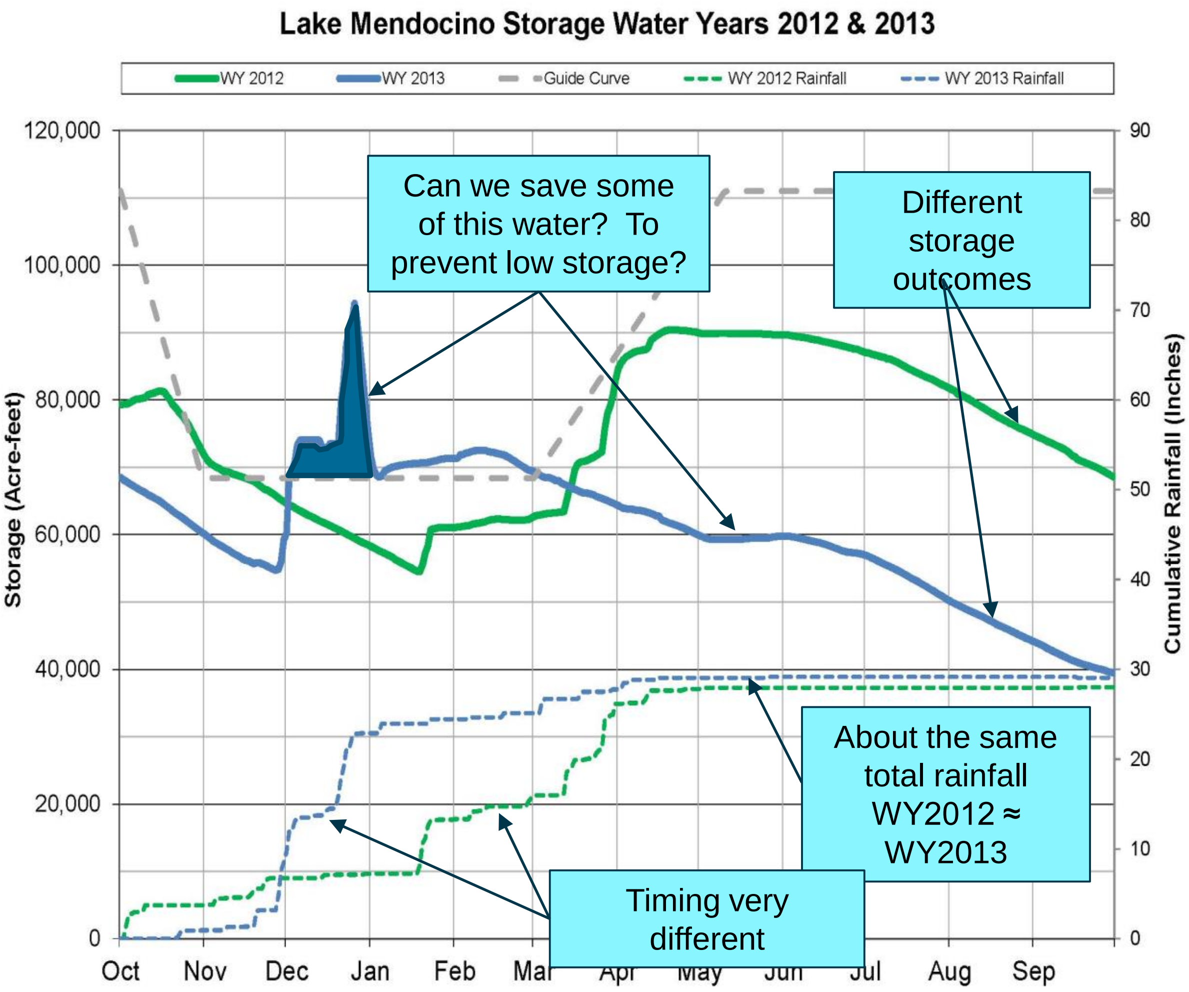
WHAT IS FORECAST INFORMED RESERVOIR OPERATIONS (FIRO)?

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…


Lake Mendocino Storage Water Years 2012 & 2013
WY 2012
WY 2013
Guide Curve
WY 2012 Rainfall
WY 2013 Rainfall
Storage (Acre-feet)
Cumulative Rainfall (Inches)
120,000
100,000
80,000
60,000
40,000
20,000
0
90
80
70
60
50
40
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Can we save some of this water? To prevent low storage?
Different storage outcomes
About the same total rainfall WY2012 ≈ WY2013
Timing very different

CURRENT USACE / CW3E FIRO PROJECTS

Yuba-Feather
Oroville and New Bullards Bar
2019

Russian River
Lake Mendocino
2014

Santa Ana River
Prado Dam
2017

FORMULA FOR FIRO PROJECTS

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

FIRO SUCCESS

Recognizes, develops, and supports relationships

VIABILITY ASSESSMENT COMPONENTS

Scientific Research & Development

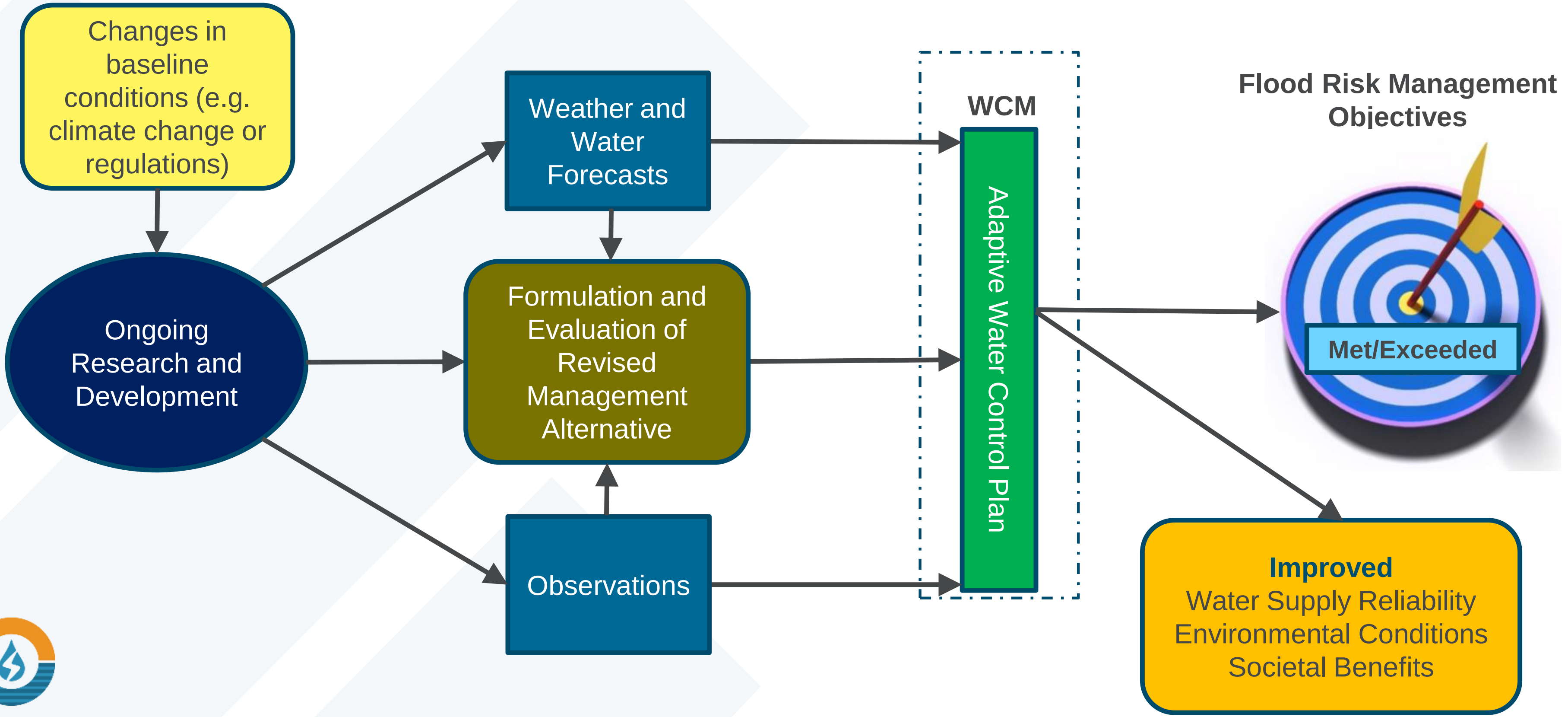
- Hydrology & WR Engineering
- Weather Forecasting
- S2S
- AR Detection / Awareness
- Observations & Monitoring

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



Thank You