HMT's Progress on Atmospheric River Storms

F. Martin Ralph
NOAA/OAR/ESRL/Physical Sciences Division

30 April 2013

Improving Drought Prediction on Seasonal to Inter-annual Timescales
Western States Water Council Workshop - San Diego, California

Outline

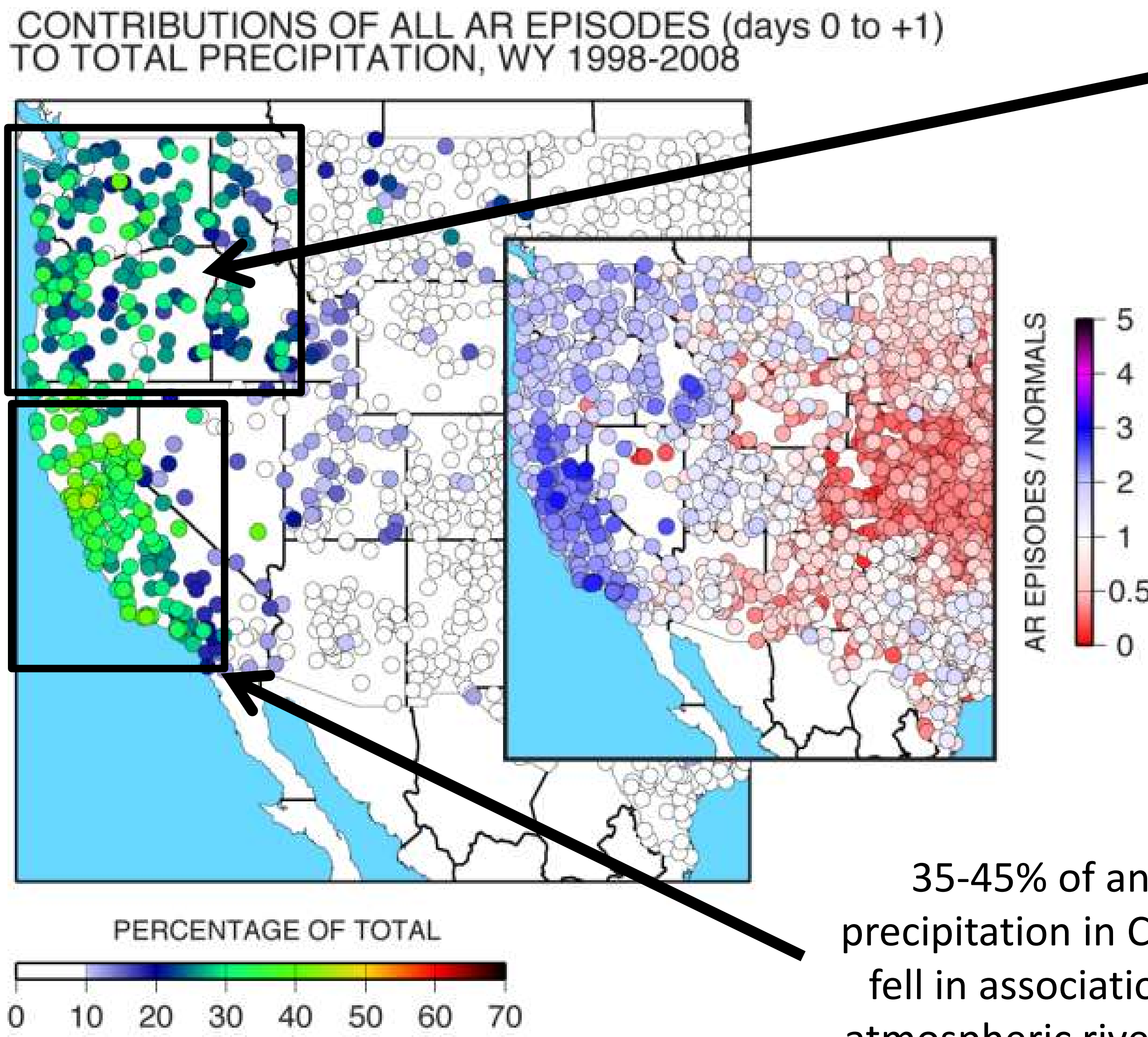
- Three HMT scientific papers appeared in April 2013
  - AR duration identified as key parameter
  - Extreme precipitation in Arizona tied to AR event
  - Automated AR Detection Tool created and put online

- Emerging directions
  - A major AR event occurred in Nov/Dec 2012
  - An AR forecasting experiment was conducted
  - MJOs and ARs

Atmospheric Rivers, Floods and the Water Resources of California

by Mike Dettinger, Marty Ralph, , Tapash Das, Paul Neiman, Dan Cayan

Water, 2011



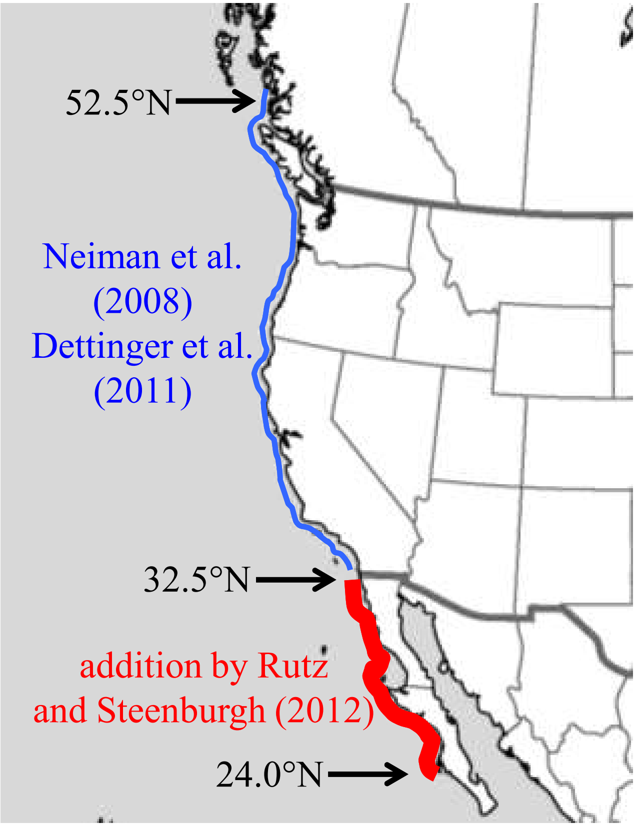
25-35% of annual precipitation in the Pacific Northwest fell in association with atmospheric river events

35-45% of annual precipitation in California fell in association with atmospheric river events

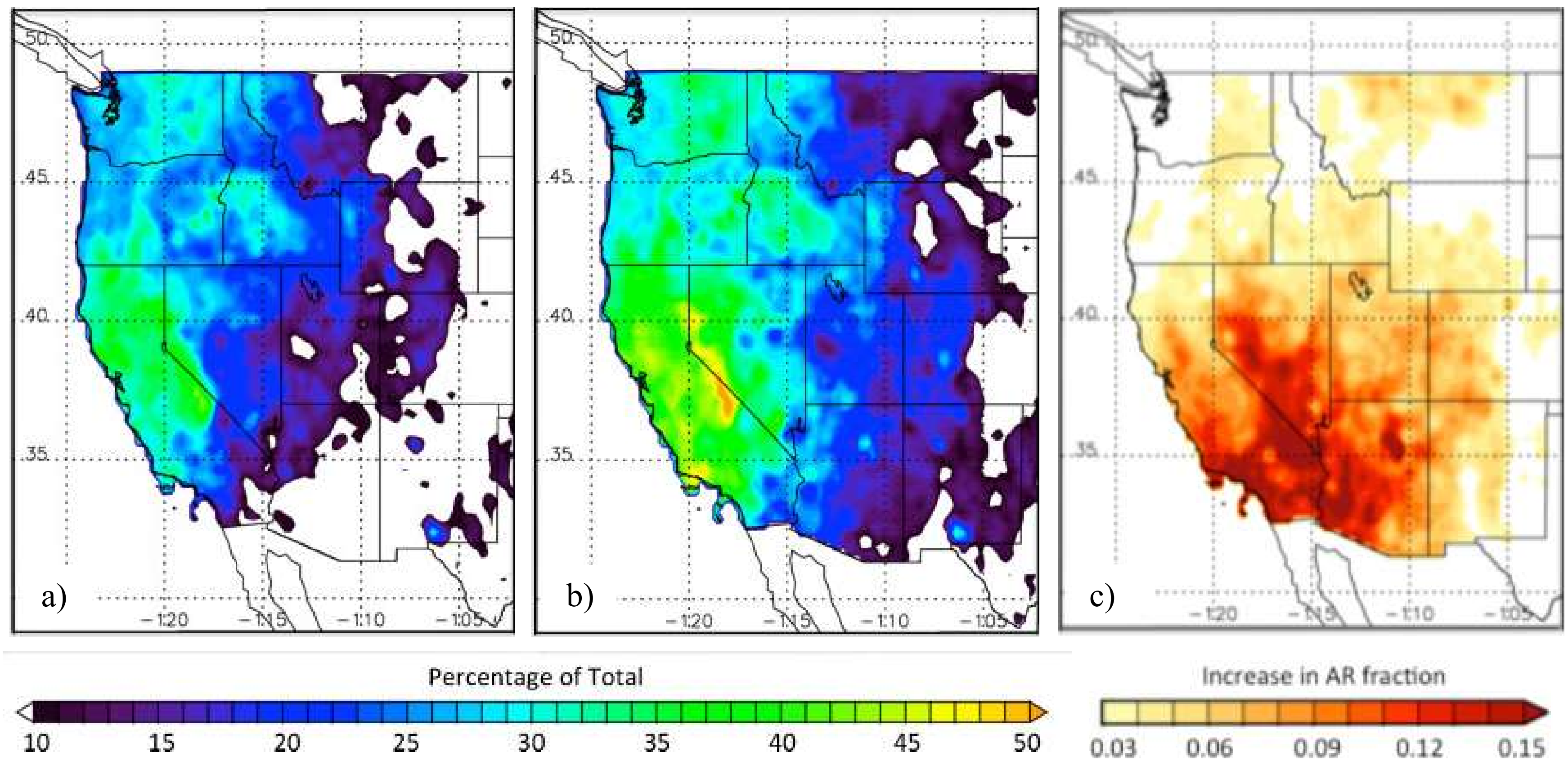
ARs crossing the Baja Peninsula

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

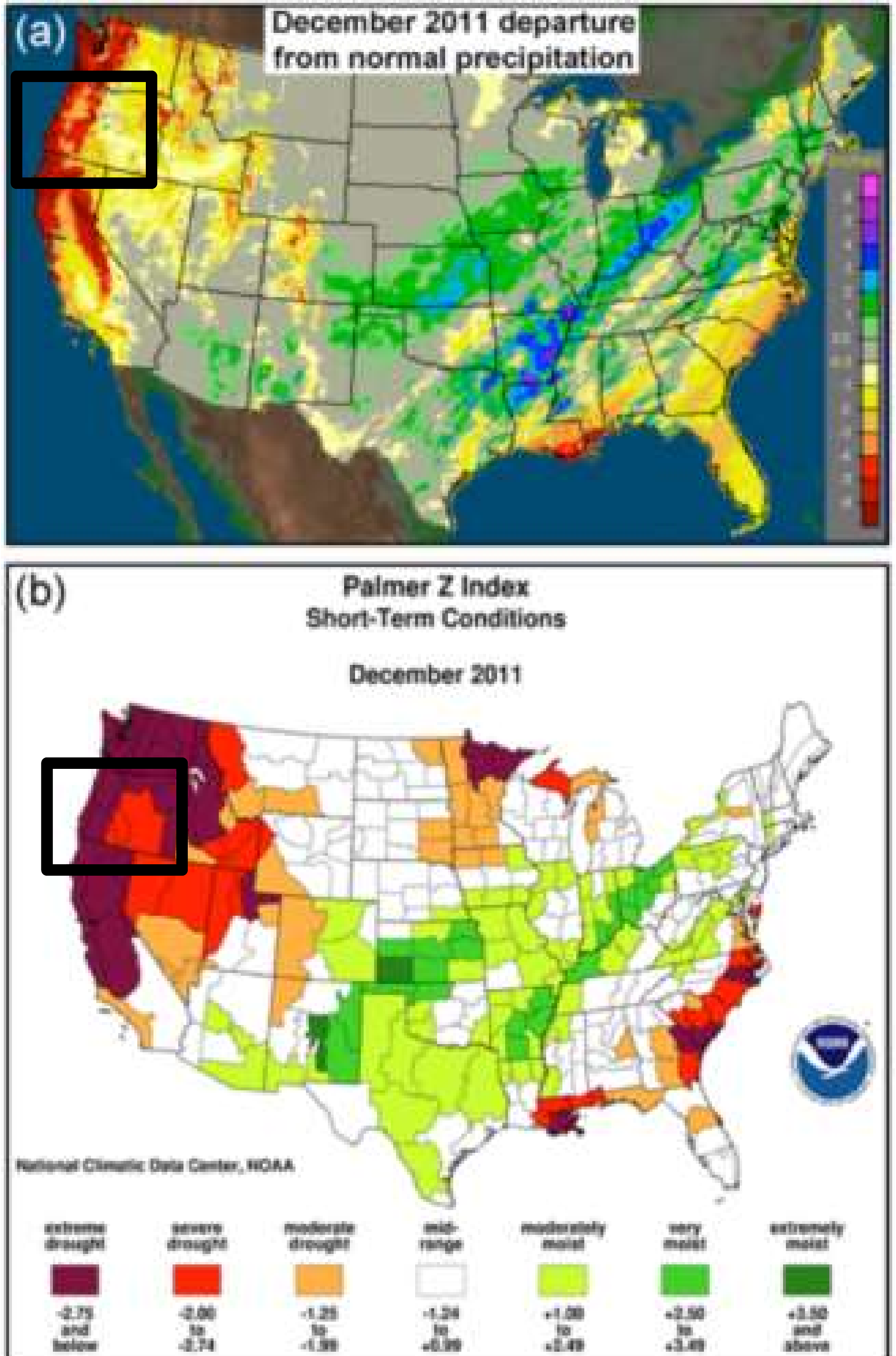
- <u>Motivation</u>
  - Provide a follow-up to the work of Dettinger et al. (2011), which assessed the influence of ARs on western U.S. precipitation, but did not consider ARs crossing the Baja Peninsula
- <u>Method</u>
  - If an AR is present for ~24 h along the North American west coast from 24–52.5°N, 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



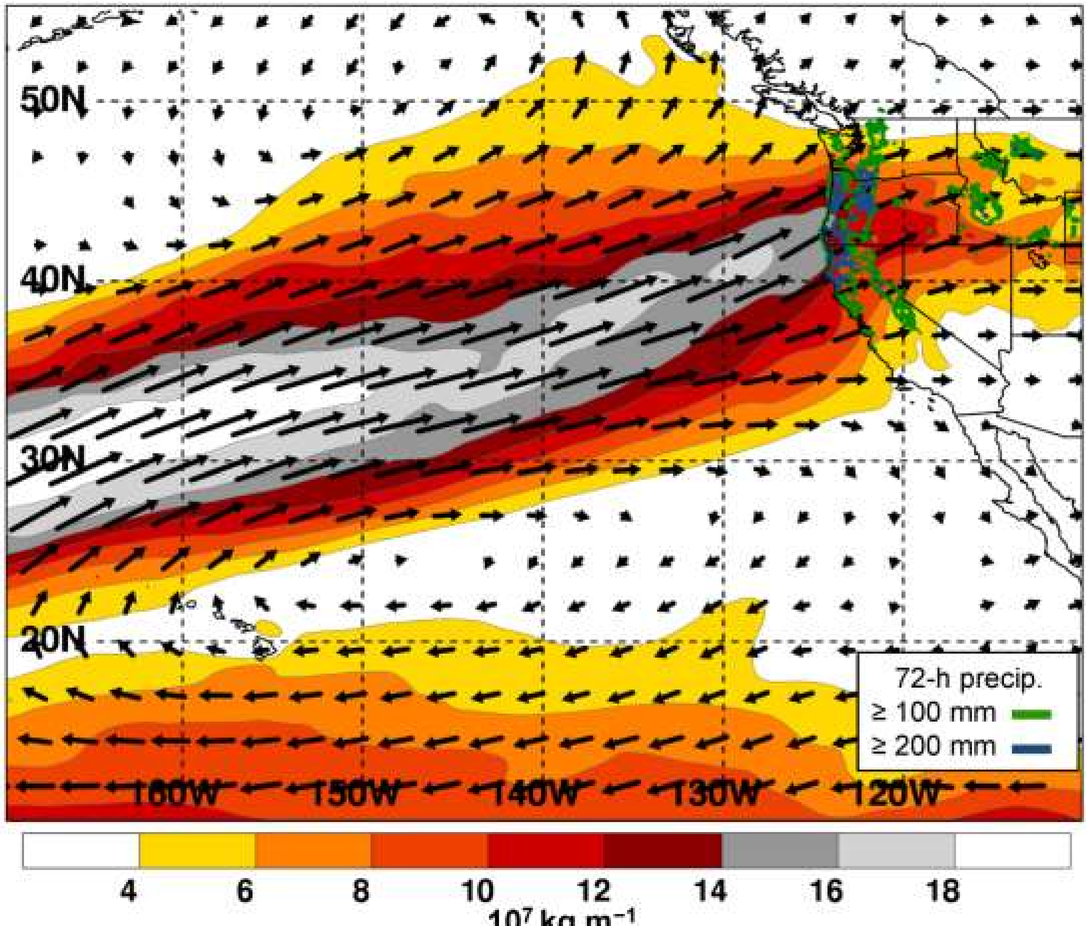
Cool-season "AR fraction" (a) without and (b) with ARs crossing the Baja Peninsula in the CPC gridded precipitation analysis during water years 1998–2008. (c) (b) - (a).

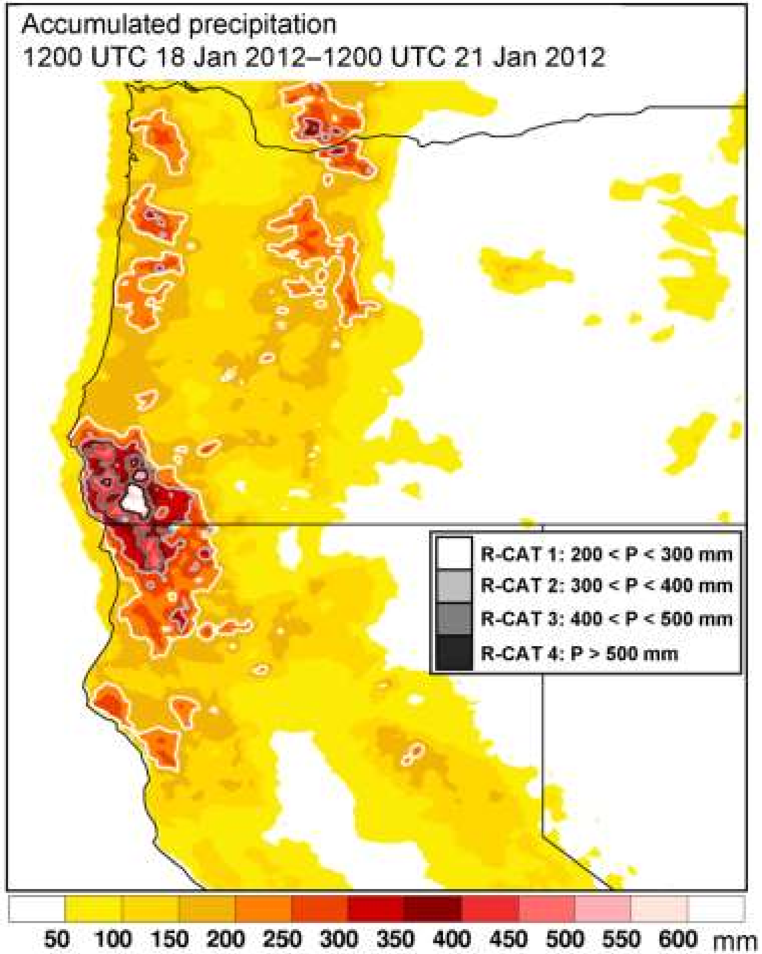

(a)
December 2011 departure
from normal precipitation
(b)
Palmer Z Index
Short-Term Conditions
December 2011
National Climatic Data Center, NOAA
extreme drought
severe drought
moderate drought
mid-range
moderately moist
very moist
extremely moist
-2.75 and below
-2.00 to -2.74
-1.25 to -1.99
-1.24 to +0.99
+1.00 to +2.49
+2.50 to +3.49
+3.50 and above

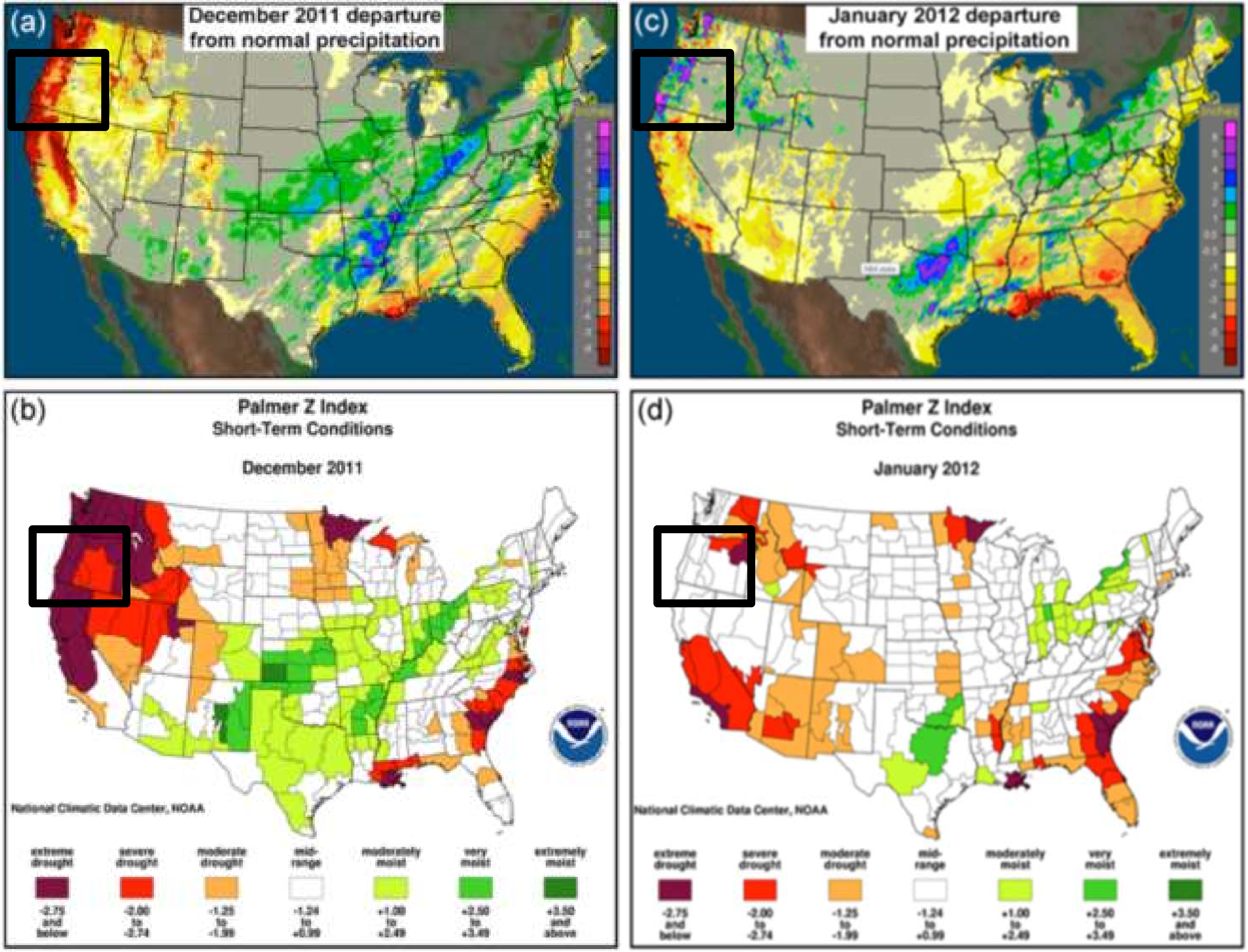
18–21 Jan 2012 AR Event

- The long duration of AR conditions in Oregon and northern California supported widespread heavy rainfall
- 72-h precipitation totals exceeding 100 mm were common along the west coast, with largest amounts observed in southwestern Oregon and northwestern CA
- Localized precip. totals ranged from 400 mm to >500 mm (R-CATs 3–4) in this region

Time-integrated IVT 12 UTC 18 Jan–12 UTC 21 Jan







(a)
December 2011 departure
from normal precipitation
(c)
January 2012 departure
from normal precipitation
(b)
Palmer Z Index
Short-Term Conditions
December 2011
National Climatic Data Center, NOAA
(d)
Palmer Z Index
Short-Term Conditions
January 2012
National Climatic Data Center, NOAA
extreme drought
severe drought
moderate drought
mid-range
moderately moist
very moist
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-2.75 and below
-2.00 to -2.74
-1.25 to -1.99
-1.24 to +0.99
+1.00 to +2.49
+2.50 to +3.49
+3.50 and above

Observed Impacts of Duration and Seasonality of Atmospheric-River Landfalls on Soil Moisture and Runoff

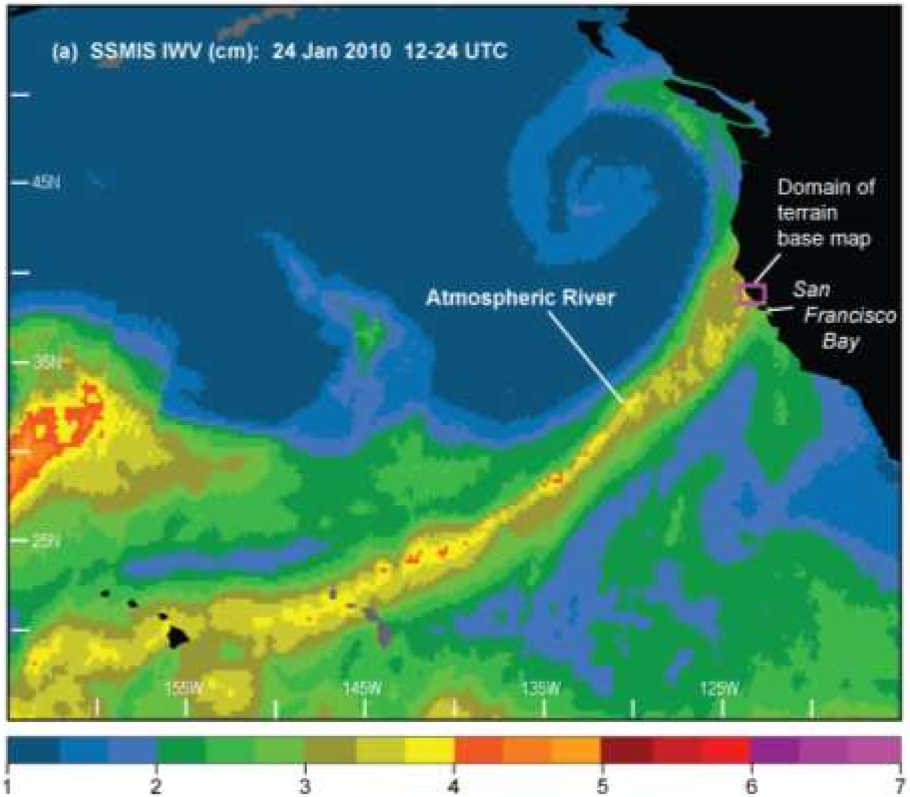
F. M. Ralph[1], T. Coleman[2], P.J. Neiman[1], R. Zamora[1], and M. D. Dettinger[3]

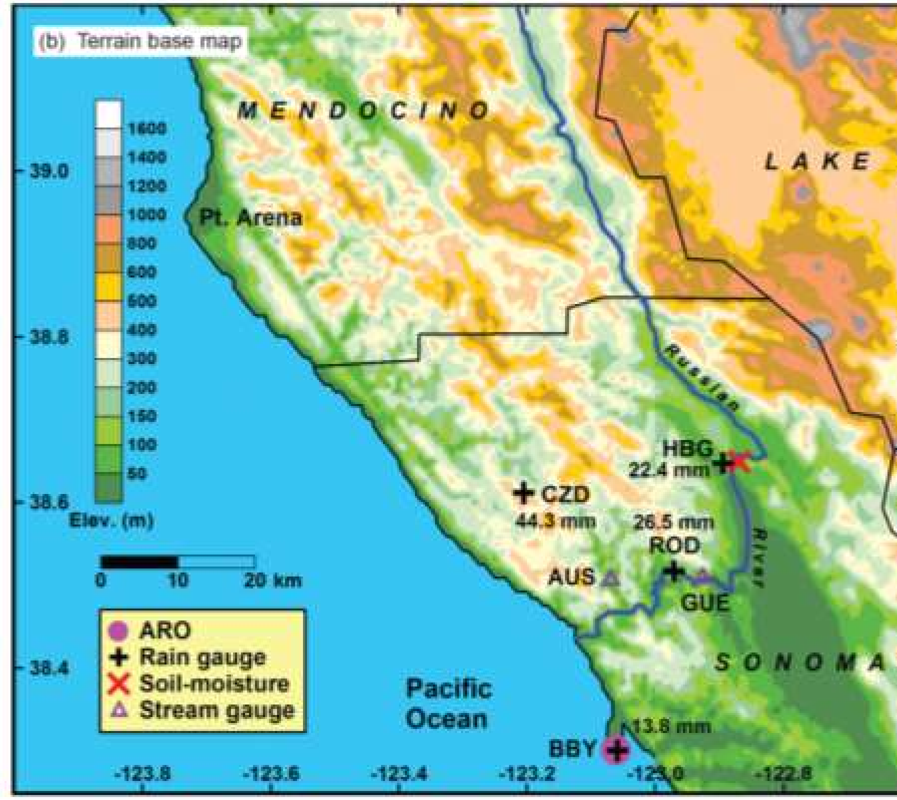
J.Hydrometeor., ***14***, *443-459*

Goals:
- Quantify typical duration of AR conditions during AR landfall
- Diagnose seasonality of AR characteristics and their impacts
- Assess importance of storm-total water vapor flux

Data:
- Hourly observations available over nearly 6 years
    - Wind profiles aloft from a 915 MHz wind profiler
    - Vertically integrated water vapor (IWV) from GPS-met
    - Precipitation
    - Soil moisture
    - Stream flow

Experimental Design





Atmospheric River (AR) as seen in SSM/I-observed IWV from polar orbiting satellites (example of a long-duration AR)

Regional terrain and observations from NOAA's Hydrometeorology Testbed (HMT) and related data (2004-2010)

Composite of 91 ARs

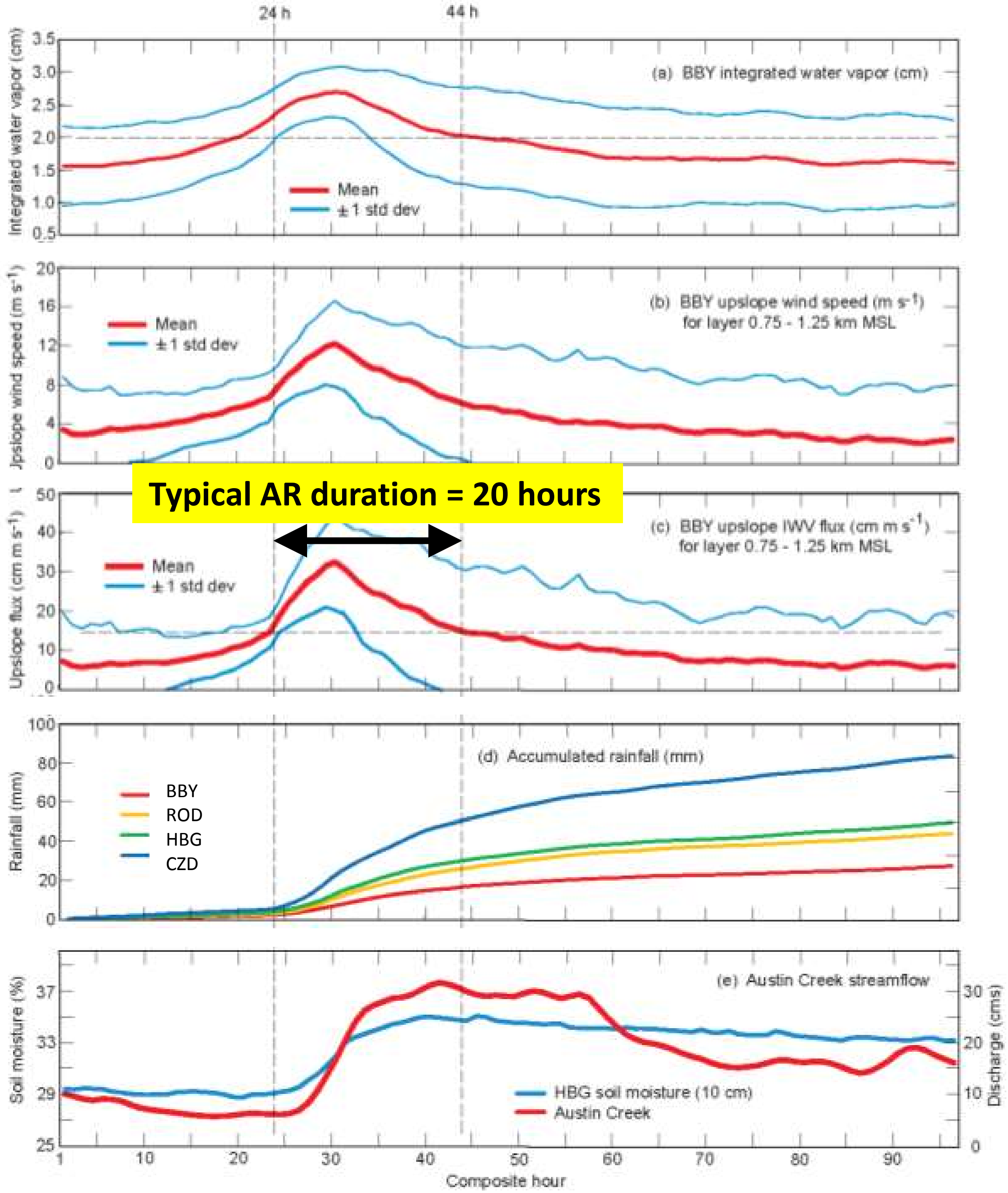
IWV

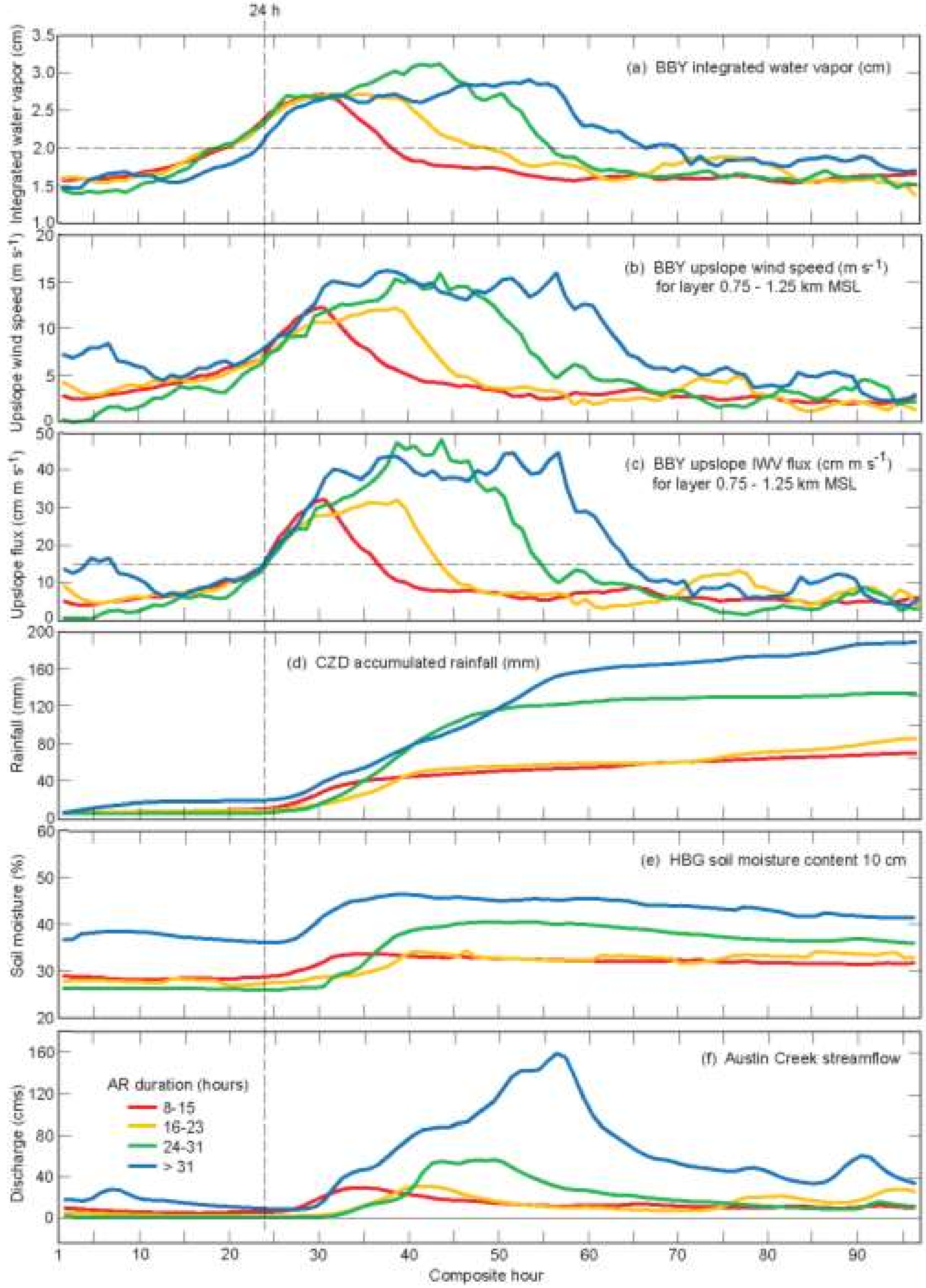
Upslope wind speed

Upslope water vapor flux

Precipitation accumulation

Soil moisture & Streamflow

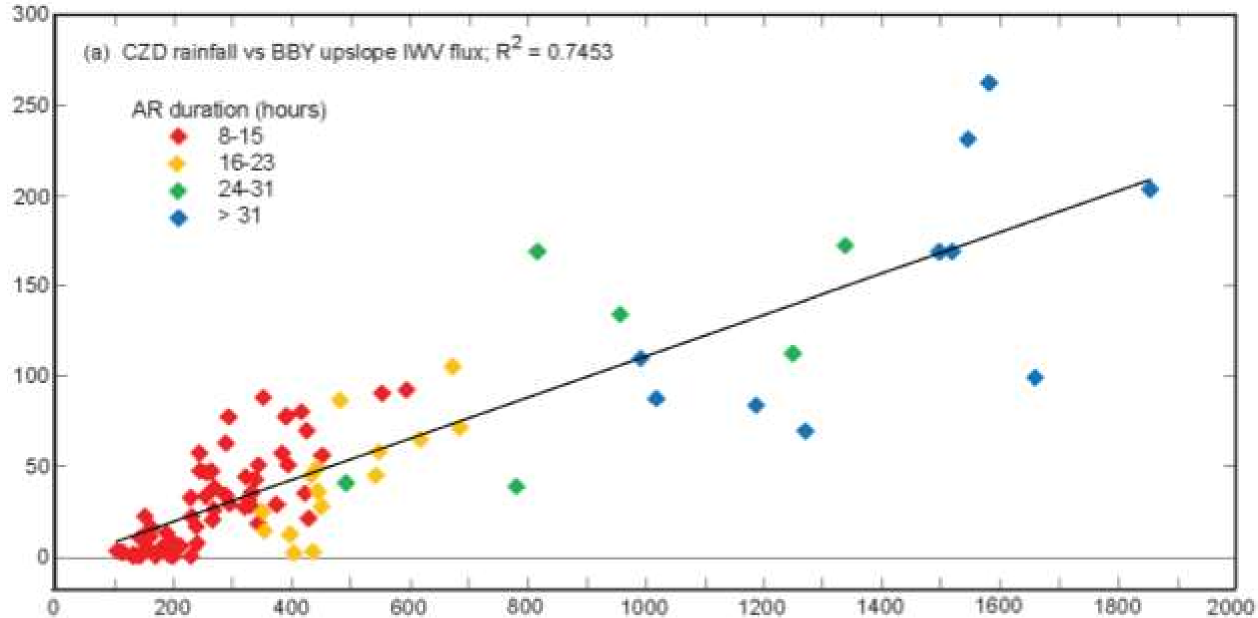




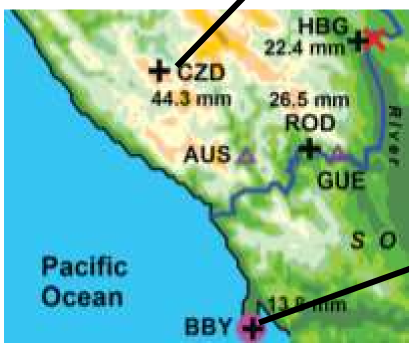
24 h
(a) BBY integrated water vapor (cm)
Integrated water vapor (cm)
(b) BBY upslope wind speed (m s-1)
for layer 0.75 - 1.25 km MSL
Upslope wind speed (m s-1)
(c) BBY upslope IWV flux (cm m s-1)
for layer 0.75 - 1.25 km MSL
Upslope flux (cm m s-1)
(d) CZD accumulated rainfall (mm)
Rainfall (mm)
(e) HBG soil moisture content 10 cm
Soil moisture (%)
(f) Austin Creek streamflow
Discharge (cms)
AR duration (hours)
8-15
16-23
24-31
> 31
Composite hour

91 AR events observed over 6 years

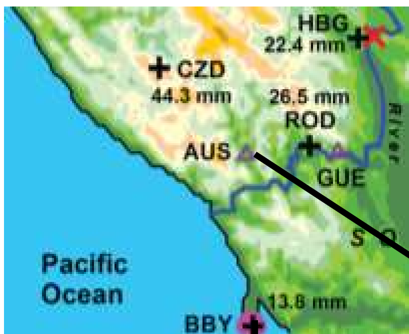
Storm-total rainfall at CZD (mm)

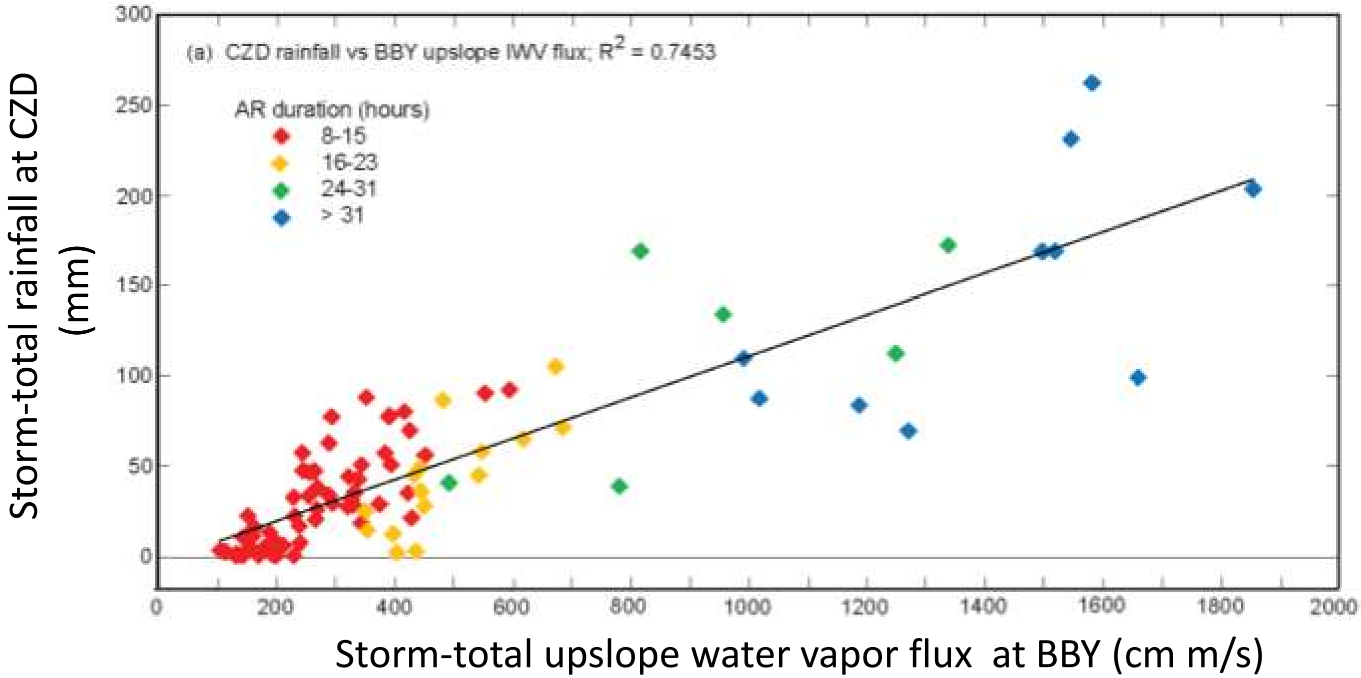


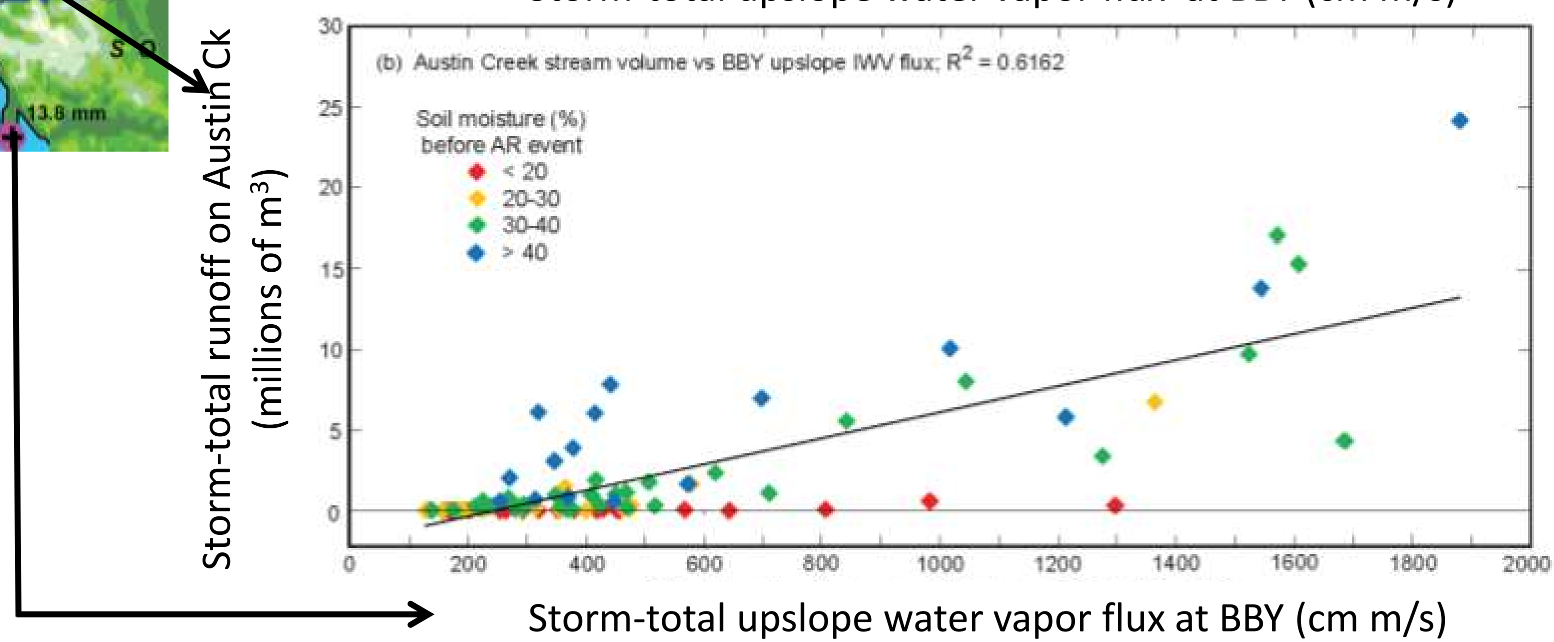
Storm-total upslope water vapor flux at BBY (cm m/s)



91 AR events observed over 6 years





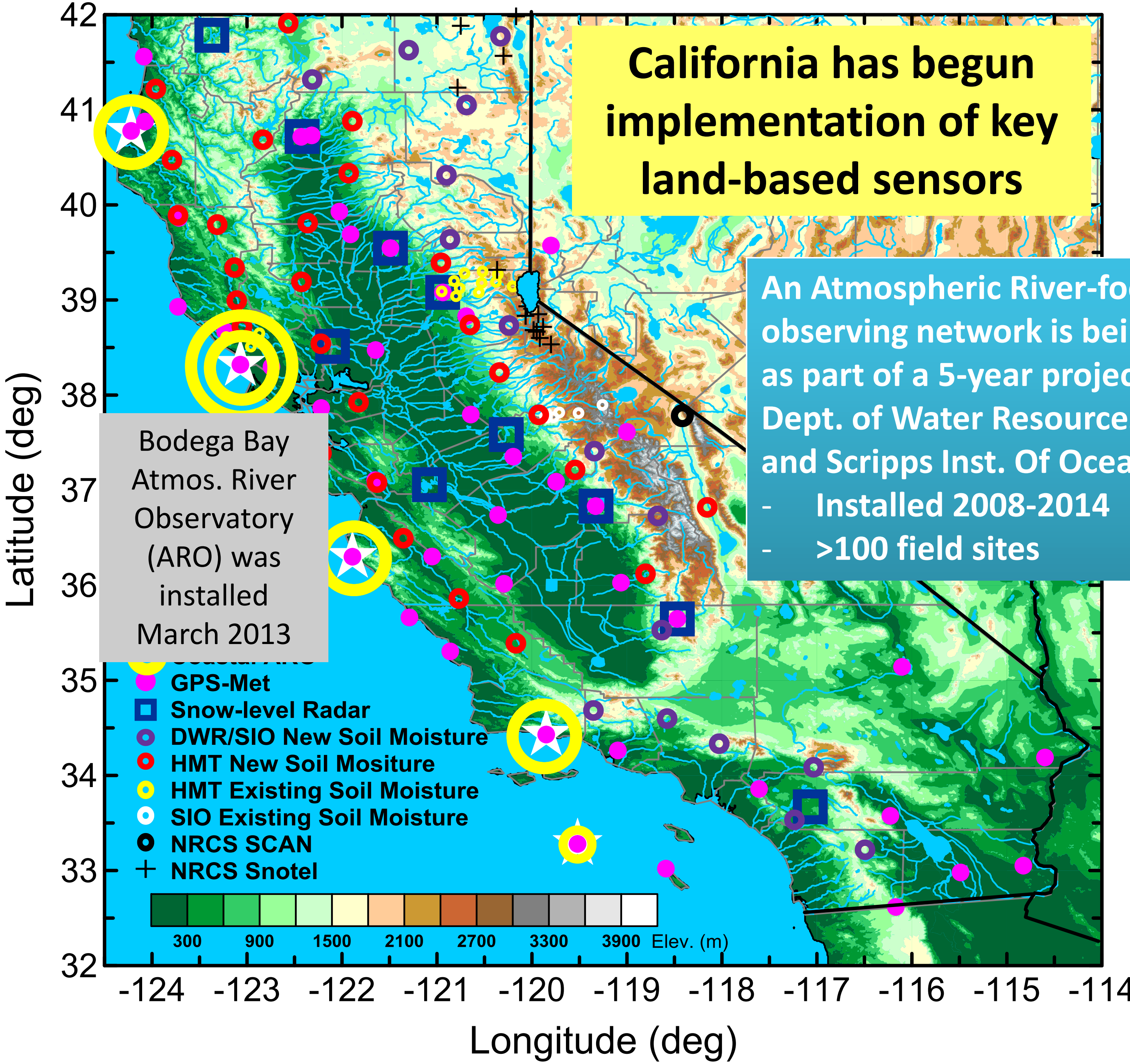


California has begun implementation of key land-based sensors

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

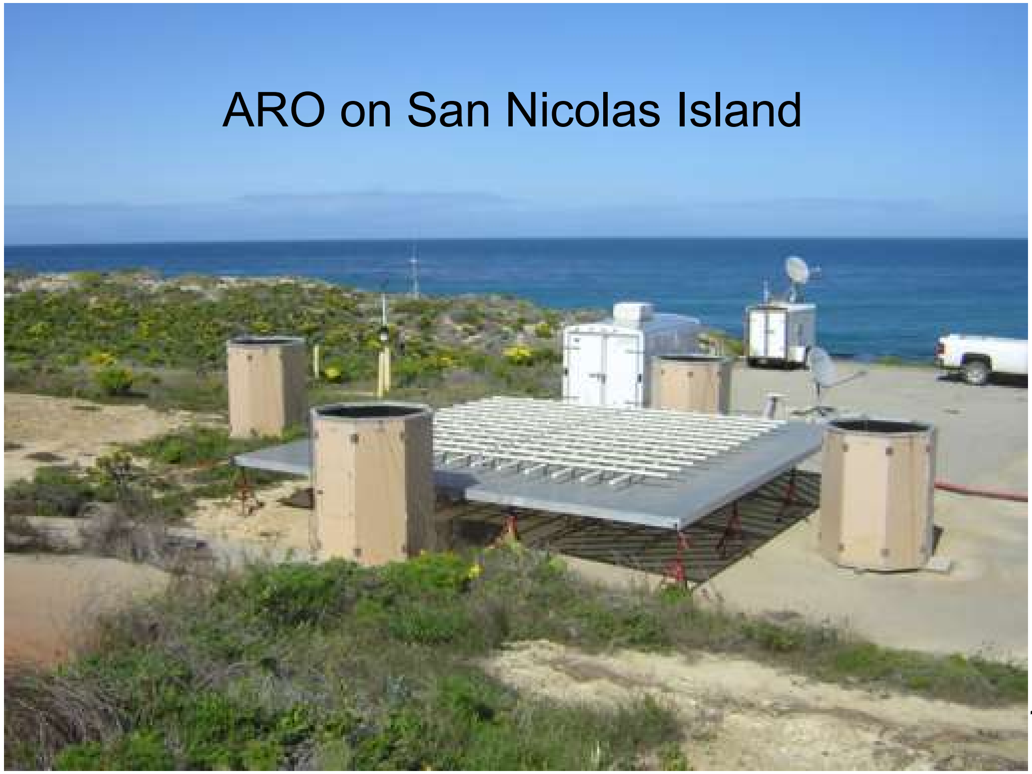
Bodega Bay Atmos. River Observatory (ARO) was installed March 2013



2012-2014 Atmospheric River Observatory (ARO) Deployment Schedule

Site ID	Name	Latitude (deg) [1]	Longitude (deg) [1]	Elev. (ft)[1]	Installed by
BBY	Bodega Bay	38.32	-123.07	39	Mar. 2013
ERK	Eureka	40.77	-124.22	6	Jun. 2013
GLA	Goleta	34.43	-119.85	10	Nov. 2013
PTS	Pt. Sur	36.30	-121.89	33	Apr 2014

[1] Approximate locations and elevations

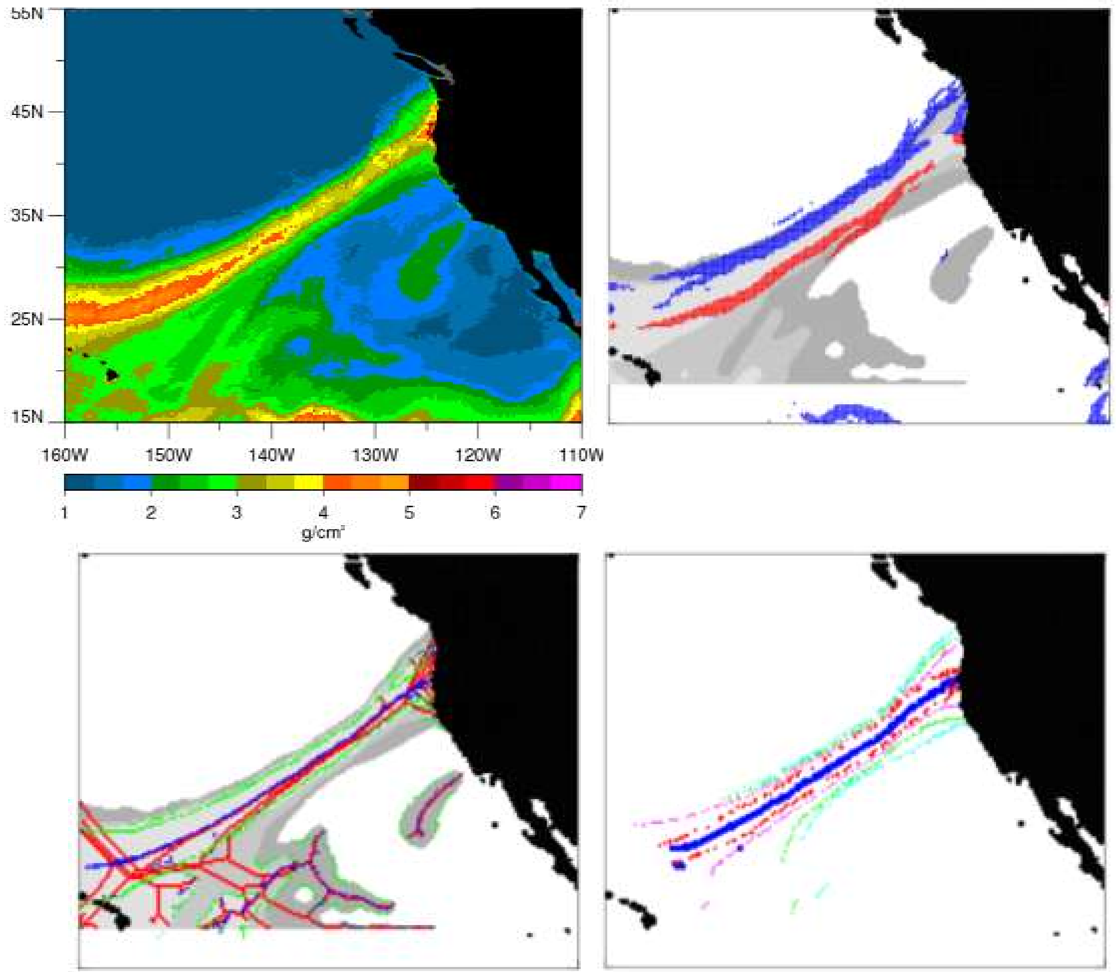


Courtesy of Dr. Allen White (NOAA/ESRL/PSD)

Automated AR Detection Tool (ARDT) for IWV

Wick et al., G. A., P.J. Neiman, and F.M. Ralph, 2013,
IEEE Trans. Geosci. Remote Sensing, **51**, 2166-2176.

- Isolate top of the tropical water vapor reservoir
- Threshold IWV values at multiple levels and compute gradients
- Cluster points above thresholds and compute skeleton to estimate axis
- Identify points satisfying width criteria
- Cluster center points to identify segments of sufficient length
- Extract AR characteristics
- Determine if AR intersects land or is potentially influenced by data gaps

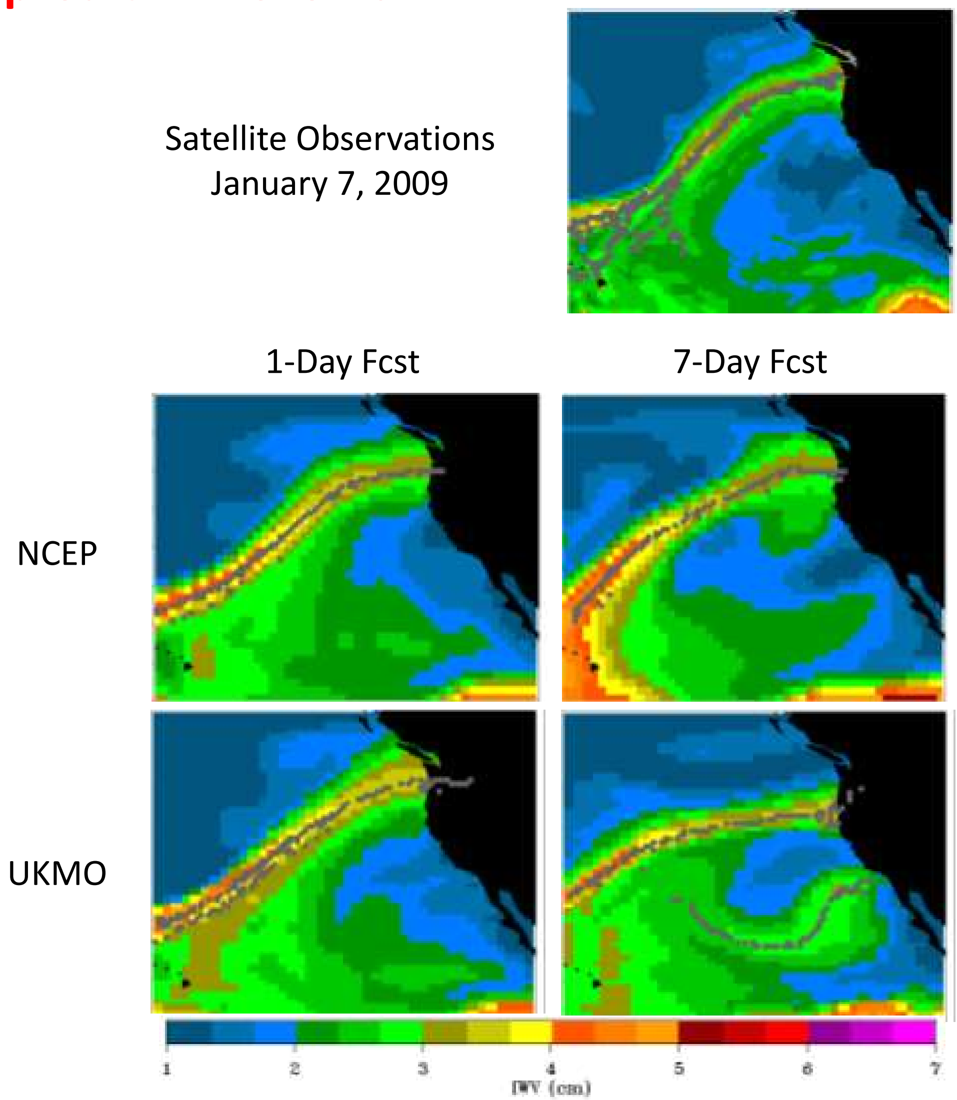


Example from November 7, 2006

Validation of AR Forecasts - Approach

Automated Atmospheric River Detection Tool (ARDT) applied to evaluate ability of operational NWP models to predict AR events

- AR features in model fields compared with satellite observations from SSMIS
- 5 models tested: NCEP, ECMWF, UKMO, JMA, & CMC
- Evaluated at lead times to 10 days
- 3 cool seasons in NE Pacific from 2008-9 to 2010-11
- Compared frequency of occurrence, width, IWV content, and landfall location



Evaluation of Atmospheric River Forecasts in Operational Ensemble Forecast Systems

G. A. Wick, P. J. Neiman, F. M. Ralph, & T. M. Hamill
NOAA ESRL/PSD, 2013

Atmospheric River Information Page

Photo by Robert Leroux

Atmospheric Rivers (AR) are relatively narrow regions in the atmosphere that are responsible for most of the horizontal transport of water vapor outside of the tropics. While ARs come in many shapes and sizes, those that contain the largest amounts of water vapor, the strongest winds, and stall over watersheds vulnerable to flooding, can create extreme rainfall and floods. These events can disrupt travel, induce mud slides, and cause catastrophic damage to life and property. However, not all ARs cause damage – most are weak, and simply provide beneficial rain or snow that is crucial to water supply. *Learn more...*

Quick Facts

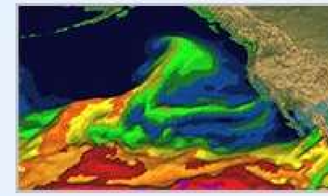
On average, about 30-50% of annual precipitation in the west coast states occurs in just a few AR events, thus contributing to water supply.

In the strongest cases ARs can create major flooding when they make land-fall and stall over an area.

ARs are a primary feature in the entire global water cycle, and are tied closely to both water supply and flood risks,

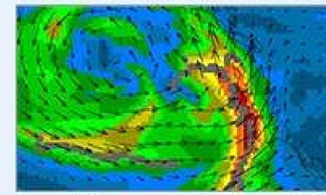
http://www.esrl.noaa.gov/psd/atmrivers/
or
Search "Atmospheric Rivers"

Latest AR Event



*Click to enlarge **3D Loop***

Real-Time Monitoring



*Click to go to **AR detection displays***

What's New?

27 November 2012

Heavy Precipitation Event Developing in Northern CA

Read about it at hmt.noaa.gov →

More Information

Q & A

Publications

Notable AR Events

Details about some major AR events

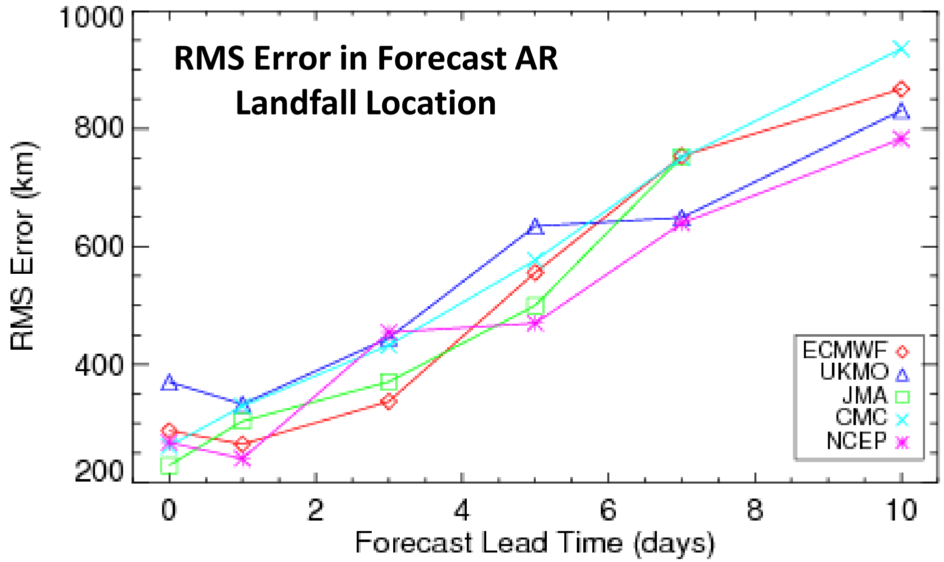
Related Projects

Overview of Projects

NOAA Hydrometeorology Testbed

Validation of AR Forecasts – Results/Implications

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 leads



- 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 (submitted to 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**

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

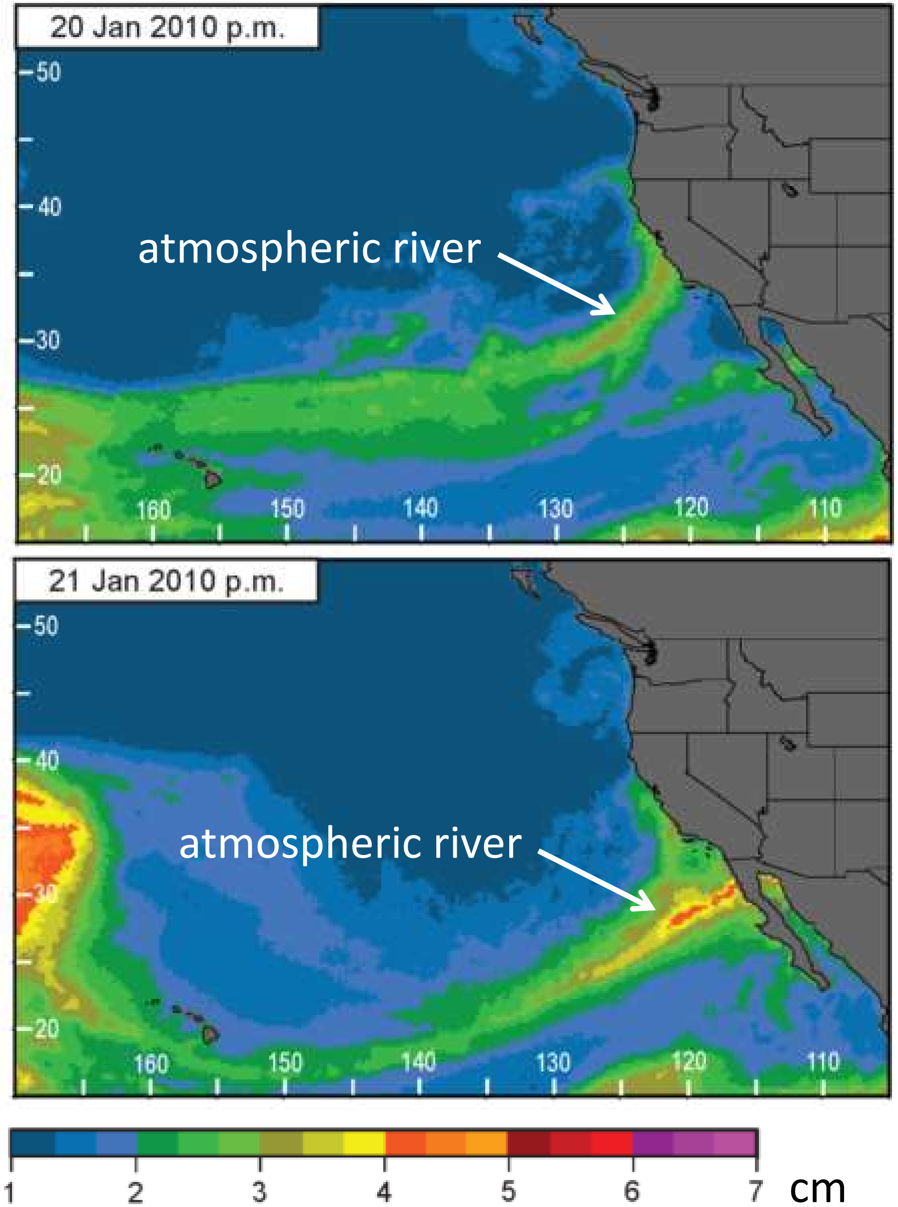
Paul J. Neiman[1], F.M. Ralph[1], B. Moore[2], M. Hughes[2], K. Mahoney[2], J. Cordeira[2], M. Dettinger[3]

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

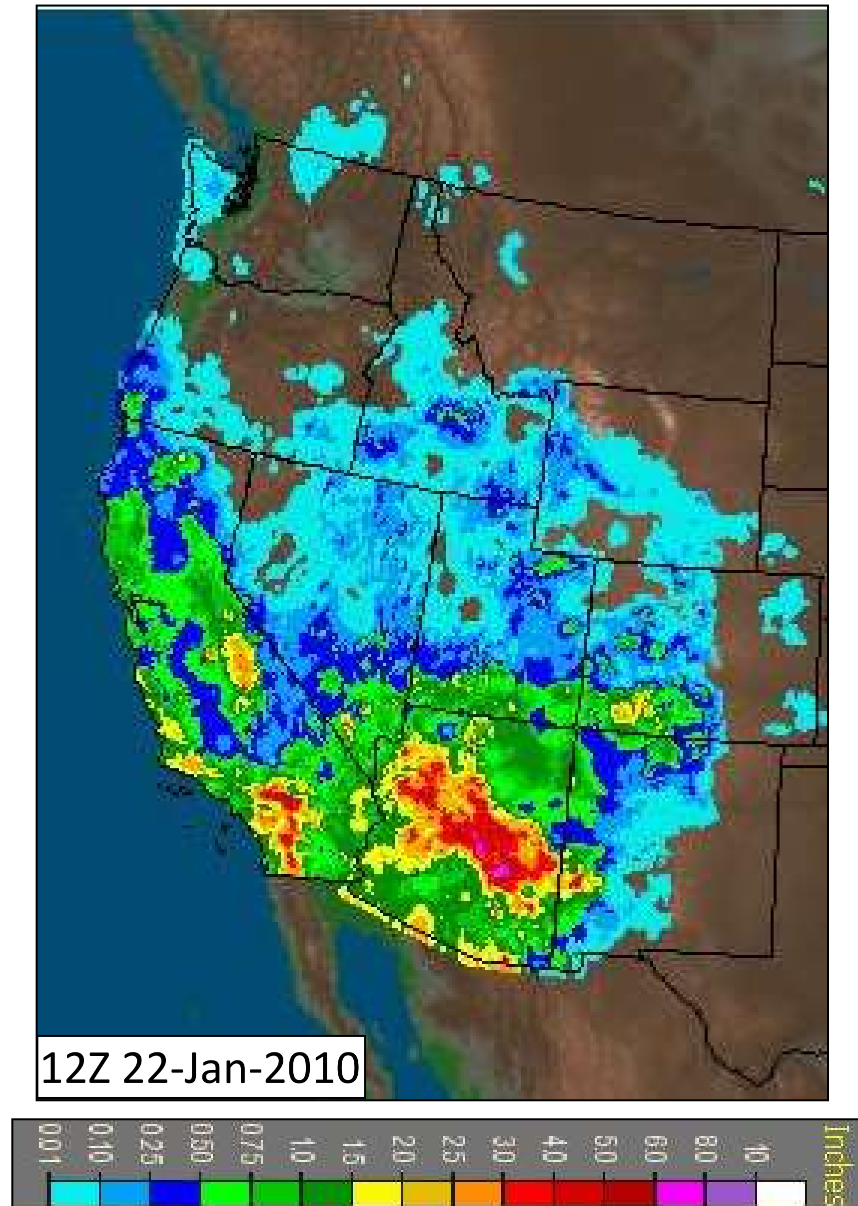
J. Hydrometeor., **14**, 460-484 (April 2013)

Grand Canyon South Rim

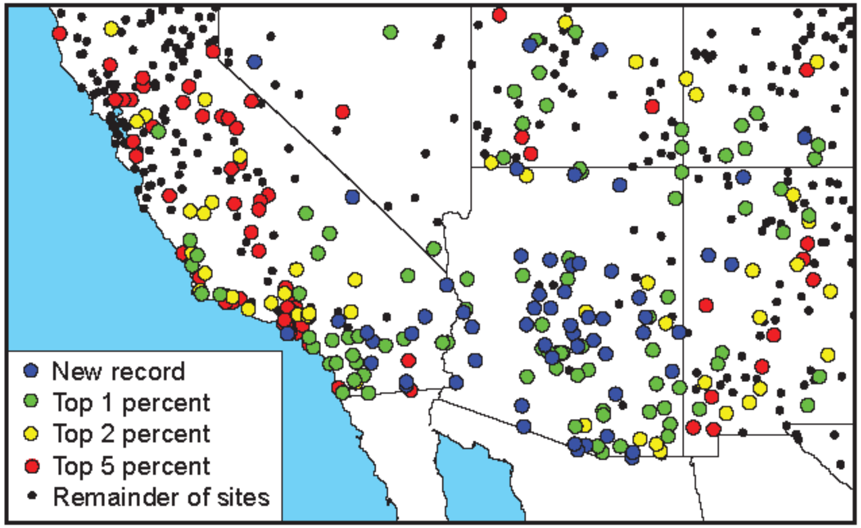
SSM/I IWV satellite imagery 20-21 Jan. 2010 depicts a strengthening AR making landfall



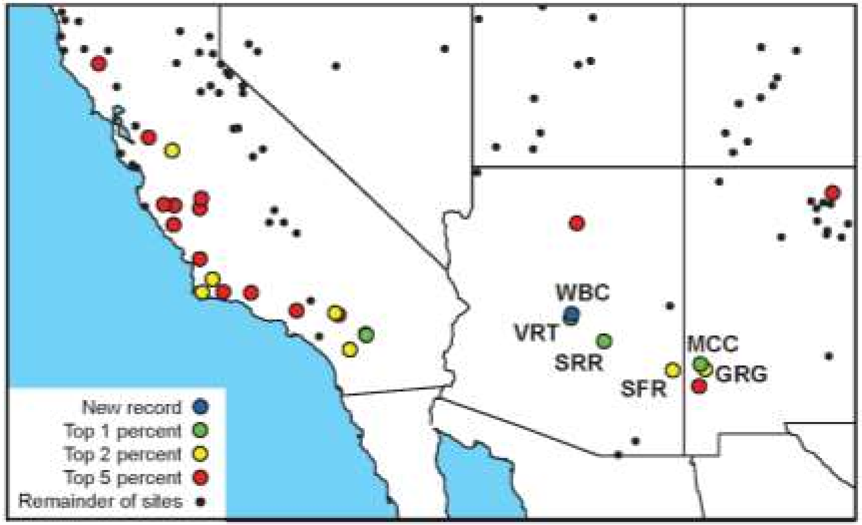
24-h precip ending 12Z 22 Jan. 2010: Advanced Hydrological Prediction Services

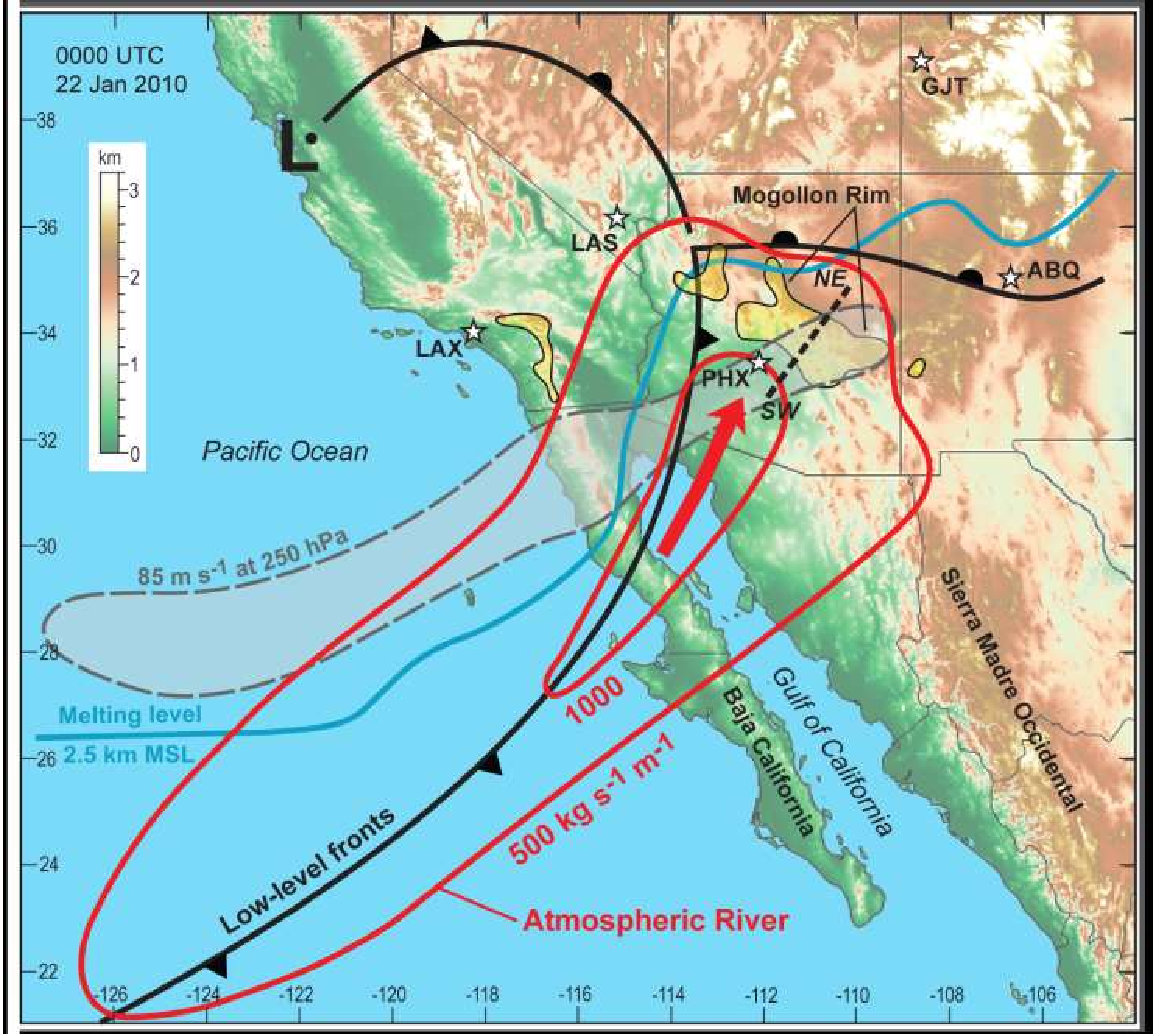


COOP precip on 21-22 Jan. 2010: Rank relative to all January pairs of days between 1950-2009 for gauges with >25 Januarys of data.



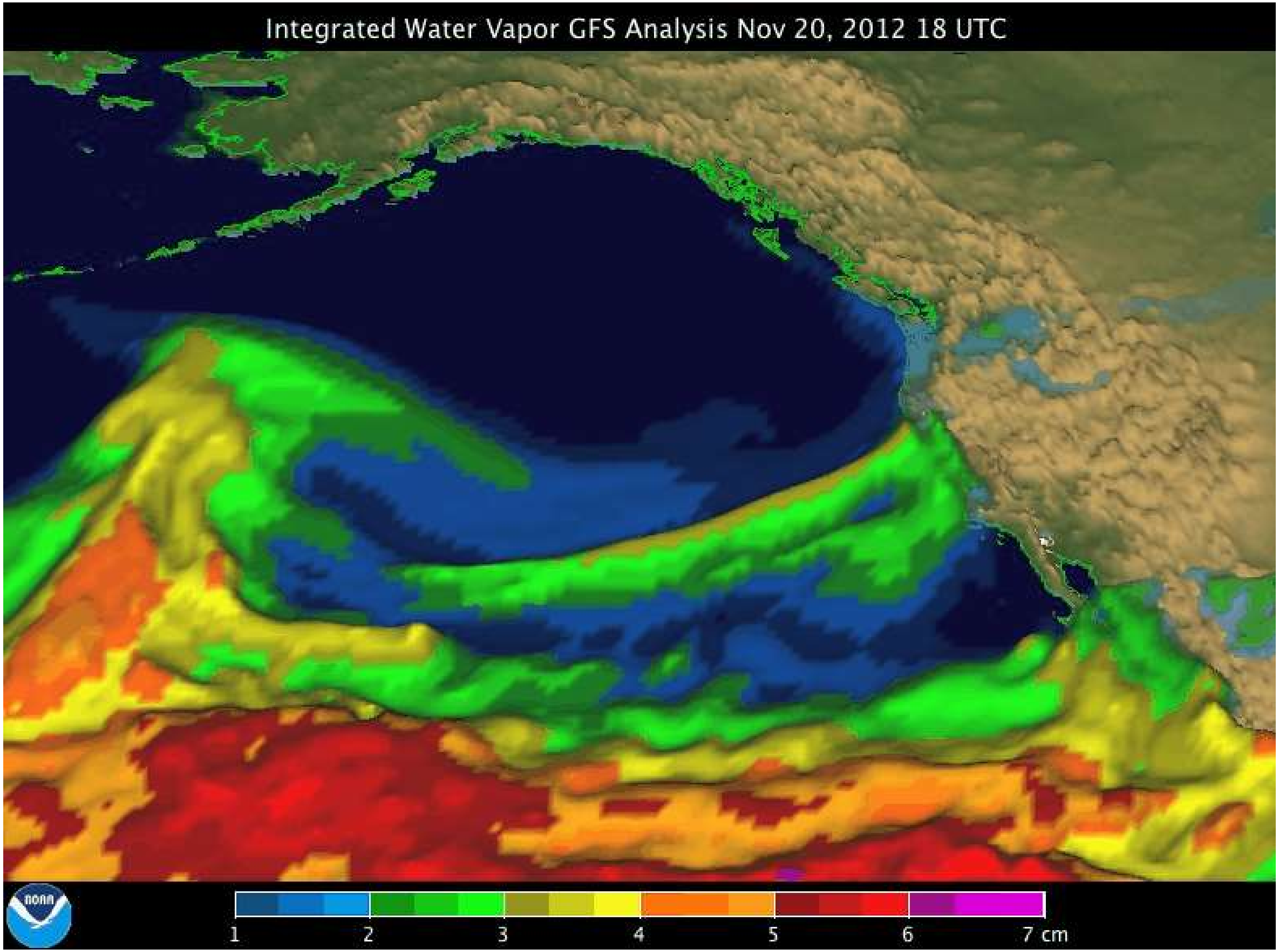
USGS streamflow on 21-22 Jan. 2010 for unregulated channels: Rank relative to all January pairs of days between 1901-2009 for gauges with >25 Januarys of data.



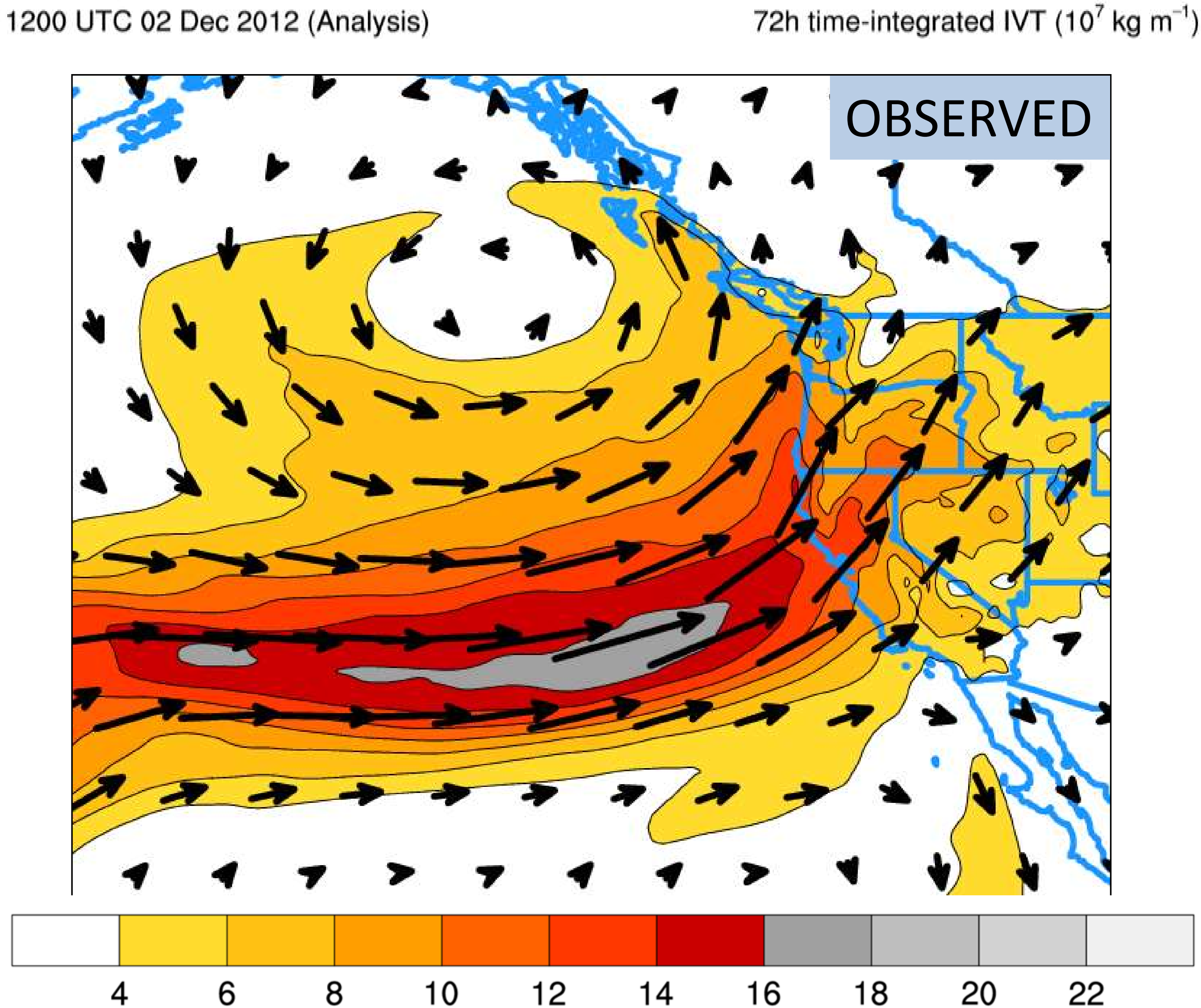


0000 UTC
22 Jan 2010
km
3
2
1
0
GJT
LAS
Mogollon Rim
ABQ
NE
LAX
PHX
SW
Pacific Ocean
85 m s-1 at 250 hPa
Melting level
2.5 km MSL
1000
500 kg s-1 m-1
Baja California
Gulf of California
Sierra Madre Occidental
Low-level fronts
Atmospheric River
38
36
34
32
30
28
26
24
22
-126
-124
-122
-120
-118
-116
-114
-112
-110
-108
-106

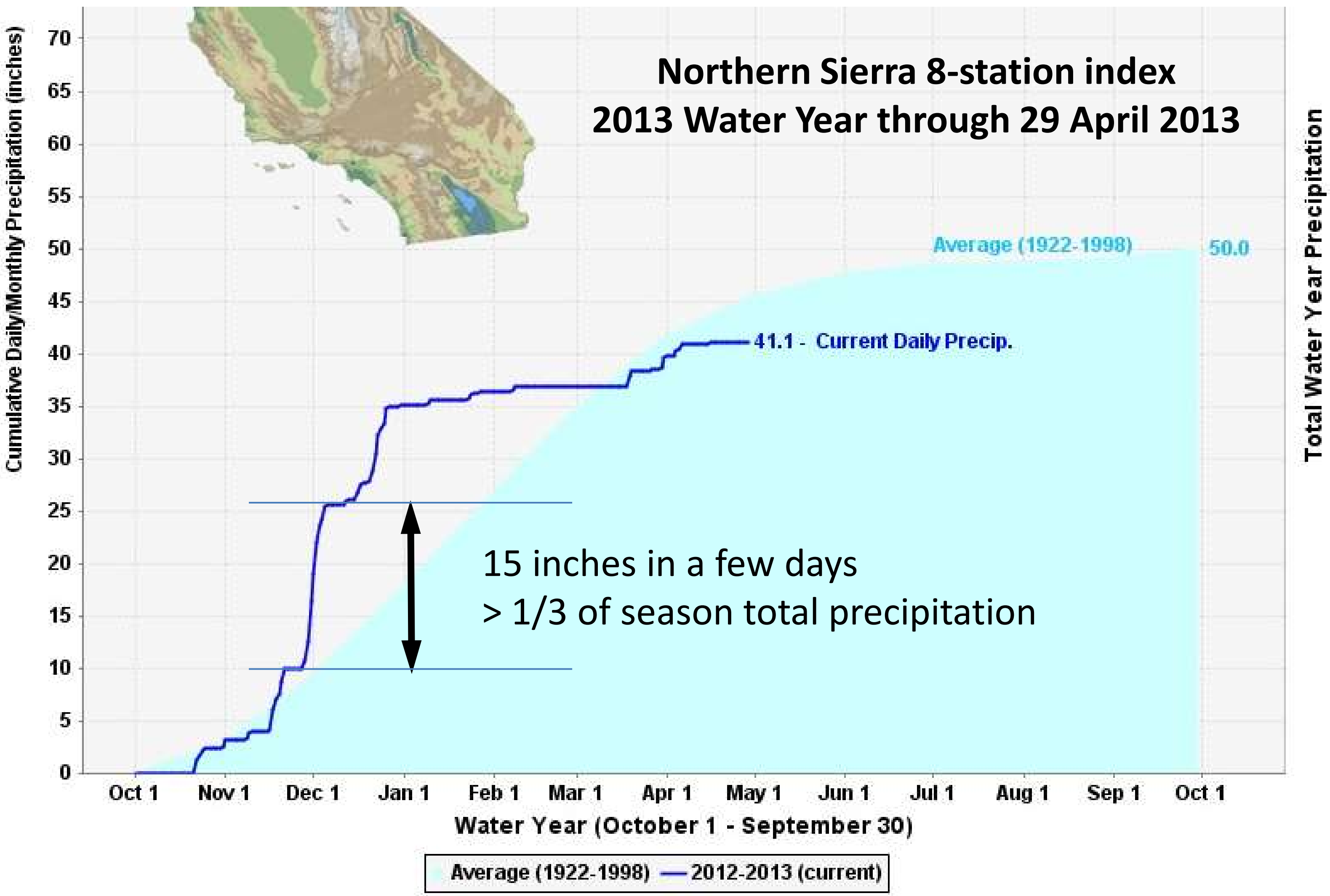
Atmospheric River Events 20 Nov-3 Dec 2012



Animation courtesy of Don Murray (NOAA/ESRL/PSD)


1200 UTC 02 Dec 2012 (Analysis)
72h time-integrated IVT (10^7 kg m^{-1})
OBSERVED
4
6
8
10
12
14
16
18
20
22

Russian River area
1-2 Dec 2013



Northern Sierra 8-station index
2013 Water Year through 29 April 2013
Cumulative Daily/Monthly Precipitation (inches)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Average (1922-1998)
50.0
41.1 - Current Daily Precip.
15 inches in a few days
> 1/3 of season total precipitation
Total Water Year Precipitation
Oct 1
Nov 1
Dec 1
Jan 1
Feb 1
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Water Year (October 1 - September 30)
Average (1922-1998)
2012-2013 (current)


Thank you!

HMT Atmospheric River Retrospective Forecasting Experiment (ARRFEX)

September 17-28, 2012

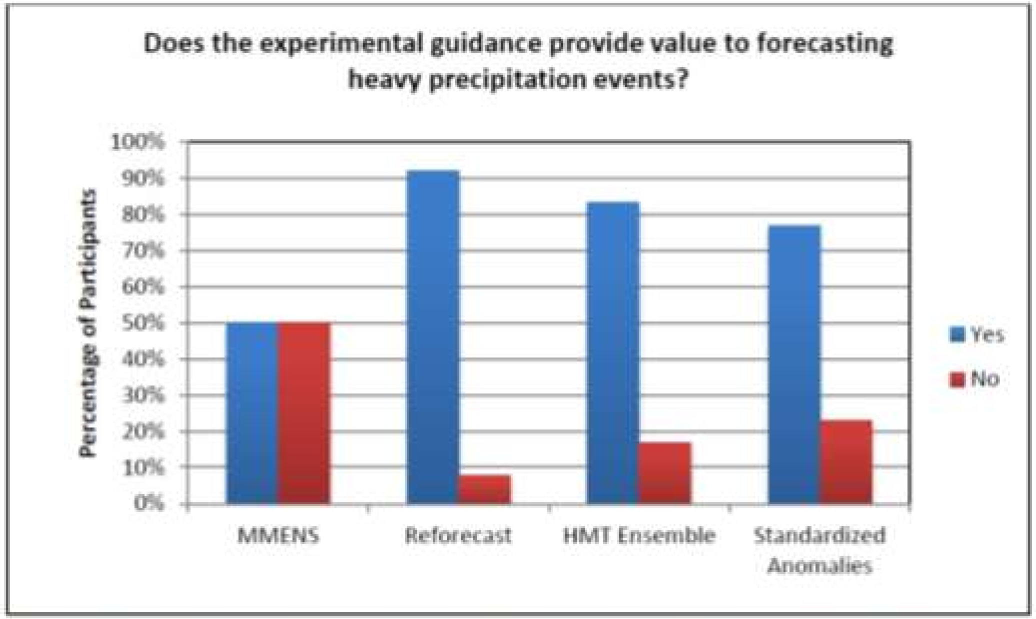
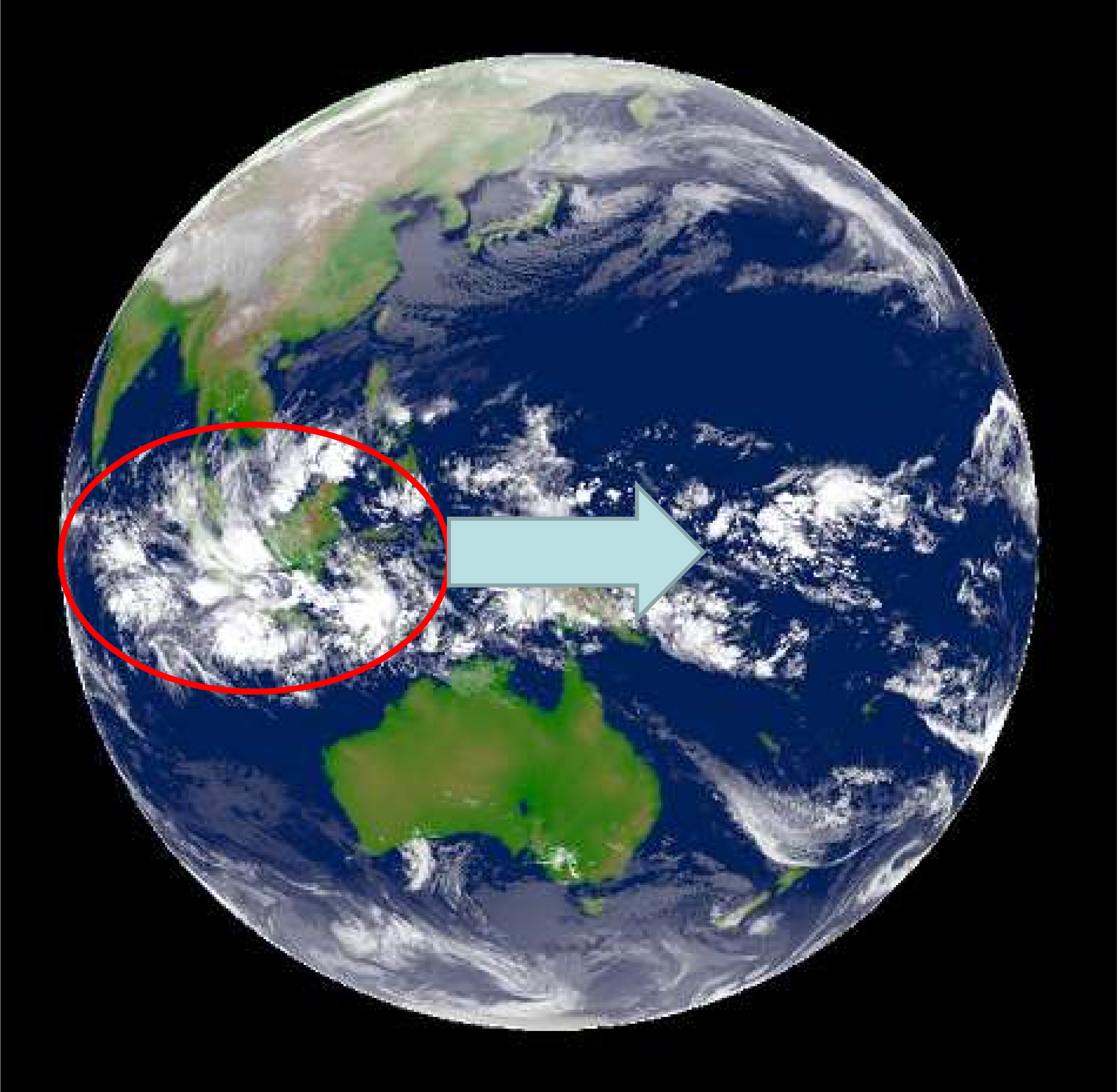


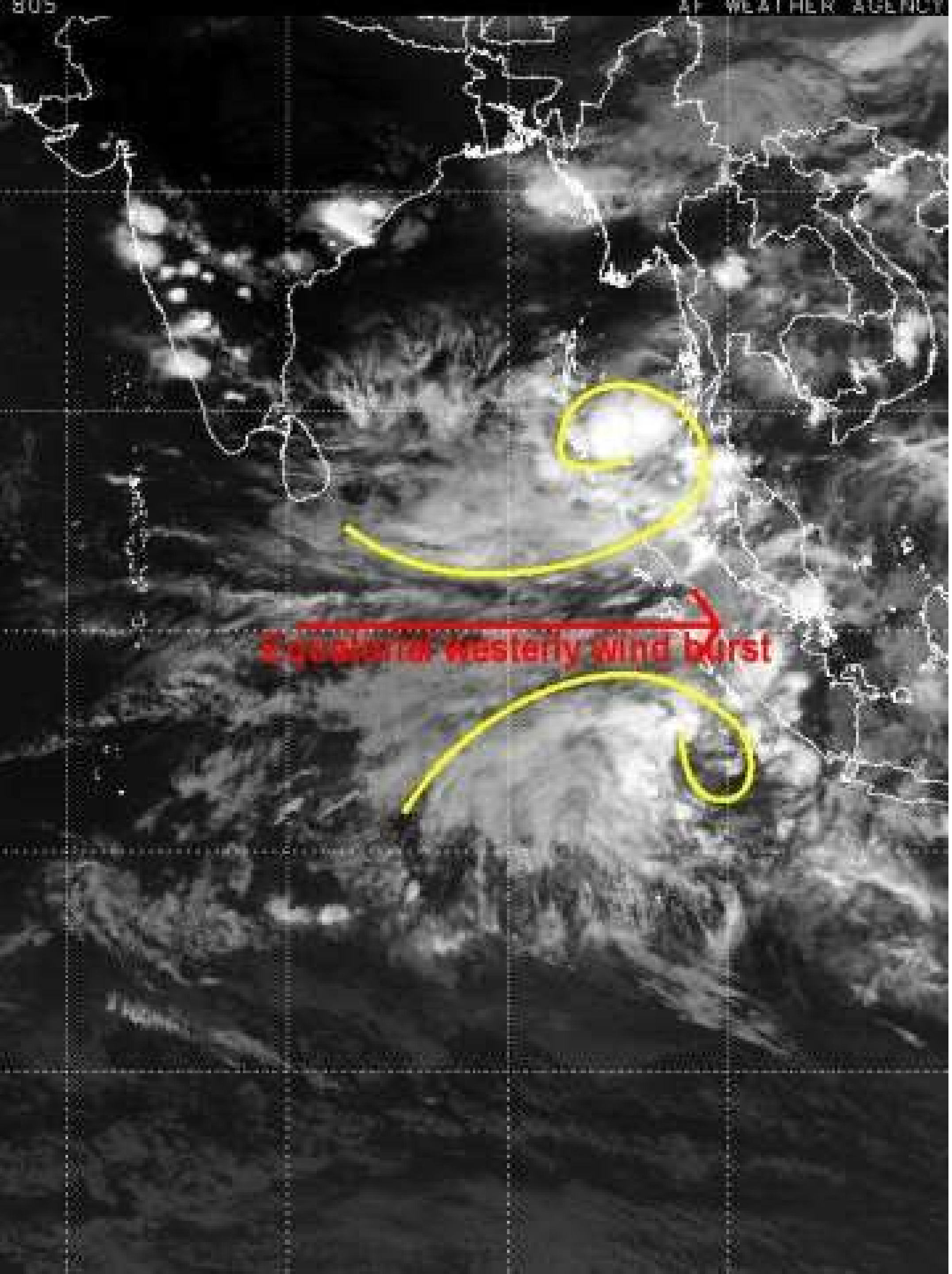
Figure 10) Participant feedback on the use and value of the experimental guidance systems featured in ARRFEX.

From Workoff et al. 2013 ARRFEX Internal Report

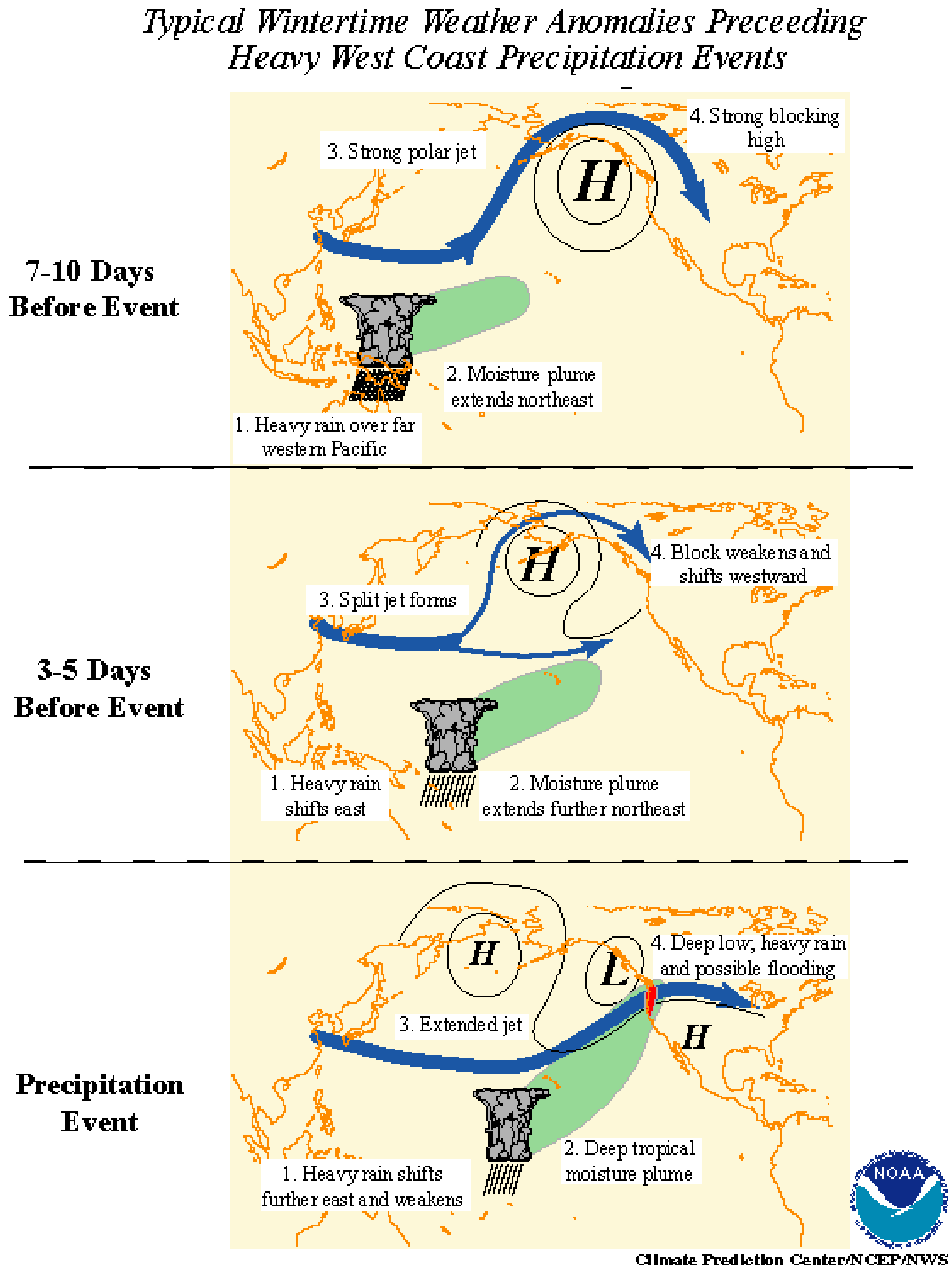


MJOs are characterized by regions of convection that create cold cloud tops seen by satellite

MJOs propagate eastward normally over 30-60 days

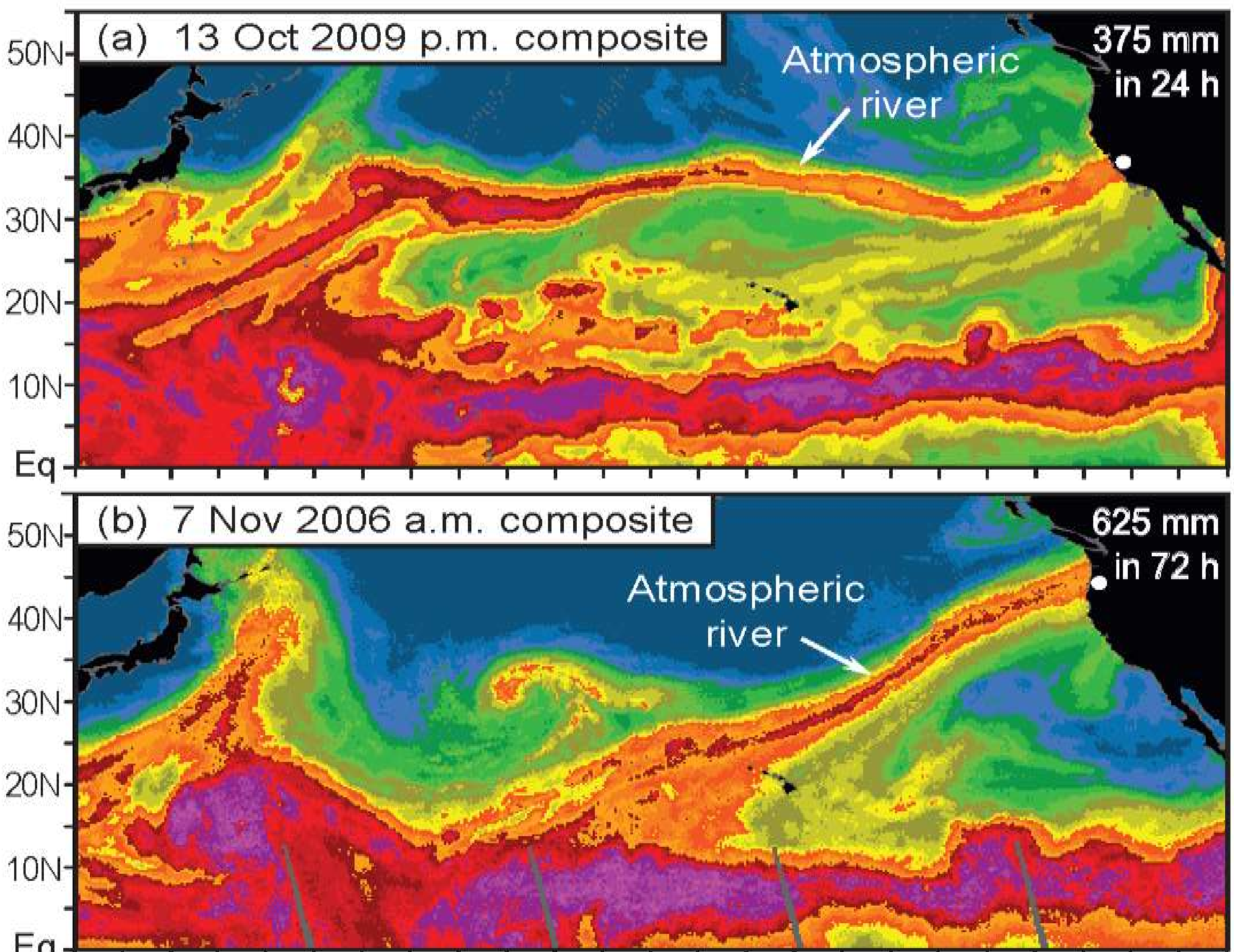


MJOs affect the wind field and include a "burst" of westerly winds where normally winds are easterly



MJOs can trigger changes in where storms develop even well outside the tropics, such as off the US West Coast

Atmospheric rivers: SSM/I Satellite data for two recent examples that produced extreme rainfall and flooding



From Ralph et al. 2011, Mon. Wea. Rev.

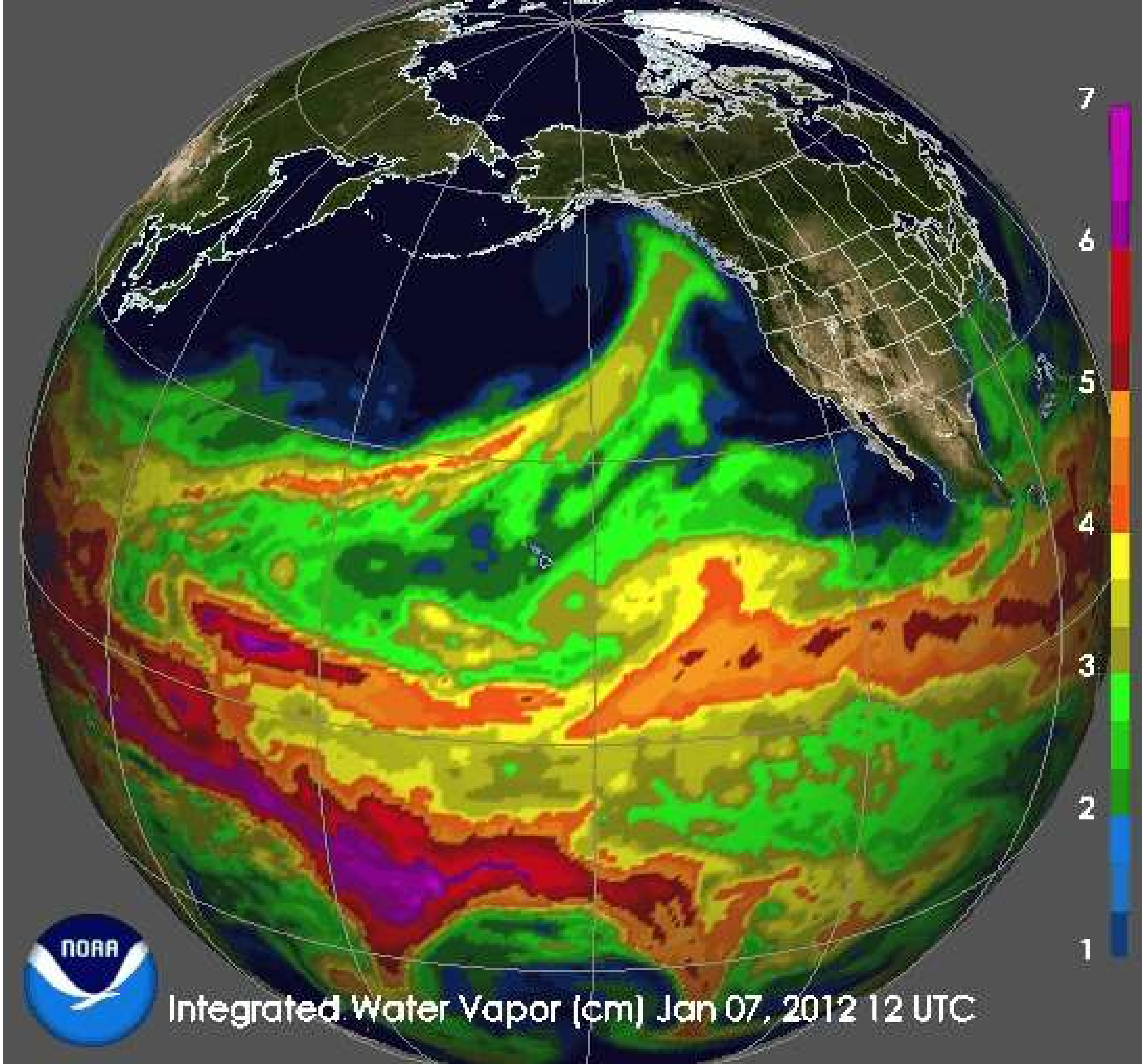
These color images represent satellite observations of atmospheric water vapor over the oceans.

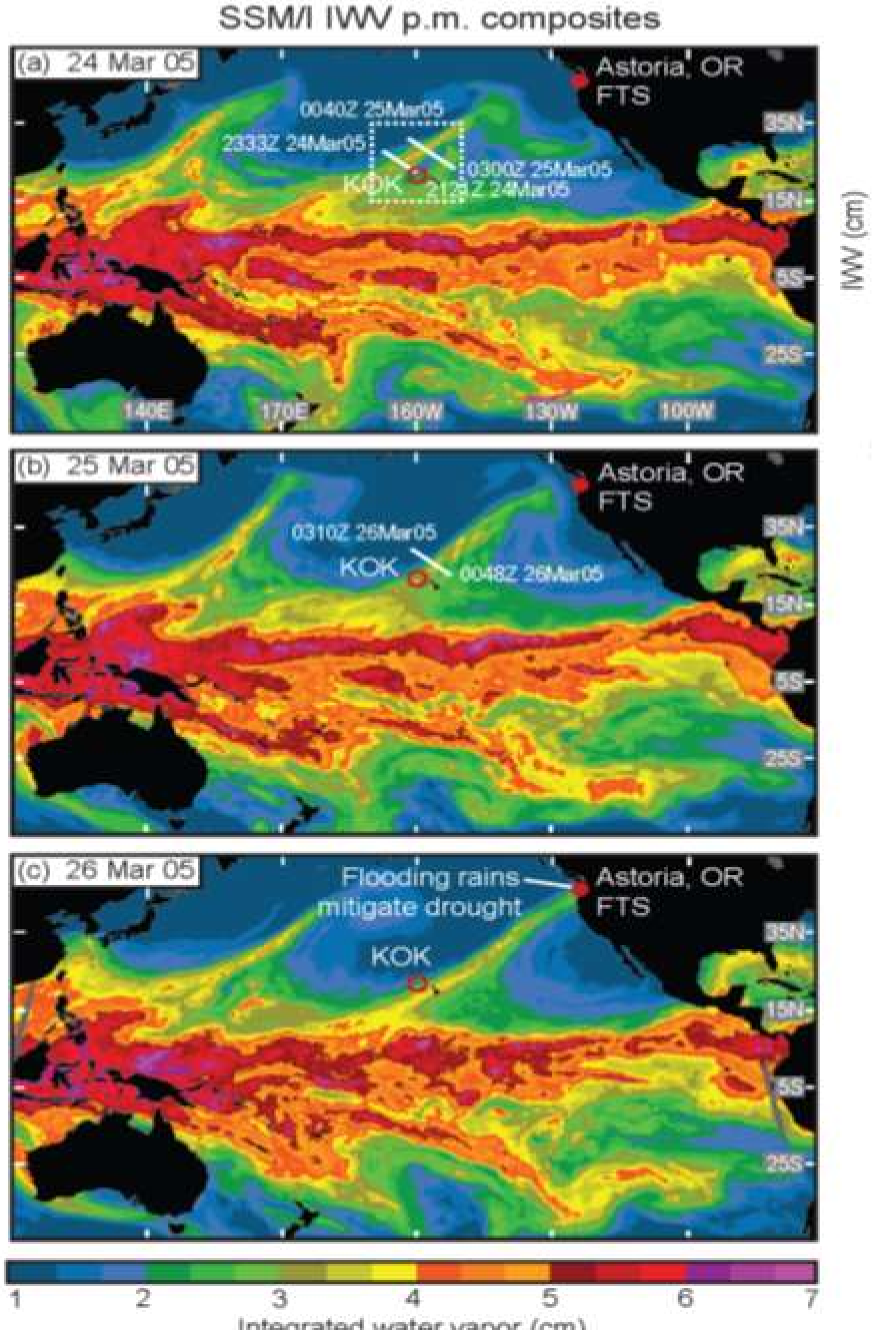
Warm colors = moist air
Cool colors = dry air

ARs can be detected with these data due to their distinctive spatial pattern.

In the top panel, the AR hit central California and produced 18 inches of rain in 24 hours.

In the bottom panel, the AR hit the Pacific Northwest and stalled, creating over 25 inches of rain in 3 days.

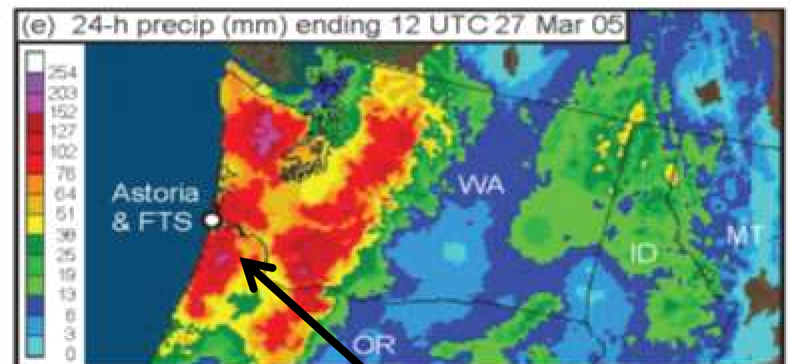

7
6
5
4
3
2
1
NOAA
Integrated Water Vapor (cm) Jan 07, 2012 12 UTC



A multi-scale observational case study of a Pacific atmospheric river exhibiting tropical-extratropical connections and a mesoscale frontal wave

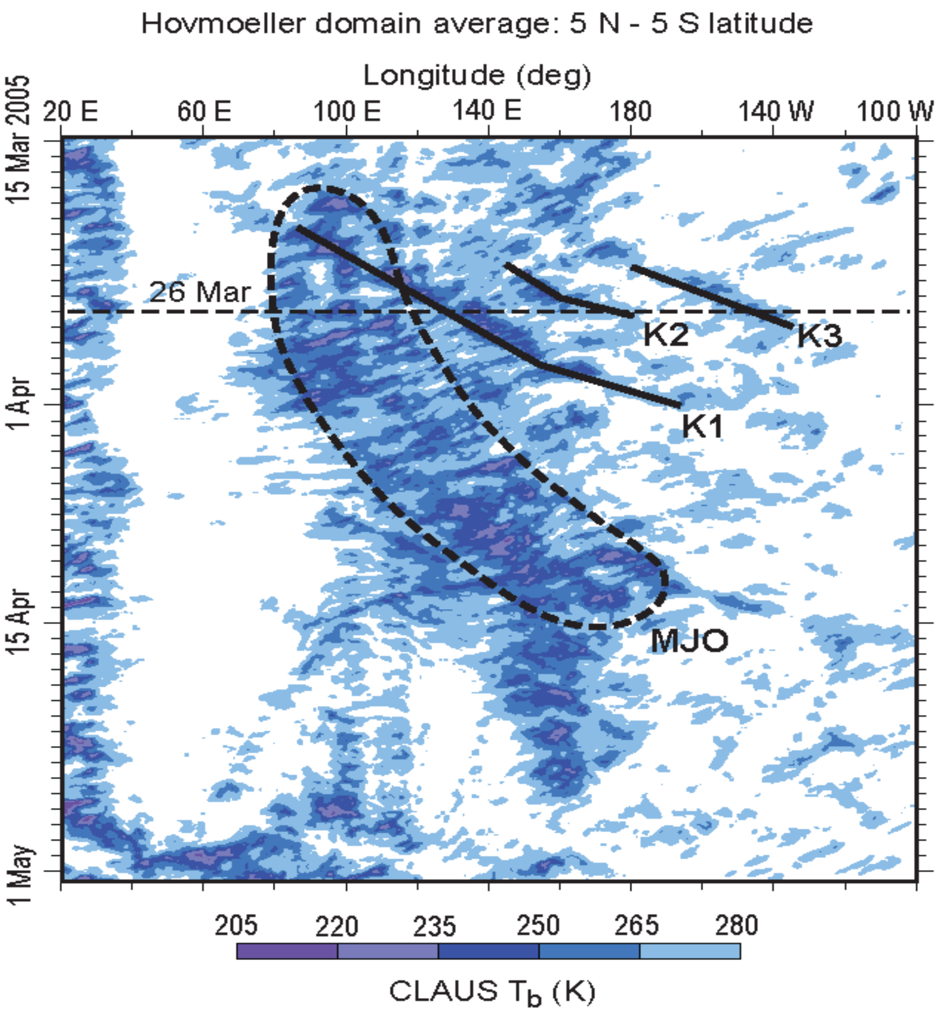
Ralph, F.M., P. J. Neiman, G. Kiladis, K. Weickman and D. Reynolds

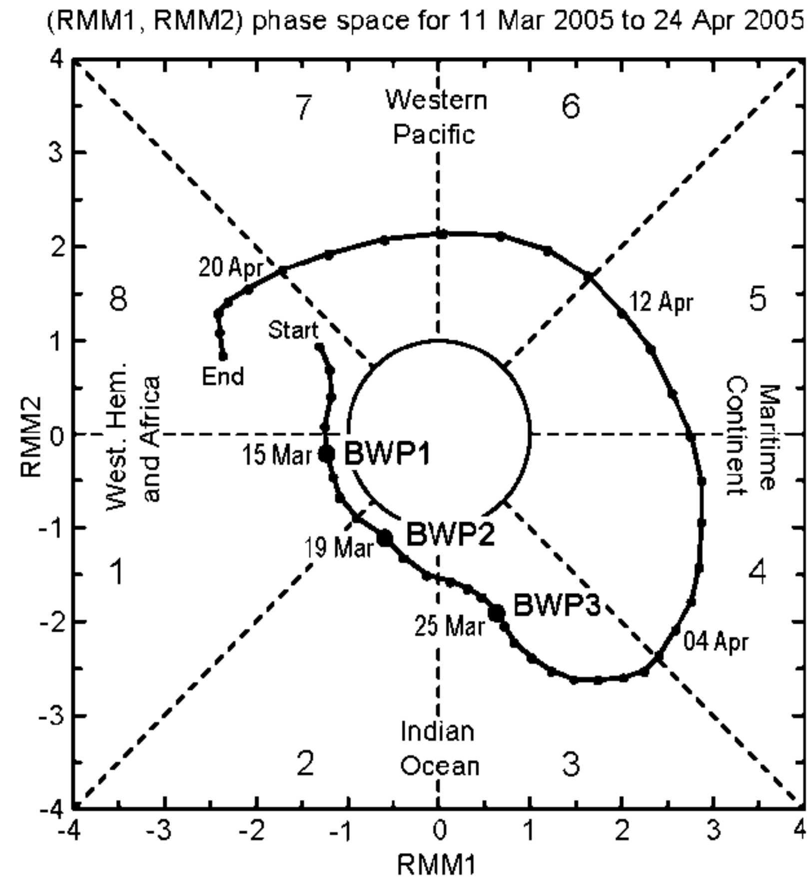
Mon. Wea. Rev., 201



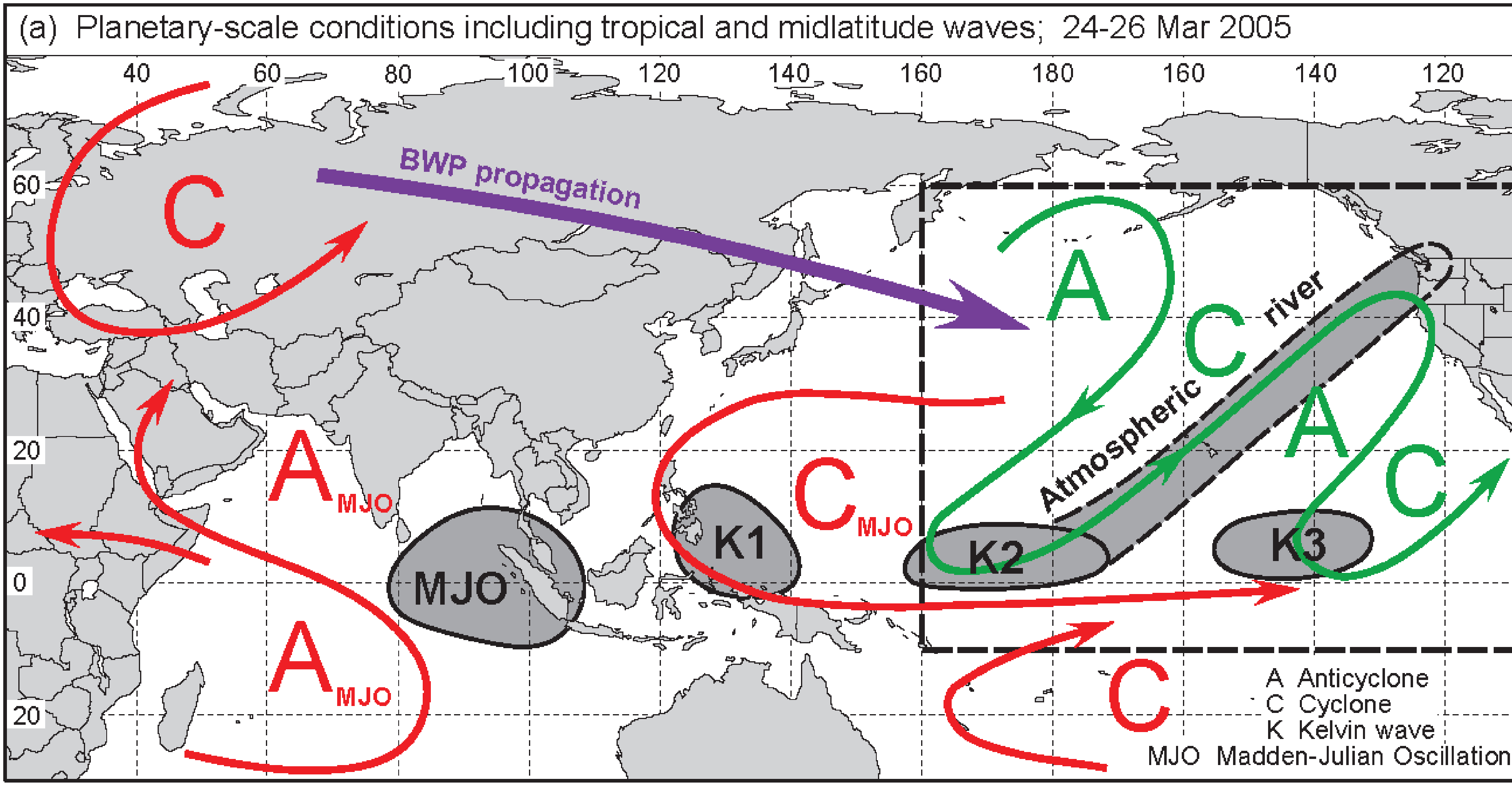
Max Rainfall: 8 inches in 30 h

An MJO and Equatorial Kelvin waves were present



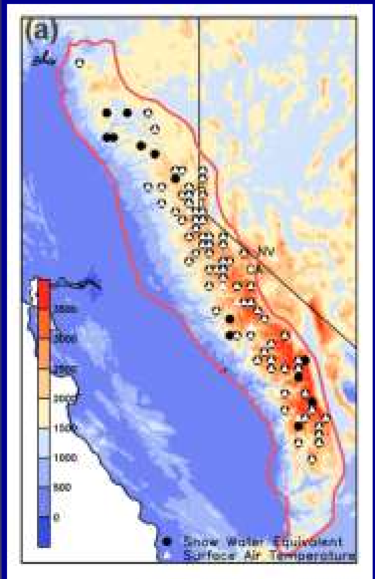


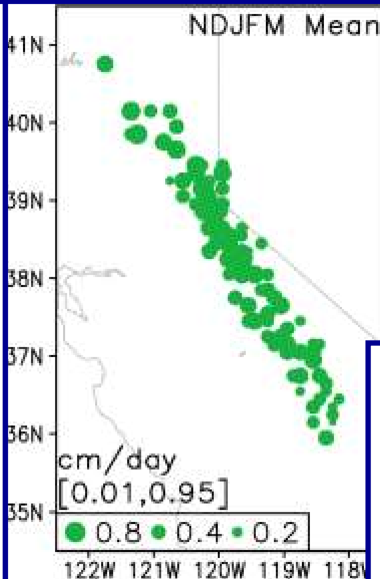
Planetary- and synoptic-scale conditions in the March 2005 case



MJO and Sierra Nevada Snowpack

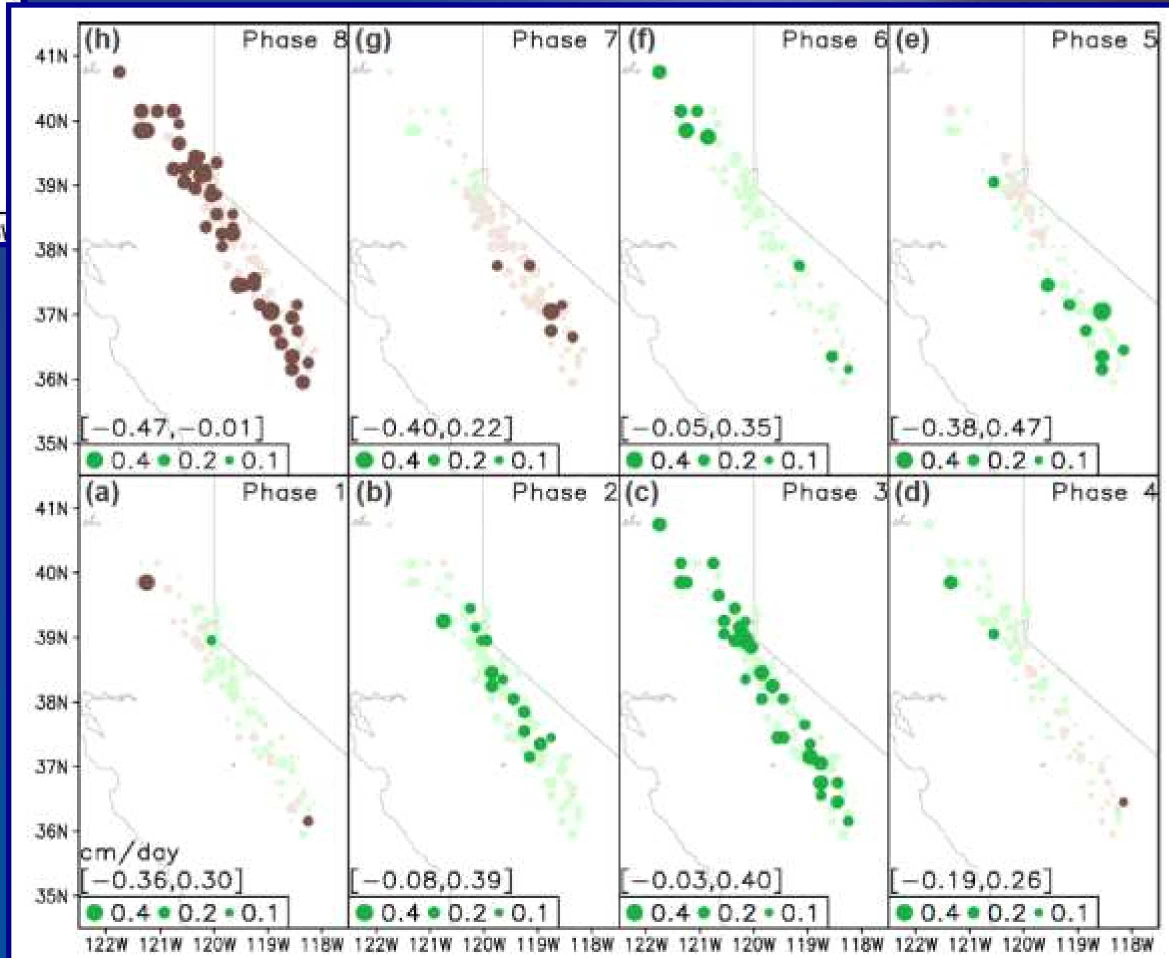
Guan et al. (2012; Mon. Wea. Rev.)





Snowpack in the Sierra acts as a natural and Important reservoir for CA.

Snowfall often comes in powerful winter storms, sometimes with Atmospheric Rivers (40-50%).



The MJO modulates snowfall Rates.

- **Phase 3 -> + 30-50%**
- **Phase 8 -> - 30-50%**

- **Implied Predictability?**
- **Source of moisture?**