Western US Precipitation and S2S Prediction

F. Martin Ralph, Ph.D.
Scripps Institution of Oceanography, UCSD

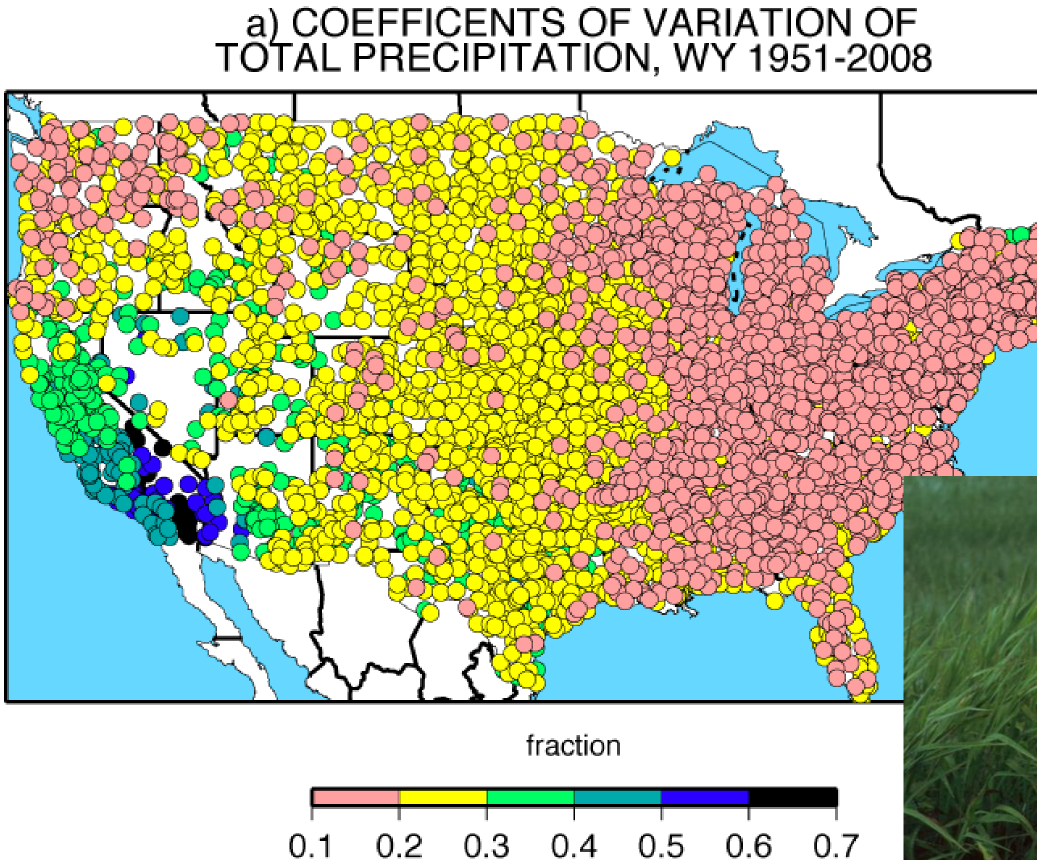
Western States Water Council and NOAA Meeting on
Seasonal Precipitation Forecasting for Water Resources

NCEP
29 April 2016

Center for Western Weather and Water Extremes

SCRIPPS INSTITUTION OF OCEANOGRAPHY UCSD

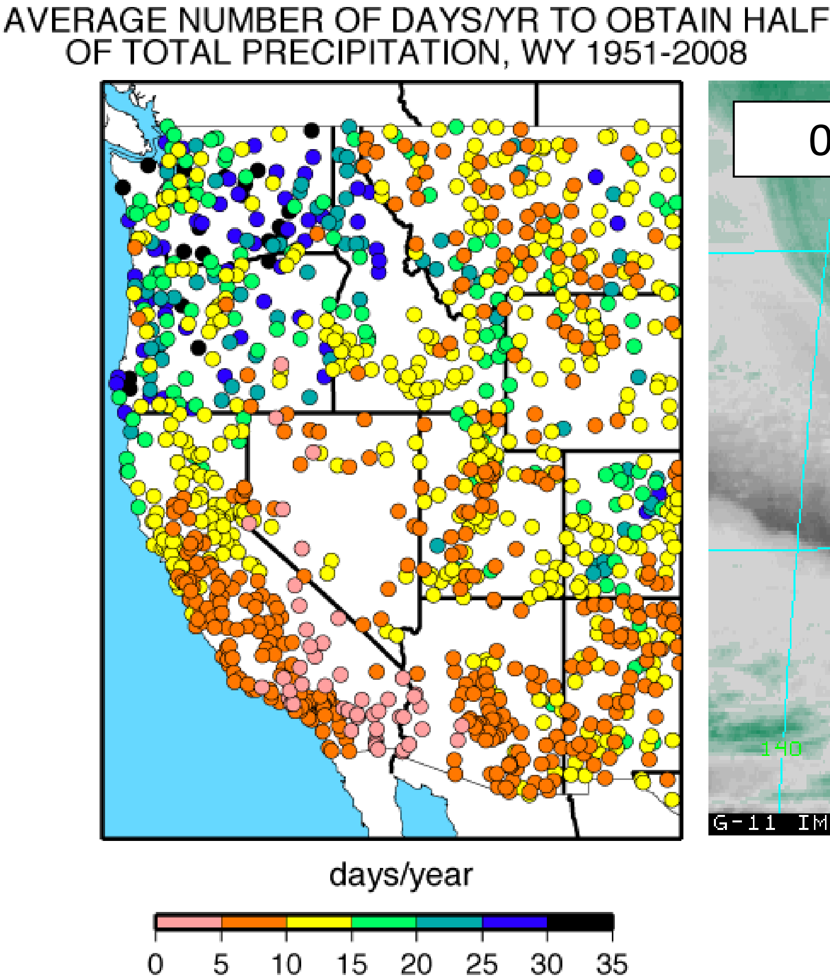
WESTERN U.S. ANNUAL PRECIPITATION IS 2-3 TIMES MORE VARIABLE THAN EASTERN U.S.

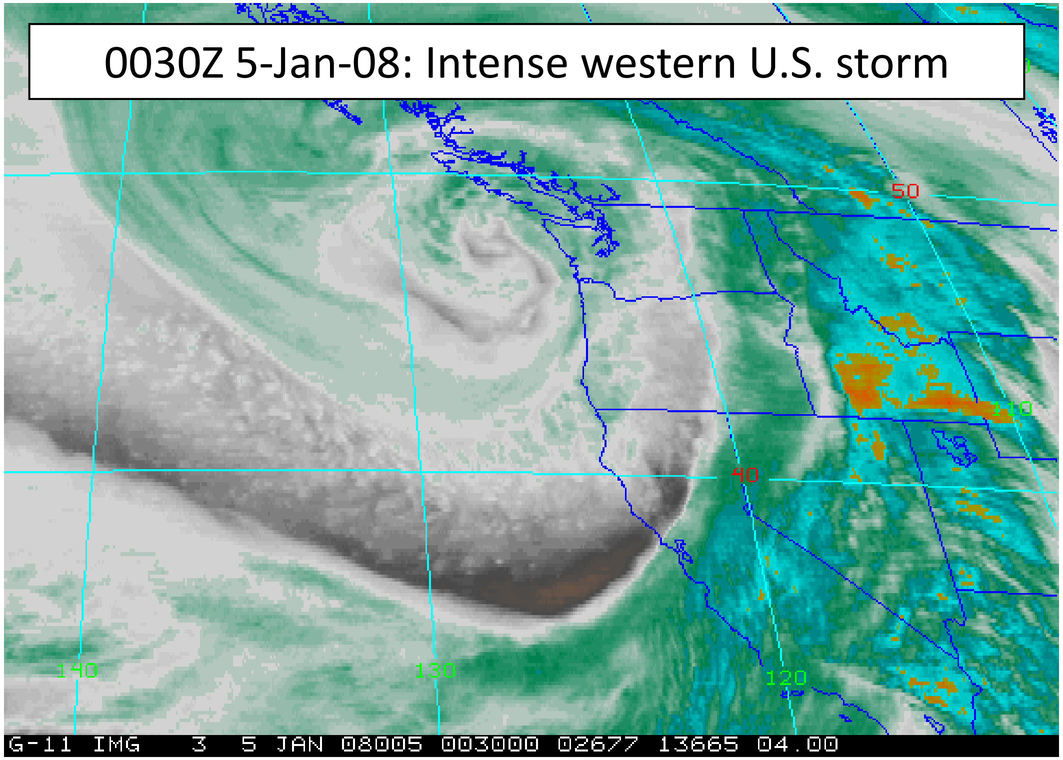


Dettinger et al. 2011, *Water*

Why study the West Coast?

Just a few winter storms each year form the core of water supply along the U.S. West Coast



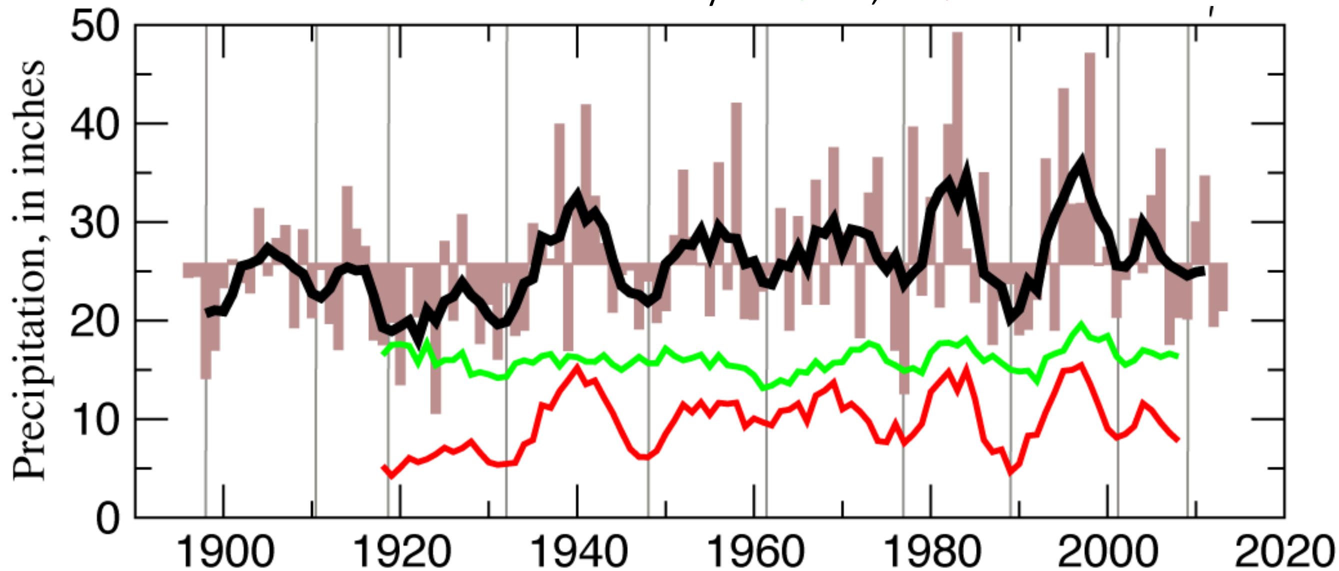


Dettinger et al, Water, 2011

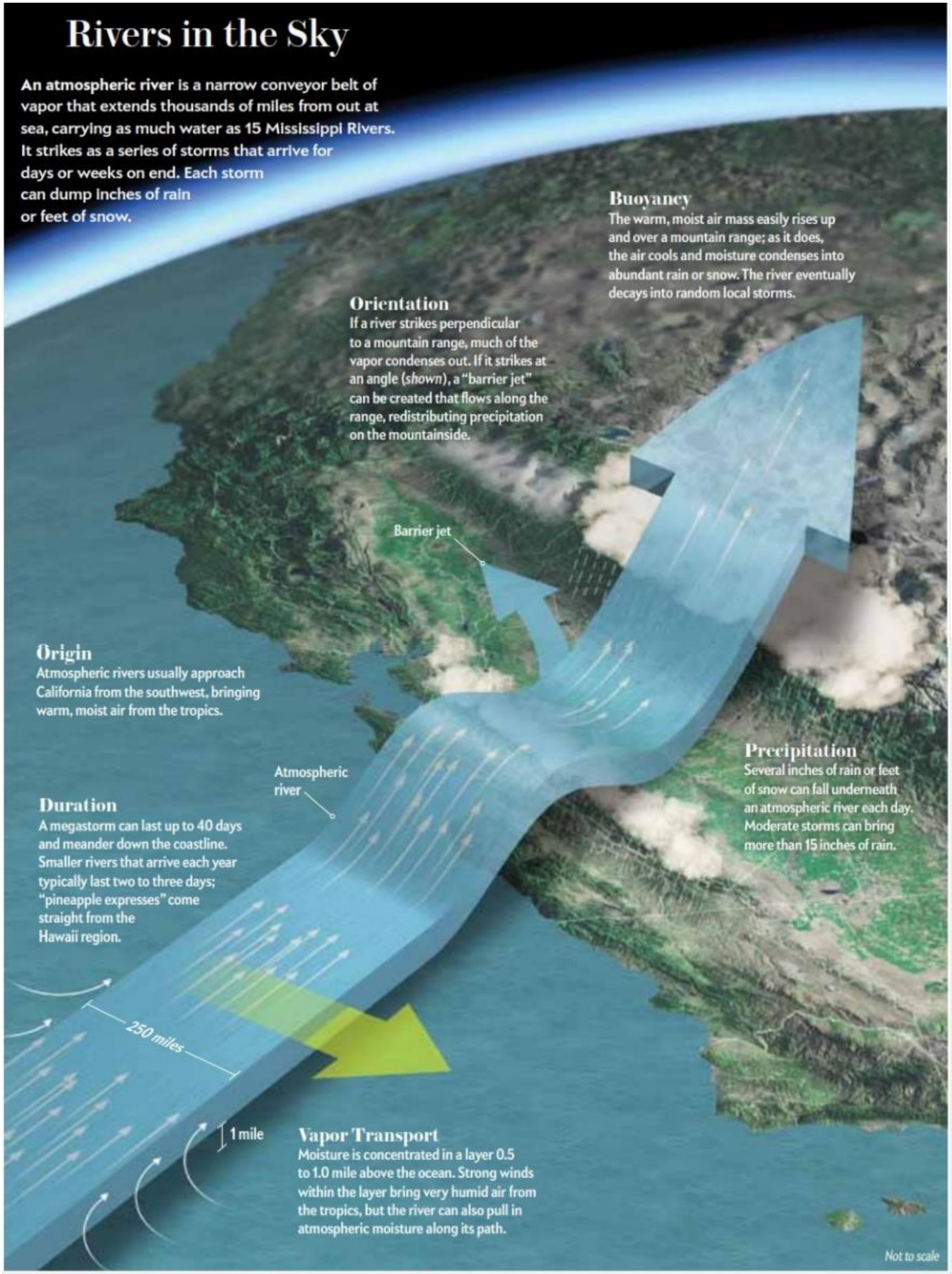
A few large storms (or their absence)

Account for a disproportionate amount of California's precipitation variability

Water year precipitation, Delta catchment
with contributions from days <95%-ile, >95%-ile



Dettinger and Cayan 2014, *San Francisco Estuary and Watershed Science*



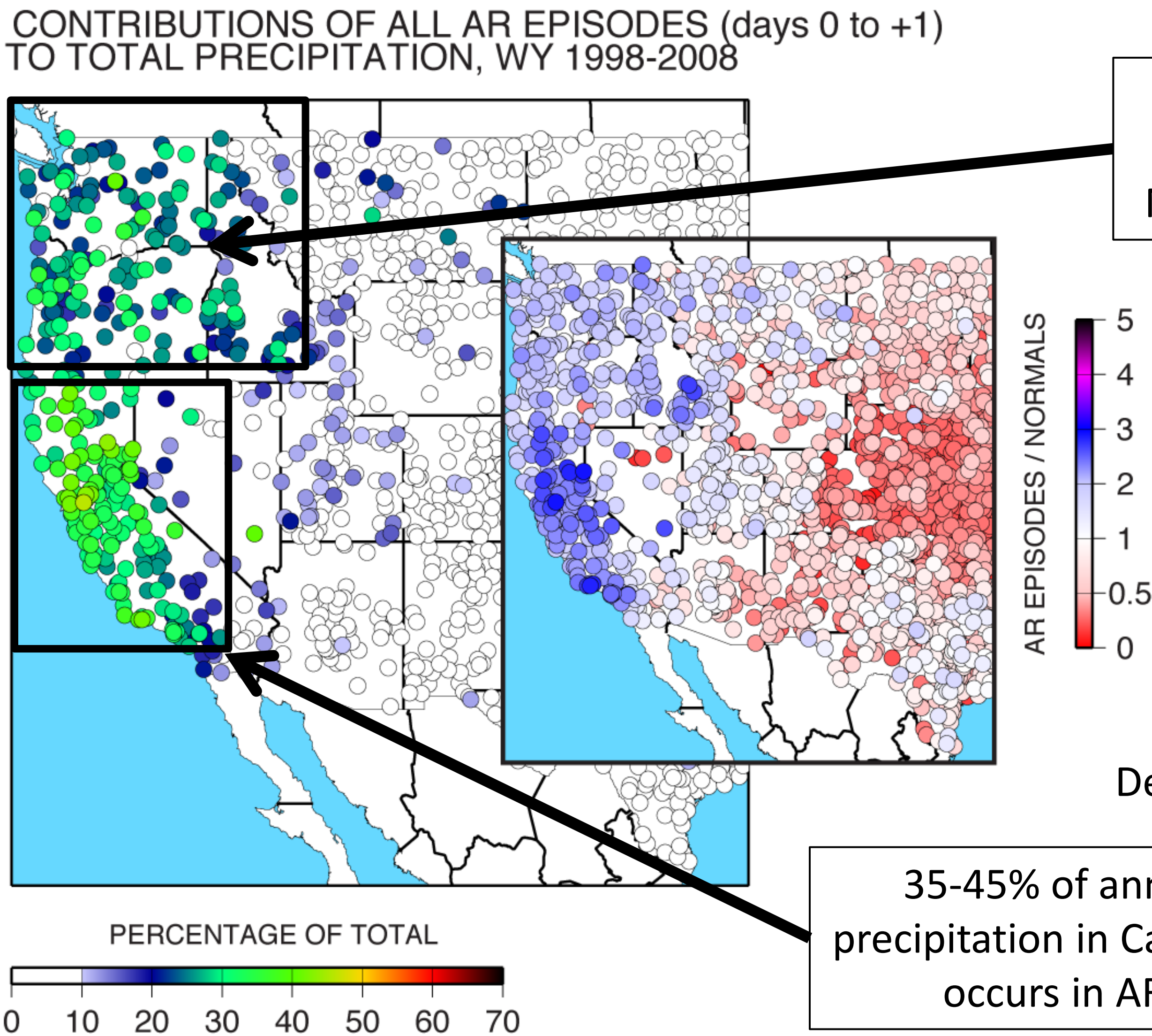
A Major Result from 10-years of Research

Atmospheric rivers – what they are, how they work, and their crucial role in both water supply and flooding across much of the U.S. West Coast

Figure from an article in Scientific American
by Dettinger and Ingram (January 2013)

Why is there a need to study and forecast ARs?

ARs are responsible for 25-45% of annual precipitation along U.S. West Coast



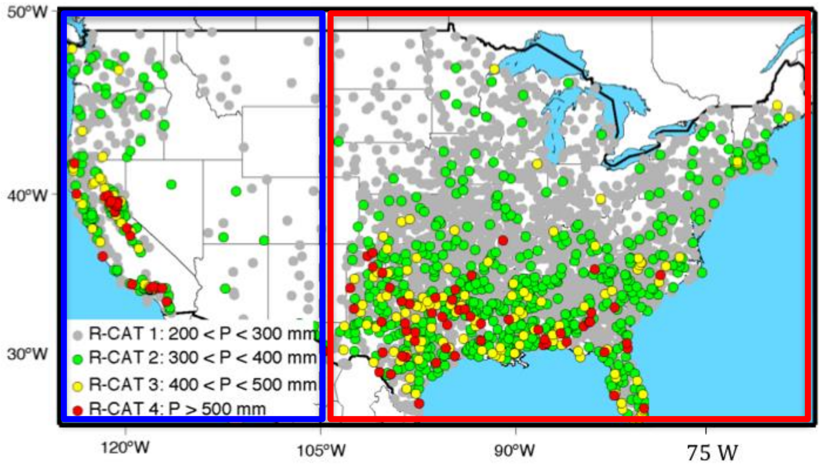
25-35% of annual precipitation in Pacific Northwest occurs in ARs

35-45% of annual precipitation in California occurs in ARs

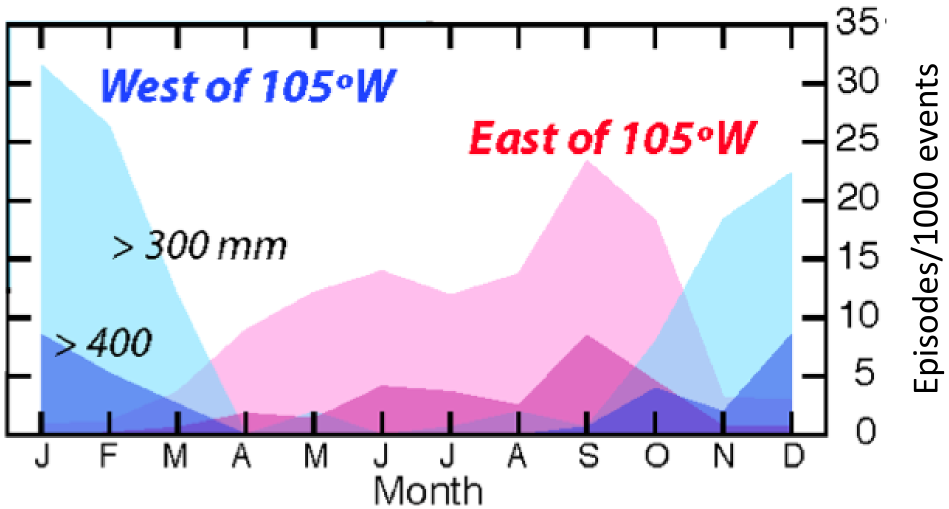
Dettinger et al. 2011, *Water*

Why study the West Coast?

Maximum 3-day precipitation totals at 5877 COOP stations in lower U.S.



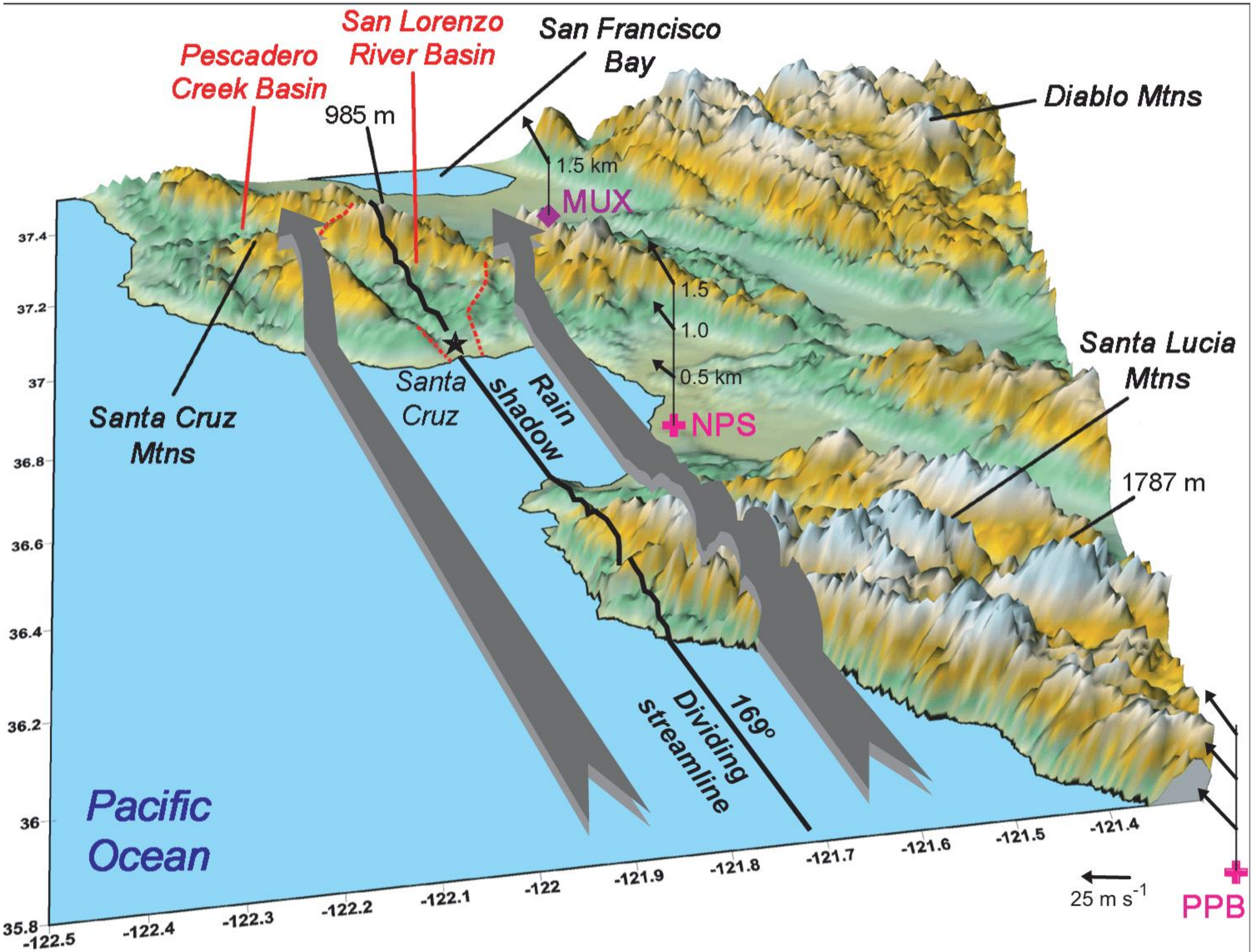
Seasonality of 3-day precipitation totals between West and East U.S.



Ralph and Dettinger (2012, *BAMS*): Intensity of extreme precipitation events over U.S.

Seasonality of extreme precipitation events

- R-CATs used to describe intensity of extreme precipitation events
- Large R-CAT events along West Coast in winter
- Large R-CAT events over south/southeast U.S. in spring, summer, and fall
- Largest precipitation events on West Coast are comparable to largest events (tropical cyclones) on the East Coast

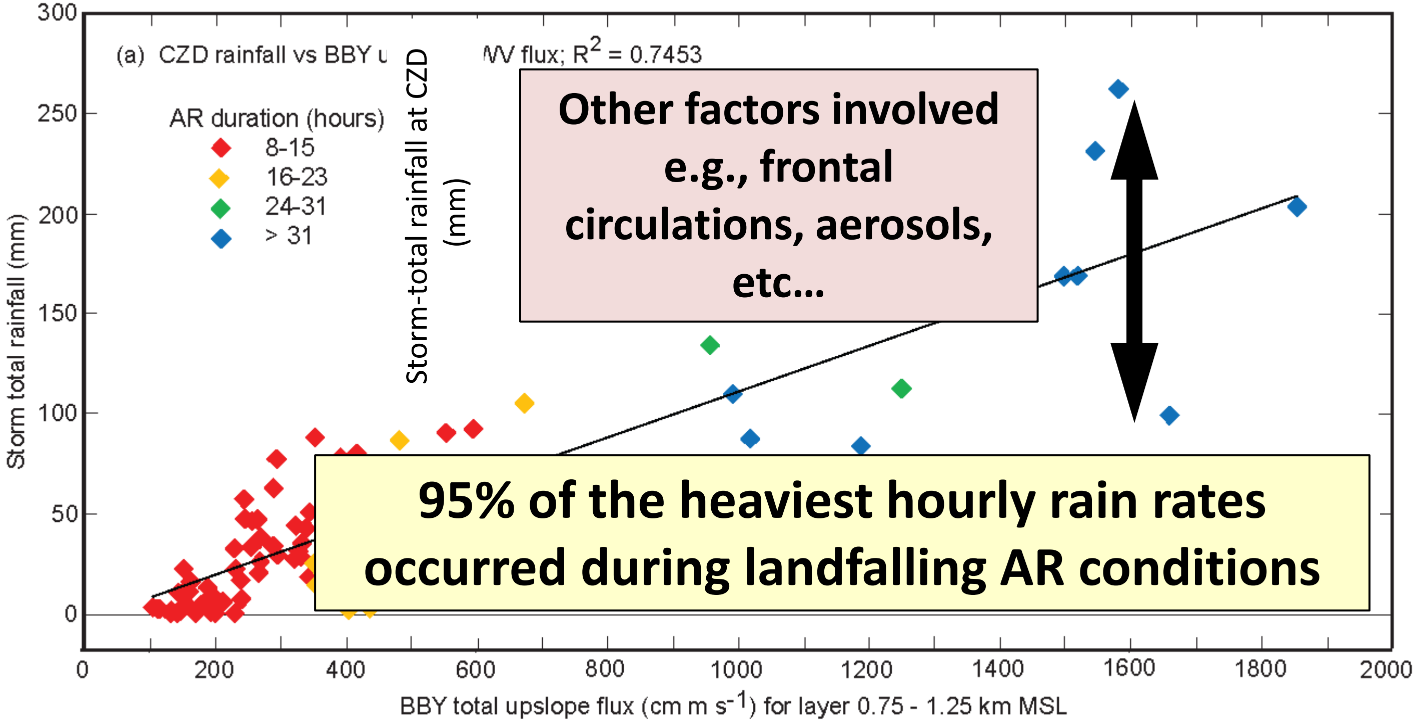


AR "Angle of Attack" can determine flooding in mountainous areas

Ralph et al. 2003

Observed impacts of duration and seasonality of atmospheric-river landfalls on soil moisture and runoff in coastal northern California

Ralph, F. M., T. Coleman, P.J. Neiman, R. Zamora, and M.D. Dettinger, J. Hydrometeorology, 2013



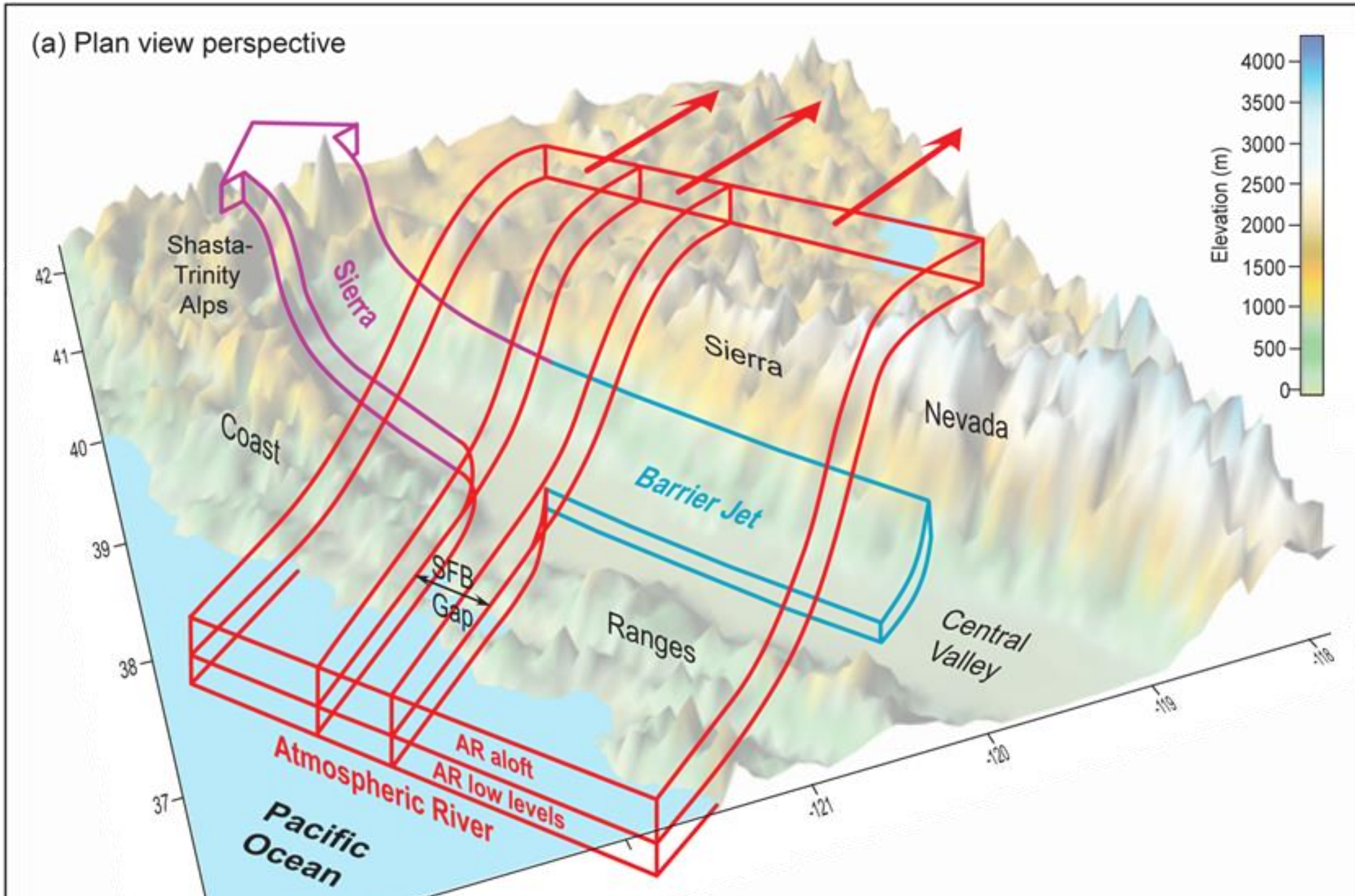
Other factors involved e.g., frontal circulations, aerosols, etc…

95% of the heaviest hourly rain rates occurred during landfalling AR conditions

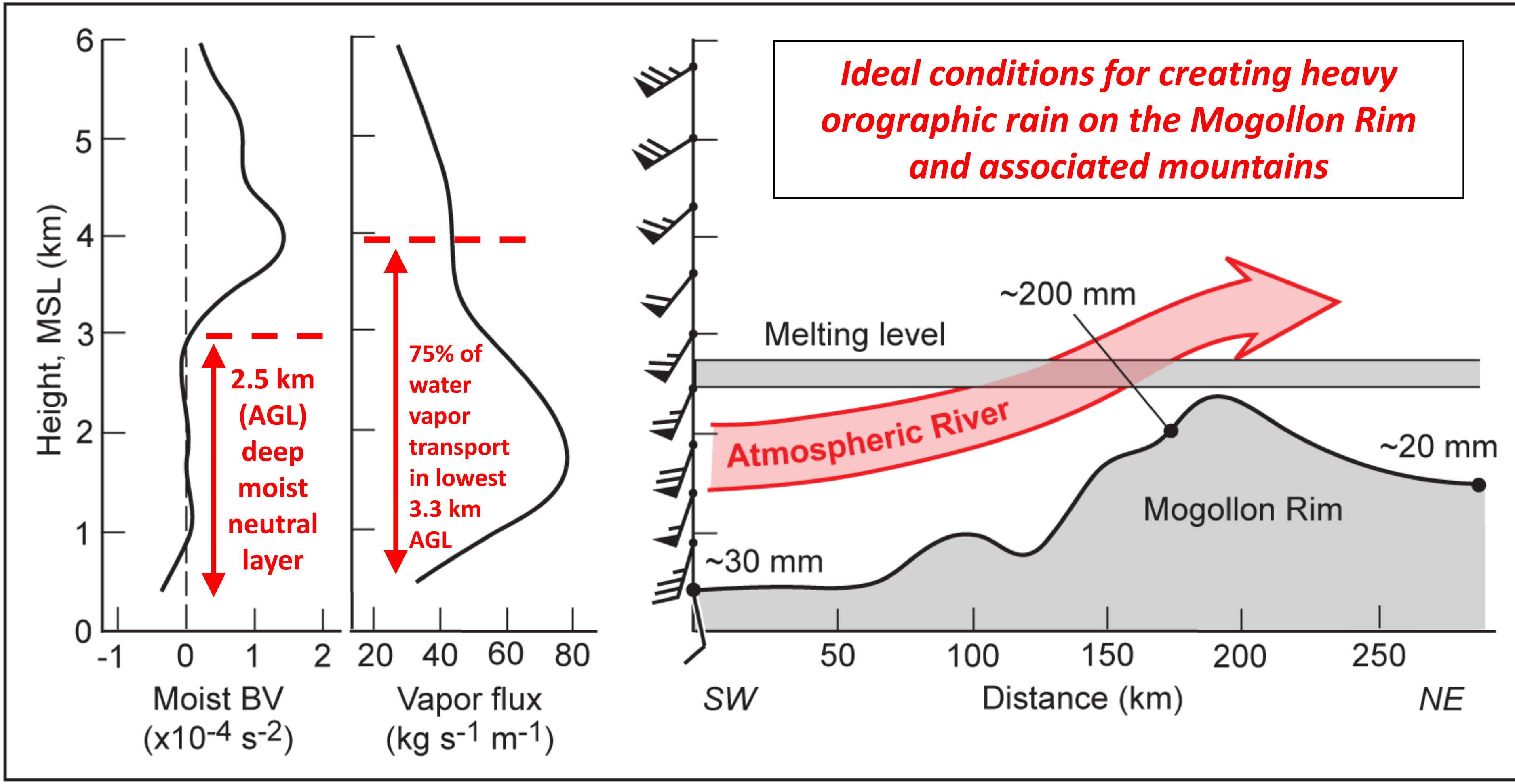
The greater the AR strength and duration

The greater the precipitation

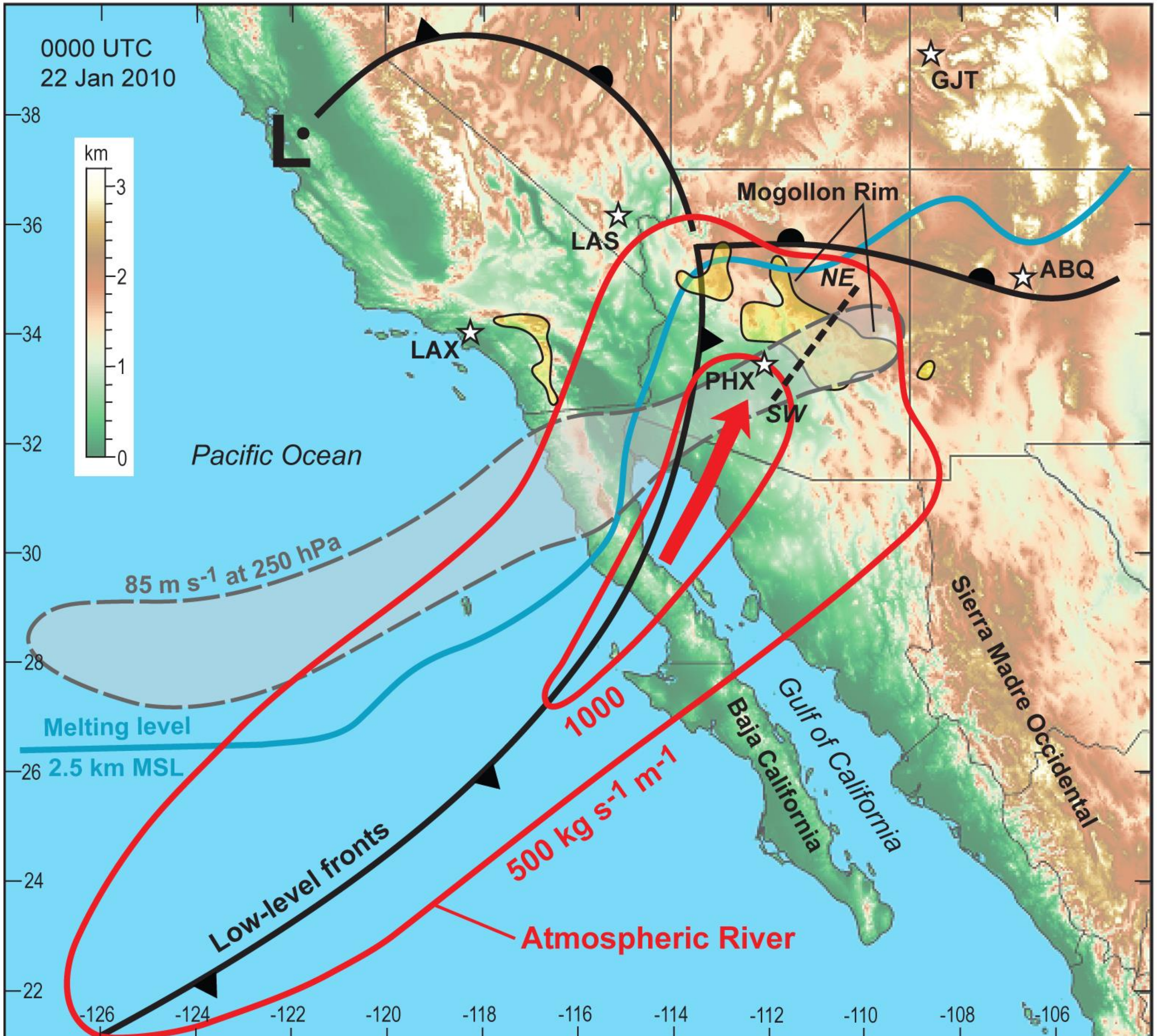
The Sierra Barrier Jet is key to regional precipitation



Neiman, Hughes, Moore,
Ralph, and Sukovich *(MWR 2013)*



Summary schematic for Jan 2010 case presented by Neiman et al. (in preparation)



0000 UTC
22 Jan 2010
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NE
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PHX
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Pacific Ocean
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Melting level
2.5 km MSL
1000
Baja California
Gulf of California
Sierra Madre Occidental
500 kg s-1 m-1
Low-level fronts
Atmospheric River
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36
34
32
30
28
26
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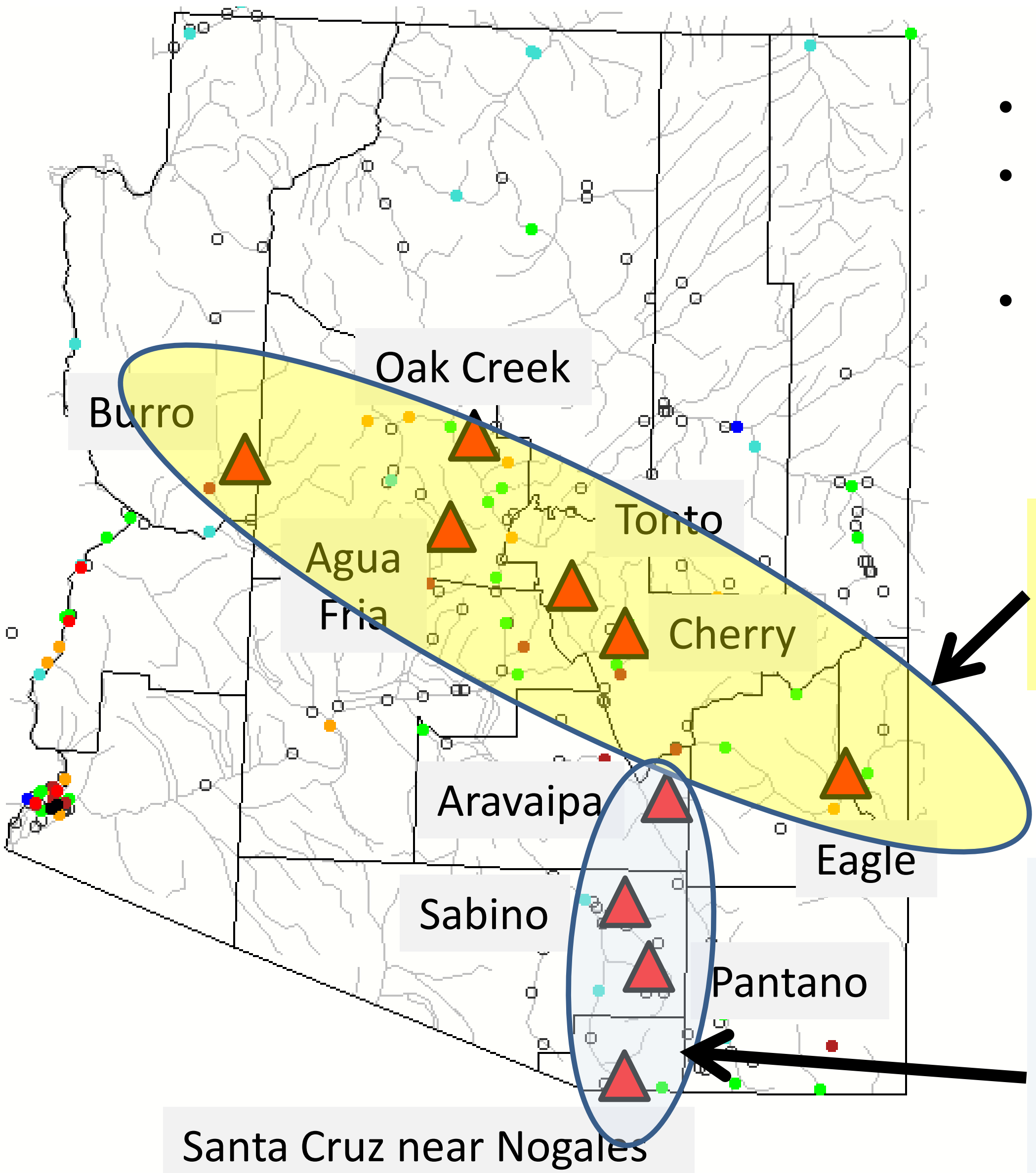
-106

Modest sized watersheds



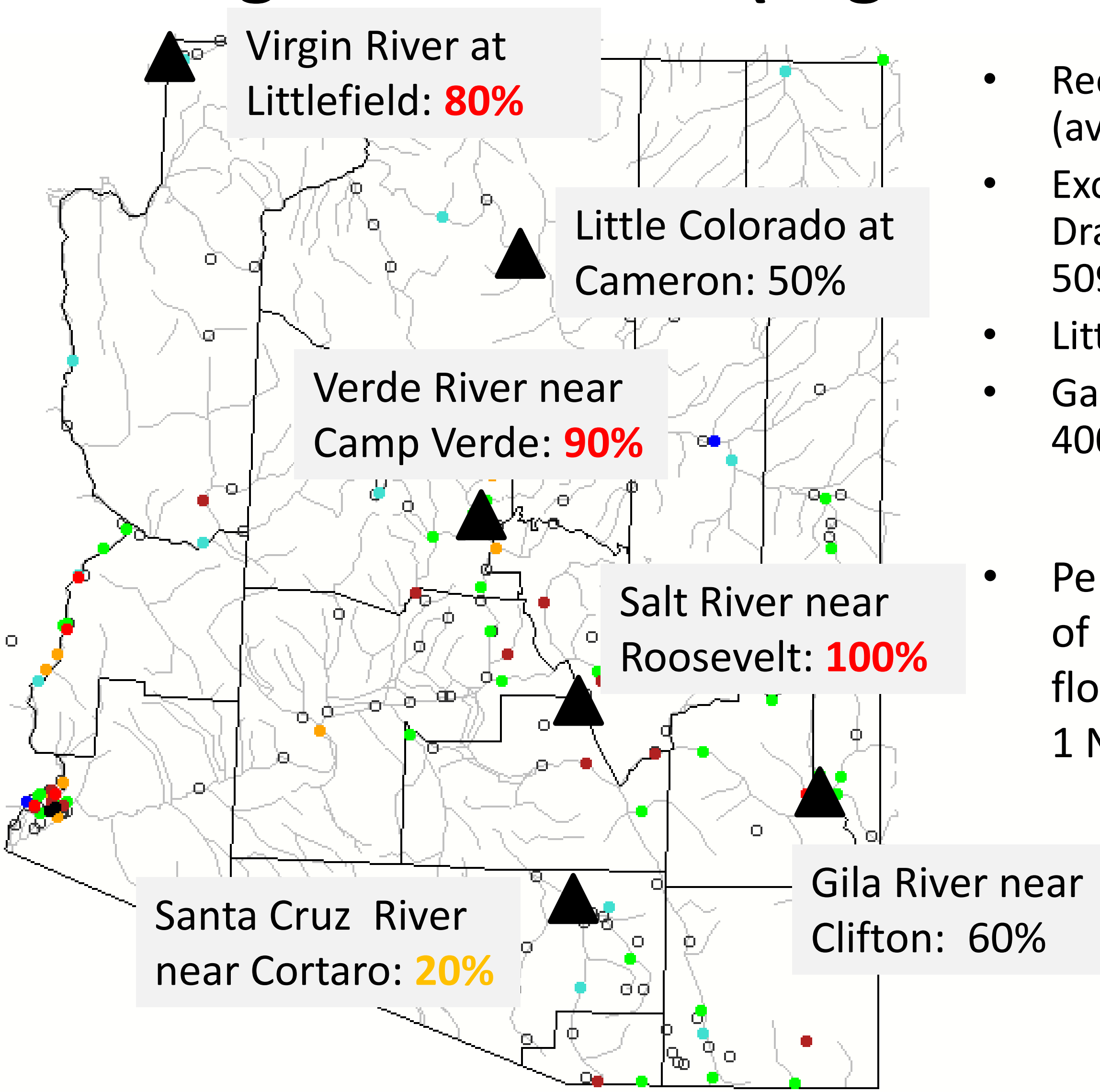
- Record flows range from 15-75 kcfs
- Drainage areas are between 200-675 sq mi (except Sabino is 36 sq mi)
- Gage elevations are between 1880-3703 ft msl

70% - 90% of the 10 highest annual peak daily flows occurred between 1 November and 31 March

0% - 40% of the 10 highest annual peak daily flows occurred between 1 November and 31 March

60% - 100% occurred from 1 July to 31 October

Large watersheds (avg area: 4329 sq mi)



- Record flows range from 25-143 kcfs (average record = 96 kcfs)
- Except for Little Colorado gage, Drainage areas are between 3503-5092 sq mi (average = 4329 sq mi)
- Little Colorado 26091 sq mi
- Gage elevations are between 1700-4000 ft msl

- Percentages listed are the percent of the top-10 annual peak daily flows that occurred between 1 November and 31 March

The Inland Penetration of Atmospheric Rivers over Western North America: A Lagrangian Analysis

J.J. Rutz, J. W. Steenburgh and F.M. Ralph

Mon. Wea. Rev., 2015

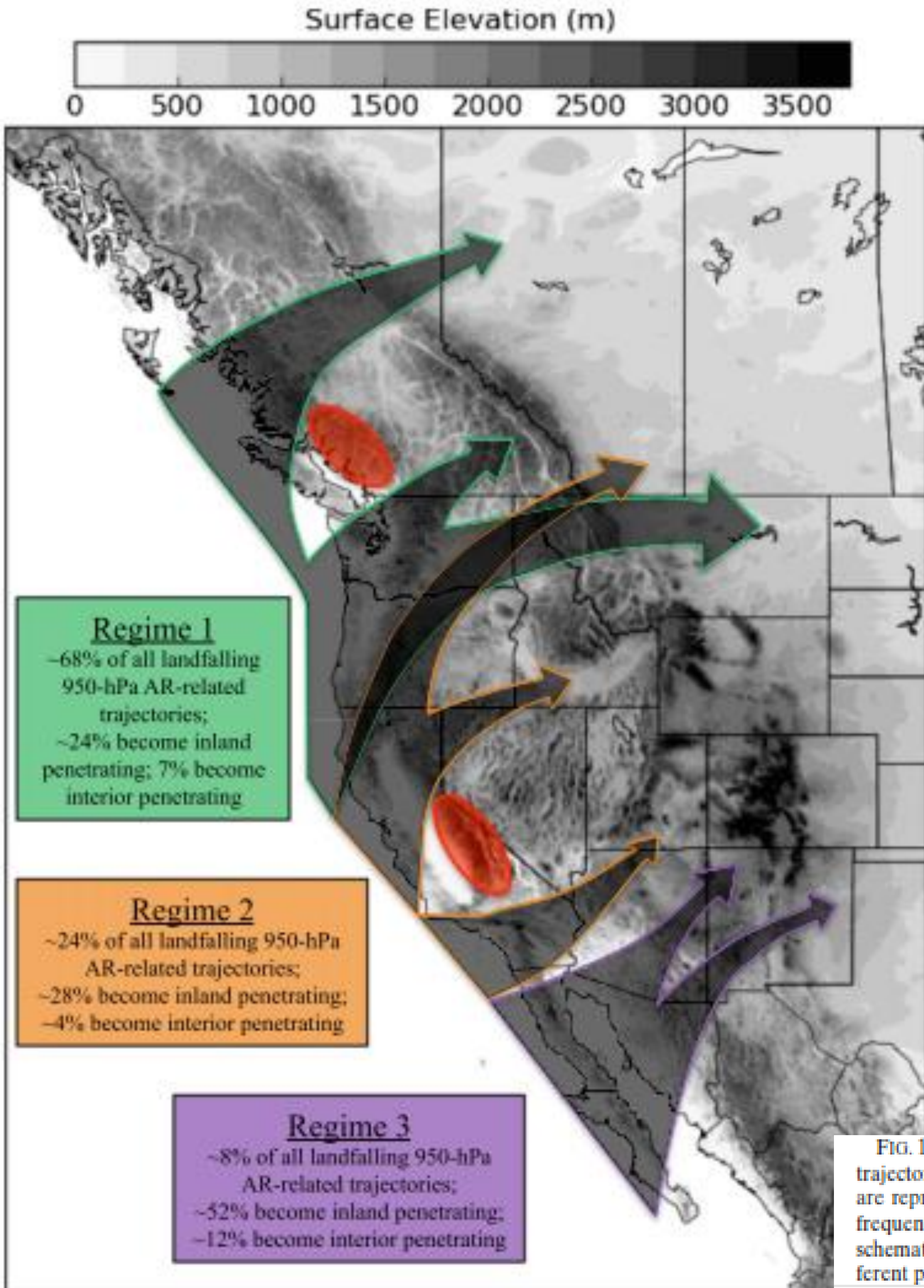
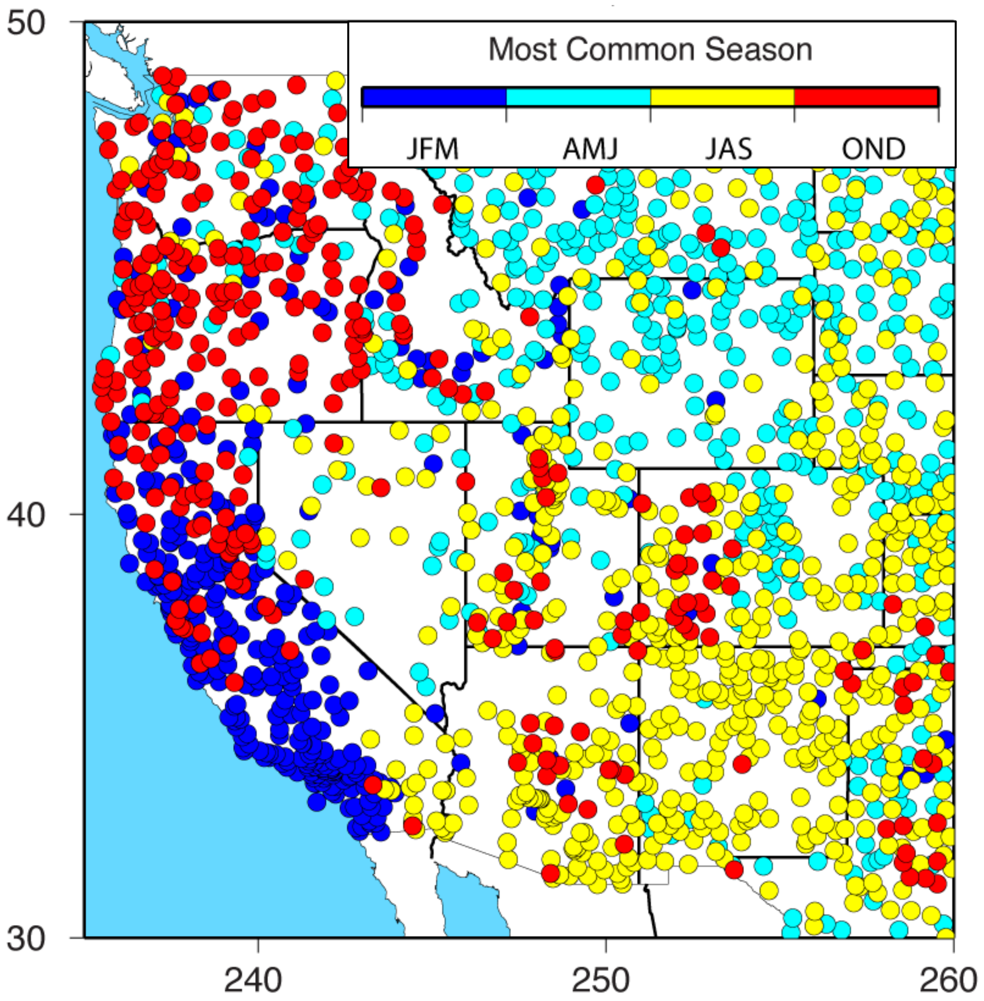


FIG. 16. Schematic showing the primary pathways for the penetration of 950-hPa AR-related trajectories into the interior of western North America. Pathways associated with regimes 1–3 are represented by green, orange, and purple arrows, respectively. Regions associated with frequent AR decay are shaded in red. Topography is shaded in grayscale. Note that while this schematic highlights common regimes and pathways, individual trajectories follow many different paths.

A vision for future observations for Western U.S. extreme precipitation and flooding

F.M. Ralph, M. Dettinger, A. White, D. Reynolds, D. Cayan, T. Schneider, R. Cifelli, K. Redmond, M. Anderson, F. Gherke, J. Jones, K. Mahoney, L. Johnson, S. Gutman, V. Chandrasekar, J. Lundquist, N.P. Molotch, L. Brekke, R. Pulwarty, J. Horel, L. Schick, A. Edman, P. Mote, J. Abatzoglou, R. Pierce, G. Wick

J. Contemporary Water Resources Research and Education, Univ. Council for Water Resources, Issue 153, 2014

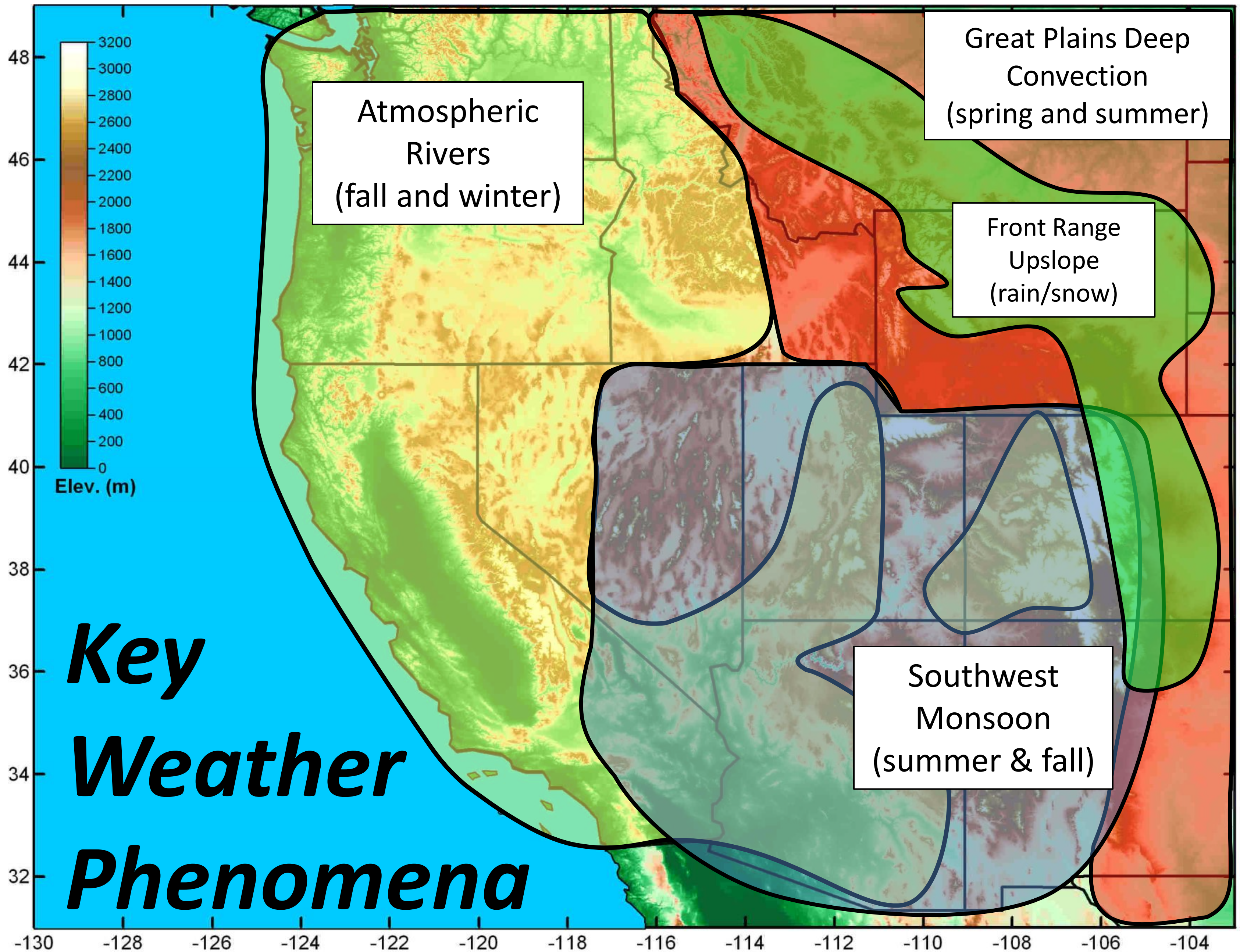


MOST COMMON SEASON AMONG TOP 10 DAILY PRECIPITATION TOTALS WY 1951-2008

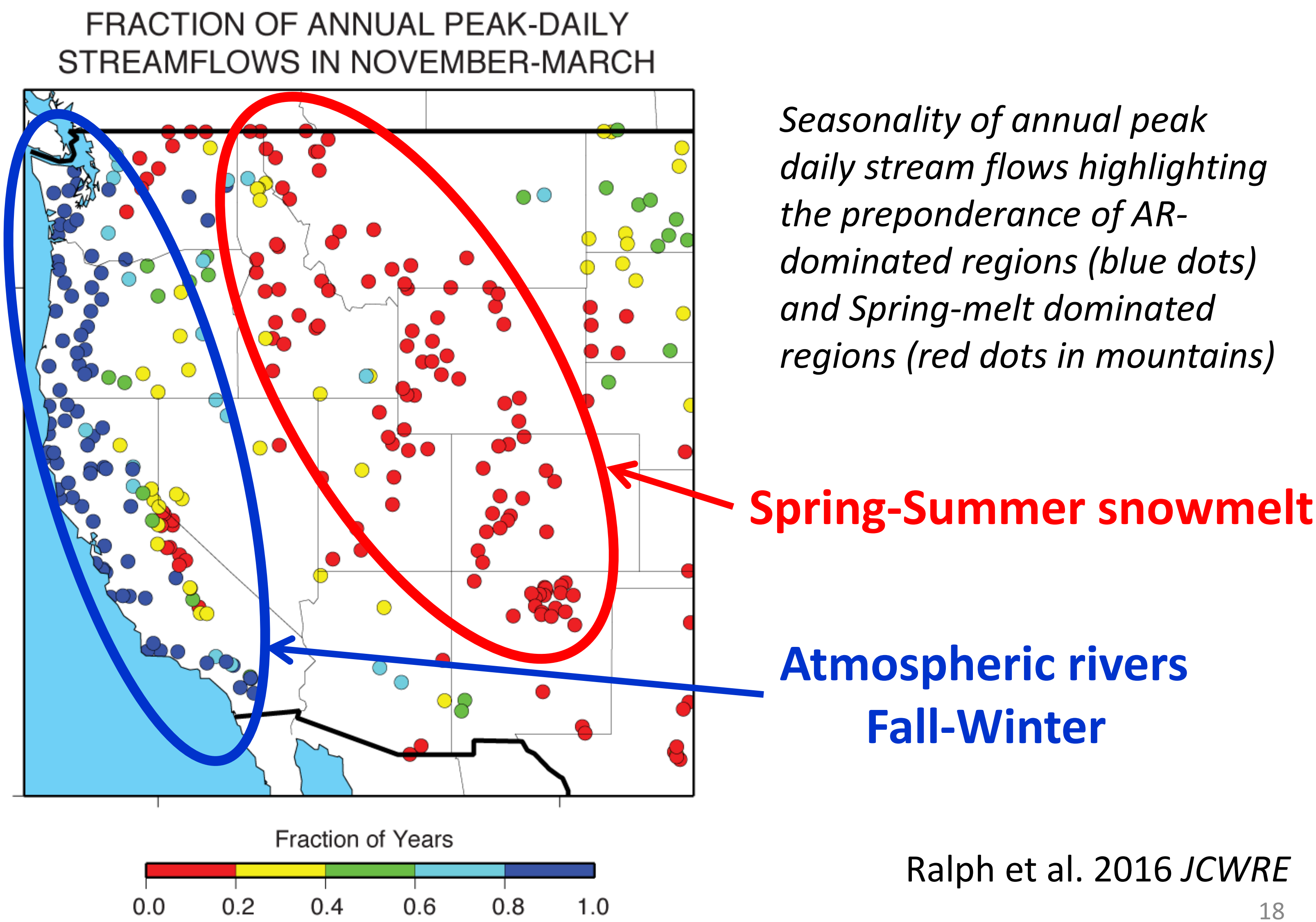
Analysis from COOP daily precipitation observations.
-Each site uses at least 30 years of data
-The top 10 daily precip dates are found
-The season for which most of these top-10 dates occurred at that site is color coded.

Ralph et al. 2016 *JCWRE*

Schematic illustration of regional variations in the primary weather phenomena that lead to extreme precipitation, flooding and contribute to water supply in the Western U.S. (Ralph et al. 2014)



Seasonality of Annual Peak Streamflow



Seasonality of annual peak daily stream flows highlighting the preponderance of AR-dominated regions (blue dots) and Spring-melt dominated regions (red dots in mountains)

Ralph et al. 2016 *JCWRE*

2016 International Atmospheric Rivers Conference

Scripps Institution of Oceanography - La Jolla, California

8^{th} – 11^{th} August 2016

http://cw3e.ucsd.edu/ARconf2016

CW3E.UCSD.EDU

Many regions face either drought or flood, or are challenged by regional water management issues. Recent advances in atmospheric sciences and hydrology have identified the key role of atmospheric rivers (AR) in determining the distribution of strong precipitation events in midlatitudes. Combined with related phenomena, warm conveyor belts (WCB) and tropical moisture exports (TME) (Fig. 1), the frequency, position and strength of ARs determines the occurrence of many water extremes. This conference brings together experts across atmospheric, hydrologic, oceanic and polar science, water management and civil engineering to advance the science and explore needs for new information.

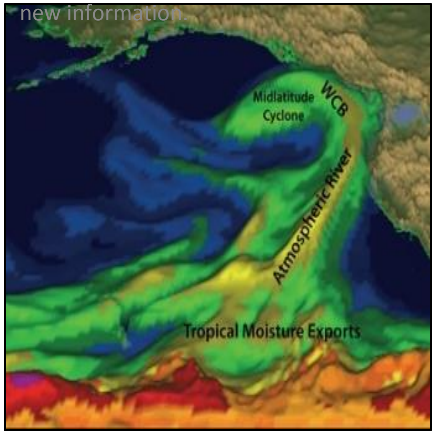


Fig. 1. Depiction of an atmospheric river, interacting with West Coast mountains. Credit: Adapted from NOAA/ESRL Physical Sciences Div. Source: EOS Meeting Report

Center for Western Weather and Water Extremes

Conference Goals

- Evaluate the current state and applications of the science of the mid-latitude atmospheric water cycle, with particular emphasis on ARs and associated processes (e.g., WCB and TME)
- Discuss differing regional perspectives
- Assess current forecasting capabilities
- Plan for future scientific and practical challenges

International organizing committee

Allen White (*NOAA ESRL/PSD; Co-Chair*)
Irina Gorodetskaya (*K.U. Leuven, Netherlands; Co-Chair*)
Andrew Martin (*CW3E, Scripps; Co-Chair*)
Maximiliano Viale (*Universidad de Chile; Co-Chair*)
Mike Dettinger (*USGS, CW3E*)
David Lavers (*Scripps Inst. Oceanography/CW3E*)
Nina Oakley (*Desert Research Institute*)
F. Martin Ralph (*Scripps Inst. Oceanography/CW3E*)
Jonathan Rutz (*U. S. National Weather Service*)
Ryan Spackman (*Science and Technology Corporation*)
Heini Wernli (*ETH Zurich*)

The conference will be held at the beautiful oceanfront venue of the Robert Paine Scripps Forum for Science, Society and the Environment located at the Scripps Inst. of Oceanography, Univ. of CA – San Diego.

Contributions for the 2016 Conference are now invited

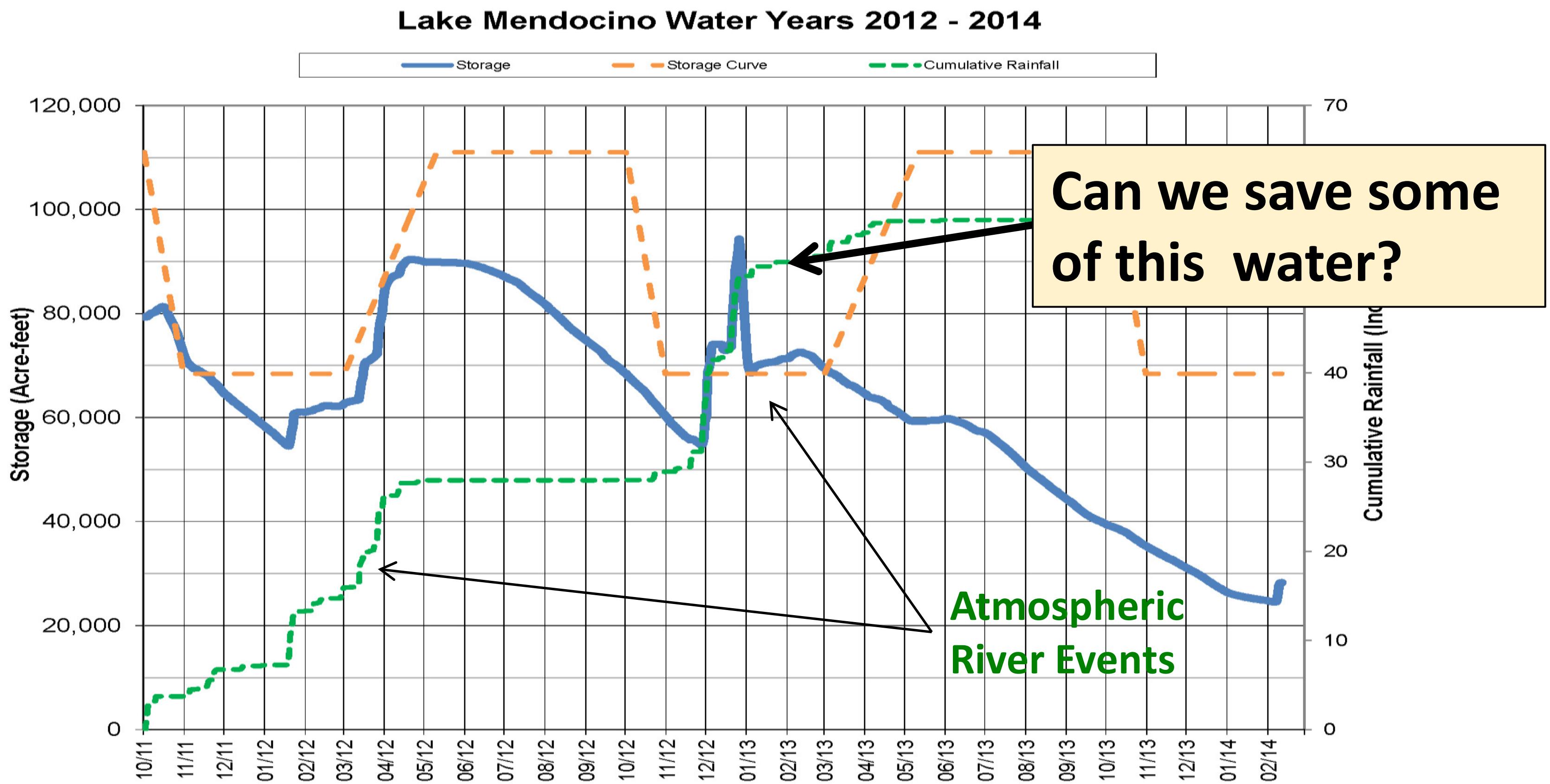
For further information or to submit an abstract, please contact:
Mike Dettinger (mddettin@usgs.gov) or
Mary Tyree (mtyree@ucsd.edu)

Lake Mendocino FIRO Viability Assessment – A Collaborative Effort

Coalition of federal, state, & regional agencies comprised of scientists & water managers
Co-Chaired by J. Jasperse (SCWA) and M. Ralph (Scripps/CW3E)

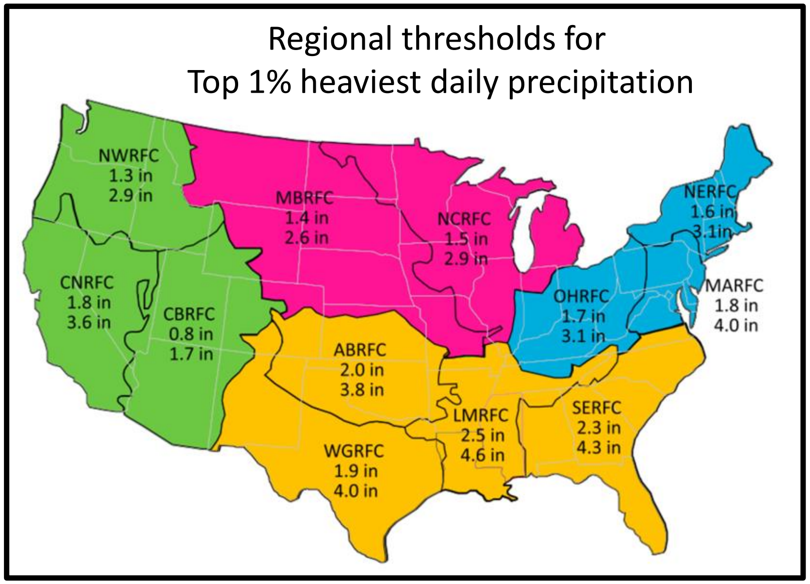
<u>Steering Committee:</u>

Federal: NOAA (OAR, NWS, NMFS), USGS, Army Corps of Engineers, & Bureau of Reclamation
State: CA Dept. of Water Resources & Scripps Center for Western Weather & Water Extremes
Regional: Sonoma County Water Agency
NOAA Habitat Blueprint, Integrated Water Resource Sciences & Services

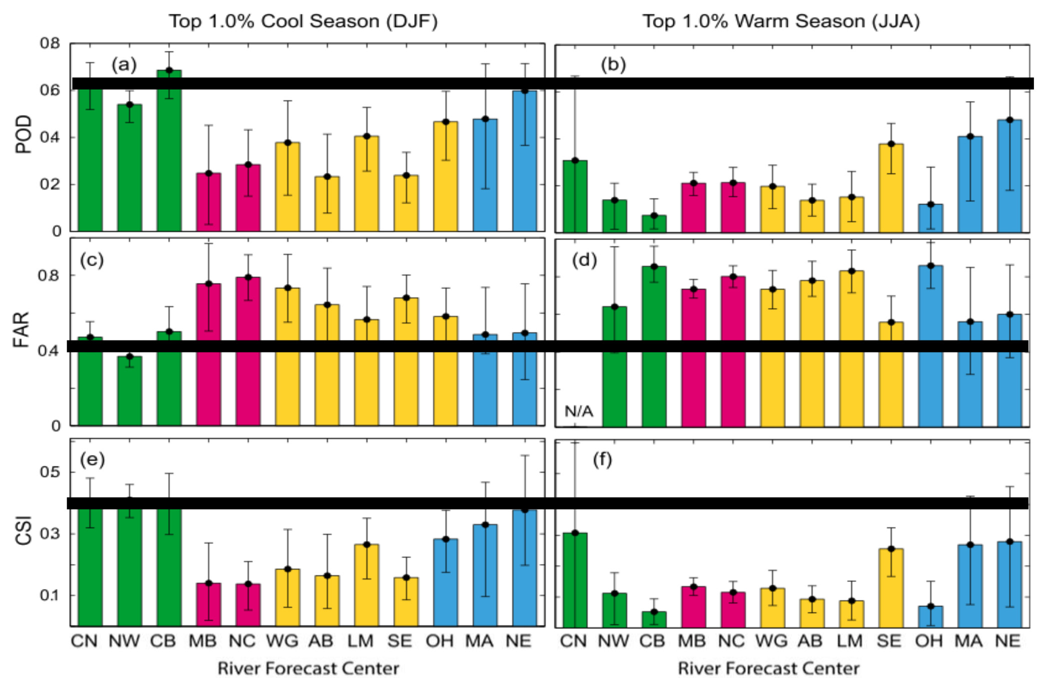


Extreme quantitative precipitation forecast performance at the Weather Prediction Center from 2001 to 2011

Sukovich, E. M., F. M. Ralph, F. E. Barthold, D. W. Reynolds and D. R. Novak
Wea. Forecast. (2014)



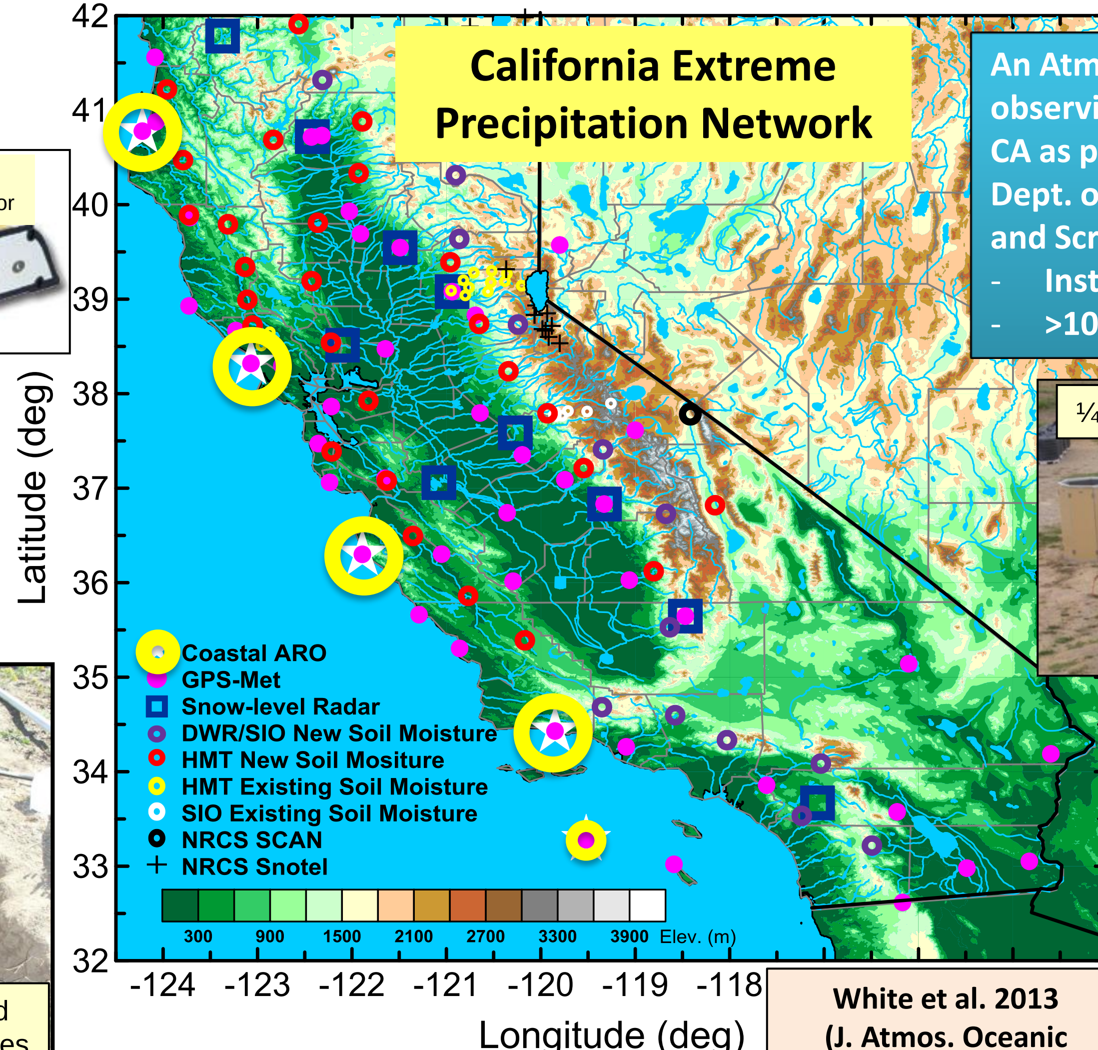
Used 32 km gridded QPE from NCEP/WPC from 2001-2011, >12,000,000 wet days



Used 32 km gridded QPE and QPF from NCEP/WPC from 2007-2011. For 1-day lead time. Note QPF for Western RFC's and New England are best.

Slide courtesy of F.M. Ralph, Scripps/CW3E

California Extreme Precipitation Network



An Atmospheric River-focused long-term observing network is being installed in CA as part of a 5-year project between CA Dept. of Water Resources (DWR), NOAA and Scripps Inst. Of Oceanography

- Installed 2008-2014
- >100 field sites

GPS receiver for integrated water vapor

¼-scale 449-MHz wind profiler with RASS

Soil Moisture and Temperature Probes

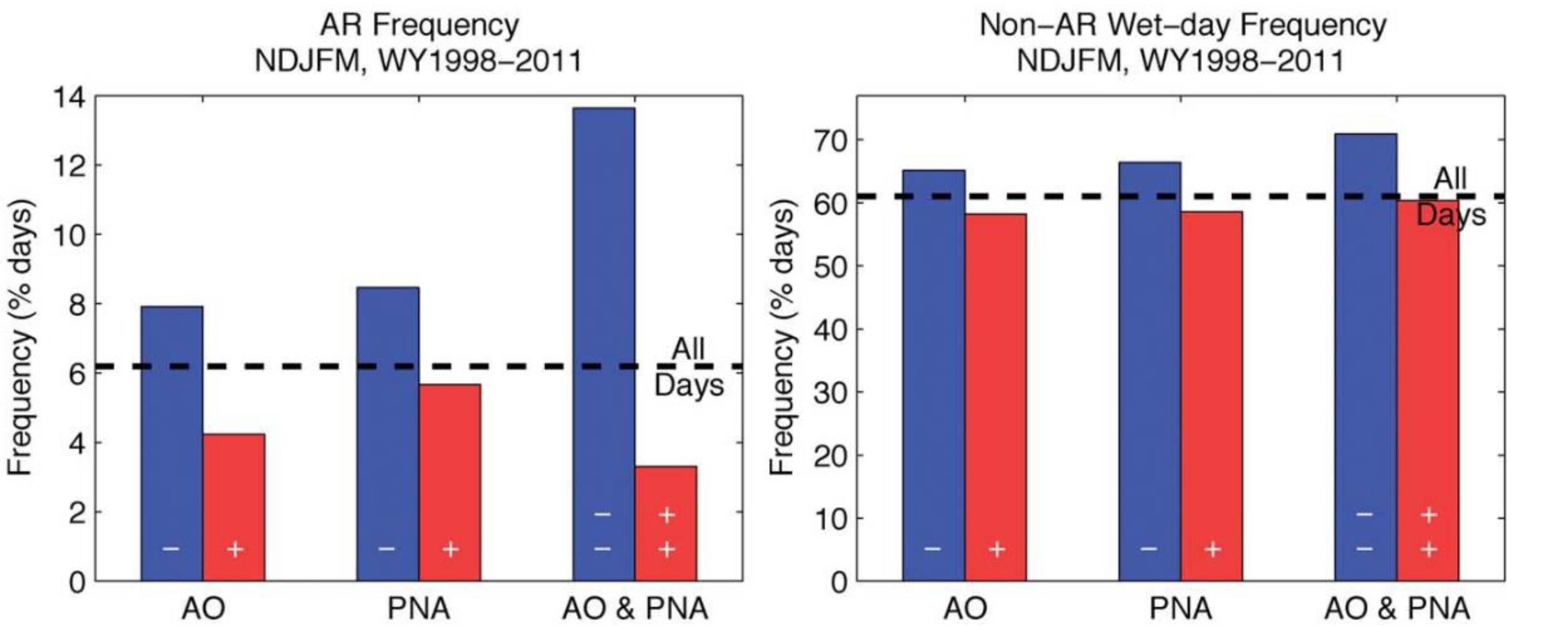
FM-CW snow-level radar

White et al. 2013 (J. Atmos. Oceanic Tech.)

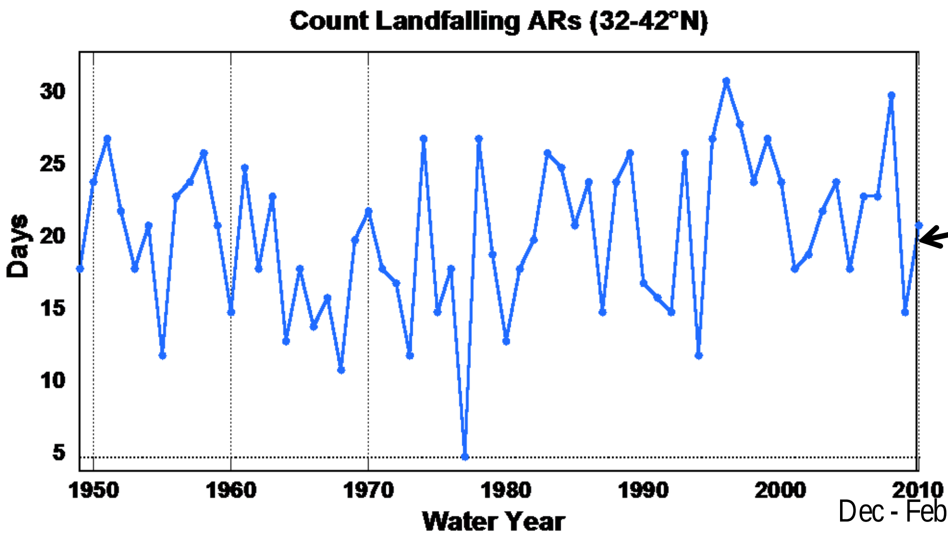
The 2010/2011 snow season in California's Sierra Nevada: Role of atmospheric rivers and modes of large-scale variability

Guan, B., N.P. Molotch, D. E. Waliser, E. Fetzer and P.J. Neiman
Water Resources Research (2013)

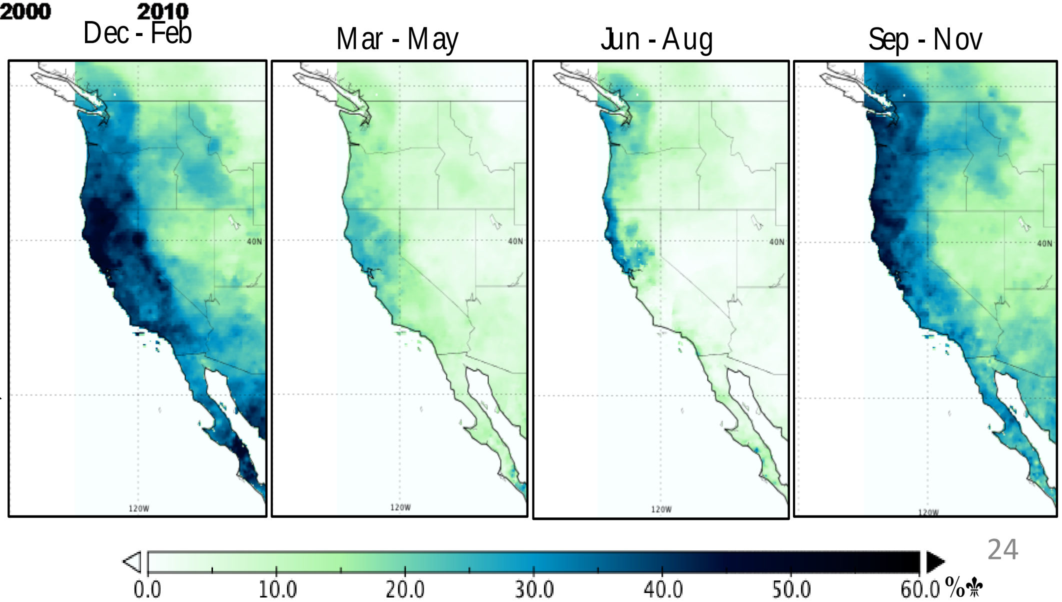
Arctic Oscillation (negative , i.e., southward cold-air outbreaks) combined with Pacific North American "teleconnections" pattern (negative, southern storm track) Favors Atmospheric river conditions striking the Sierra and causing precipitation



Application of AR Detection Scheme to Reanalysis Output



Annual number of days with landfalling ARs along California coast



Percent of total precipitation associated with nearby landfalling AR

Gershunov, Shulgina, Ralph
Scripps/CW3E

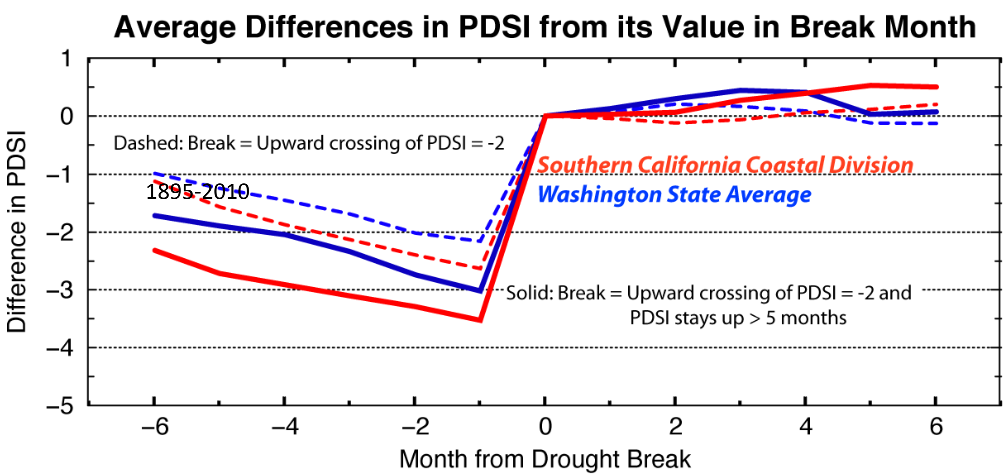
Thank you

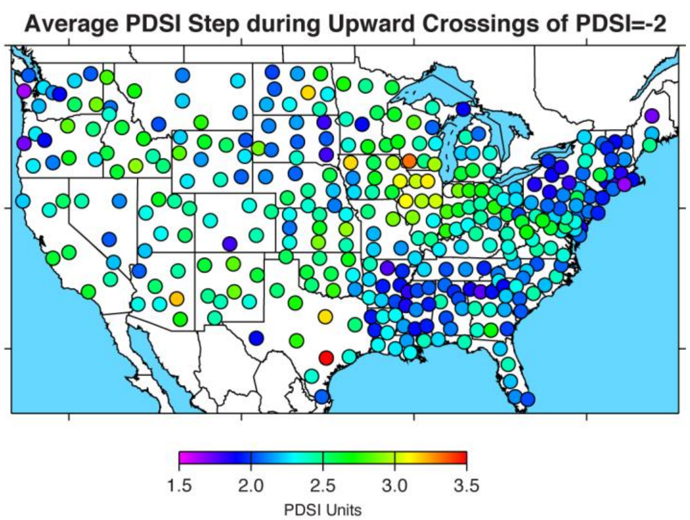
mralph@ucsd.edu
cw3e.ucsd.edu

Center for Western Weather and Water Extremes

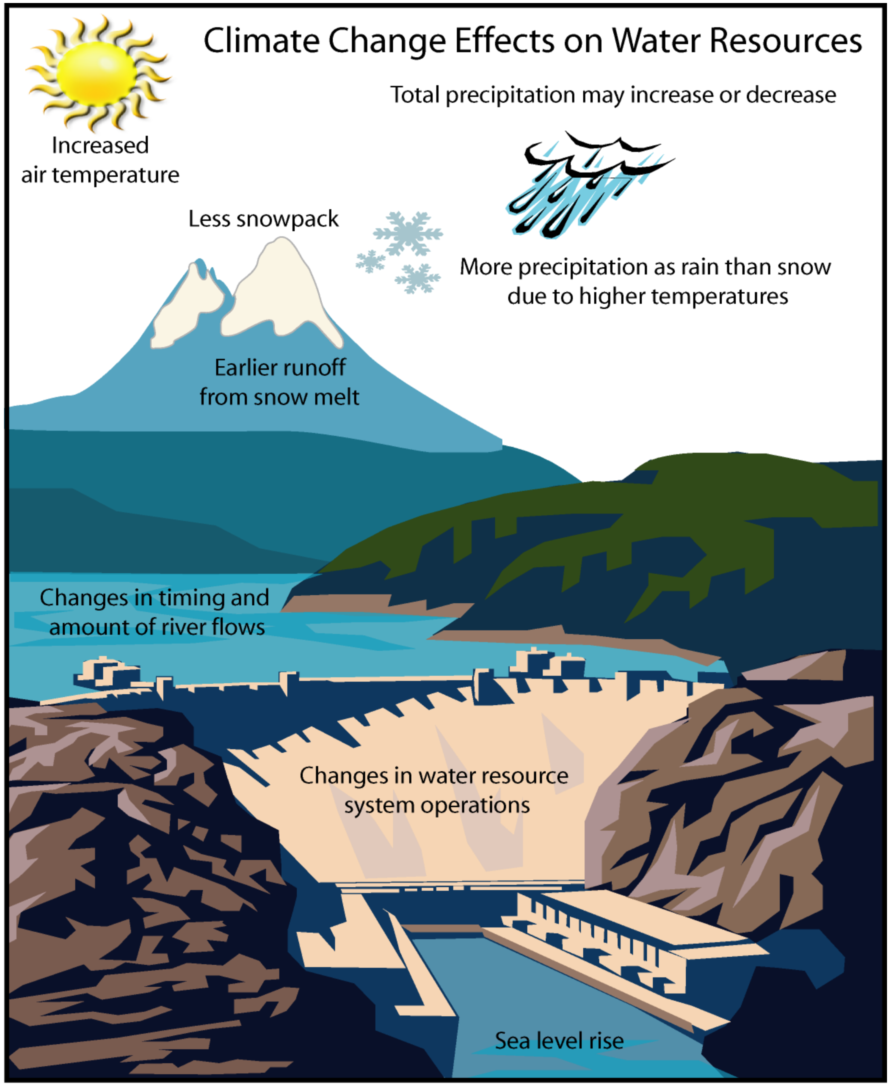
Droughts, on average, end with a bang (and begin with a whimper) all over the U.S.

- **Atmospheric rivers provide the bang** in a large fraction of the west coast drought breaks, especially in winters





Dettinger, Michael D., 2013: Atmospheric Rivers as Drought Busters on the U.S. West Coast. *J. Hydrometeor*, **14**, 1721–1732.



DWR Program Applications of Atmospheric Rivers Network Data

- Flood Preparedness and Response
- Flood Planning
- Reservoir Coordinated Operations
- Water Supply Forecasting
- Monitoring Climate Change

Courtesy of Mike Anderson
- CA Dept. Water Resources
- CA State climatologist

Seasonality of Annual Peak Daily Flow in Arizona

Aravaipa Canyon Wilderness, April 2013

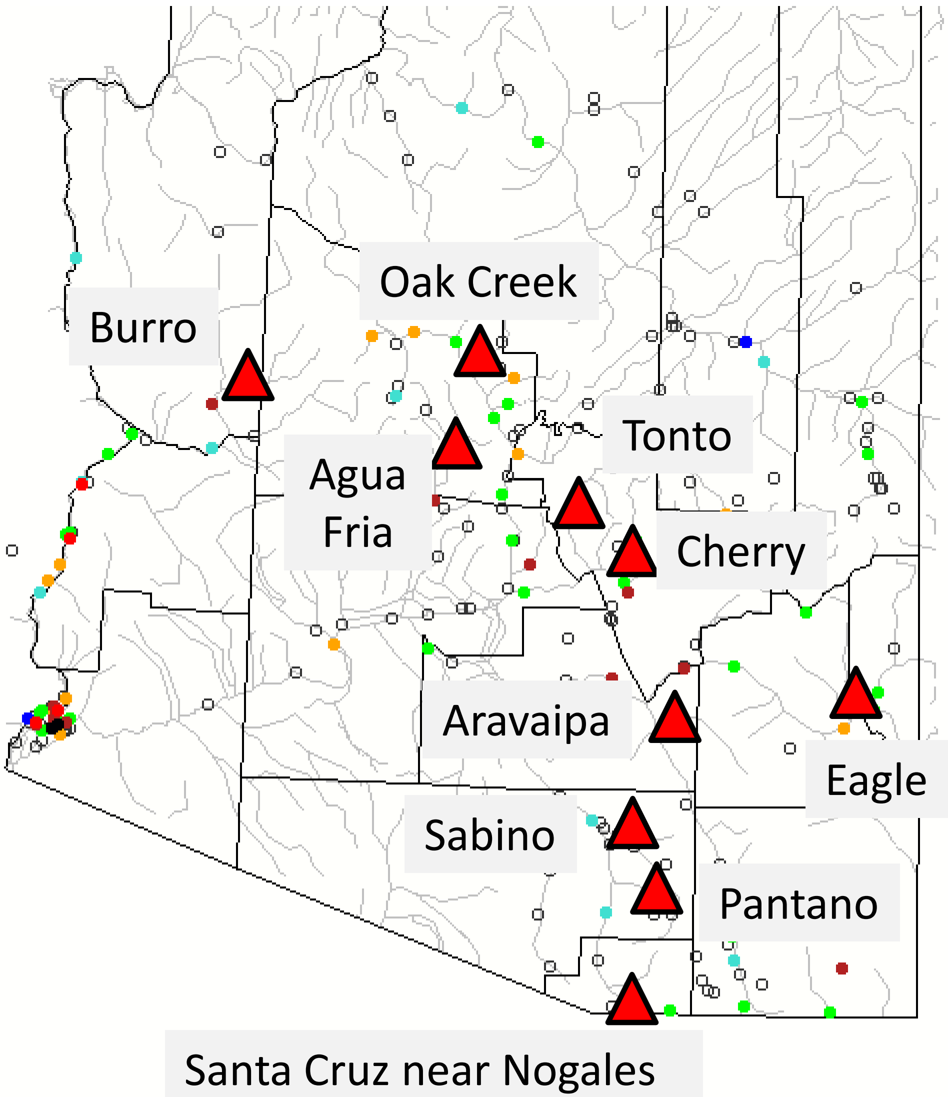
Are ARs a factor inland from the coastal states?

- Seasonality of Annual Peak Daily Flow in Arizona – Preliminary analysis using USGS data
  - 10 Moderate sized basins (avg. area is 460 sq miles)
  - 5 Large basins (avg. area is 4329 square miles)
    - Stream Gage sites used for the "Large" basins
      - Santa Cruz River near Cortaro
      - Gila River near Clifton
      - Salt River near Roosevelt
      - Verde River near Camp Verde
      - Virgin River at Littlefield
  - Little Colorado near Cameron (29,000 square miles)

Methodology

- Annual peak daily flows available online from USGS are examined.
- Watersheds of modest or large size and covering a range of latitudes and longitudes across central and southern AZ were selected.
- Each one needed to have at least 20 years of record
- Spring snowmelt dominated watersheds were avoided
- Most watersheds had an aspect facing southerly or southwesterly.
- Annual peak flow was examined
- All dates fell either in Jul-Sep, or in Oct, or in Nov-Mar
- Nov-Mar events were considered “cool season”
- Oct events were likely remnant tropic systems as on 2-3 Oct 1983

Modest sized watersheds



- Record flows range from 15-75 kcfs
- Drainage areas are between 200-675 sq mi (except Sabino is 36)
- Gage elevations are between 1880-3703 ft msl

The Landfall & Inland Penetration of a Flood-Producing Atmospheric River in Arizona: Part 1: Observed Synoptic-scale, Orographic, & Hydrometeorological Characteristics

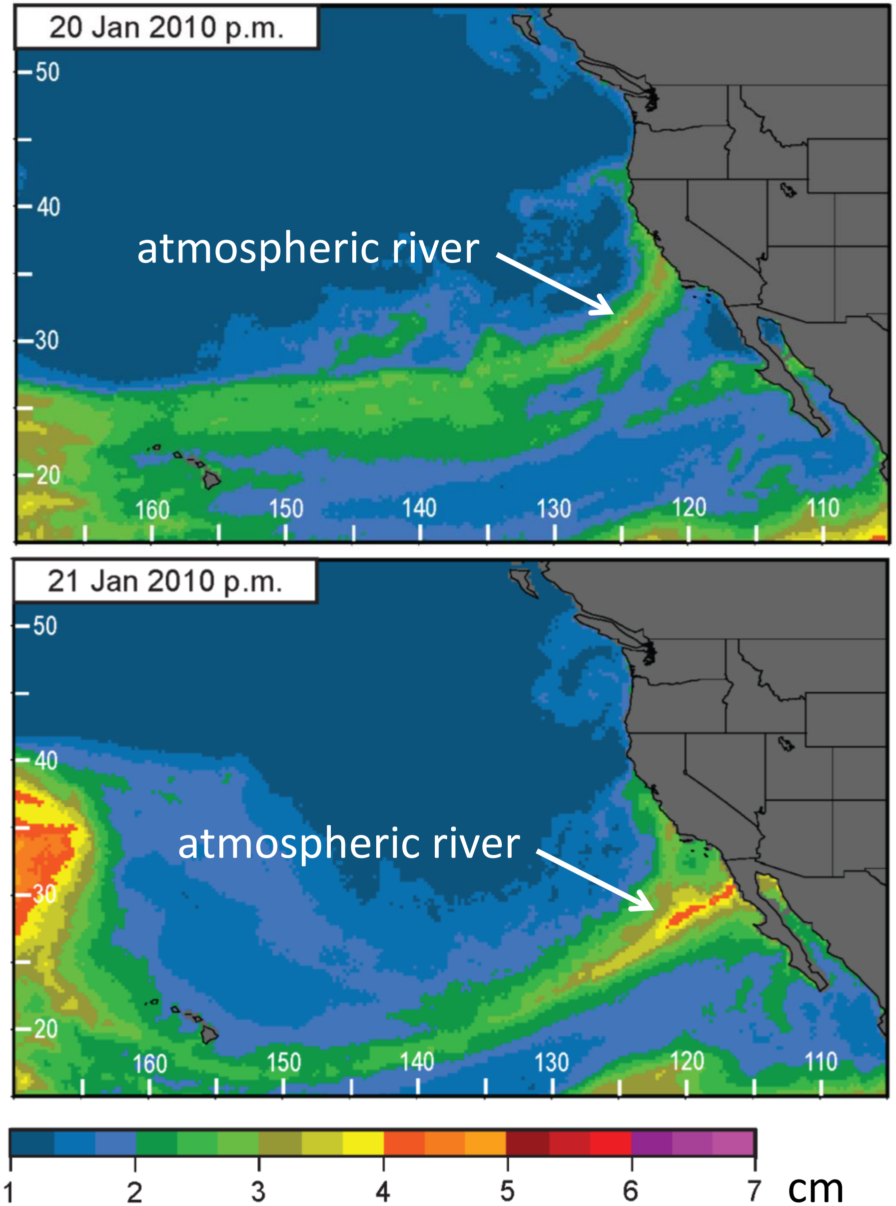
Paul J. Neiman[1], F.M. Ralph[1], B. Moore[2], M. Hughes[2], K. Mahoney[2], J. Cordeira[2], M. Dettinger[3]

[1]NOAA/Physical Sciences Div., Boulder, CO; [2]CIRES/NOAA, Boulder, CO; [3]Scripps, La Jolla, CA

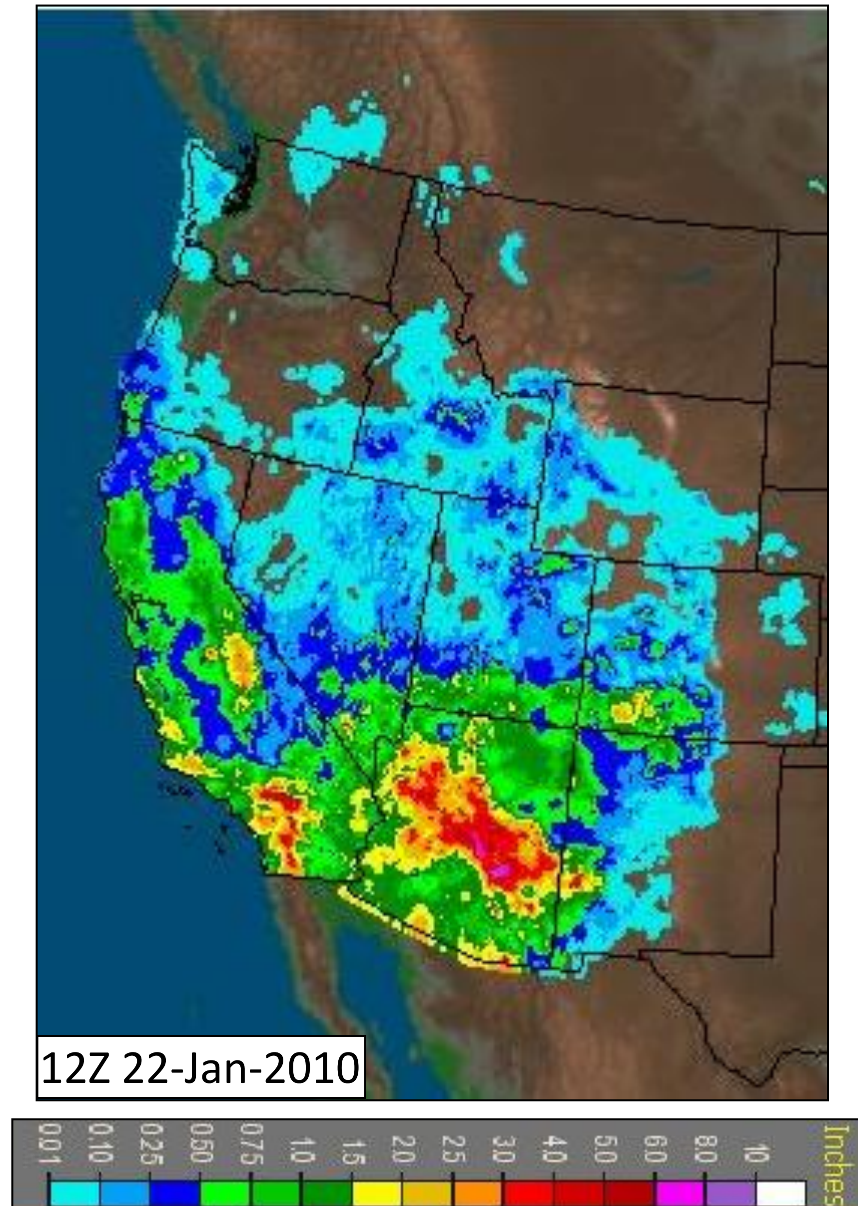
J. Hydrometeor., **14**, 460-484 (April 2013)

Grand Canyon South Rim

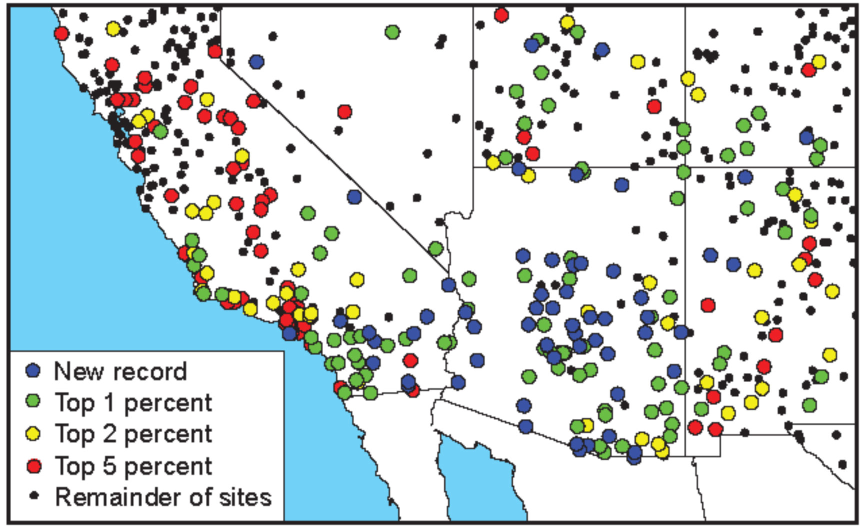
SSM/I IWV satellite imagery 20-21 Jan. 2010 depicts a strengthening AR making landfall



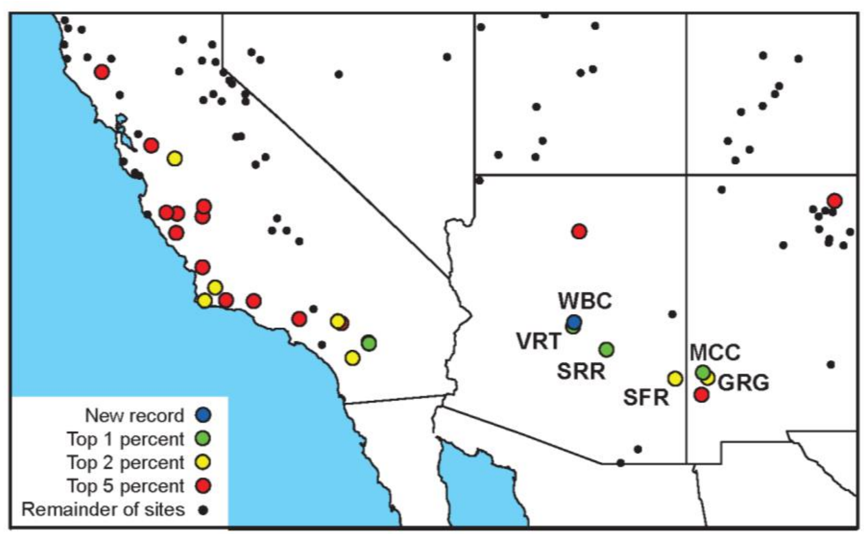
24-h precip ending 12Z 22 Jan. 2010: Advanced Hydrological Prediction Services



COOP precip on 21-22 Jan. 2010: Rank relative to all January pairs of days between 1950-2009 for gauges with >25 Januarys of data.



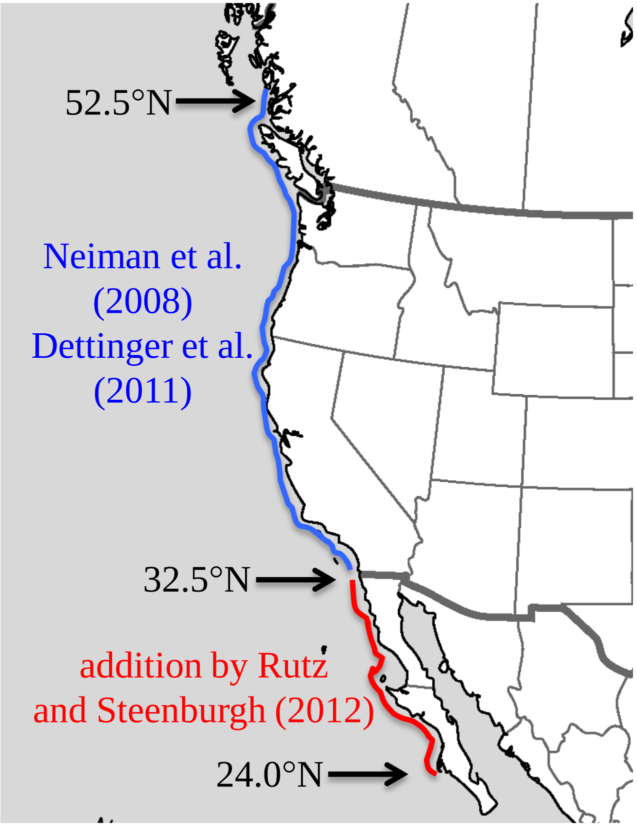
USGS streamflow on 21-22 Jan. 2010 for unregulated channels: Rank relative to all January pairs of days between 1901-2009 for gauges with >25 Januarys of data.



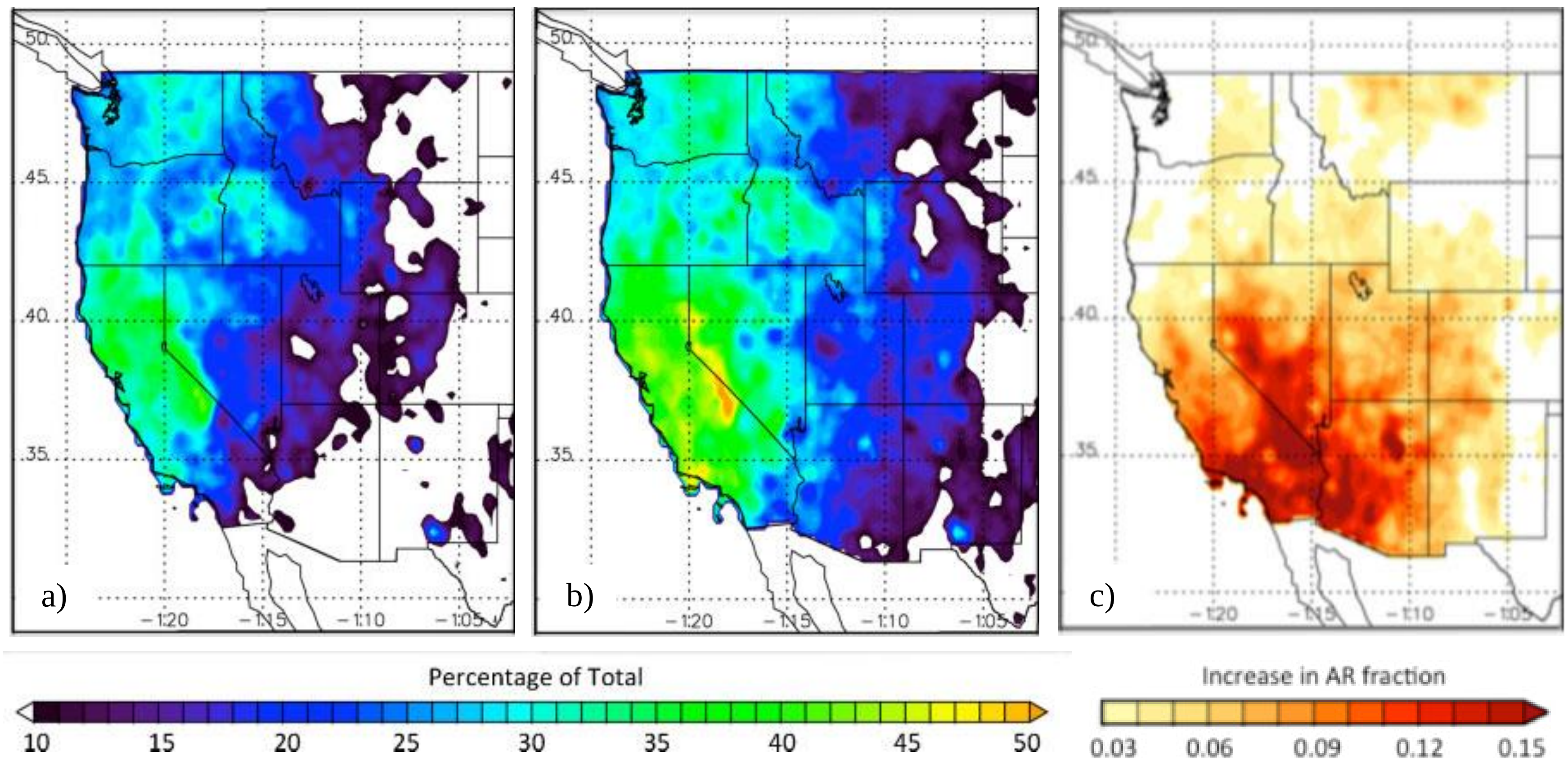
ARs crossing the Baja Peninsula

Rutz, J. J. and Steenburgh, W. J. (2012), Quantifying the role of atmospheric rivers in the interior western United States. Atmos. Sci. Lett., 13: 257–261. doi: 10.1002/asl.392

- <u>Motivation</u>
  - Provide a follow-up to the work of Dettinger et al. (2011), which assessed the influence of ARs on western U.S. precipitation, but did not consider ARs crossing the Baja Peninsula
- <u>Method</u>
  - If an AR is present for ~24 h along the North American west coast from 24–52.5°N, precipitation on that day and the next are attributed to the AR.
  - The "AR fraction" is the fraction of total cool-season (Nov – Apr) precipitation attributed to ARs
  - Includes Baja Peninsula



ARs crossing the Baja Peninsula



Cool-season "AR fraction" (a) without and (b) with ARs crossing the Baja Peninsula in the CPC gridded precipitation analysis during water years 1998–2008. (c) (b) - (a).

Climatology of extreme daily precipitation in Colorado and its diverse spatial and seasonal variability

Mahoney, K., F.M. Ralph, K. Wolter, N. Doesken, M. Dettinger, D. Gottas, T. Coleman, and A. White
J. Hydrometeorology, 2015

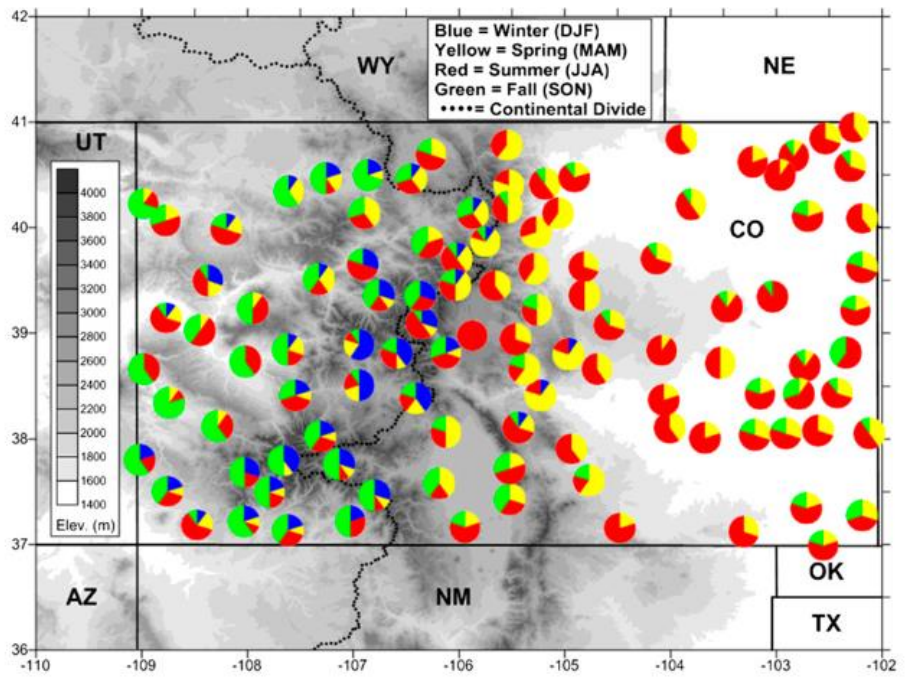


FIG. 2. Seasonality of the top 10 daily precipitation events measured at Colorado COOP stations that have at least 30 years of data since 1950. Circles represent totals of 10 events. Seasons shaded as winter (DJF; blue), spring (MAM; yellow), summer (JJA; red), and fall (SON; green). Terrain elevation (m; gray shading) as in legend at left; Continental Divide shown by dashed black line.

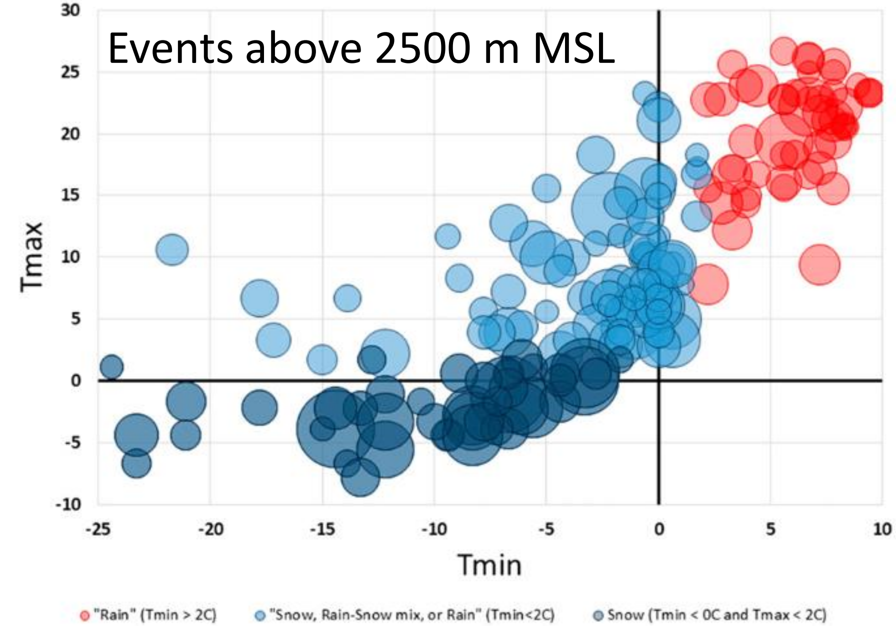
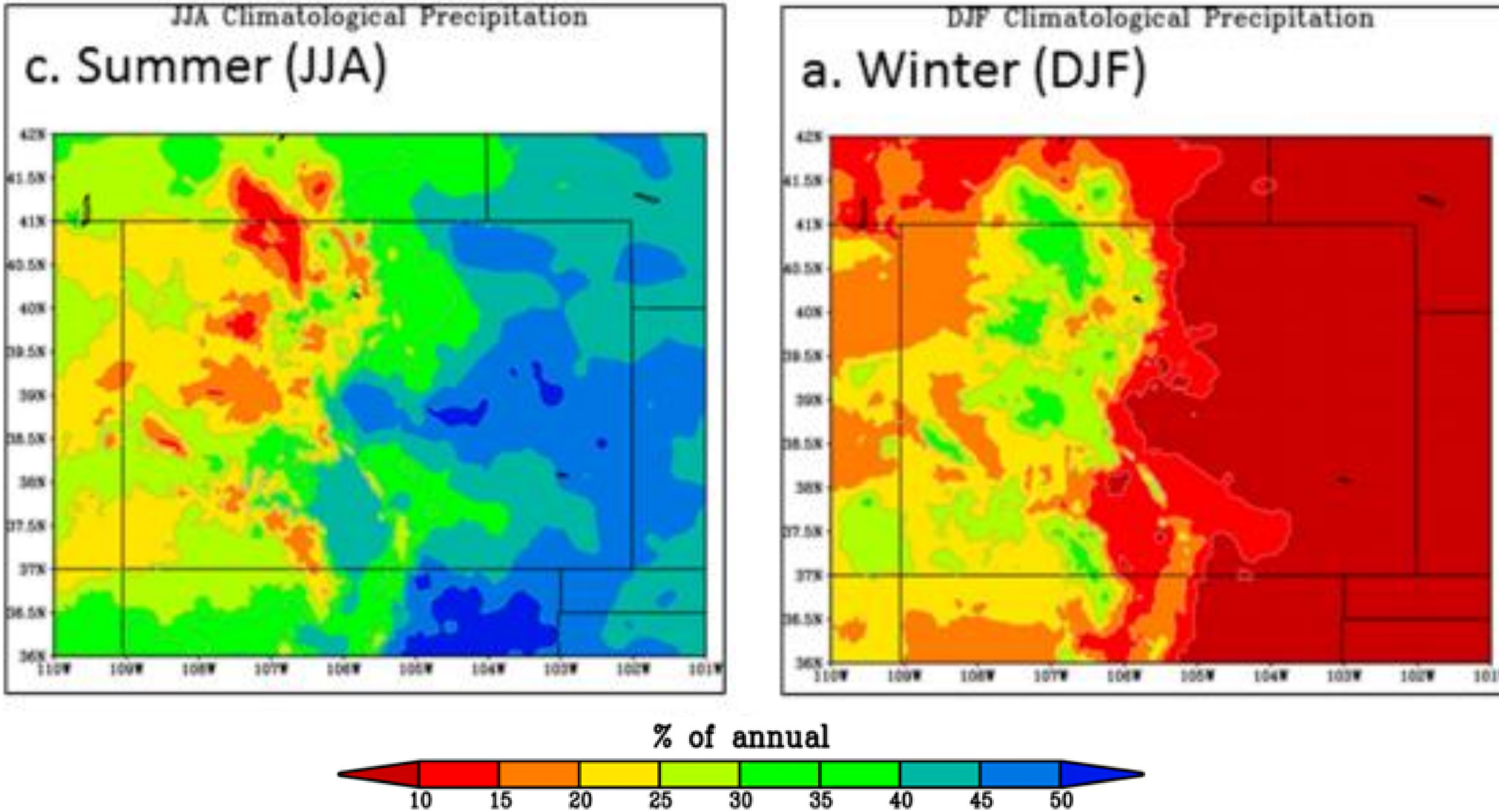


FIG. 5. Min daily temperature (x axis; °C) vs max daily temperature (y axis; °C) for precipitation events occurring above 2500-m elevation. Circle color indicates likely phase (rain, snow, or mixed) of precipitation shaded according to legend. Circle size indicates relative magnitude of 24-h precipitation total per event.

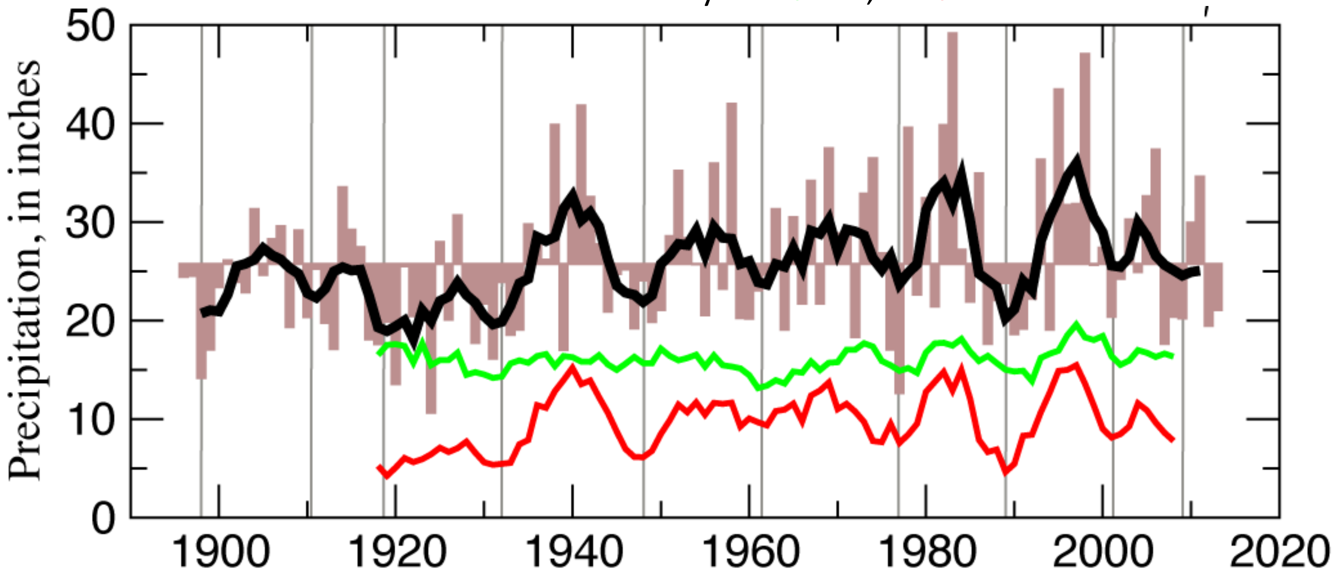
Seasonal contribution to annual precipitation



A few large storms (or their absence)

Account for a disproportionate amount of California's precipitation variability

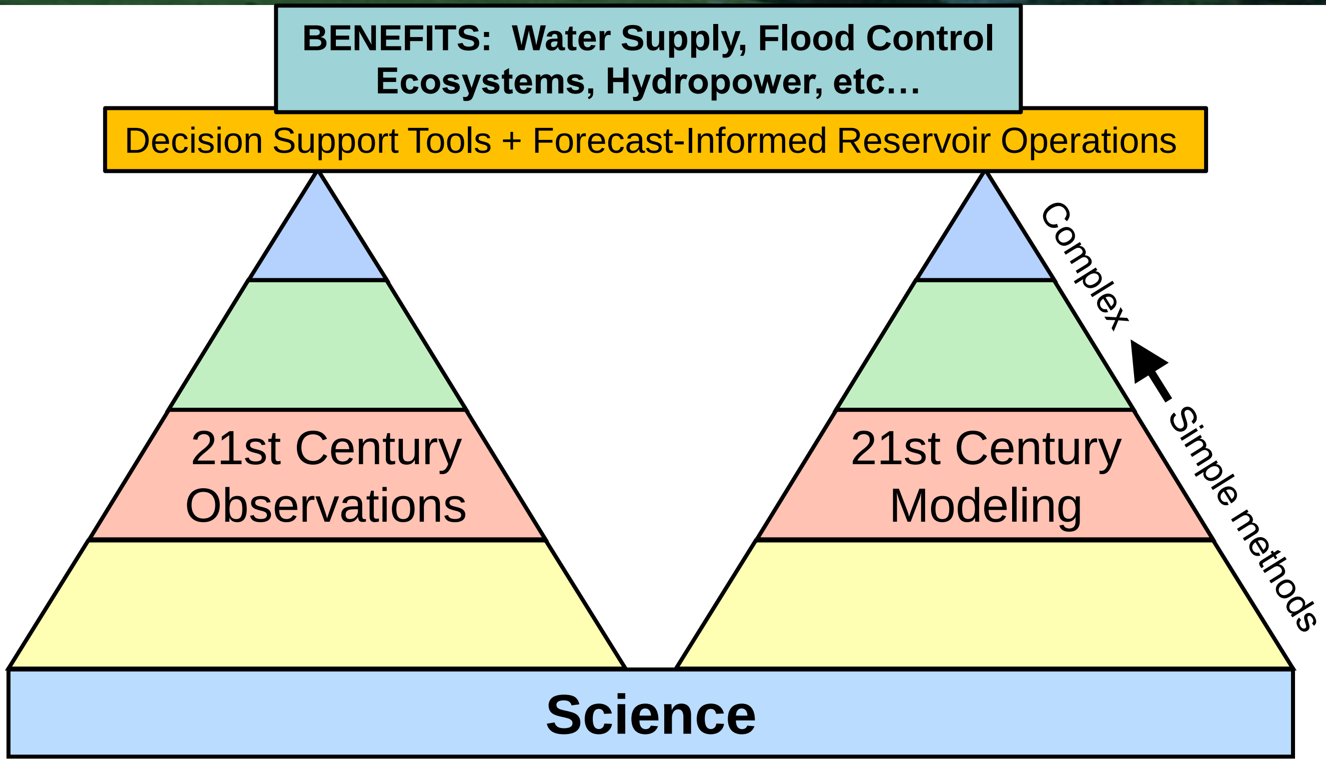
Water year precipitation, Delta catchment
with contributions from days <95%-ile, >95%-ile



Dettinger and Cayan 2014, *San Francisco Estuary and Watershed Science*

There is no "silver bullet"

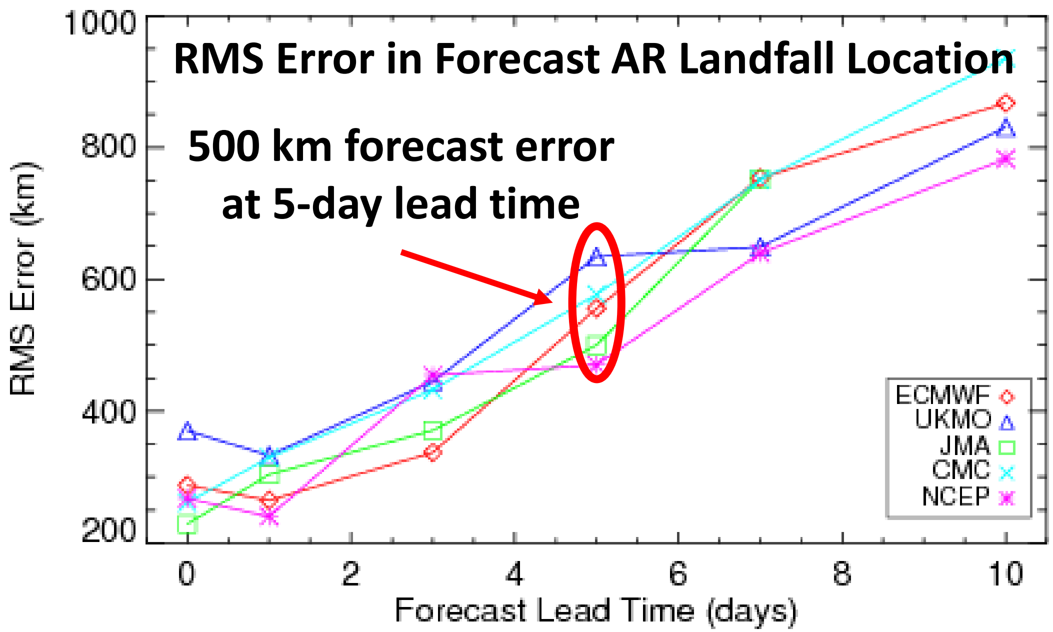
Requires an Integrated, Multi-disciplinary Strategy



F.M. Ralph
Scripps/CW3E

AR Landfall Position Forecast Errors

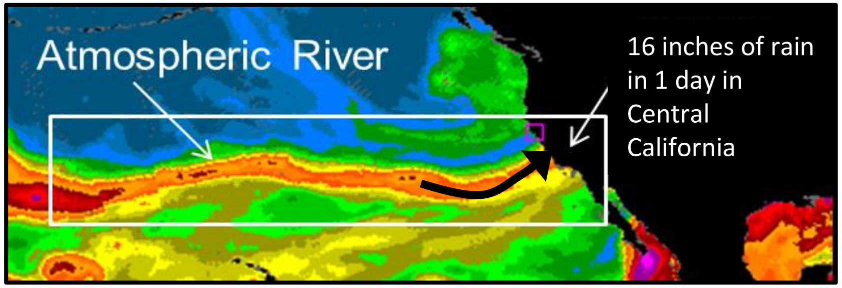
While overall occurrence well forecast out to 10 days, landfall is less well predicted and the location is subject to significant errors, especially at longer lead times



- Errors in location increase to over 800 km at 10-day lead
- Errors in 3-5 day forecasts comparable with current hurricane track errors
- Model resolution a key factor

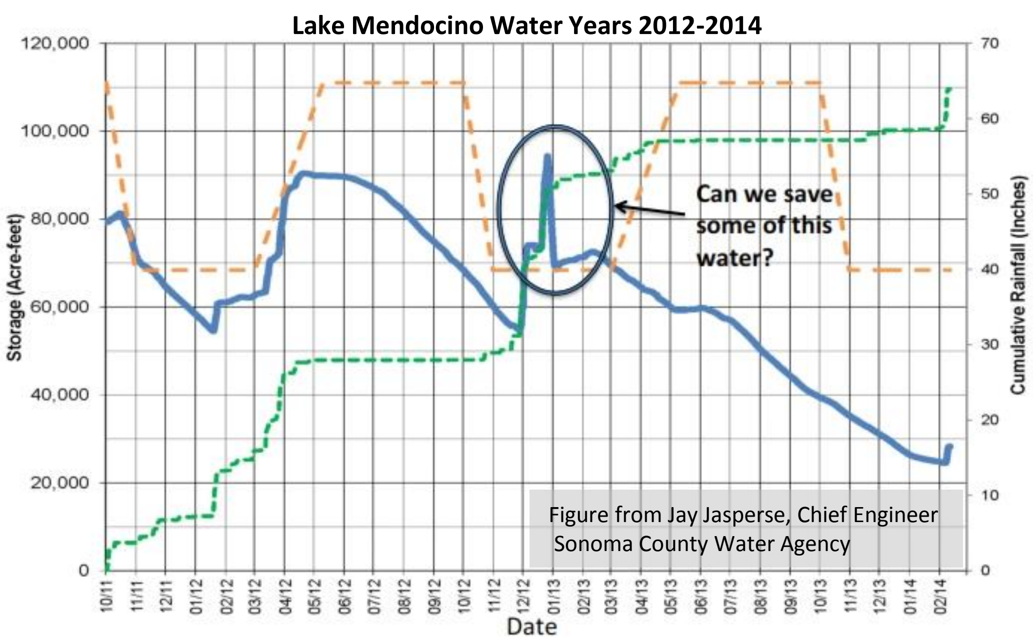
From Wick et al., 2013 (Weather and Forecasting)

- **Models provide useful heads-up for AR impact and IWV content, but location highly uncertain**
- **Location uncertainty highlights limitations in ability to predict extreme precipitation and flooding**
- **Improvements in predictions clearly desirable**



Forecast-Informed Reservoir Operations: A Concept Supporting Water Supply, Flood Control, Ecosystems

Steering Committee Co-Chairs:
J. Jasperse (SCWA), M. Ralph (Scripps)



Slide courtesy of F. M. Ralph (UC San Diego/Scripps/CW3E; mralph@ucsd.edu) and J. Jasperse (Sonoma County Water Agency) – FIRO Steering Committee Co-Chairs

FIRO Steering Committee

Local, State, Federal and University weather and water experts working to evaluate the potential viability of using forecasts of atmospheric rivers, rain and streamflow to enable safe retention of extra water if major storms are not predicted over the watershed in the coming days, or to enhance flood control if strong storms *are* predicted.