Jet Propulsion Laboratory
California Institute of Technology

Atmospheric Rivers & The Madden-Julian Oscillation: Key Phenomena for Predicting California Water Availability and Extremes

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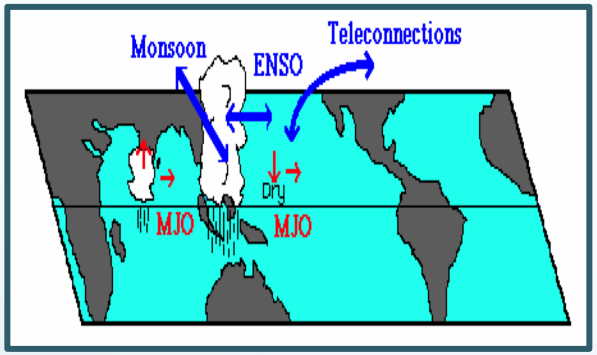
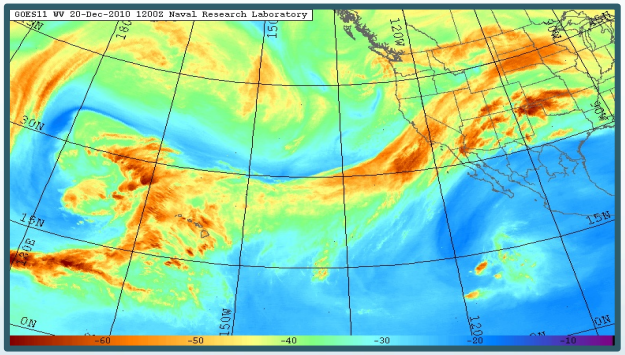
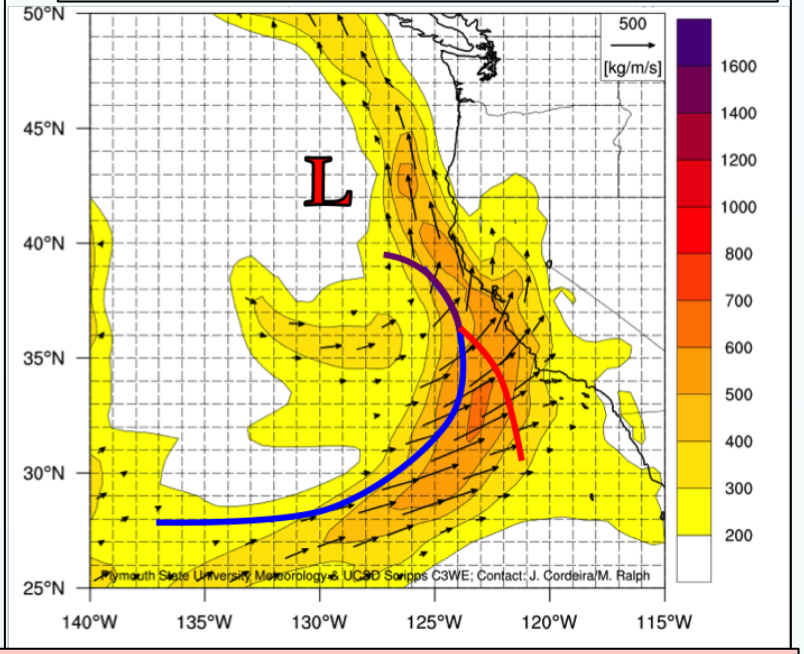




Presentation for
WORKSHOP ON REMOTE SENSING APPLICATIONS FOR WATER RESOURCES MANAGEMENT AND DROUGHT
February 25-26, 2014

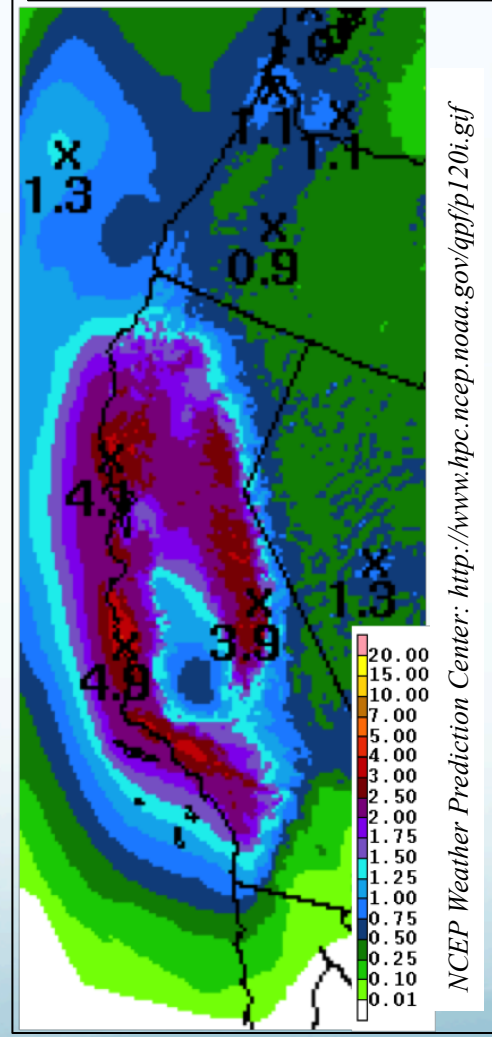
This Week's Forecast – Precipitation for CA !!

Forecast of Water Vapor Transport on Wednesday



About 5 times the water flow of the Mississippi **River** with about 20-30% converted to precipitation

Precipitation Total Through Saturday



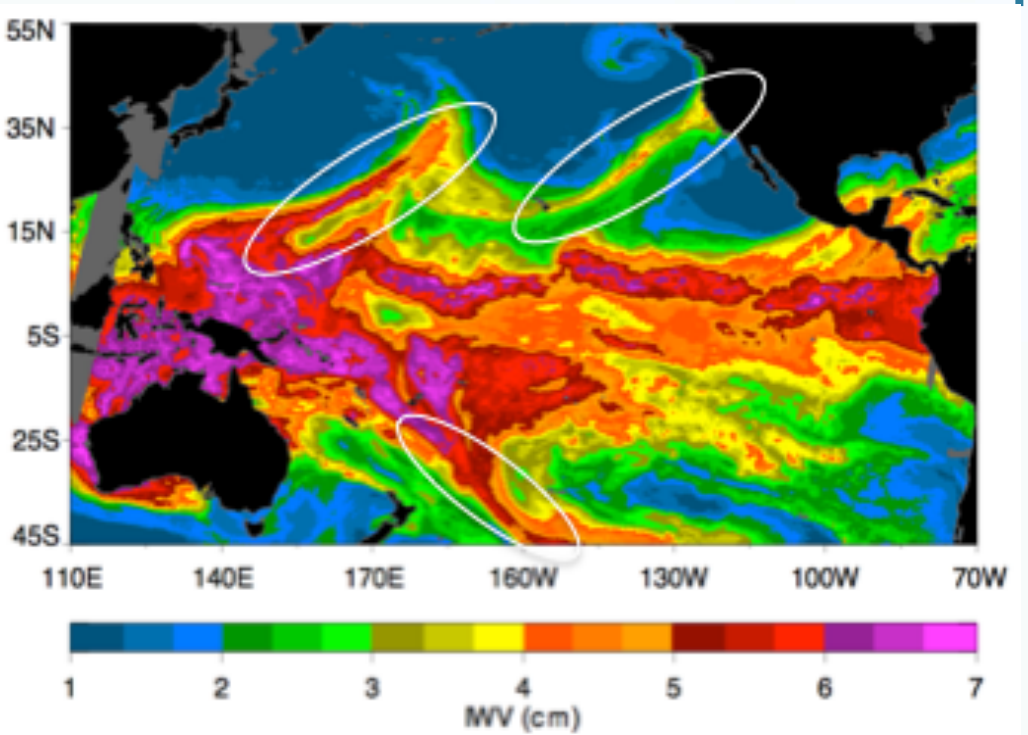
Precipitation for most of the State.

Expected precipitation storm totals: 3-5in

Another key contribution to drought relief – <u>a few inches at a time</u>.

Imagery generated by Prof. Jason Cordeira (Plymouth State University) and Dr. Marty Ralph (CW3E/UCSD) unless otherwise noted.

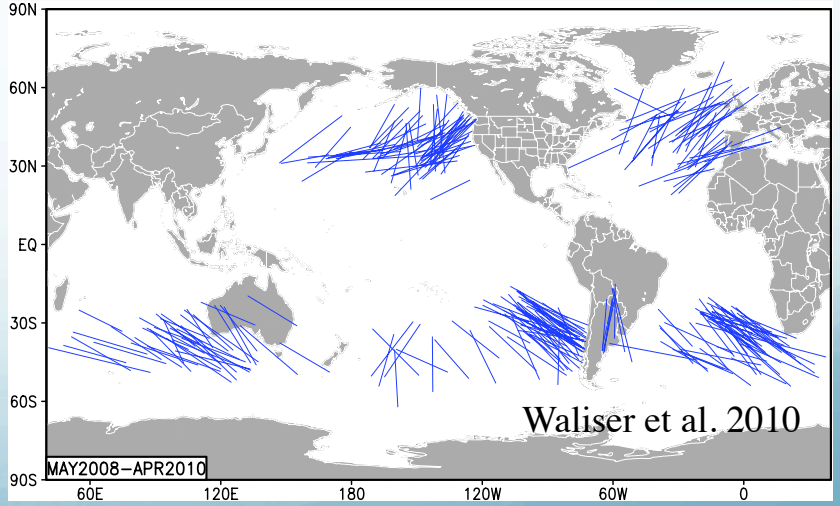
Rivers in the Sky: Key Characteristics of "Atmospheric Rivers"



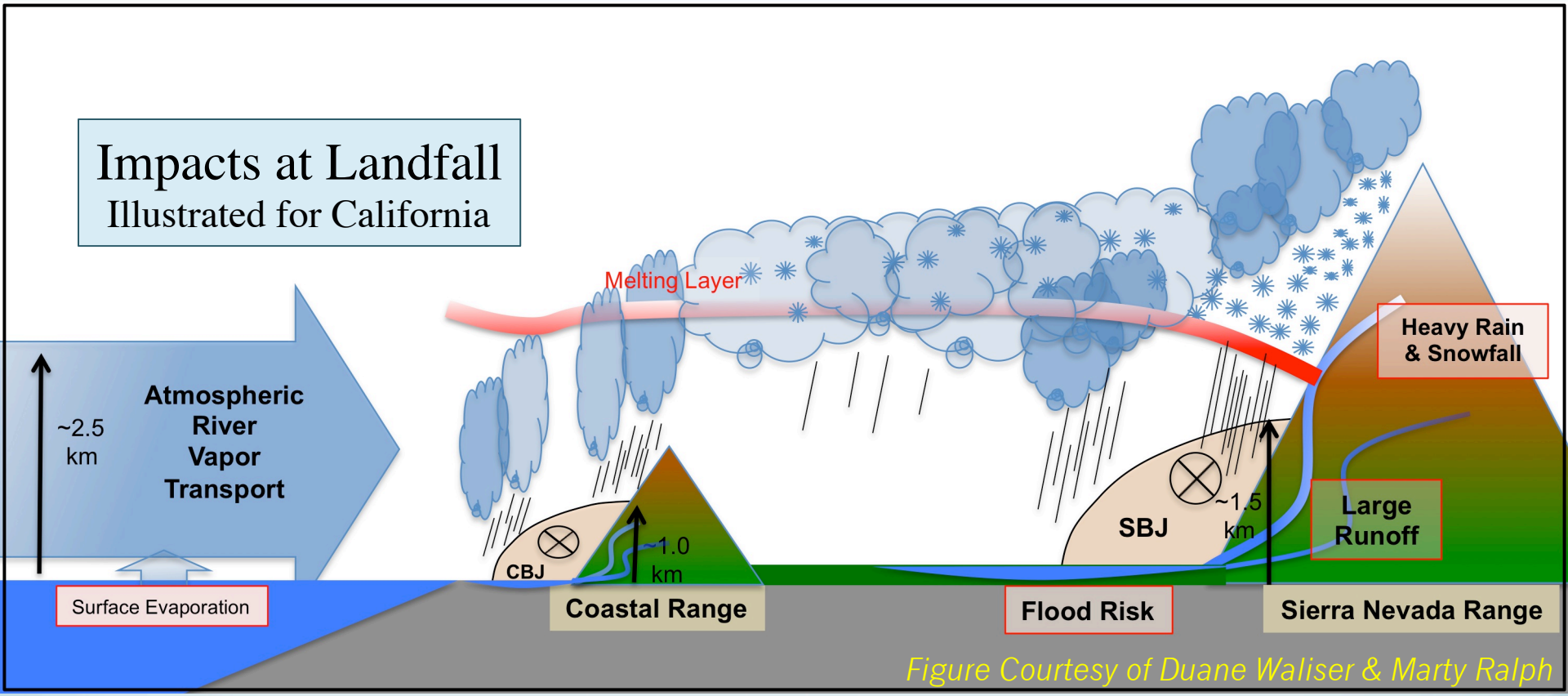
Satellite Measurements of (Total Column) Water Vapor Highlight Streams of Moisture that Transport Water Vapor Poleward & Westward: "Atmospheric Rivers (ARs)"

Occur Globally
Impact West Coasts of Continents
Role in Weather, Water & Hazards

ARs transport as much as 5-10 times the flow of the Mississippi River



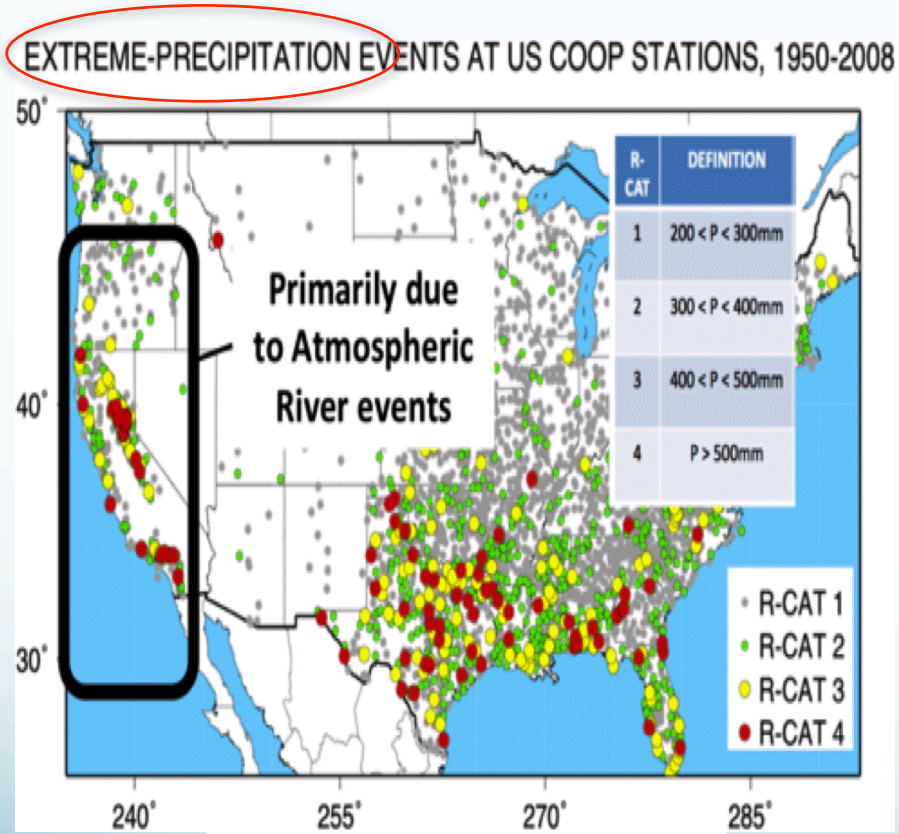
When Atmospheric Rivers Make Landfall Extreme Precipitation Occurs Near Mountains



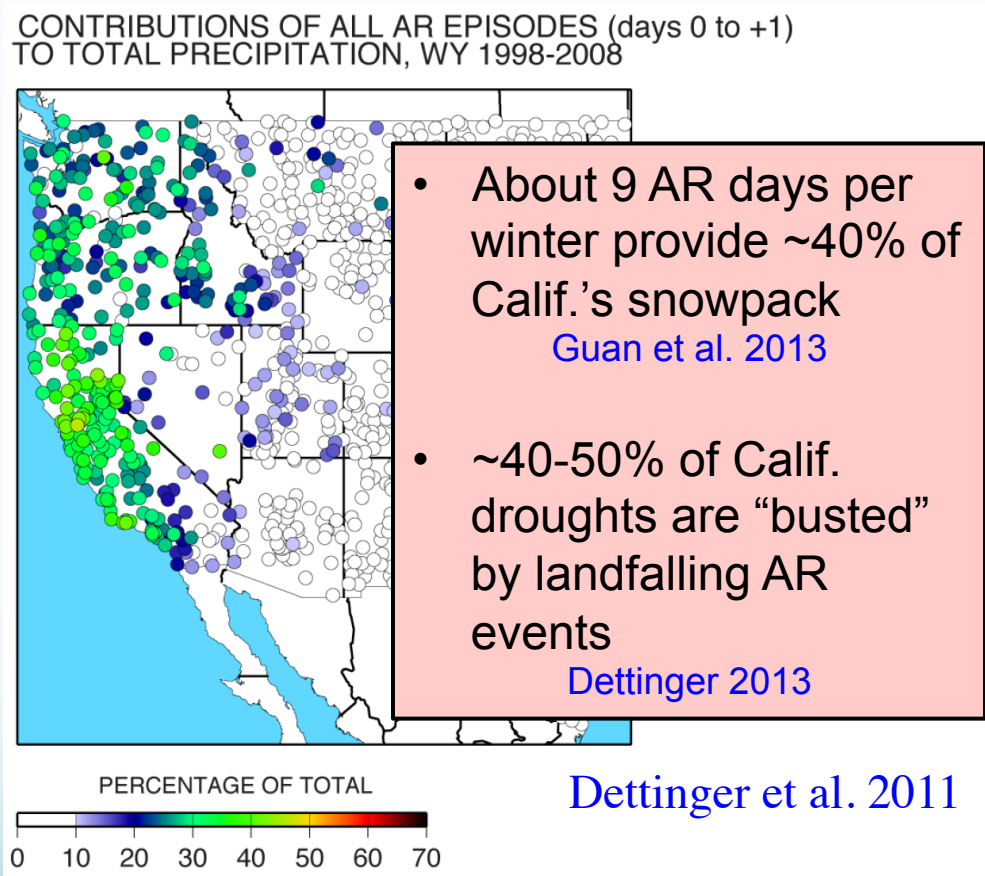
Most flooding / peak streamflow in U.S. coastal states is associated with ARs (e.g. Ralph et al. 2006; Neimen et al. 2011)

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

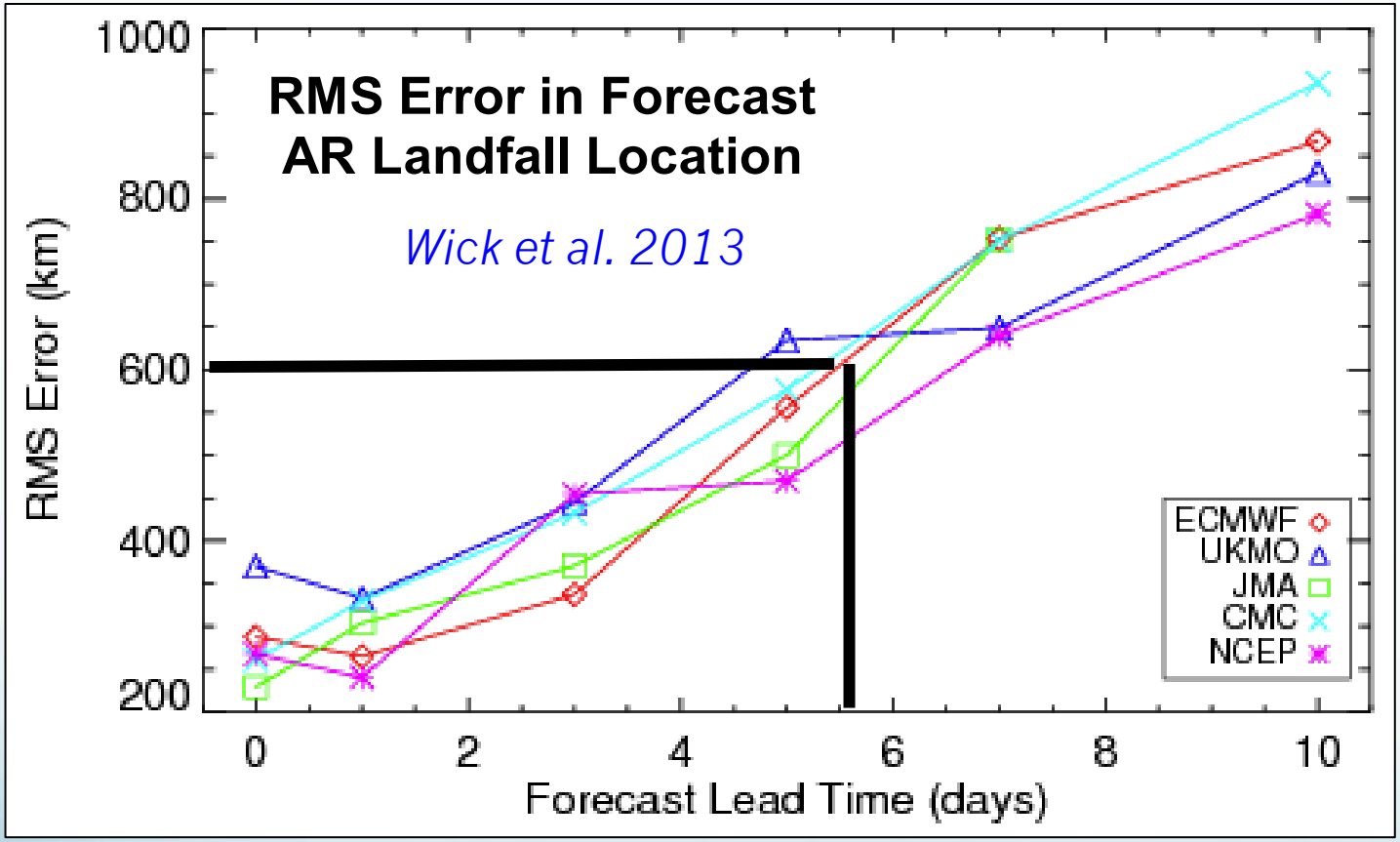


- About 9 AR days per winter provide ~40% of Calif.'s snowpack
  Guan et al. 2013
- ~40-50% of Calif. droughts are "busted" by landfalling AR events
  Dettinger 2013

Dettinger et al. 2011

AR forecasts are Critical for Water and Hazard Support

Timing, Location & Intensity 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

JPL/NASA is teaming with DWR, UCSD, and other agencies/colleagues to carry out **airborne field campaigns, satellite studies, and analysis of weather/climate models** in a steadfast effort to improve our forecasts of atmospheric rivers.

The Unusually Snowy Winter of 2010/2011

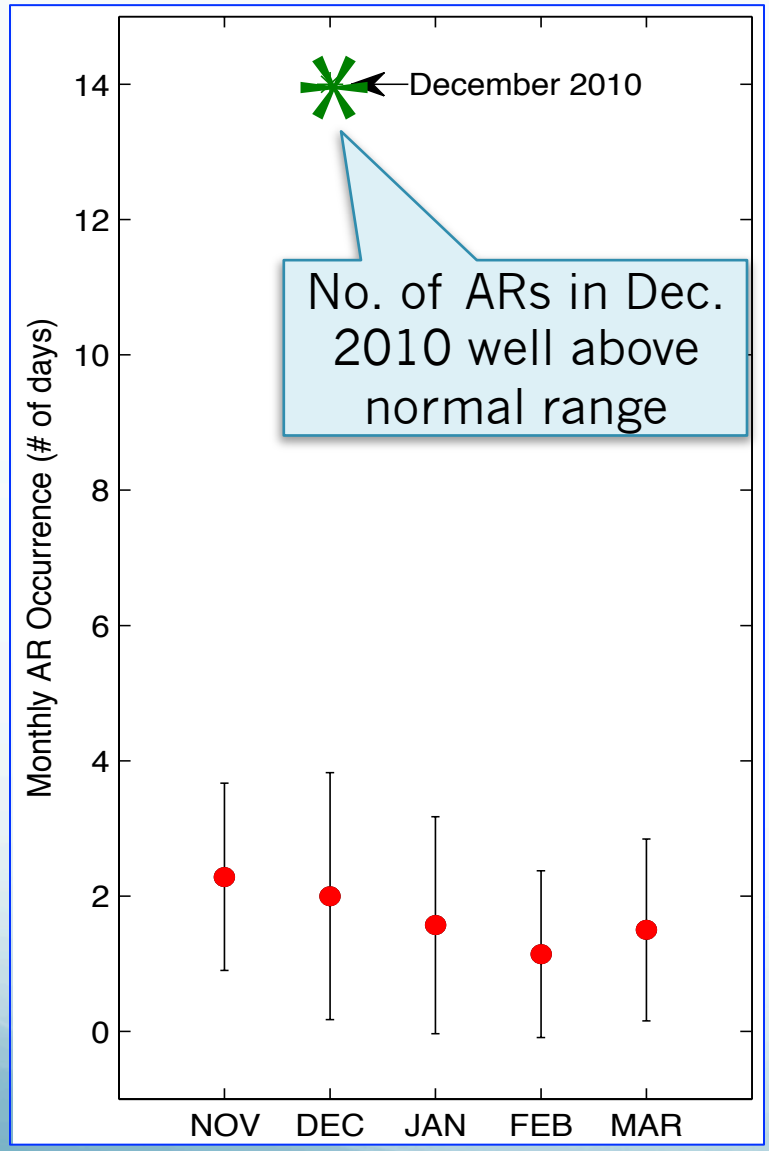


Figure Courtesy
B.Guan UCLA/JPL

Typical Year in CA

9 AR days occur over entire winter and contribute ~40% total snow

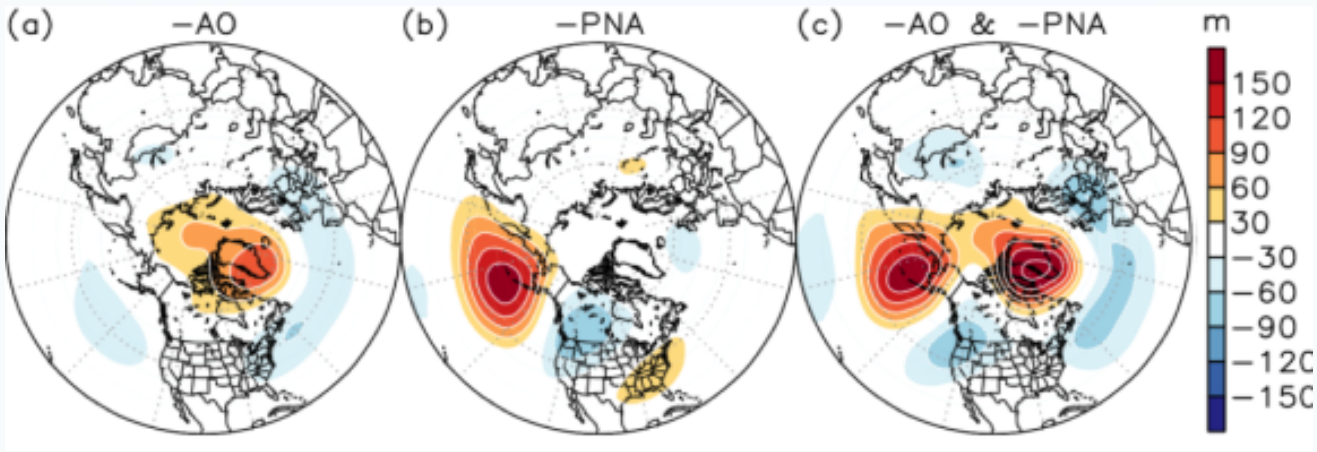
2010/2011 Winter

- Largest total seasonal snow in previous 14 Years (~170% of normal)
- Largest # of AR days (twice normal)

Dec 18 to 22

- Five Straight Days of AR
- >13 feet of snow in the Sierras
- >6 inches of rain in LA and >21 inches in nearby foothills

Common Climate Modes Linked to Atmospheric River Frequency

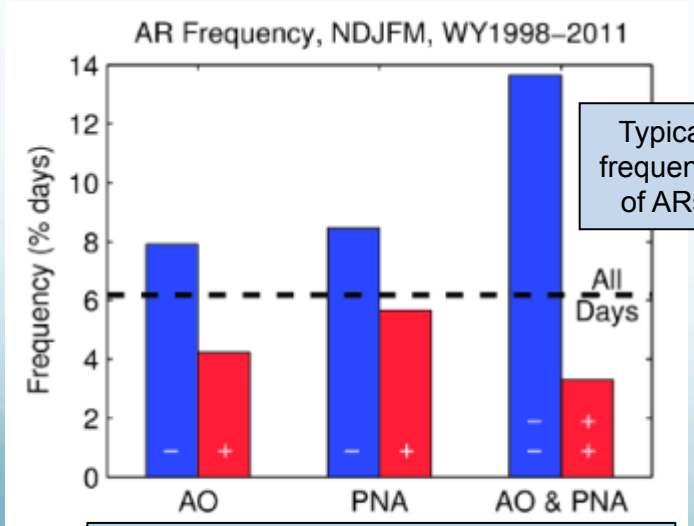


500 mb Geopotential Height Anomalies

"Arctic Oscillation" (AO)

"Pacific North American" (PNA)

Circulation anomaly when both PNA and AO in "negative" phase



Changes in AR frequency by AO & PNA

- When PNA & AO are in "negative" phases, there is a doubling of the frequency of ARs.
- <u>This "double negative" occurred in 2010-11.</u>
- Since PNA&AO exhibit some long-lead predictability, it may be possible to predict high frequency AR periods in the future.

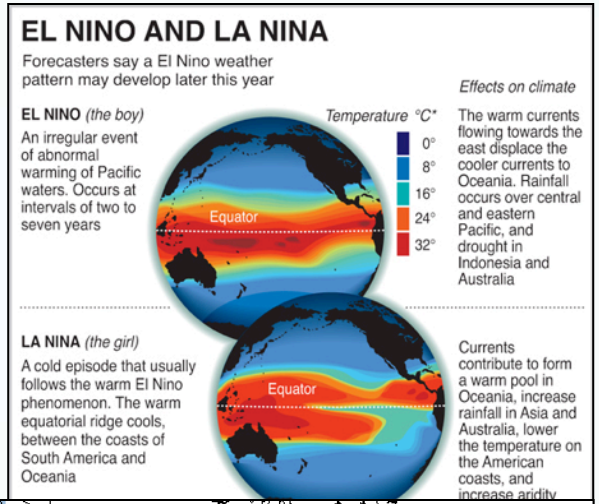
Guan et al. (2104)

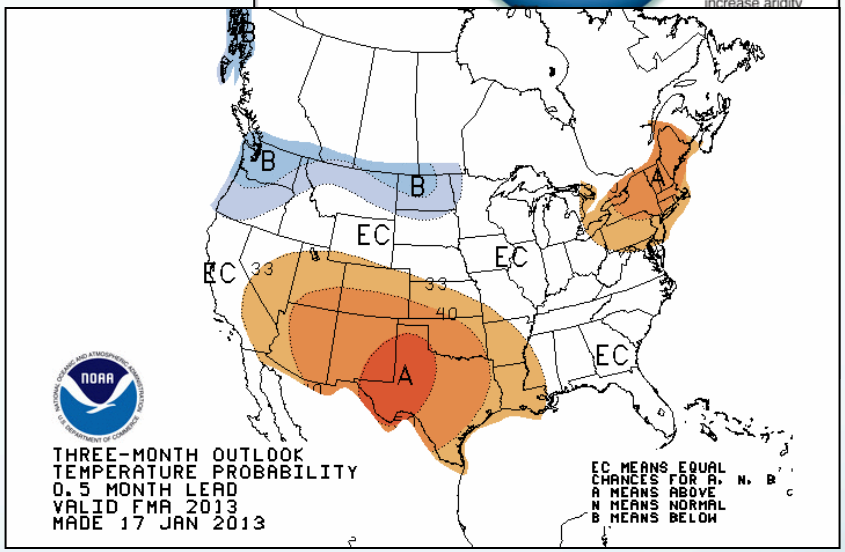
A Forecast Gap

AR Event

Weather Forecasts ~ O (10 Days)

(Mid-Latitude Baroclinic Instability & Cyclone Lifetime)





Seasonal Forecasts ~ O (100 Days)

(ENSO Phenomena & Local/Remote Circulation Impacts)

What about forecast information between "weather" and "climate"?

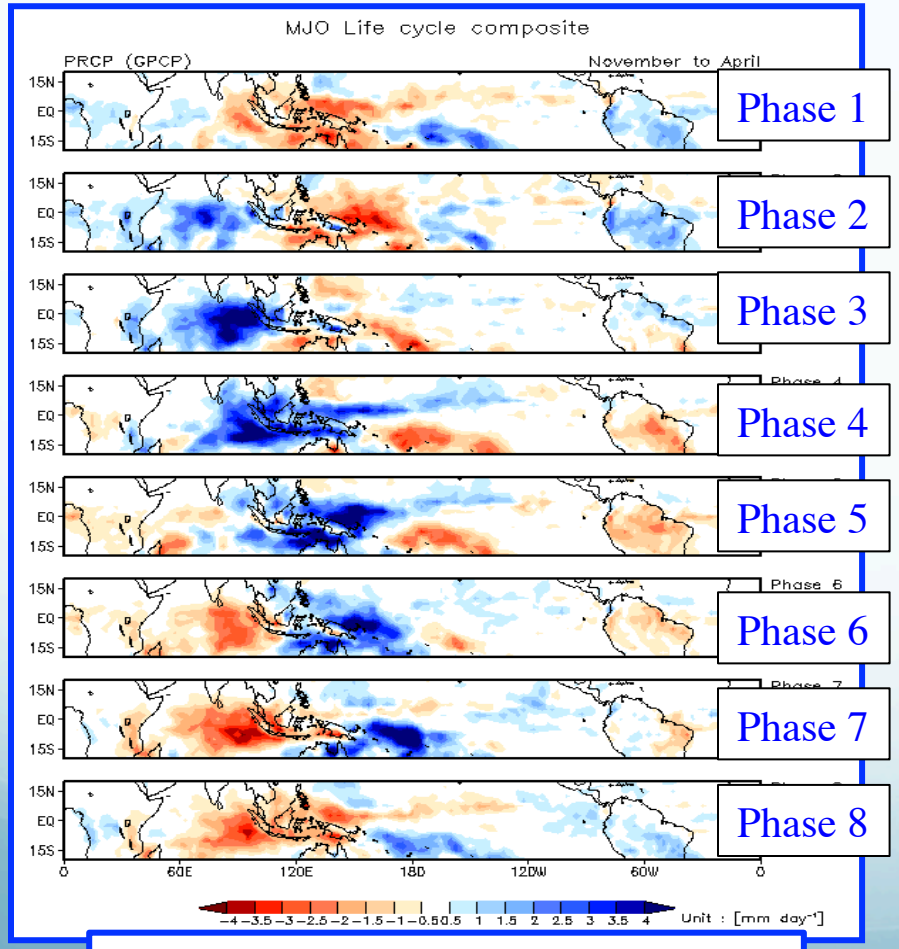
Newly, emerging opportunities from the so-called "MJO"

The dominant "subseasonal" variation of the atmosphere – provides unique long-lead prediction potential!

Madden-Julian Oscillation (MJO)

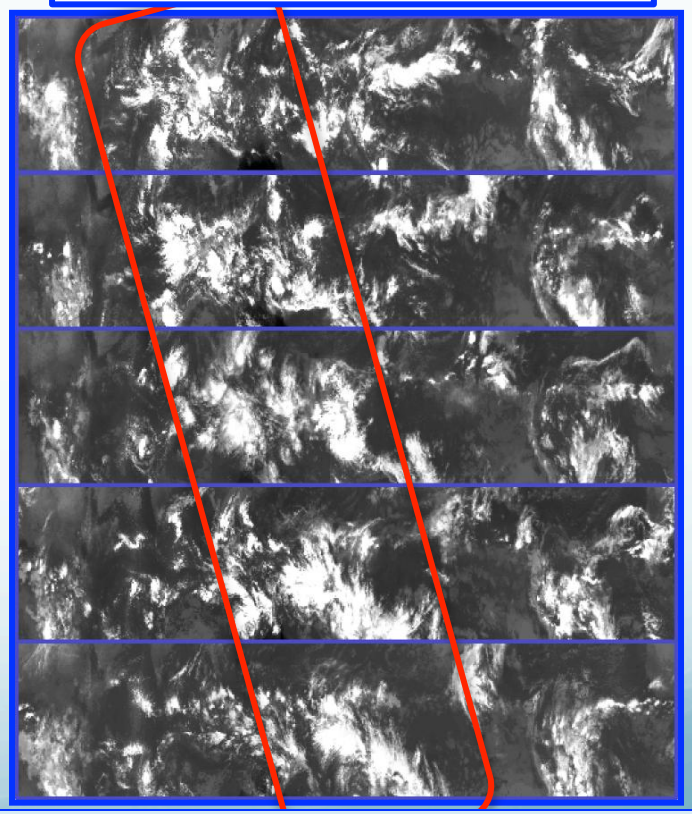
Discovered by Madden & Julian, 1972

Average MJO Life Cycle ~50 Days



Precipitation anomalies -5 to +5 mm/day

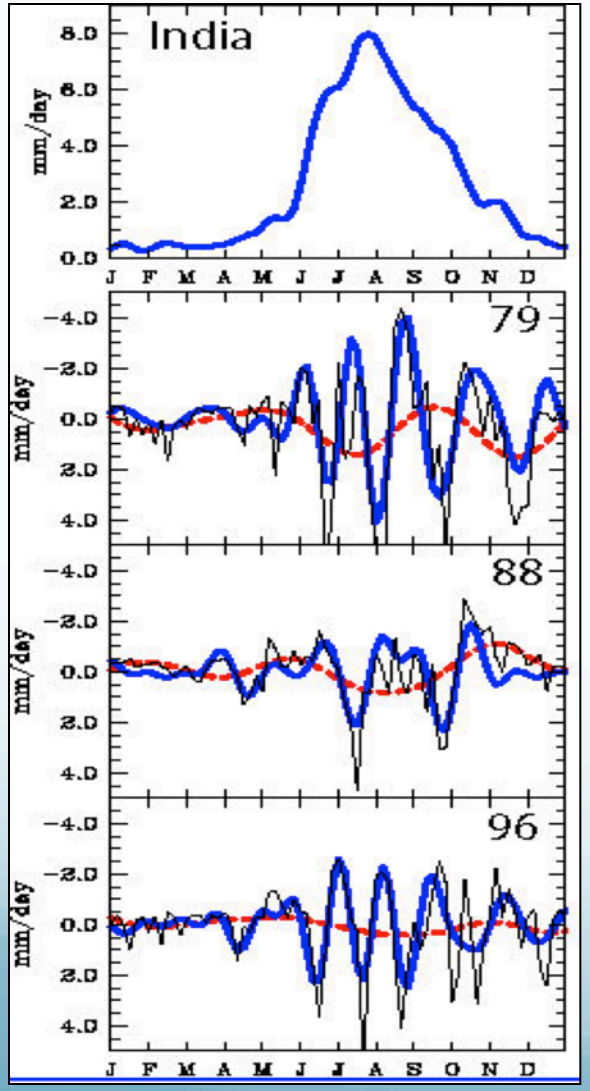
Actual MJO Event in 1987



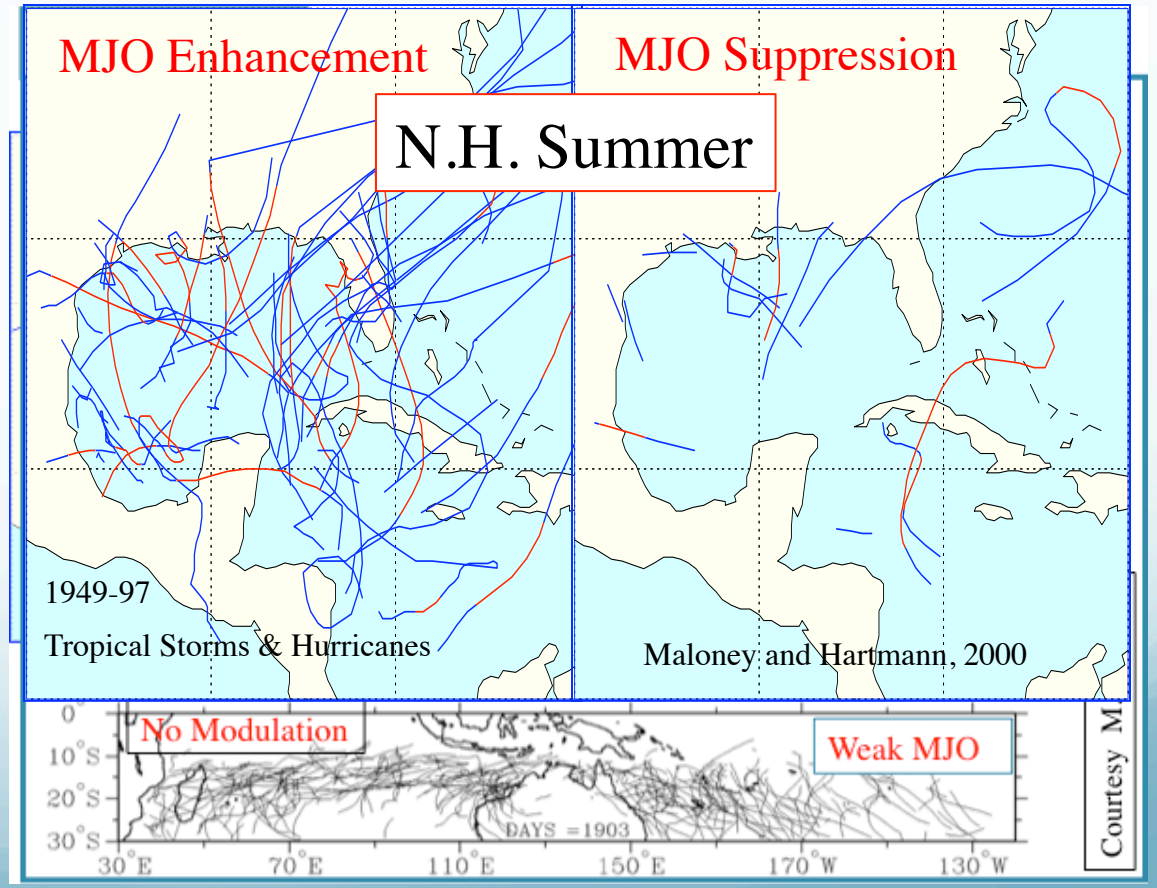
B&W "Photo" of whole tropics every 6 days

Examples of Why Accurate MJO Forecasts are of Exceptional Value

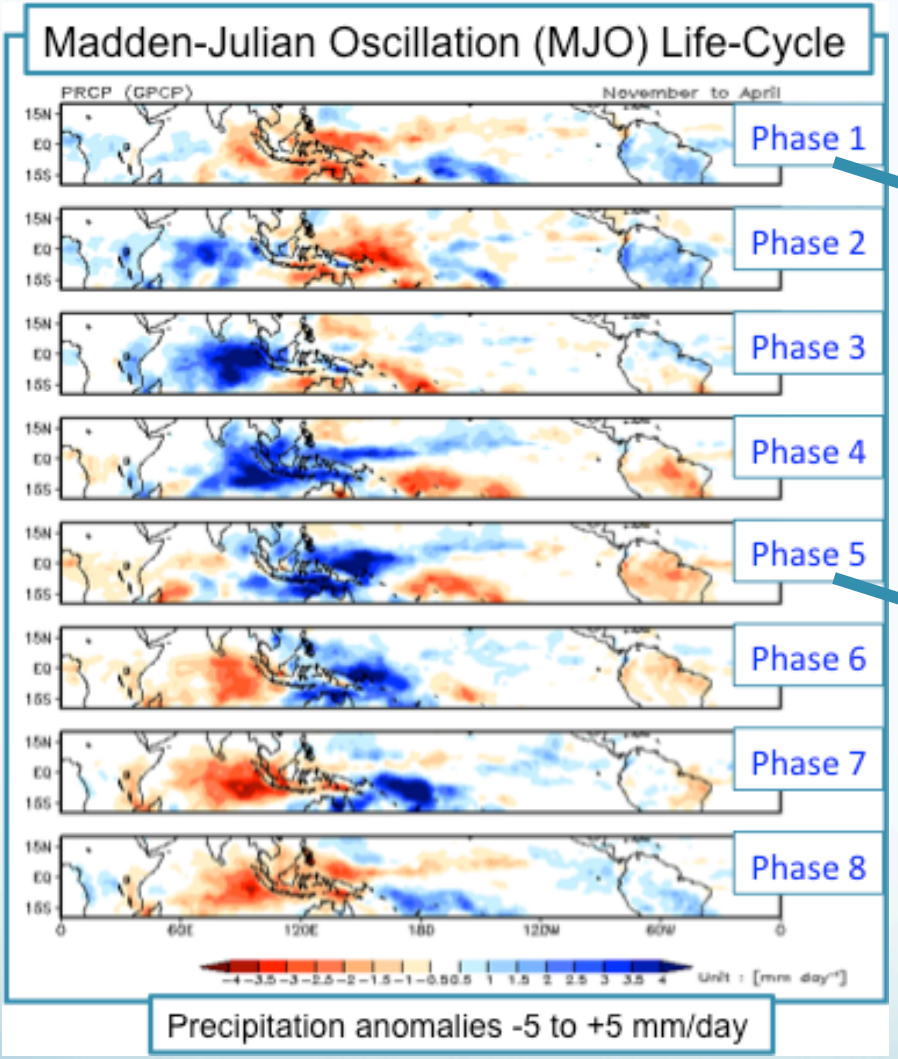
Multi-week Insight into Monsoon Onsets & Breaks



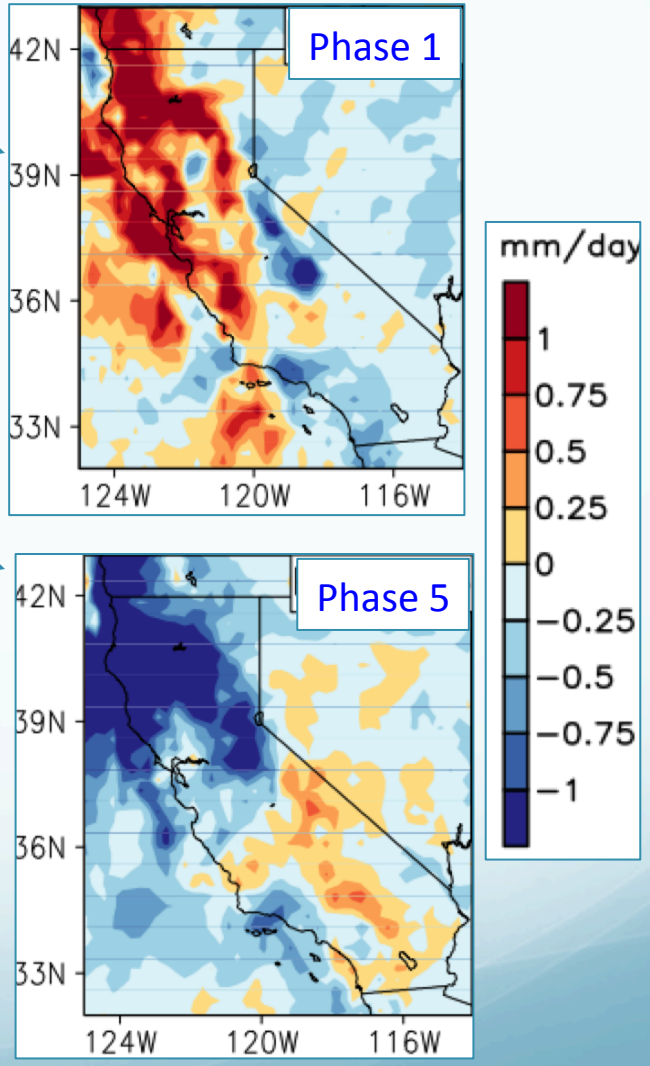
Multi-week Insight into Hurricane Frequency Including Atlantic / S.E. USA Hurricanes



The MJO & CA Winter Precipitation



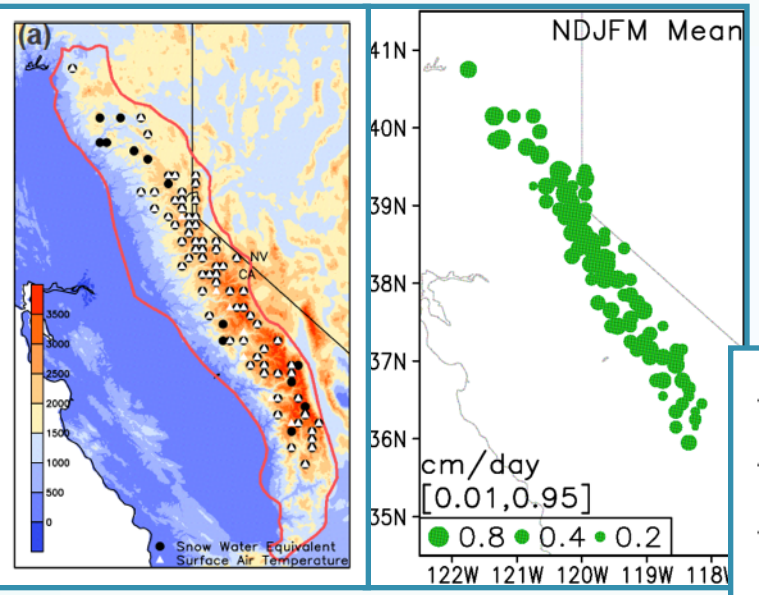
Typical Impact of MJO on California Precipitation

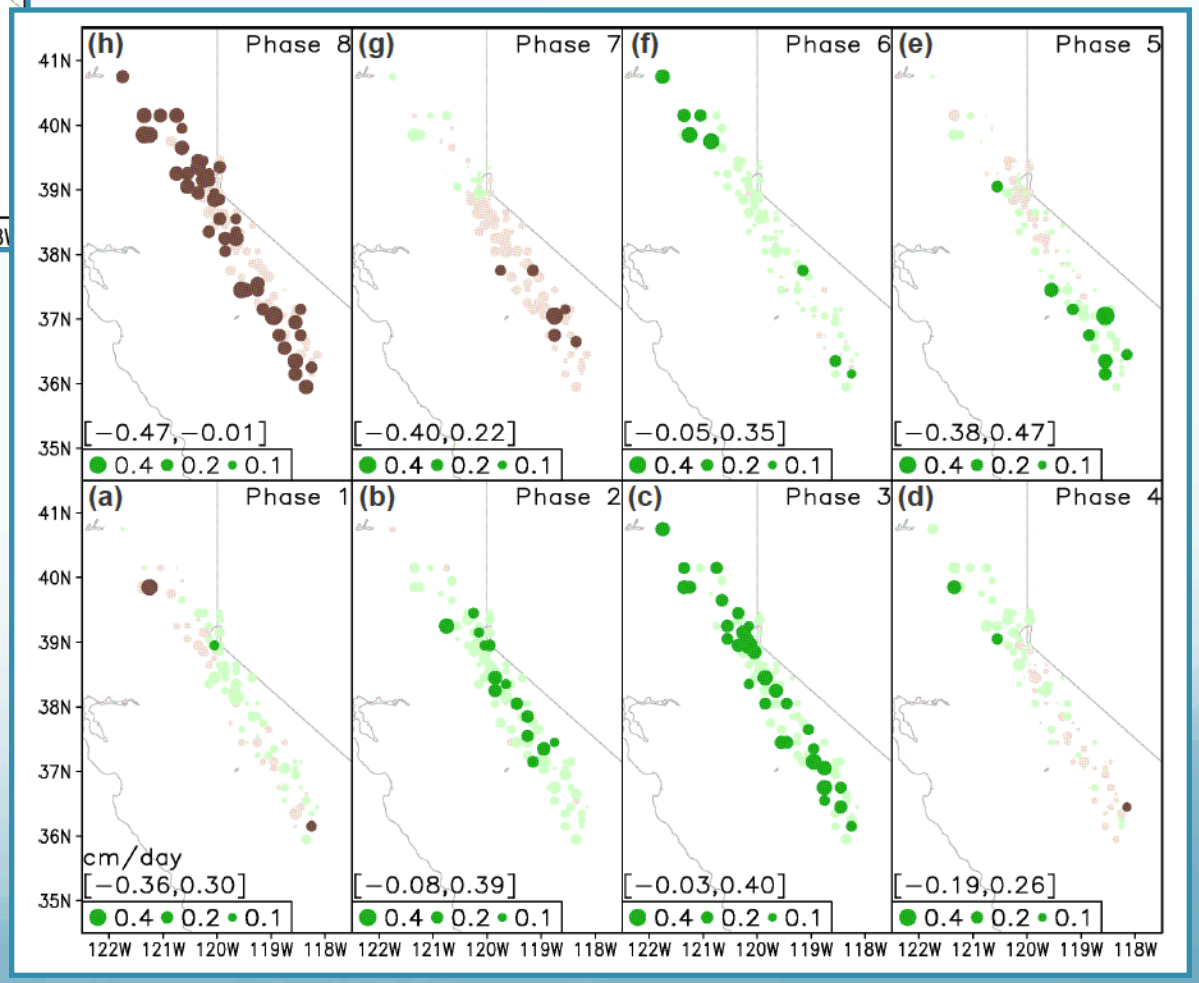


Typical CA Wintertime
Precipitation Rates ~2-4 mm/day (not shown);
MJO Modulation ~ +/- 1 mm/day (~25-50%)

Left Figure CLIVAR MJO Working Group
Right Figure Courtesy B.Guan, JPL/UCLA

MJO Modulation of Sierra-Nevada Snow Pack





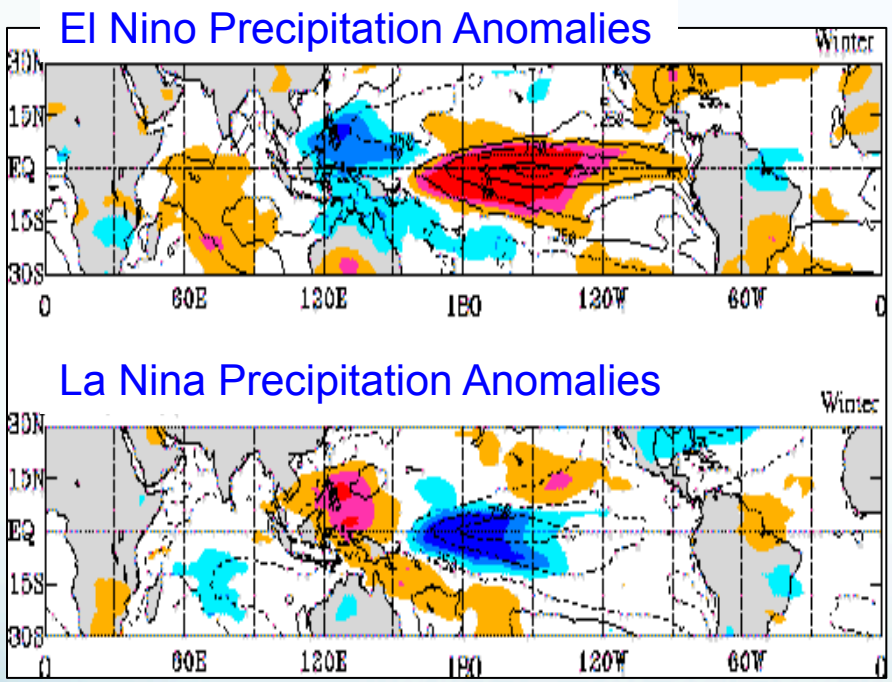
- The MJO impart a strong modulation of CA snowfall.
- Phase 3 -> + 30-50%
- Phase 8 -> - 30-50%

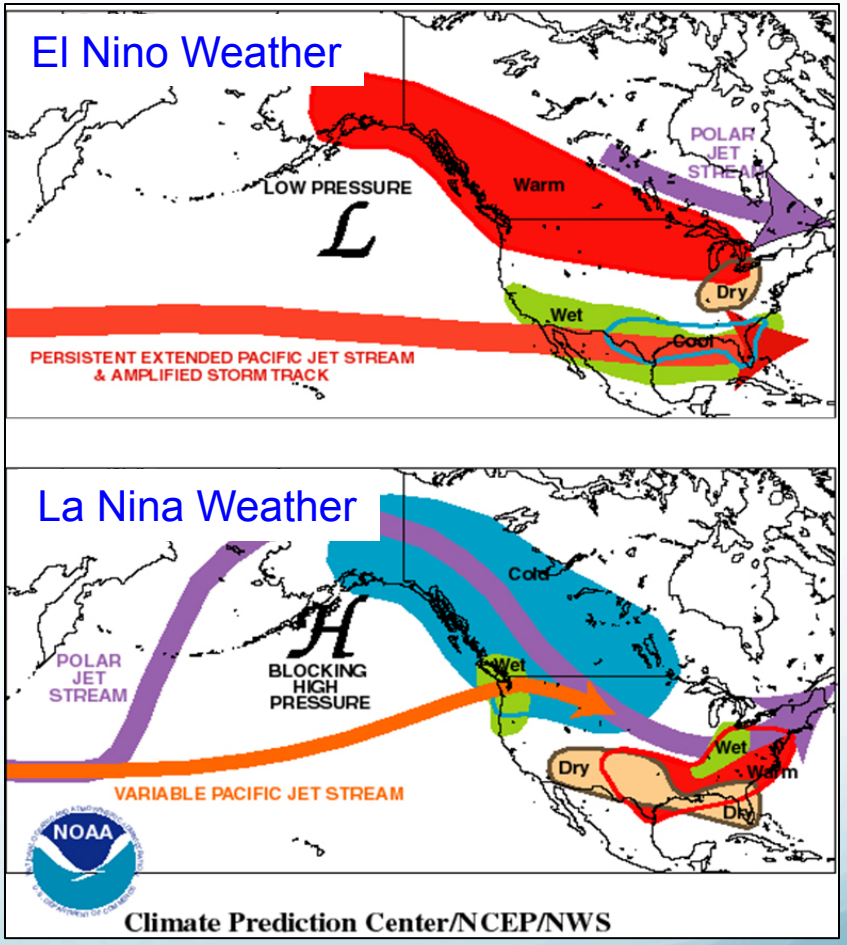
Guan et al. (2012)

ENSO Modulates Wintertime US Precipitation

Ocean Temperature -> Tropical Precipitation ->
Atmospheric Circulation -> Midlatitude Precipitation

ENSO cycle is many months
- basis for Seasonal Forecasts





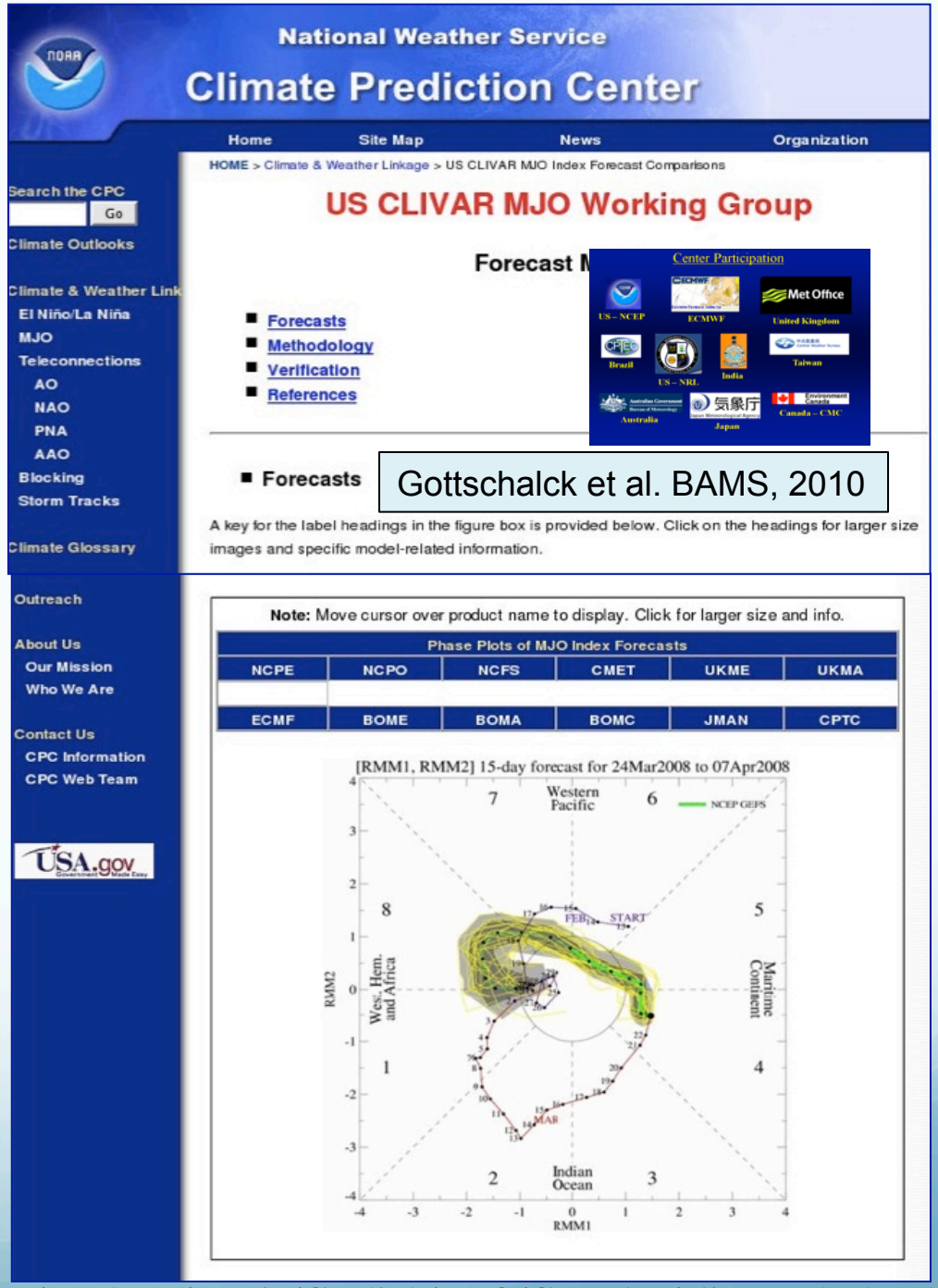
MJO is a modulation of Tropical precipitation with a shorter cycle of a few weeks - also effects mid-latitude weather & precipitation

Operational MJO Forecasts

This has been a GREAT challenge, but many operational weather prediction centers now routinely produce useful MJO predictions

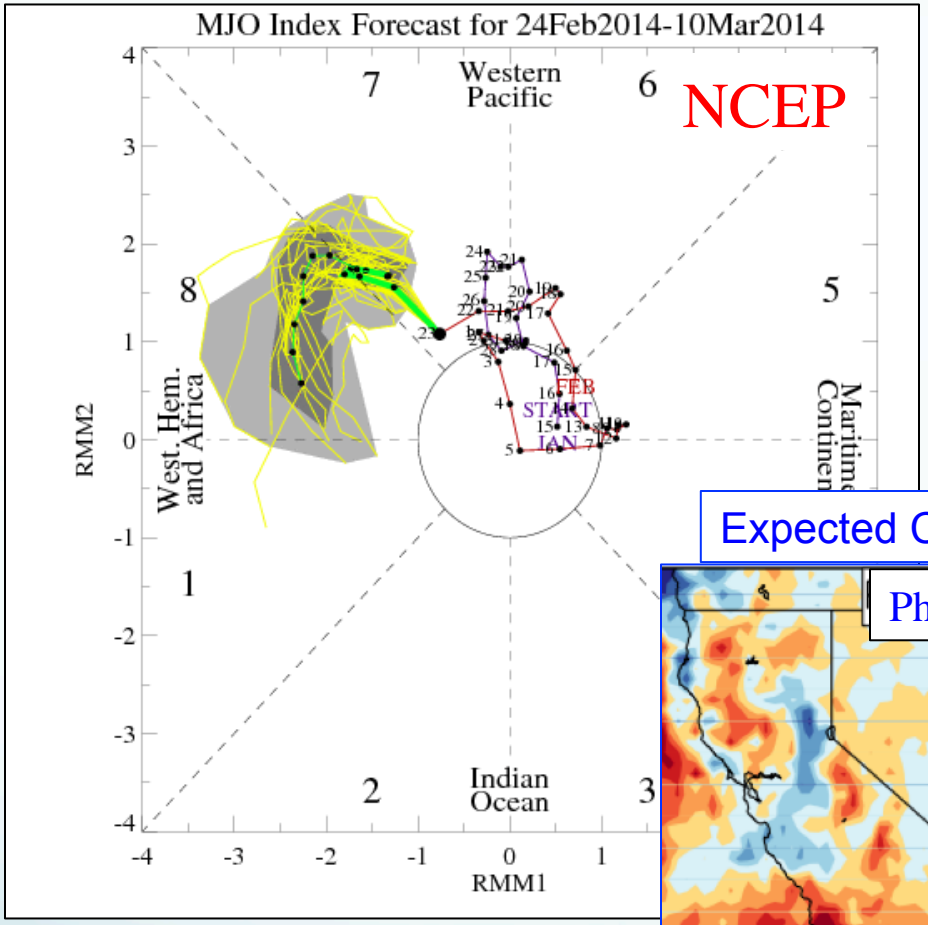
JPL/NASA has teamed with the global weather & climate forecast communities to enable and improve MJO forecasts.

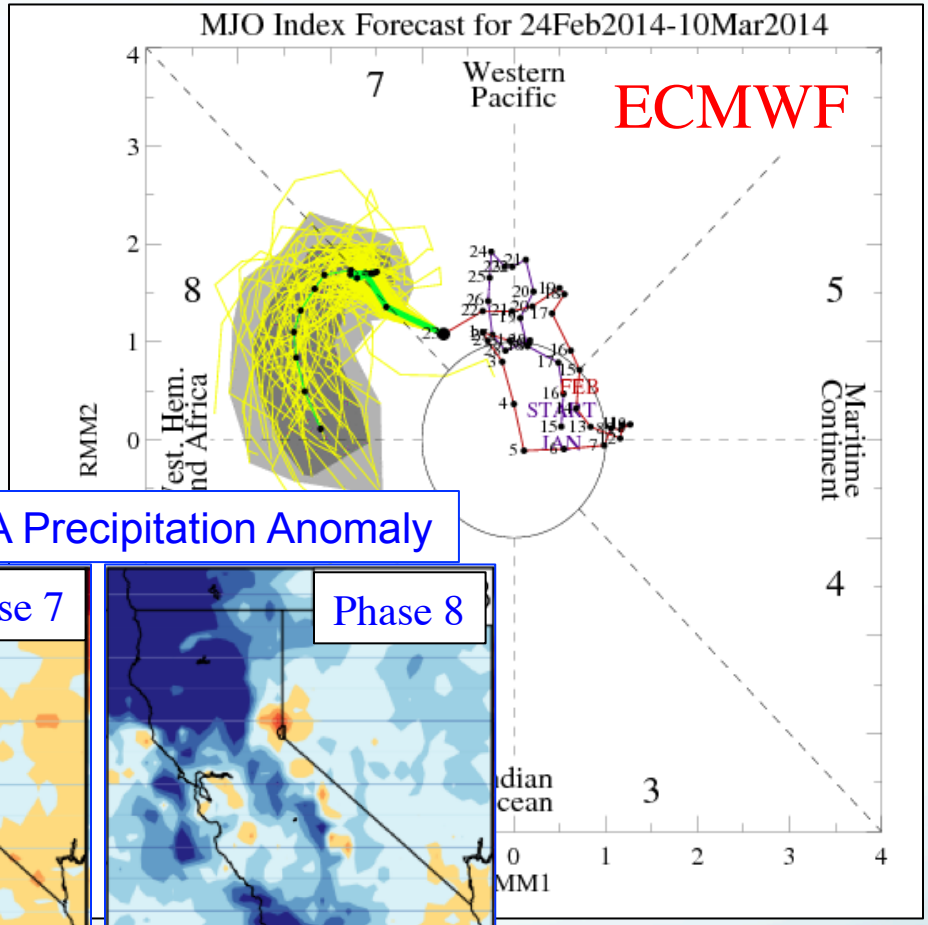
Next Steps: Research to Operation activities with DWR.



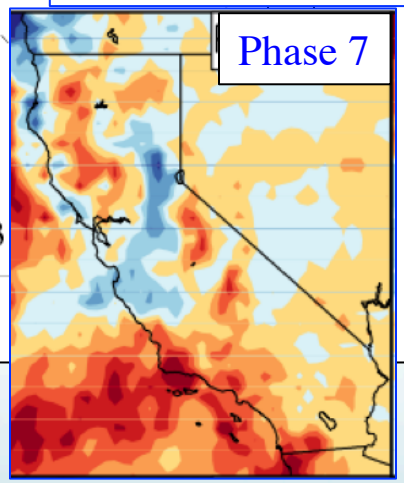
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml

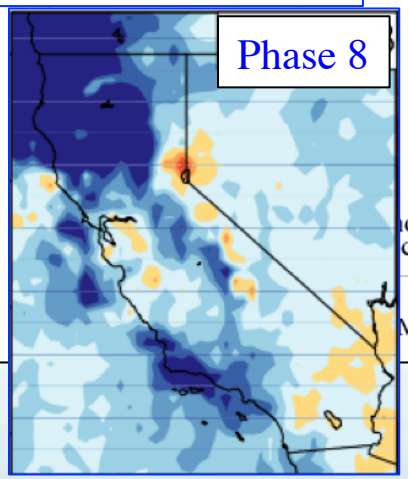
This Week's Operational MJO Forecasts





Expected CA Precipitation Anomaly





- Note : Only a few MJO events per year (~2-8).
- As with ENSO, MJO represents a "forecast of opportunity"

Summary

- Atmospheric Rivers are important to climate, weather, and water.
- Advancing our ability to forecast ARs for weather, water and hazard decision-support requires additional airborne/satellite observations and improved weather/climate models.
- NASA contributions: satellite characterizations of ARs, analysis of precipitation/snow impacts, interactions between ARs and other dominant weather/climate patterns, airborne field campaign support (e.g. NASA Global Hawk, remote sensing instruments, science strategy/planning).

- The Madden-Julian Oscillation impacts global climate and weather, including west coast/CA precipitation and snowpack.
- MJO forecasting has become operational and useful with lead-times of 3-6 weeks –> great progress in last 5-10 years.
- NASA contributions to date include satellite characterizations of the MJO, climate/weather model evaluation, community leadership in enabling/ improving forecast models, etc.

- **MJO & AR forecasts are poised to contribute to operational decision-support by DWR and related weather, water and hazard agencies.**