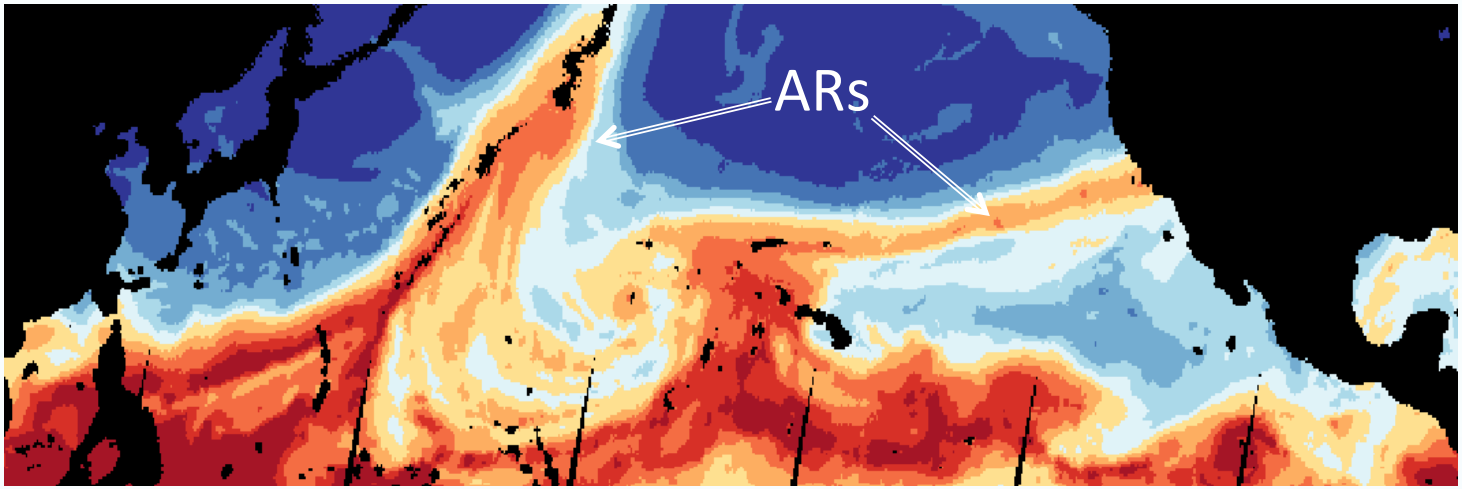
Atmospheric Rivers*: Water Extremes that Impact Global Climate, Regional Weather & Water Resources



Duane Waliser[1], Bin Guan[3], Marty Ralph[2]

[1]NASA Jet Propulsion Laboratory, Caltech

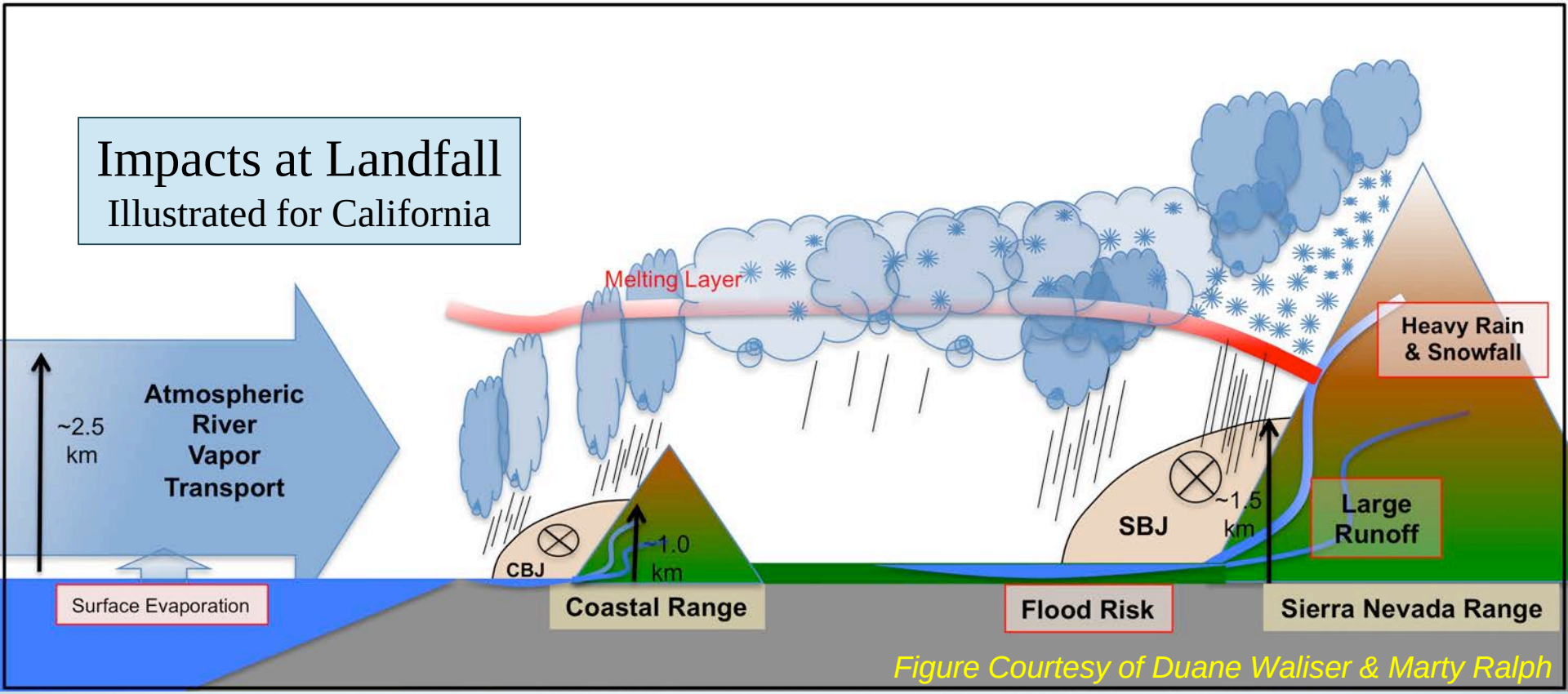
[2]Center for Western Water and Weather Extremes, SIO, UCSD

[3]Joint Institute for Regional Earth System Science and Engineering, UCLA

Support from NASA NEWS, MAP & NCA

*Name from Zhu & Newell, 1994; ARs transport ~10 times the flow of the Mississippi River

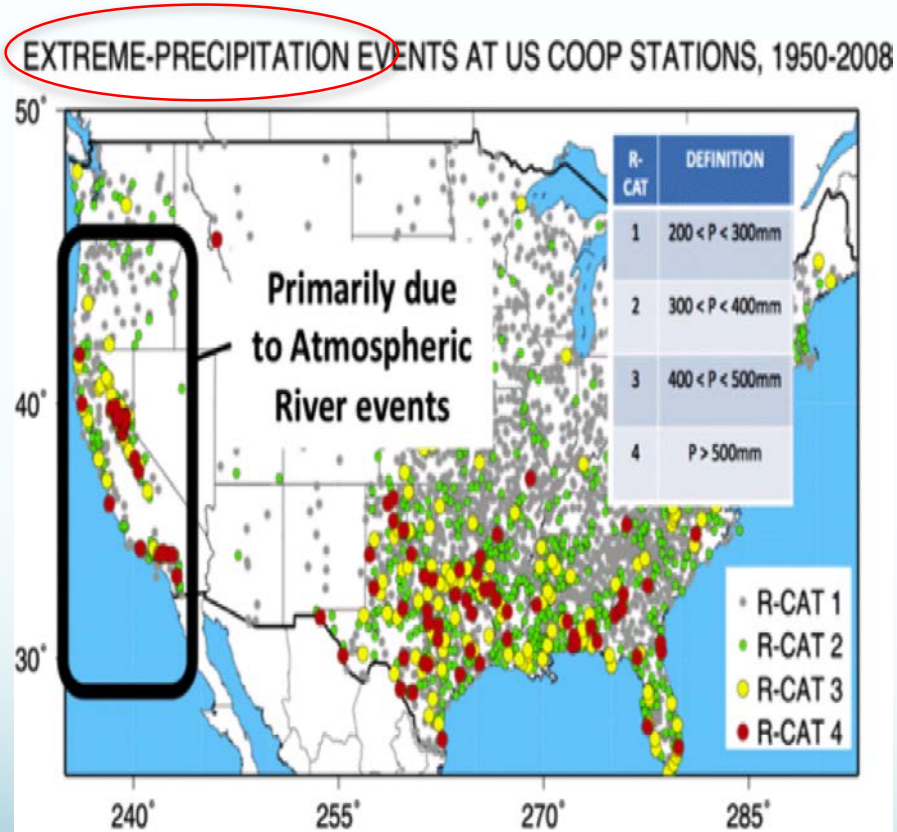
When Atmospheric Rivers Make Landfall Extreme Precipitation Occurs Near Mountains



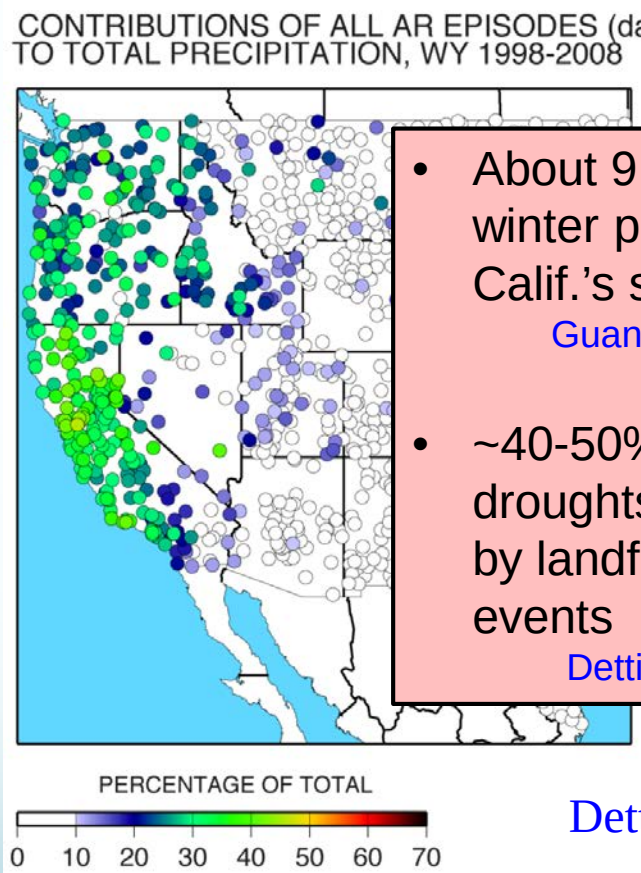
Most flooding / peak streamflow in U.S. coastal states is associated with ARs (e.g. Ralph et al. 2006; Neimen et al. 2011)

Atmospheric Rivers are to the West What Hurricane Hazards are to the Southeast

Atmospheric Rivers account for 30-40% of the freshwater supply in the West



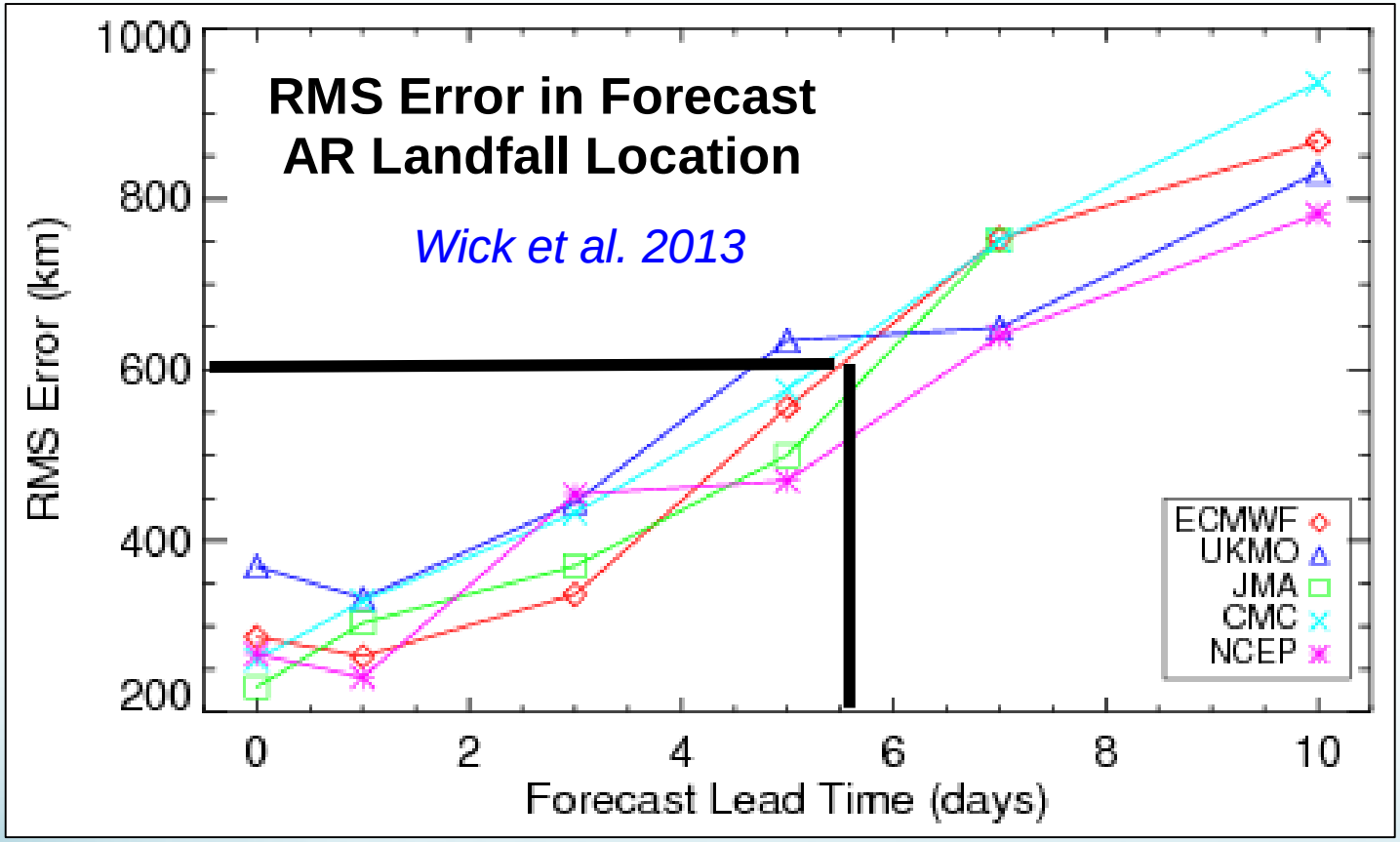
Ralph & Dettinger, 2012



- About 9 AR days per winter provide ~40% of Calif.'s snowpack
  Guan et al. 2013
- ~40-50% of Calif. droughts are "busted" by landfalling AR events
  Dettinger 2013

Dettinger et al. 2011

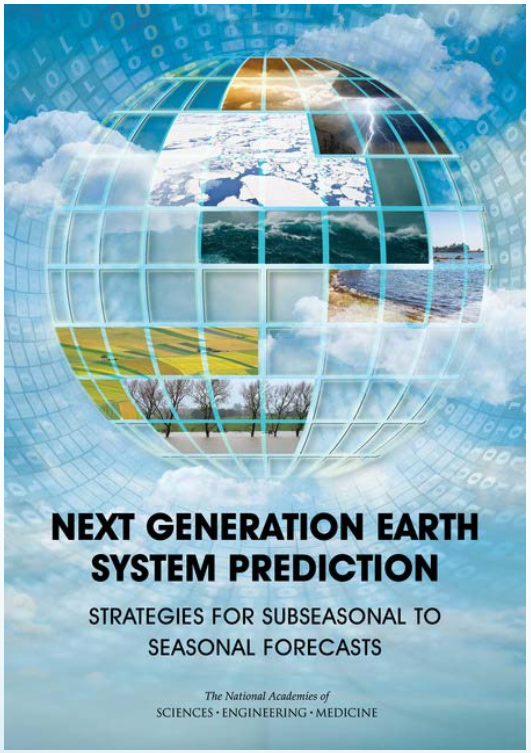
Forecasts of Timing and Location of AR Landfall Needs to Improve



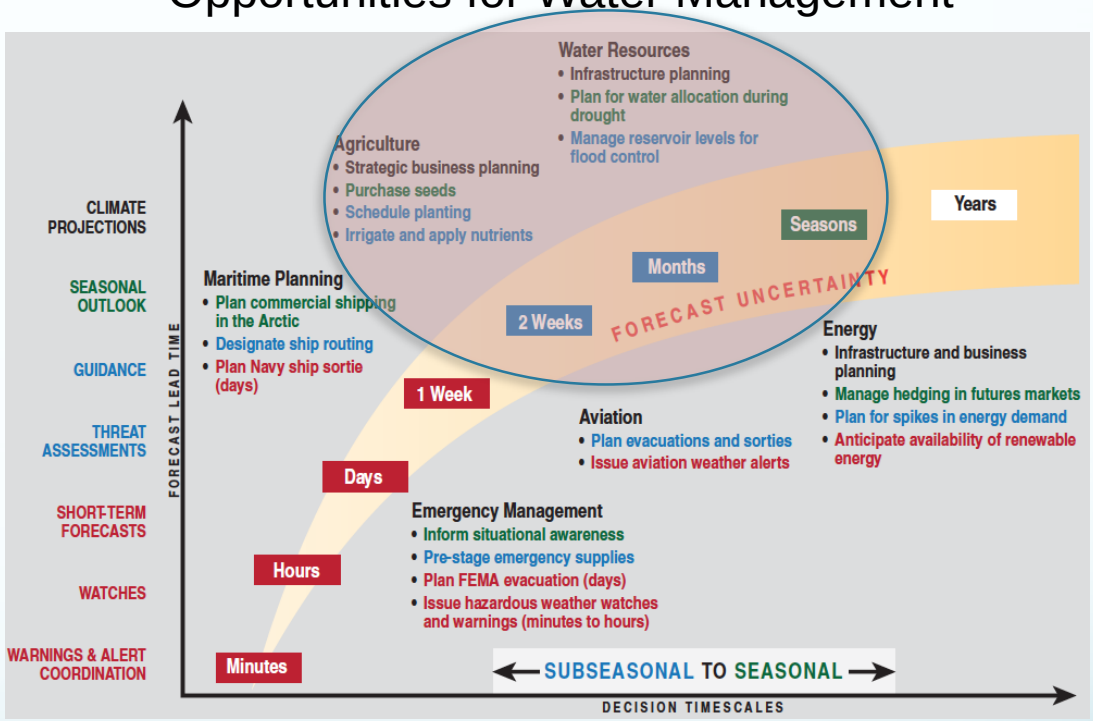
For example: at 5-6 day lead time, global weather forecasts cannot determine if AR will hit L.A. or San Francisco

A key objective of our current research is to more thoroughly quantify AR prediction skill and estimate their predictability under various climate conditions.

2016 National Academy Study: Strategies for **Subseasonal to Seasonal** Prediction

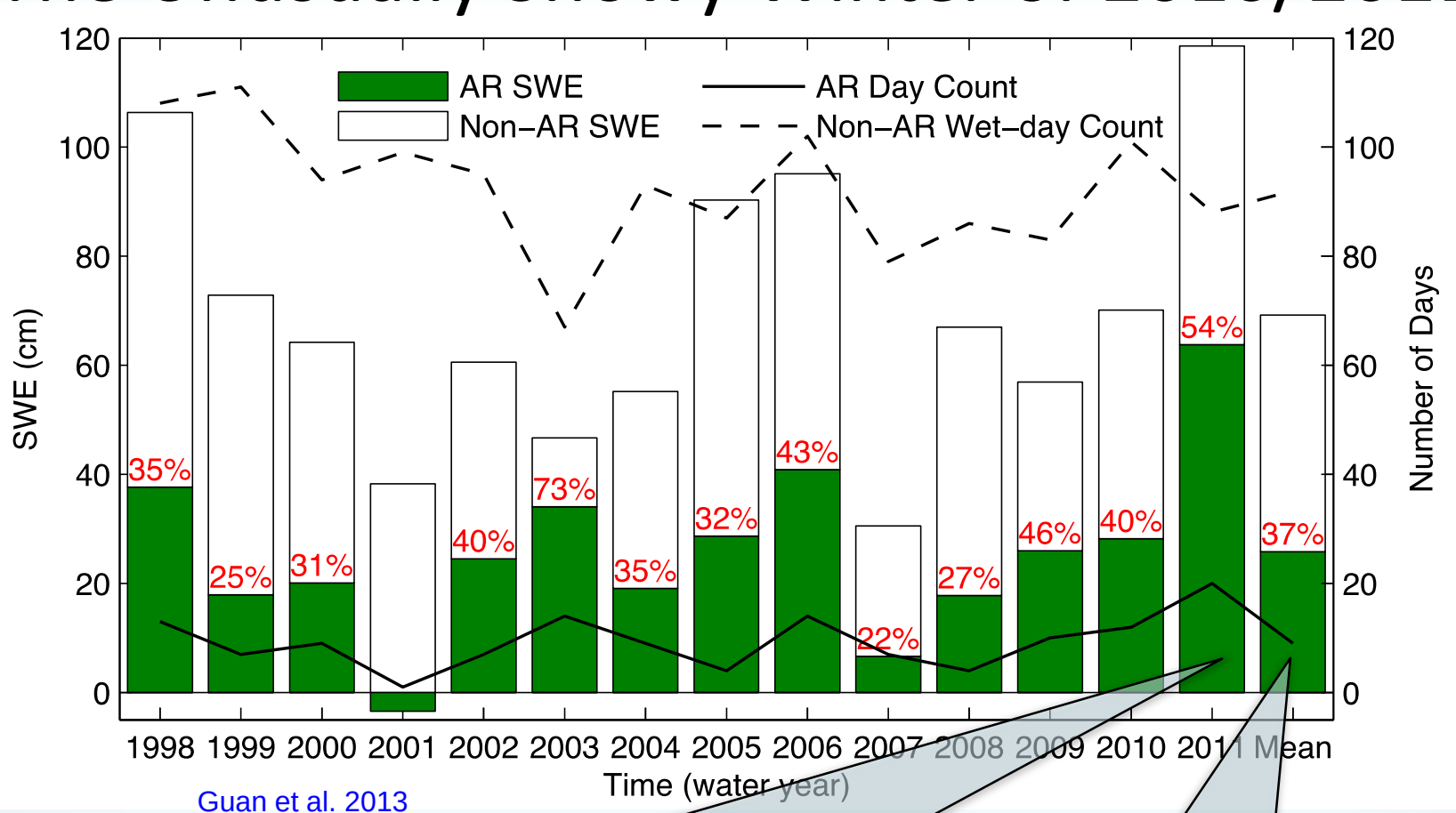


Opportunities for Water Management



Sponsored by NASA, ONR and Heising-Simons Foundation

The Unusually Snowy Winter of 2010/2011



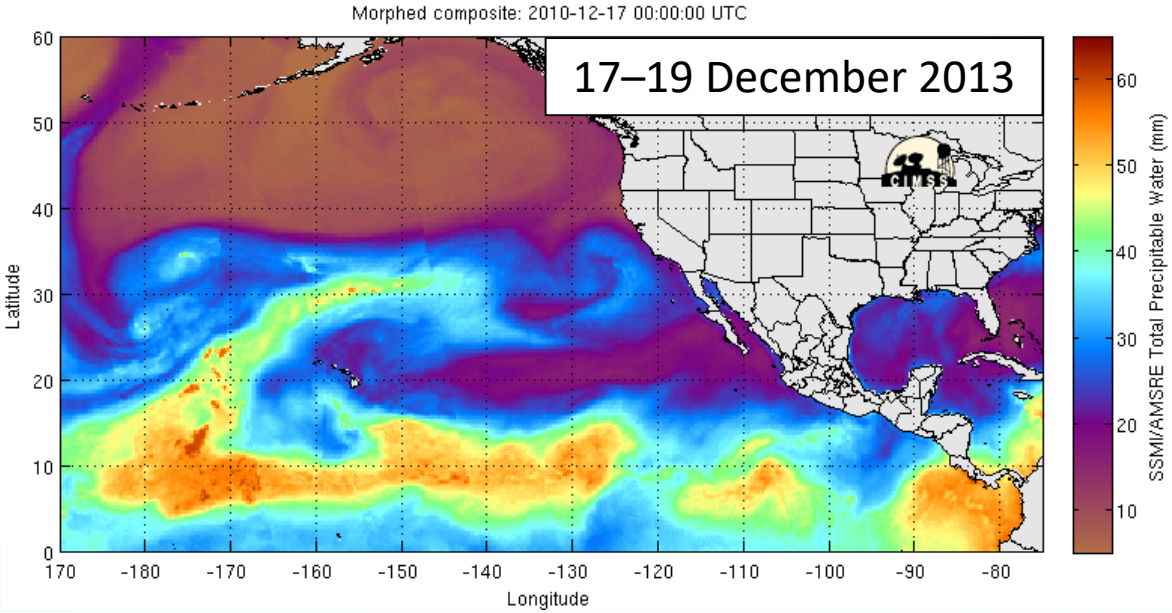
Guan et al. 2013

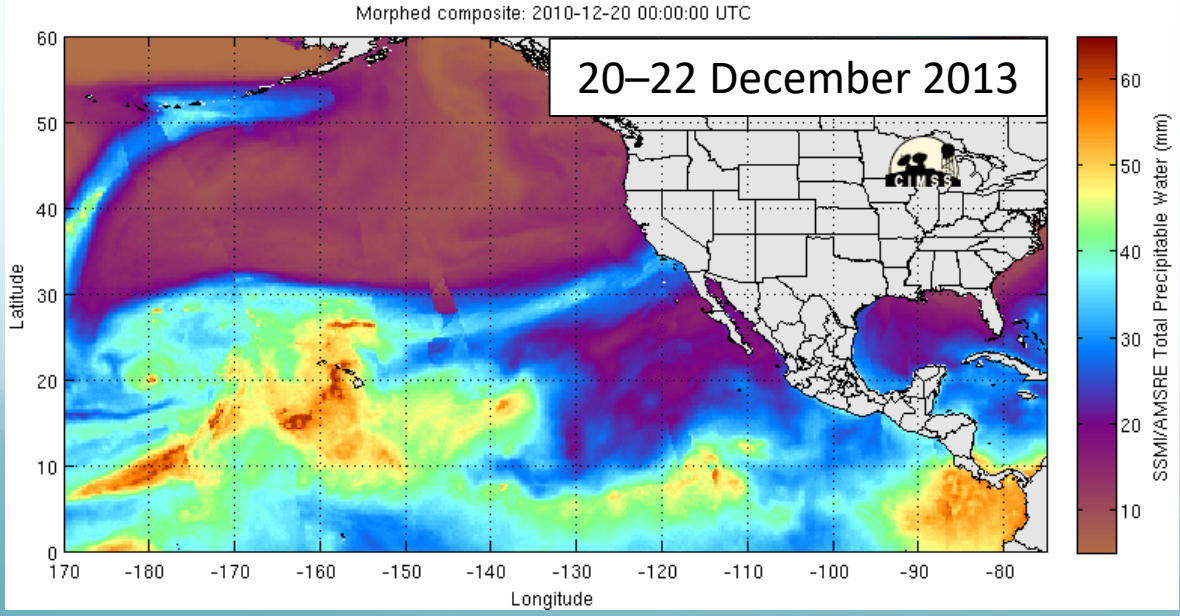
2010/2011 winter

- Largest total seasonal snow (~170% above normal)
- Largest number of AR dates (twice normal)
- Largest AR-related snow accumulation

On average 9 AR dates per winter contribute 37% total snow

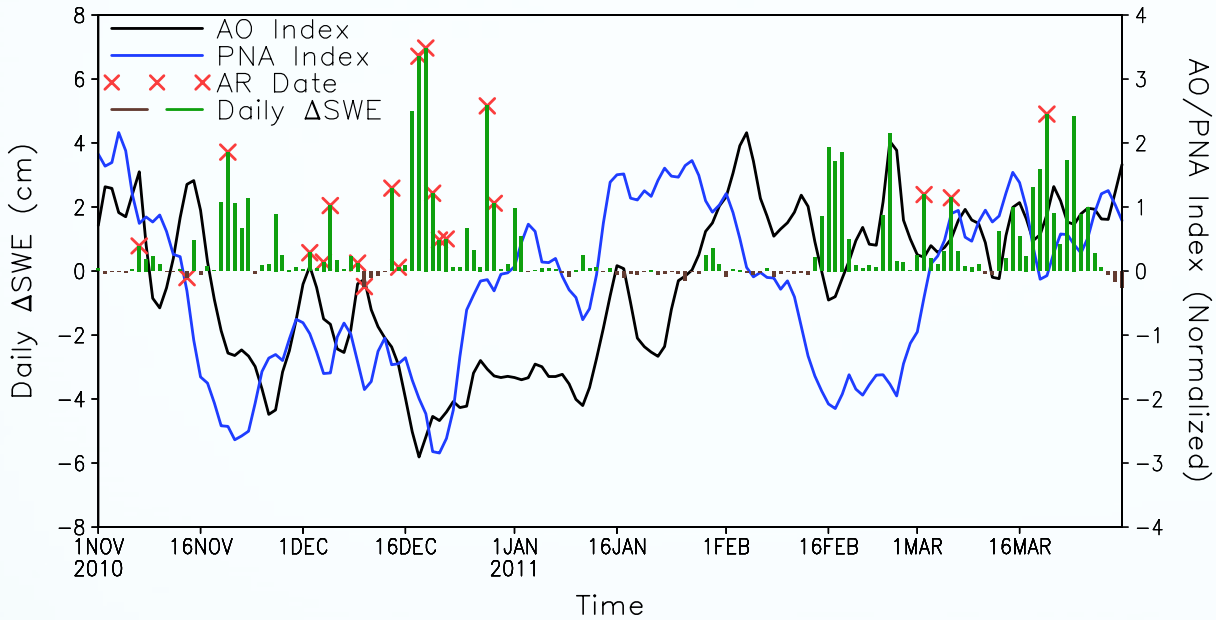
Dec 18 to 22 – Five Straight Days of ARs



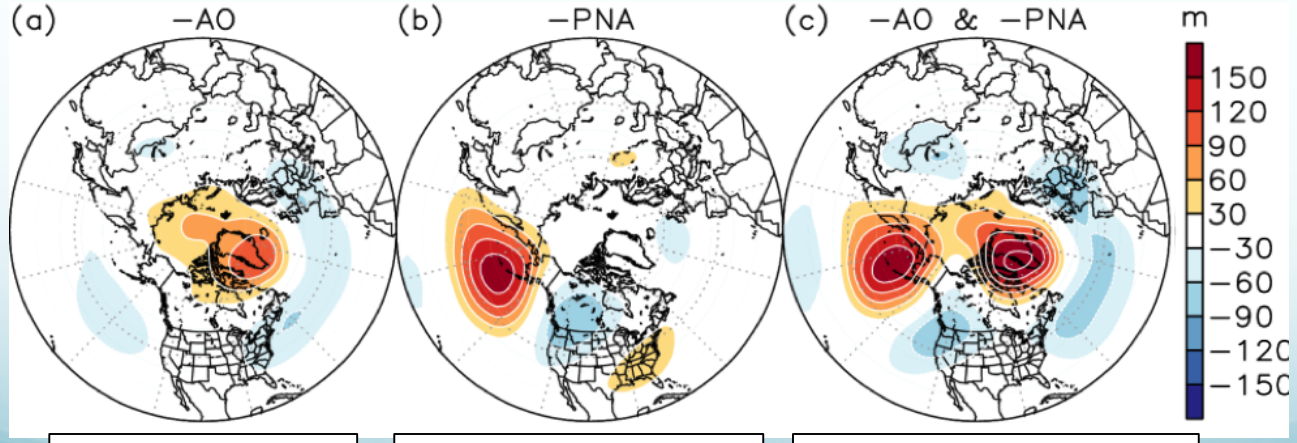


- >13 feet of snow in the Sierras
- >6 inches of rain in LA and >21 inches in parts of the foothills
- Spread into Nevada/Arizona/Utah ; Zion NP evacuated

Climate Conditions of the 2010/2011 Winter



–AO and –PNA tend to be associated with more stormy weather in California



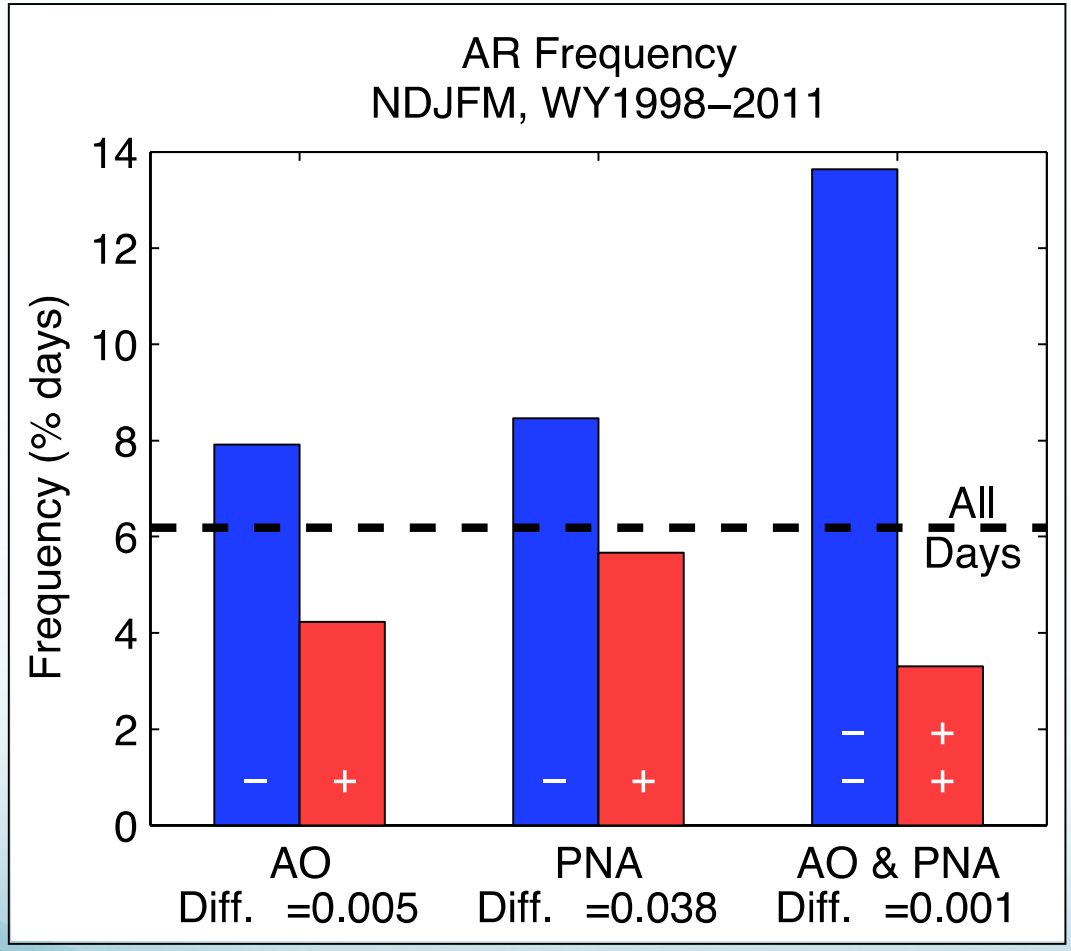
500 mb Geopotential Height Anomalies

"Arctic Oscillation" (AO)

"Pacific North American" (PNA)

Both PNA and AO in "negative" phase

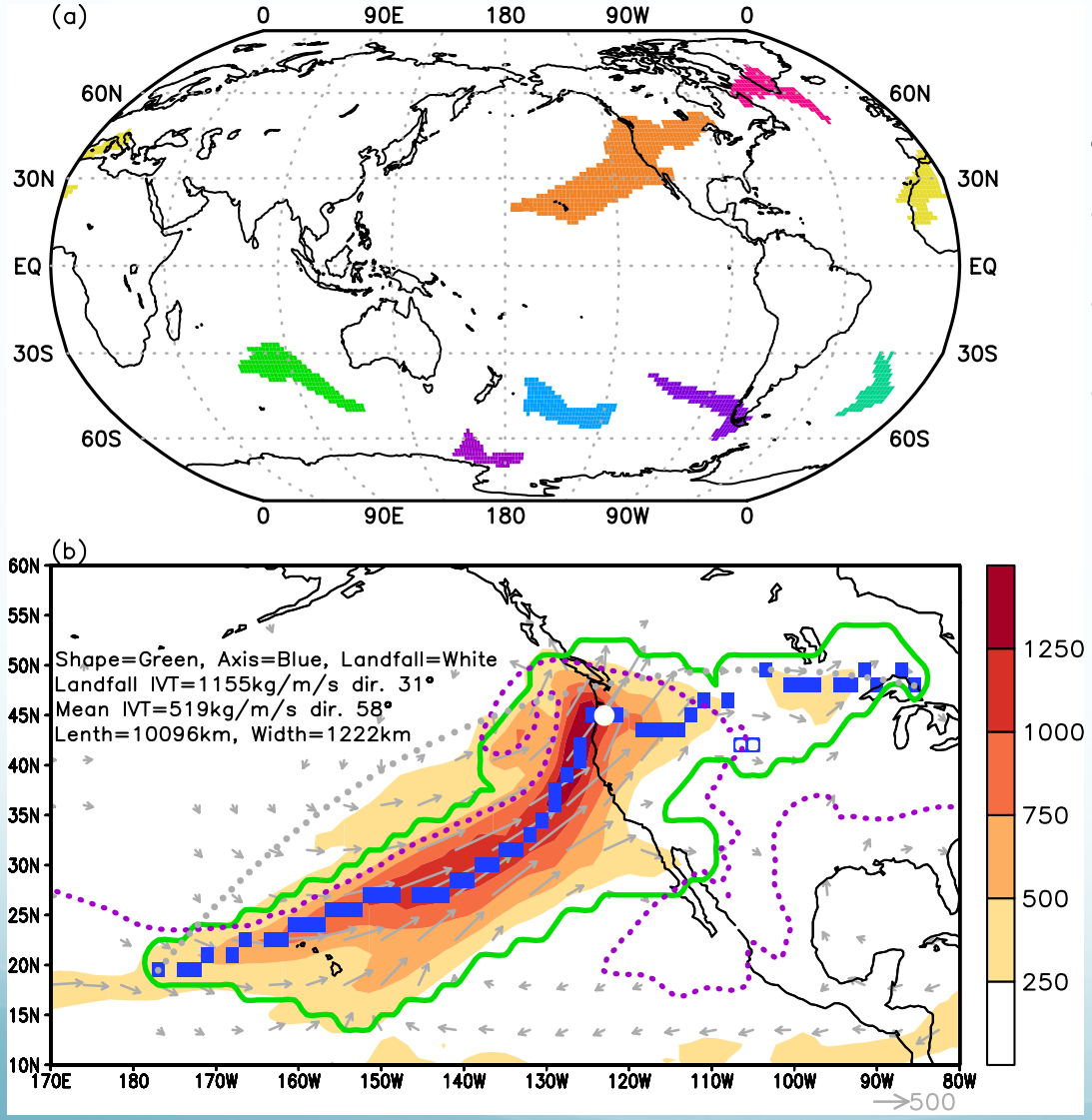
Phasing of AO/PNA vs. AR Frequency in California



When the AO and PNA are both in the negative phase, ARs are significantly more likely to occur.

Global AR Detection

Example Output of AR Shape, Axis, Landfall Location, Etc.



Based on ERA-Interim 6-hourly IVT

Specifically needed for:

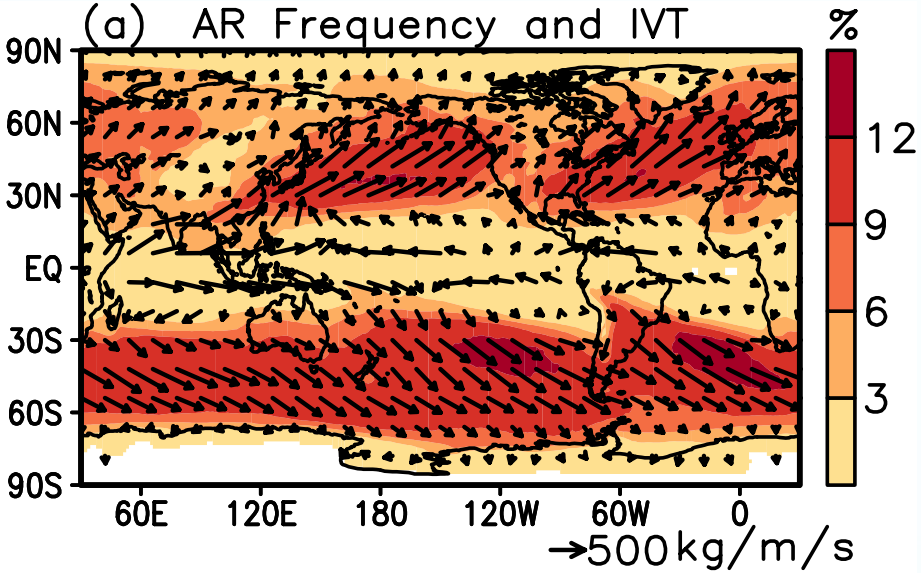
- Global characterization
- GCM evaluation
- Predictability Studies

Over ~90% agreement in detected AR landfall dates compared to 3 independent studies in western US, Britain, and East Antarctica (Neiman et al. 2008; Lavers et al. 2011; Gorodetskaya et al. 2014)

ERA-I: 1979-2015
MERRA2: 1980-2015
NCEP/NCAR: 1948-2015
CFSR: TBS

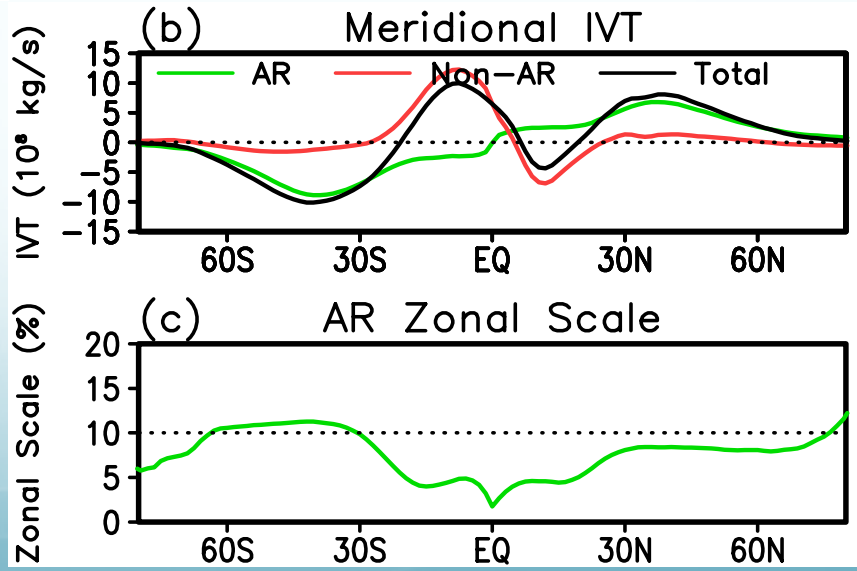
Global View of AR Frequency & Intensity

Relevant to Climate & Water Extremes

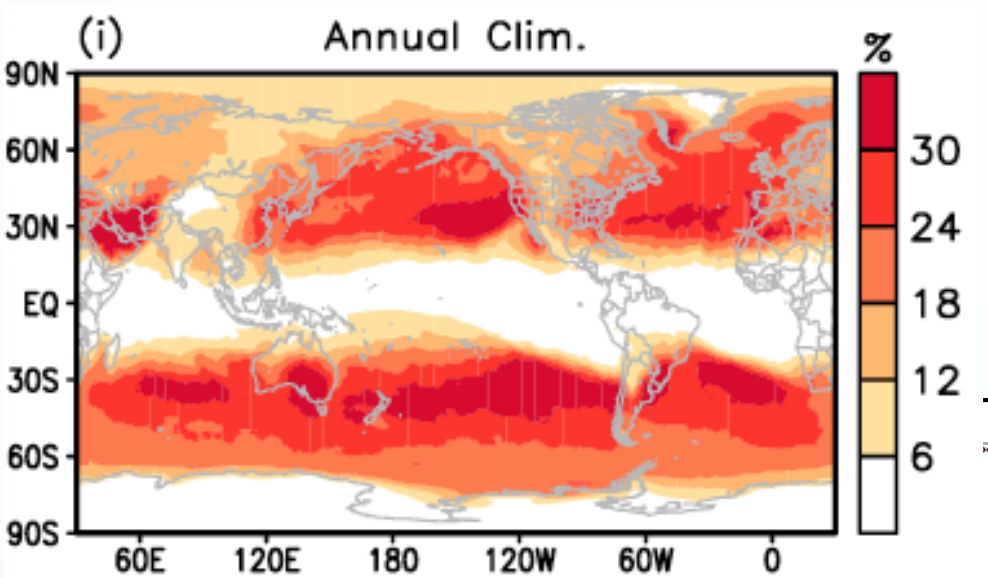


- **Northward component** key to **climate** – water vapor distribution and thus energy and water cycles
- **Eastward component** key to landfalls, inland penetration, and weather/water **extremes**

AR fractional poleward IVT and zonal scale consistent with Zhu and Newell (1998)

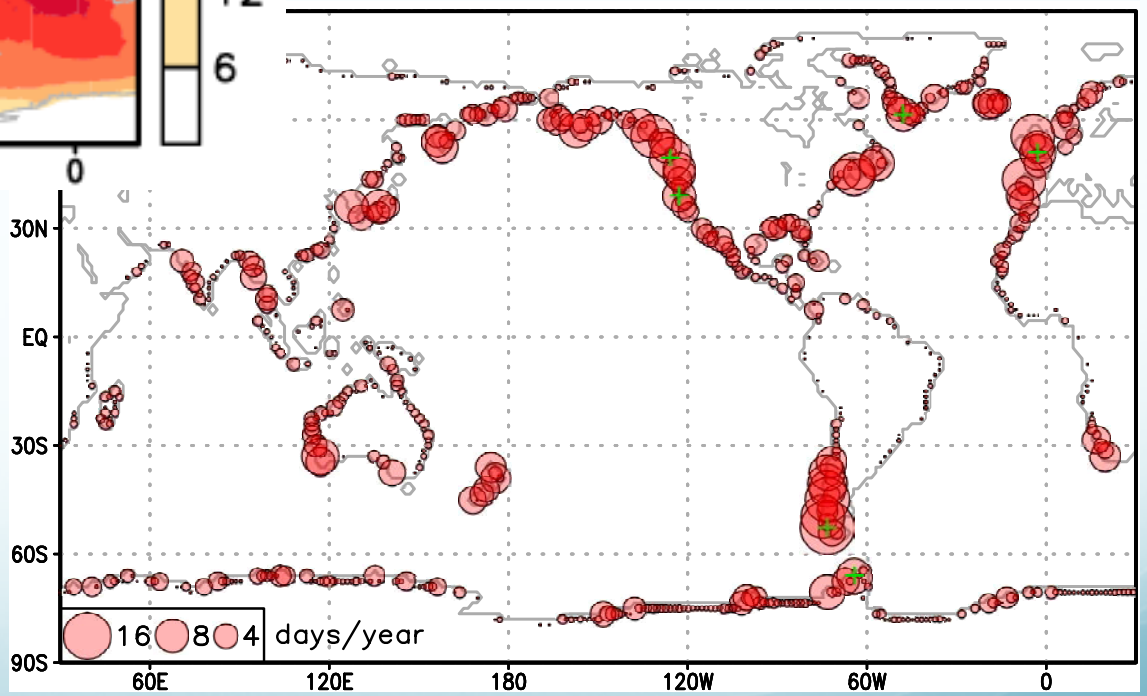


Global View of AR Precipitation & Landfalls



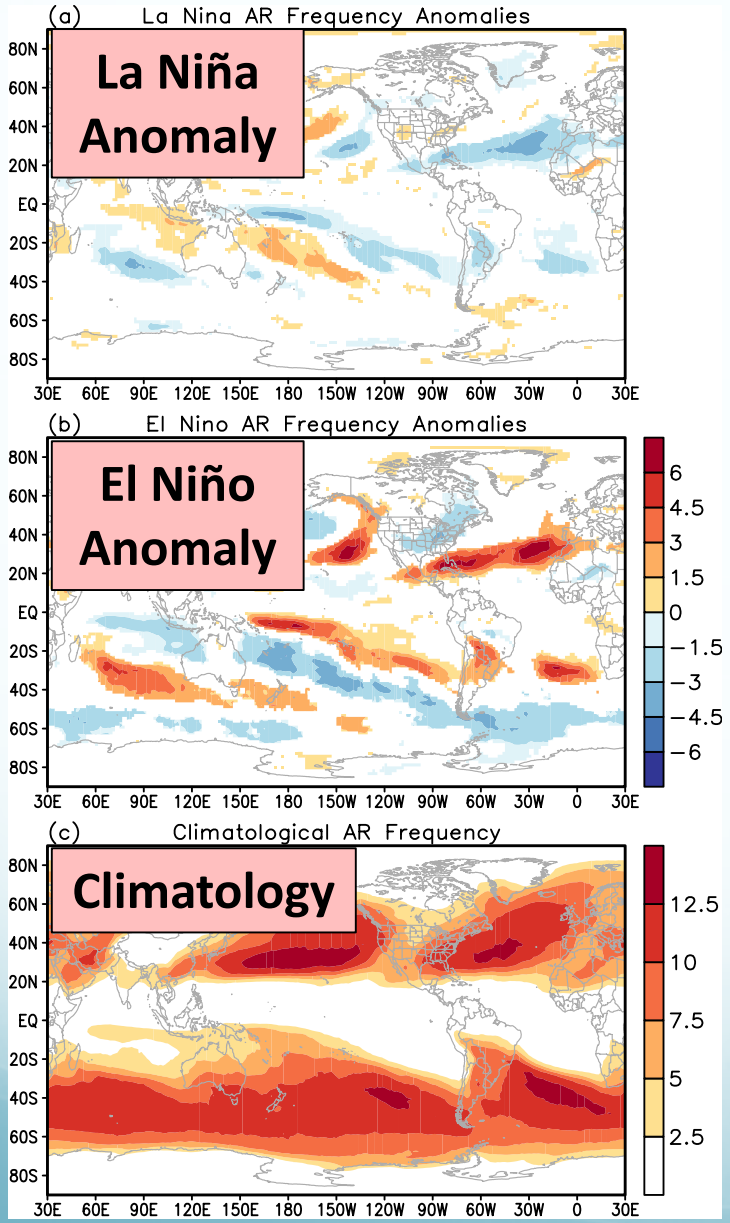
Fraction of Total Precipitation Due to ARs

Number of AR Landfalls per year

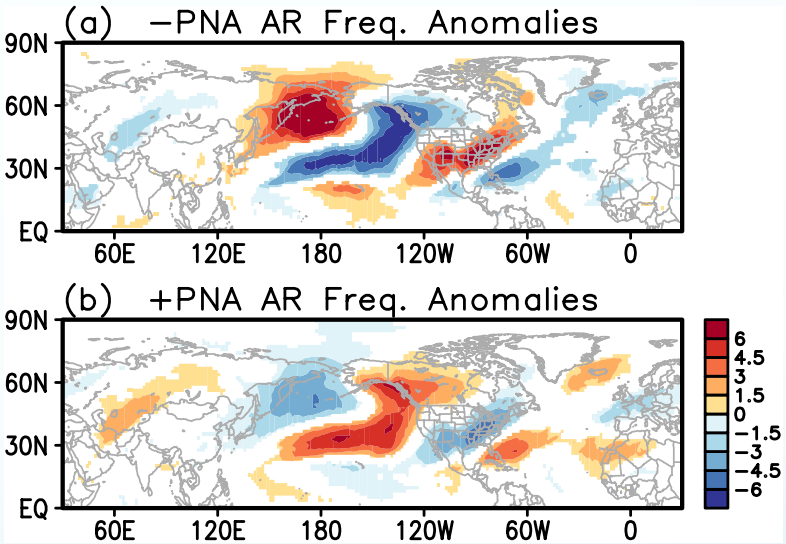


Guan and Waliser, 2015

Quantifying Climate Modulation of Global ARs



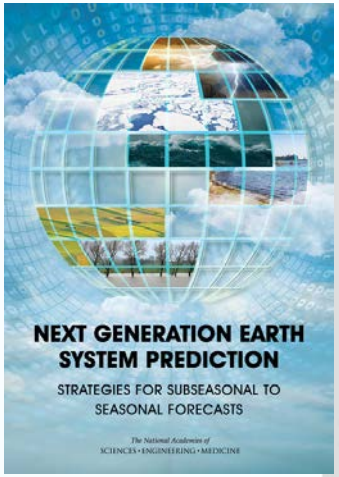
Pacific-North American



Similar results also for
Arctic Oscillation
Madden-Julian Oscillation

Guan and Waliser, 2015

Water/Flood Management at 2 Week to 2 Month Leads

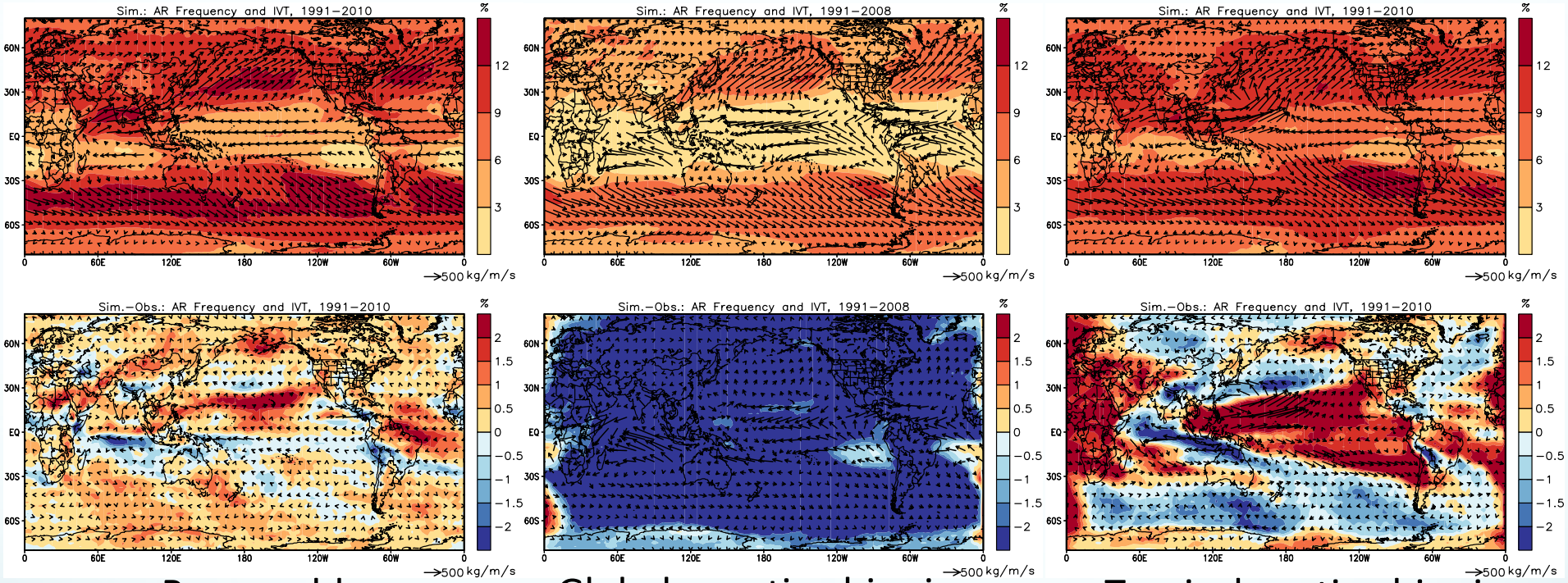


Relies on weather/climate forecast model fidelity for

- Atmospheric Rivers
- Low-frequency variations (e.g., ENSO, MJO, AO, PNA)
- Their Interaction

Model Evaluation : Bias of AR Frequency & IVT

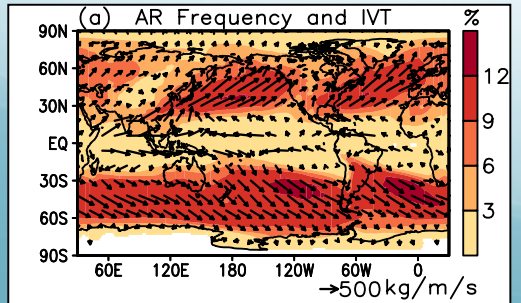
01_NASAGMAO_GEOS5 | 17_MetUM_GA3 | 35_BCCAGCM2.1



Reasonable representation

Global negative bias in AR frequency

Tropical postive bias in AR frequency



Observations

YOTC/MJOTF+GEWEX GASS Multi-Model Experiment

(3 out of 28 models; work in progress)

Current and Future Work

- ARL 1 - Continue GCM and physical process evaluation, including using CalWater airborne experiment data – working toward atmospheric and terrestrial water budgets

- ARL 2-3 Continue global and regional AR impact studies (e.g. extreme precipitation, rain on snow, impact on ice sheet mass balance, wind hazards)

- AR 3-8 Synoptic, subseasonal and seasonal prediction skill and predictability studies with WCRP-WWRP S2S Project Database – with some emphasis on operations and decision support (e.g. CA DWR).

Guan and Waliser (2015, JGR), Detection of atmospheric rivers: Evaluation and application of an algorithm for global studies.
Guan, Waliser, Ralph, Fetzer and Neiman (2016, GRL), Hydrometeorological characteristics of rain-on-snow events associated with atmospheric rivers.
Guan, Molotch, Waliser, Fetzer and Neiman (2013, WRR), The 2010/2011 snow season in California's Sierra Nevada: Role of atmospheric rivers and modes of large-scale variability
Guan, B., D. E. Waliser, N. Molotch, E. Fetzer, and P. Neiman (2012), Does the Madden-Julian Oscillation Influence Wintertime Atmospheric Rivers and 1 Snowpack in the Sierra Nevada?, *Monthly Weather Review*, *140*, 325-342.

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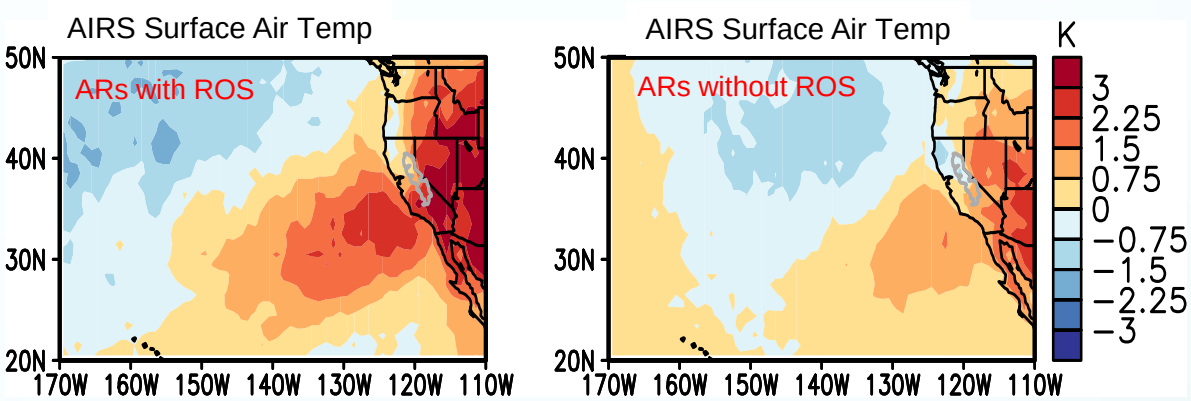
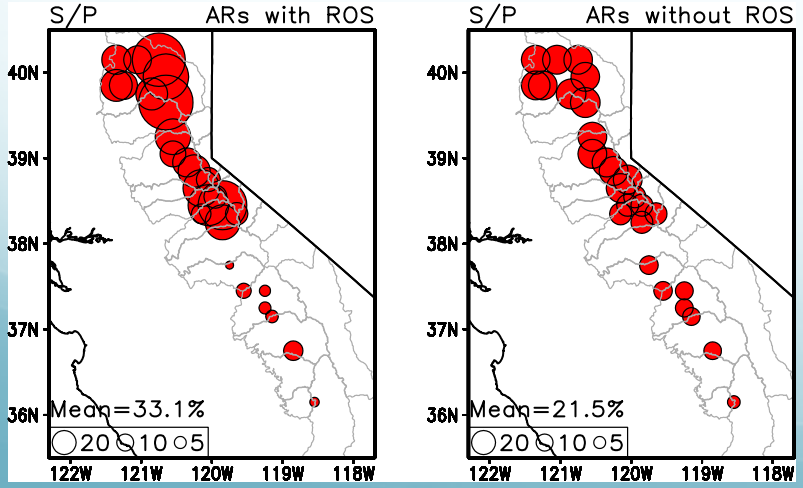
Atmospheric Rivers and Rain on Snow Events

AR conditions are associated with 50% of ROS events during 1998-2014.

AIRS data, and other sources, show that ARs with ROS are on warmer by ~2° C.



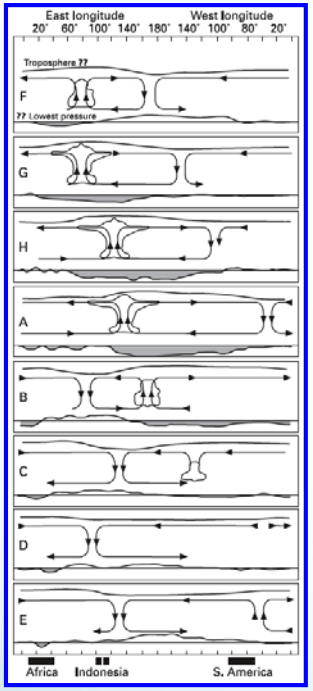


ARs with ROS have 50% higher streamflow/precipitation fraction (in %), i.e. enhanced flood risk.

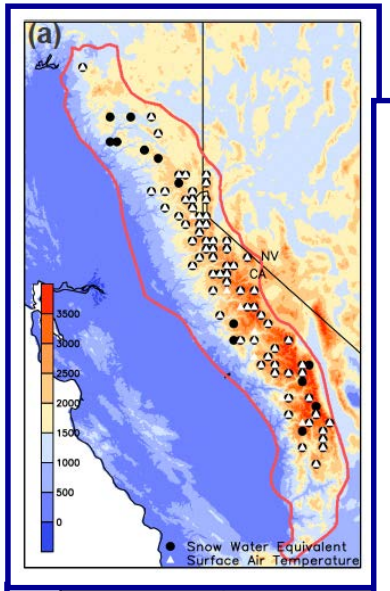
Guan, Waliser, Ralph, Fetzer, Neiman (2016)

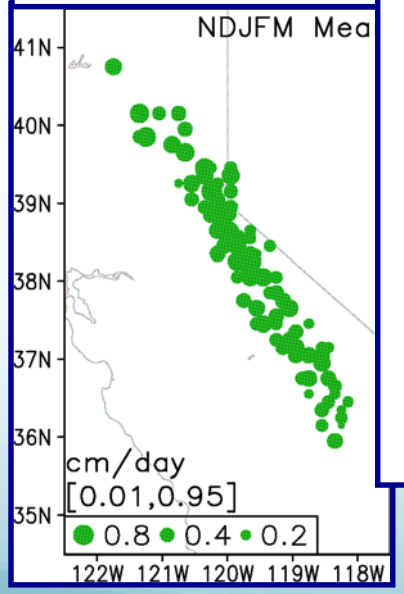
MJO Influence on Sierra Snowpack

Madden Julian Oscillation

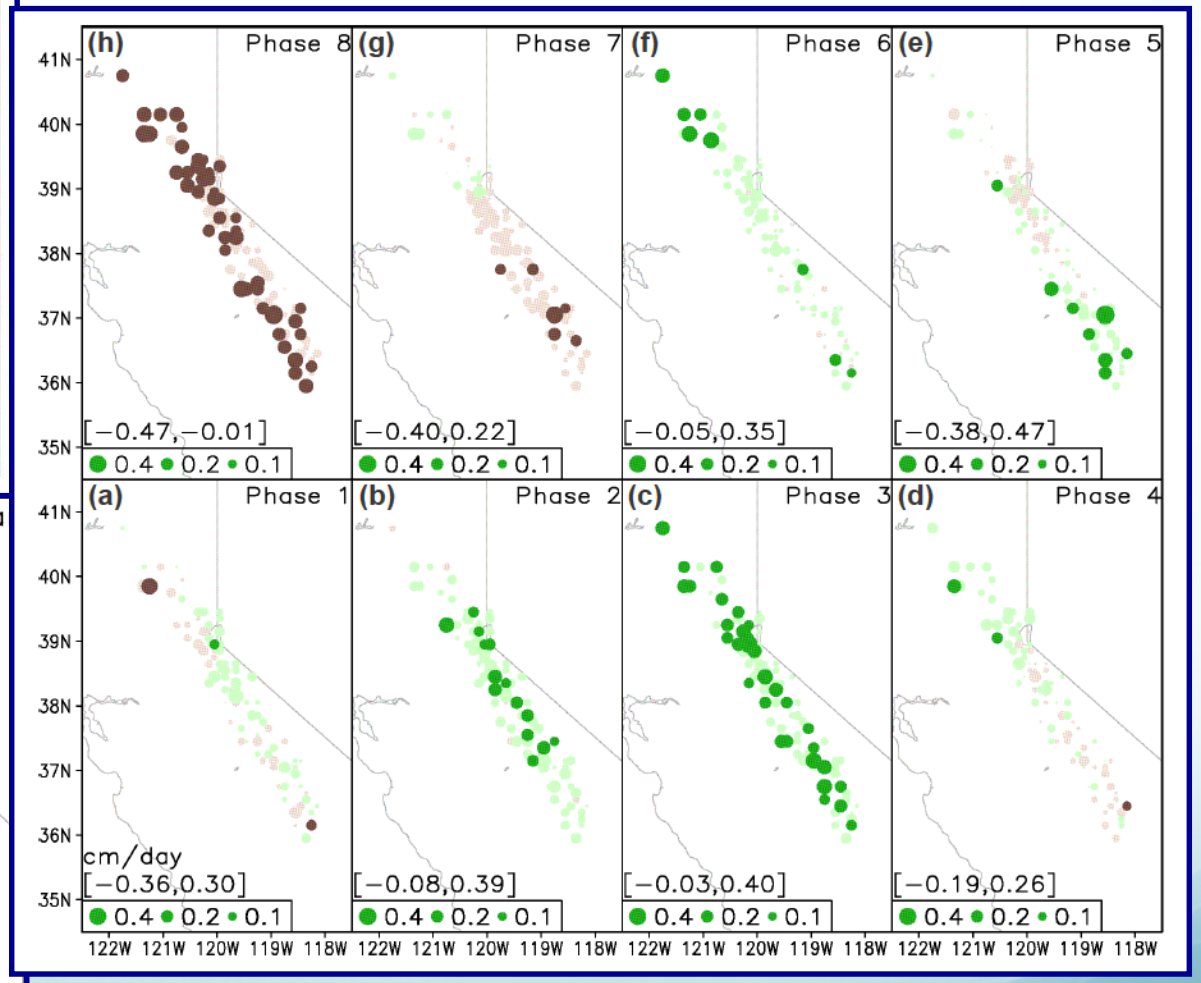


40-50 Day Eastward Propagating Tropical Variation





Results Suggests Subseasonal Predictability

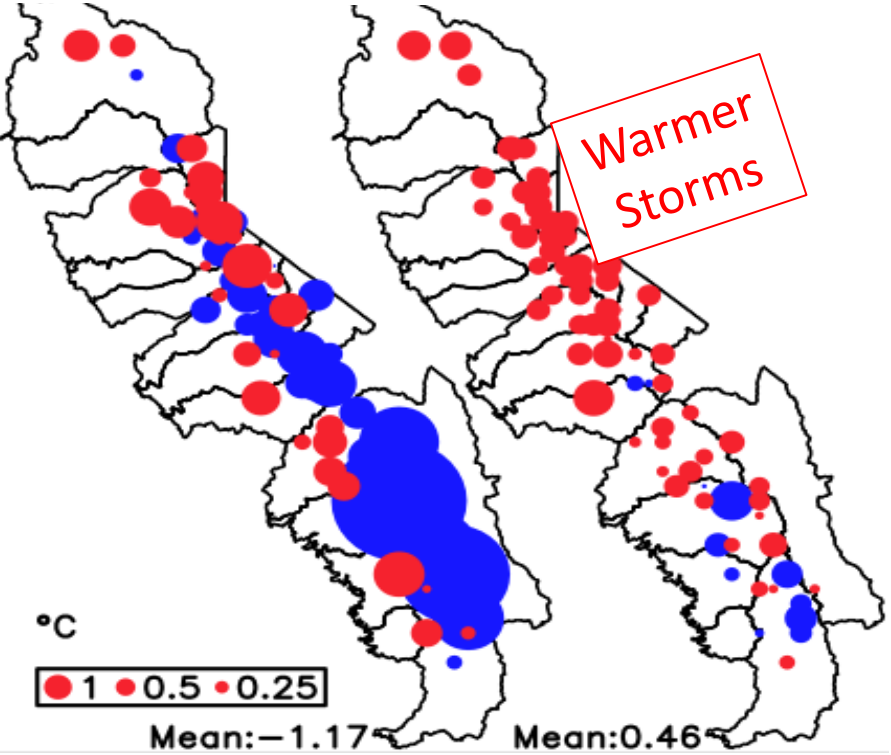


Changes in AR Impacts Due to El Niño

Surface Air Temperatures

Typical

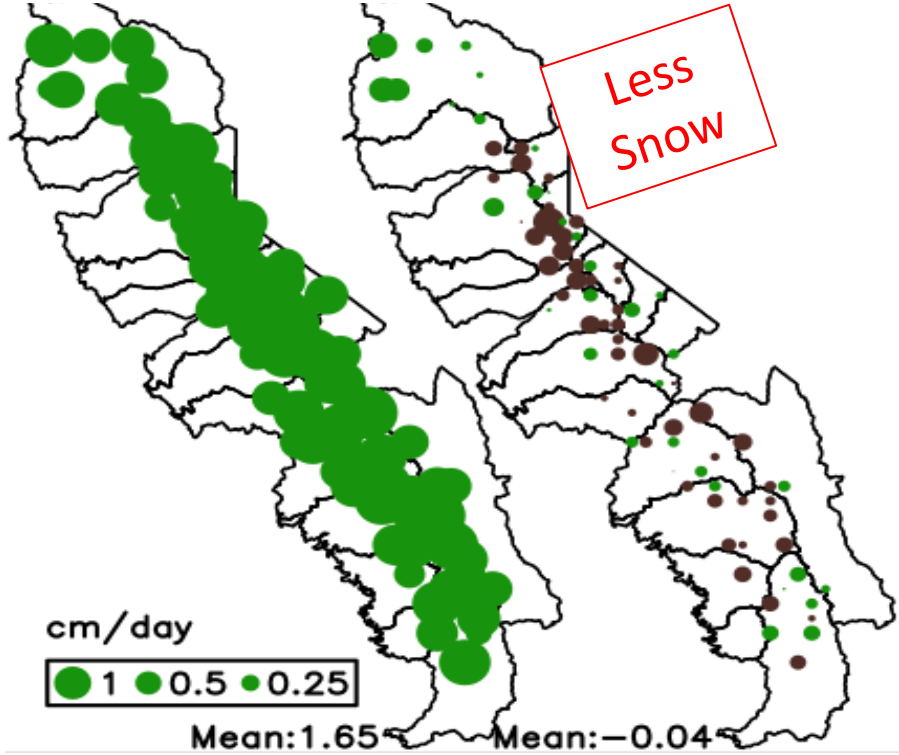
El Nino



Snowpack Accumulation

Typical

El Nino



Result here based on Guan et al. (2013; WRR) using Neimen et al. (2008) IWV AR detection and SNOTEL sites 1997-2011.