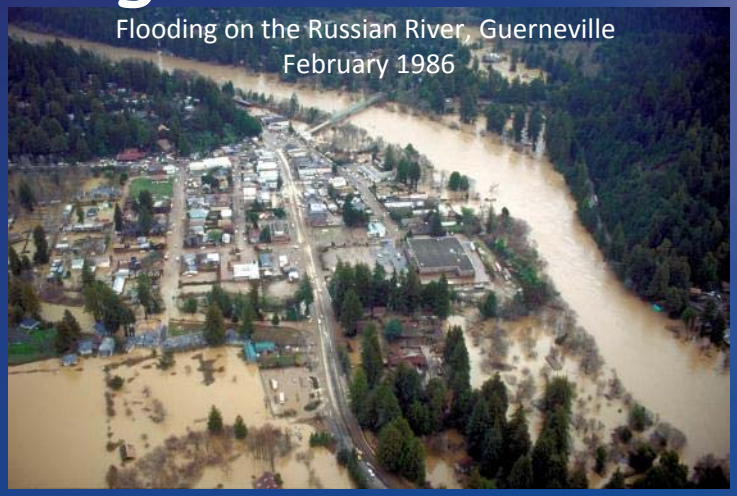
Pacific Atmospheric Rivers: Impacts on Extreme Rainfall, Flooding and Water Supply



Flooding on the Russian River, Guerneville
February 1986

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Presentation at 7th Biennial Bay–Delta Science Conference

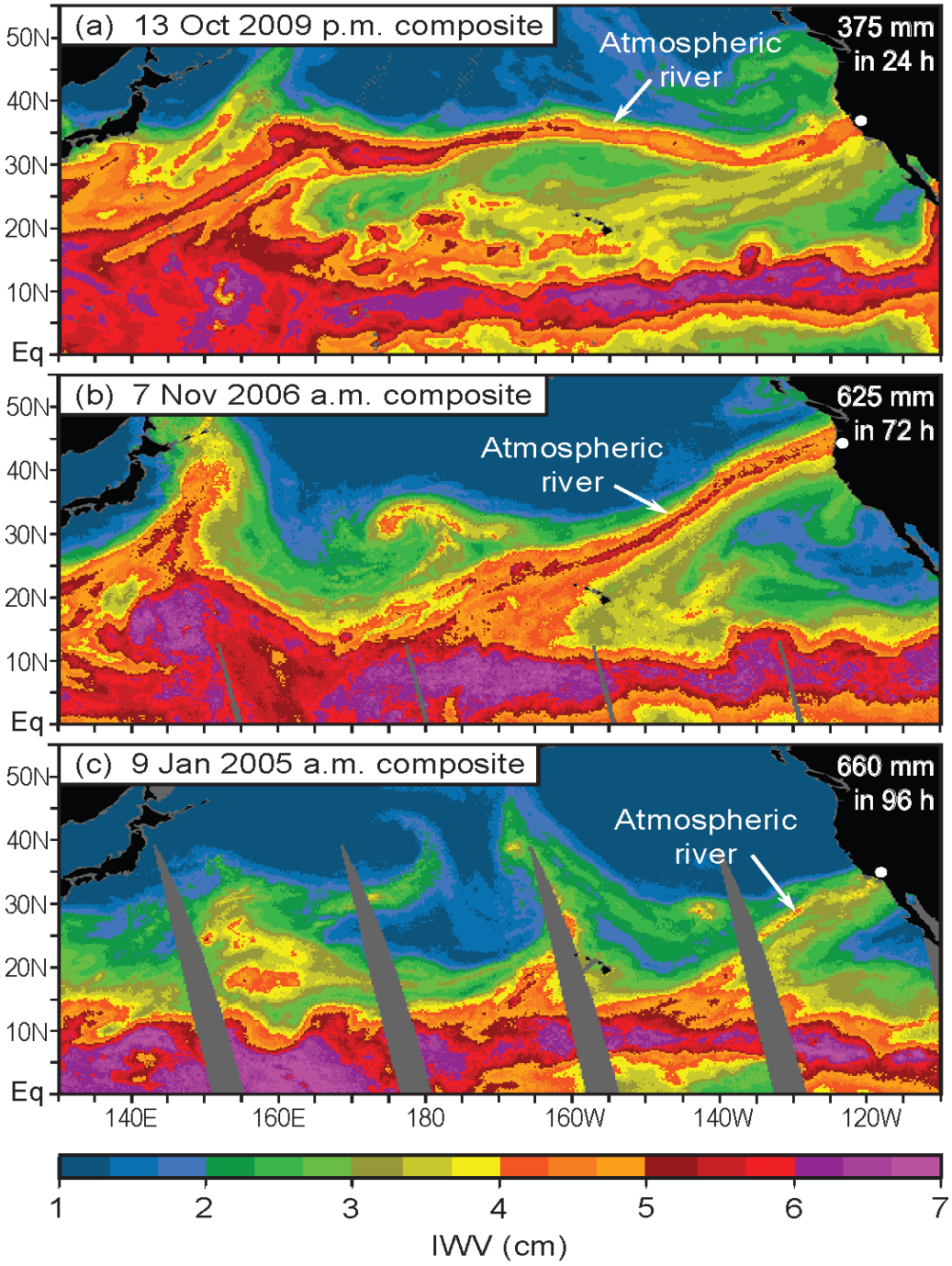
Ecosystem Reconciliation: Realities Facing the San Francisco Estuary

Sacramento, CA

17 October 2012

Major Talking Points

- Pacific ARs are critical phenomena impacting the West Coast of North America
  - formation and physical processes
  - contribution to water supply
  - contribution to flooding
- Outstanding Forecast Challenges
  - Classifying strength of AR offshore
  - QPF for land-falling ARs still poor
  - Snow-level forecasts for the mountains



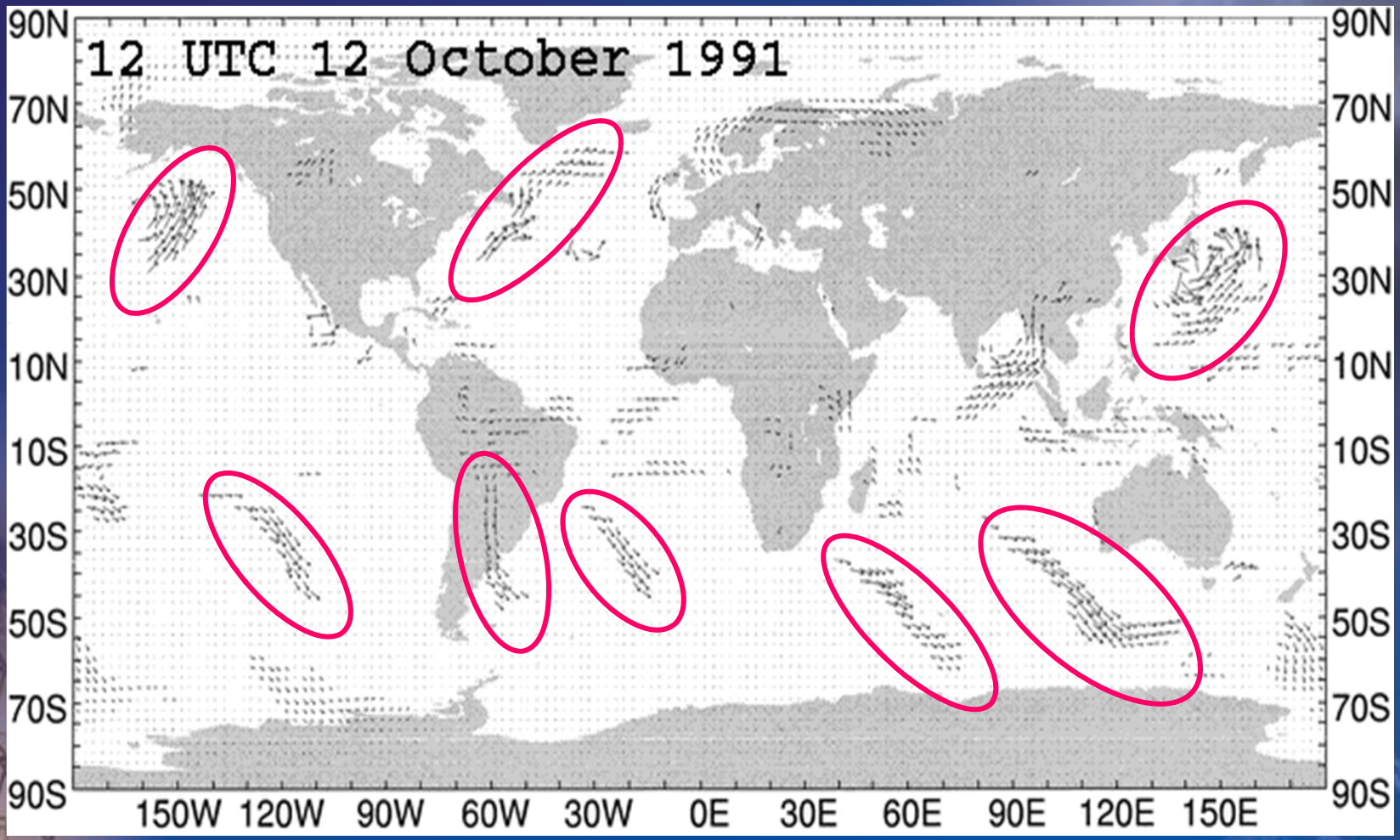
A Key Finding:

atmospheric rivers produce extreme precipitation and flooding, as well as water supply and stream flow on the U.S. West Coast

Examples of AR events that produced extreme precipitation on the US West Coast, and exhibited spatial continuity with the tropical water vapor reservoir as seen in SSM/I satellite observations of IWV.

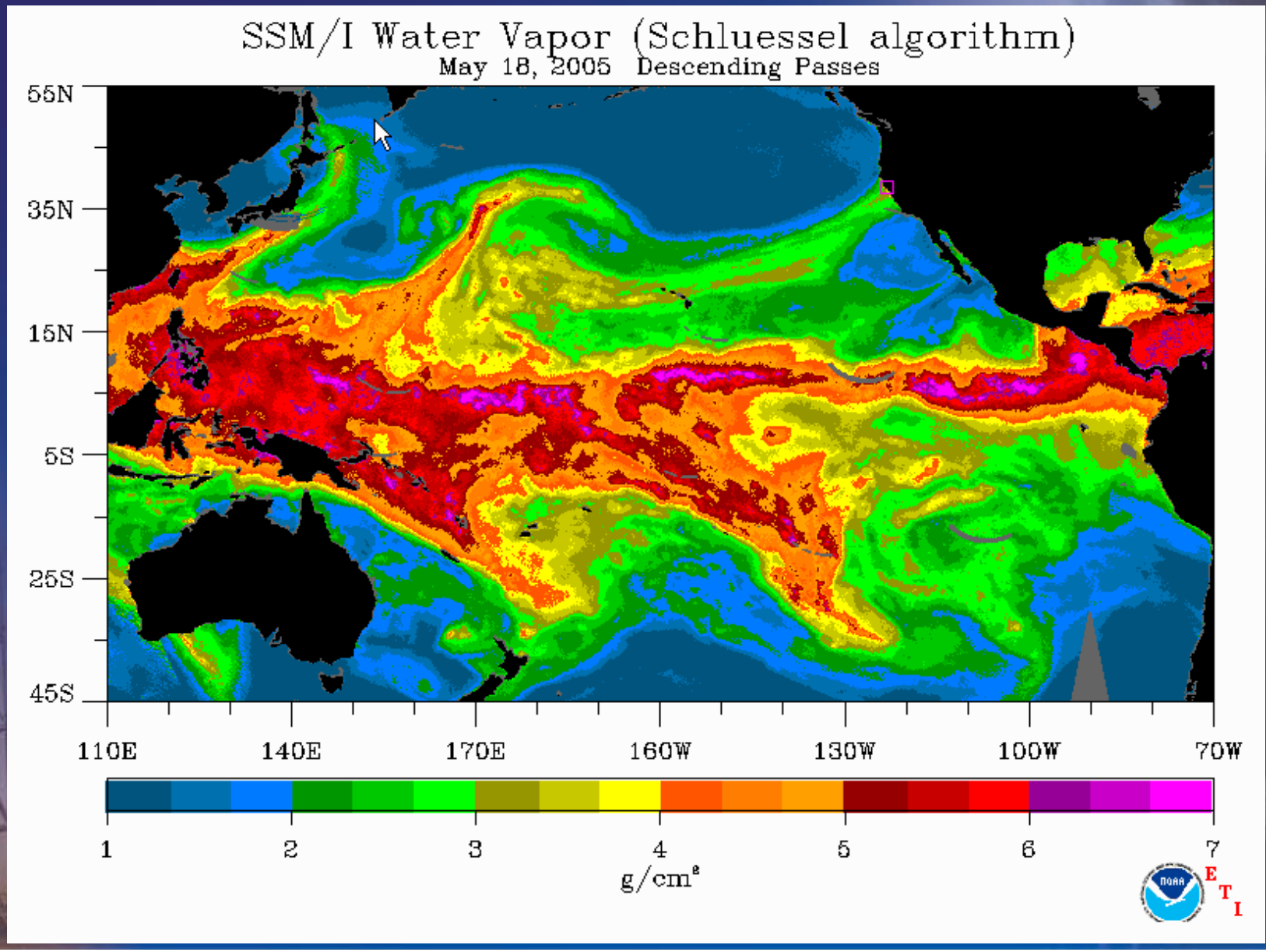
Zhu & Newell (in Monthly Weather Review, 1998) concluded that

1) Most water vapor transport occurs in only a few narrow regions
2) There are 4-5 of these within a hemisphere at any one moment
3) They are part of extratropical cyclones and move with the “storm track”

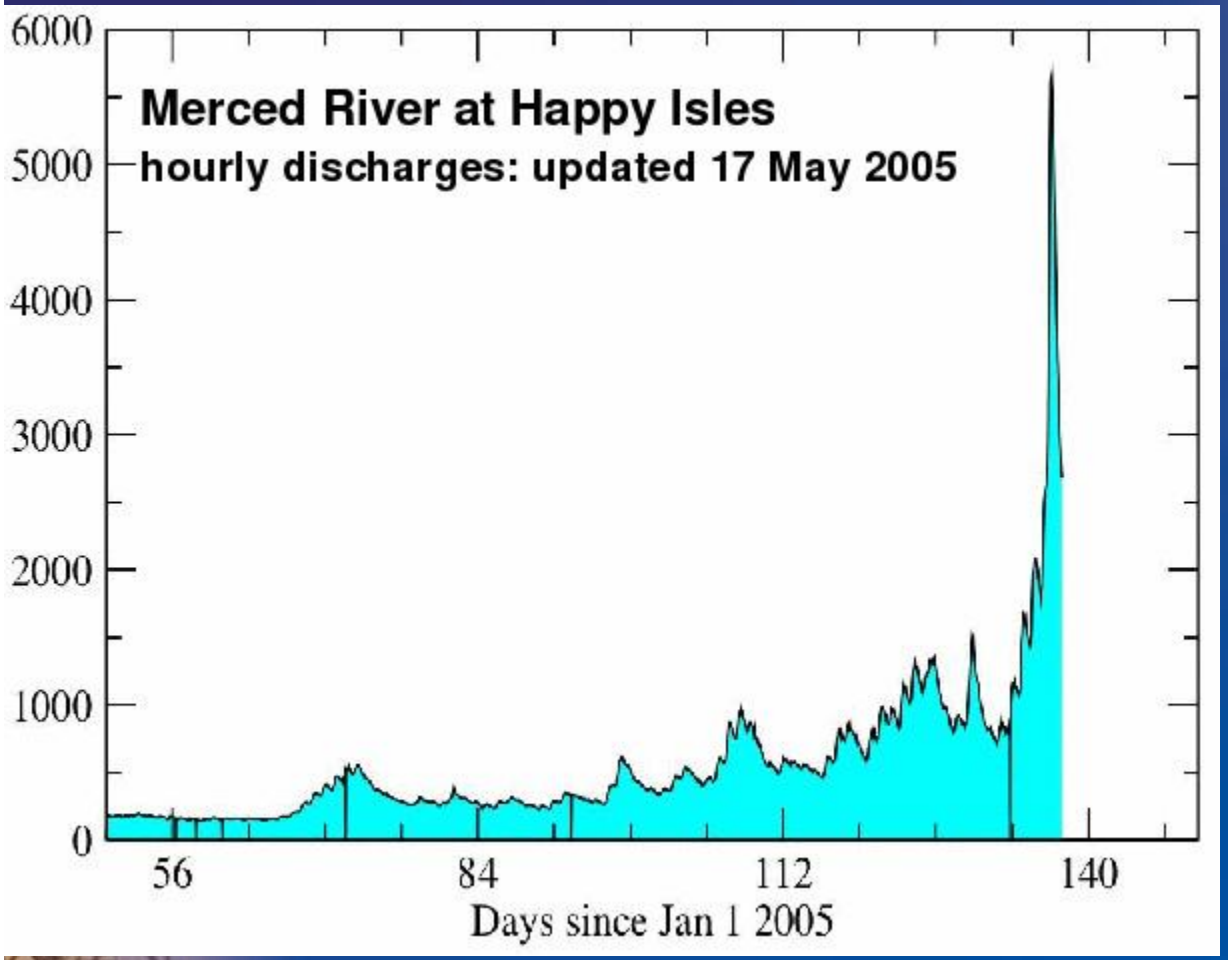


Coined the term “atmospheric river”

AR May 2005


SSM/I Water Vapor (Schluessel algorithm)
May 18, 2005 Descending Passes
55N
35N
15N
5S
25S
45S
110E
140E
170E
160W
150W
100W
70W
1
2
3
4
5
6
7
g/cm²
NOAA
ETI

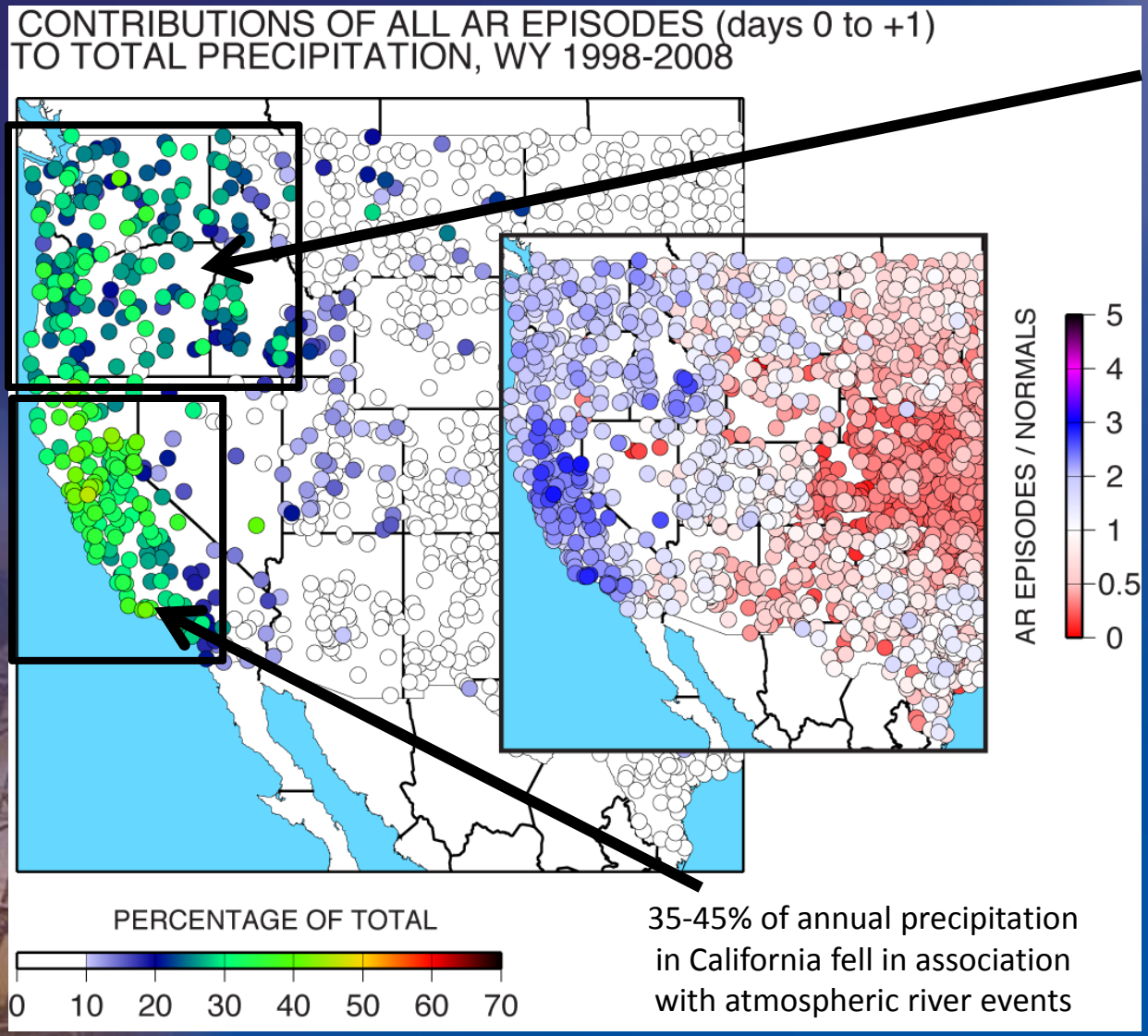
Yosemite Flooding



Atmospheric Rivers, Floods and the Water Resources of California

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

***Water,* 3, 445–478 (2011)**

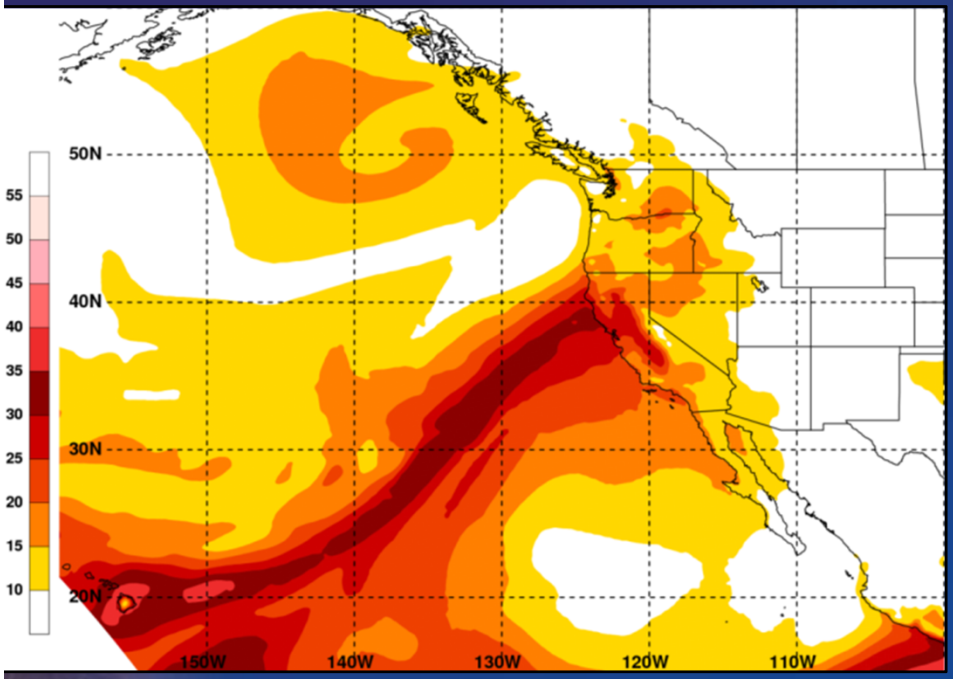


35-45% of annual precipitation in California fell in association with atmospheric river events

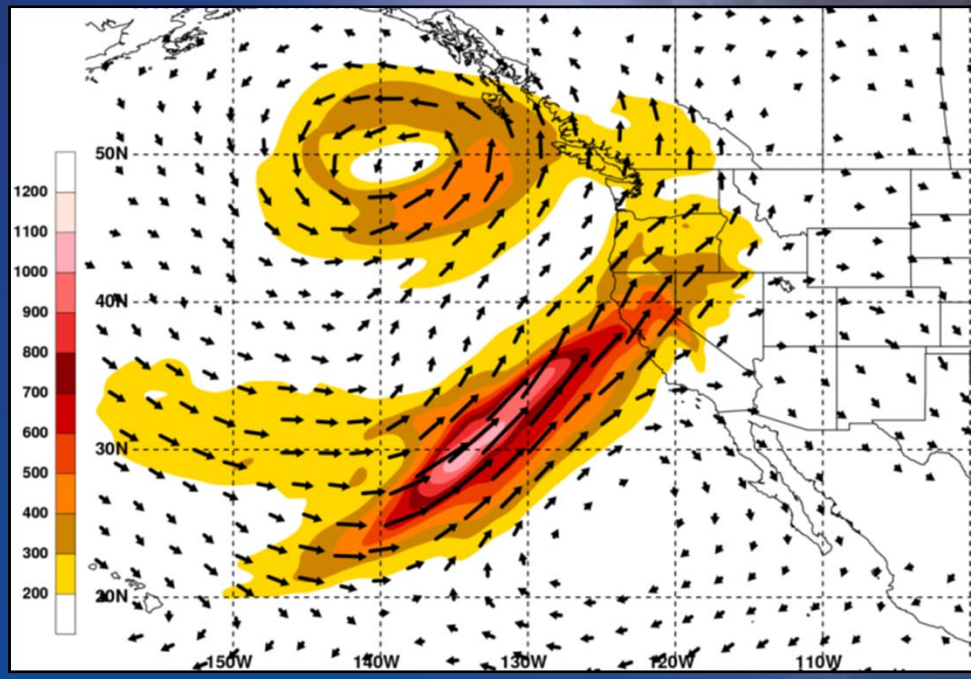
25-35% of annual precipitation in the Pacific Northwest fell in association with atmospheric river events

An average AR transports the equivalent of 7.5 times the average discharge of the Mississippi River, or ~10 M acre feet/day

0000 UTC 17 Feb 2004



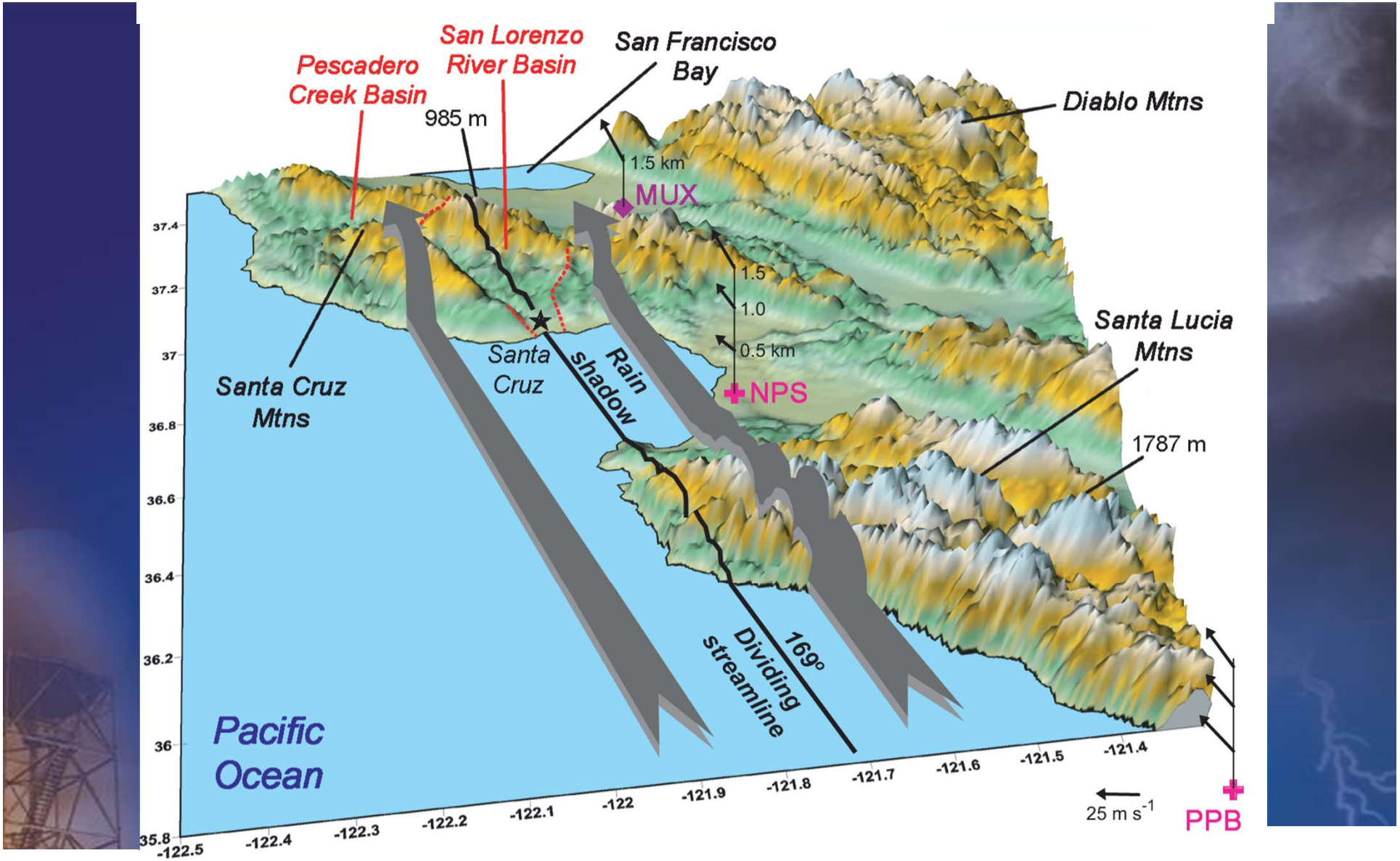
Total precipitable water (mm)



1000–200-hPa vertically integrated moisture flux (kg m^{-1} s^{-1})

Moisture flux in ARs is the key, but offshore winds are difficult to diagnose and forecast

Source: NARR



When atmospheric rivers strike coastal mountains (Ralph et al. 2003)

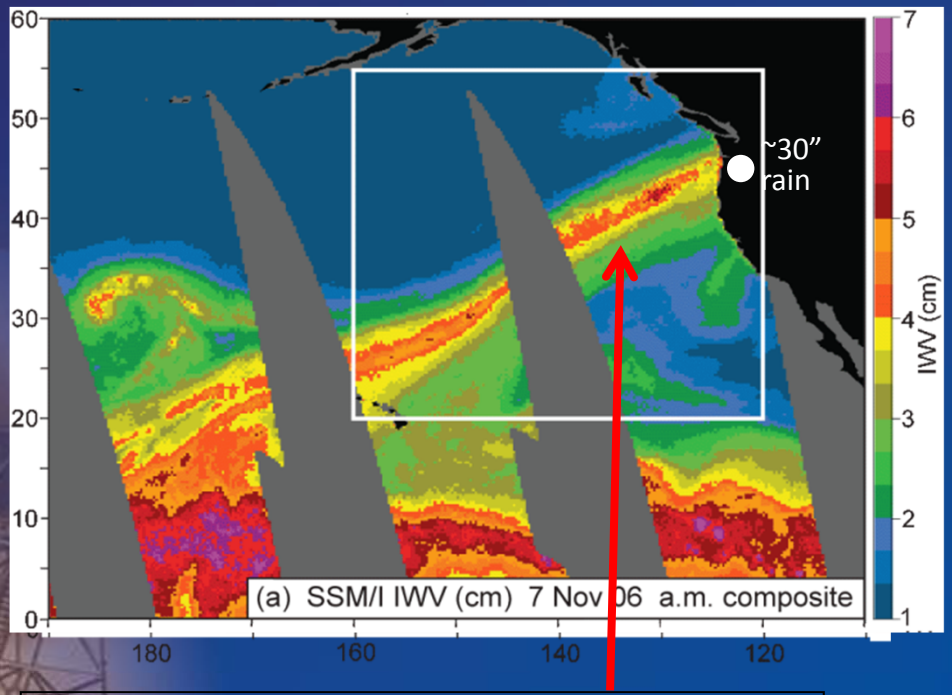
➢Details (e.g., wind direction) of the atmospheric river determine which watersheds flood

Diagnosis of an Intense Atmospheric River Impacting the Pacific Northwest: Storm Summary and Offshore Vertical Structure Observed with COSMIC Satellite Retrievals

by Paul J. Neiman, F. Martin Ralph, Gary A. Wick, Y.-H. Kuo, T.-W. Wee, Z. Ma, G. H. Taylor, M.D. Dettinger

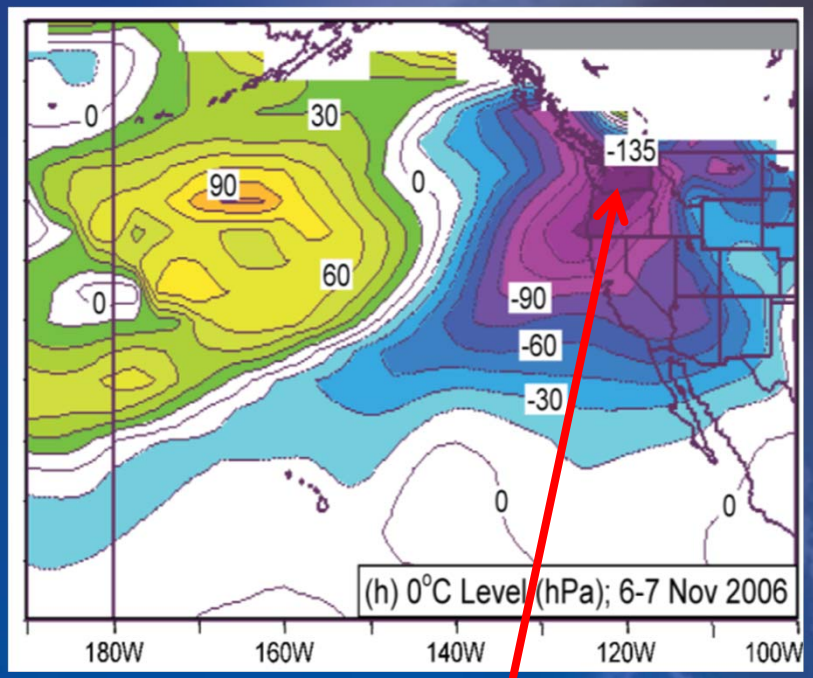
Monthly Weather Review, **136**, 4398-4420.

SSM/I satellite imagery of integrated water vapor (IWV, cm)



The AR is located near the leading edge of a cold front, with strong vapor fluxes (as per reanalysis diagnostics)

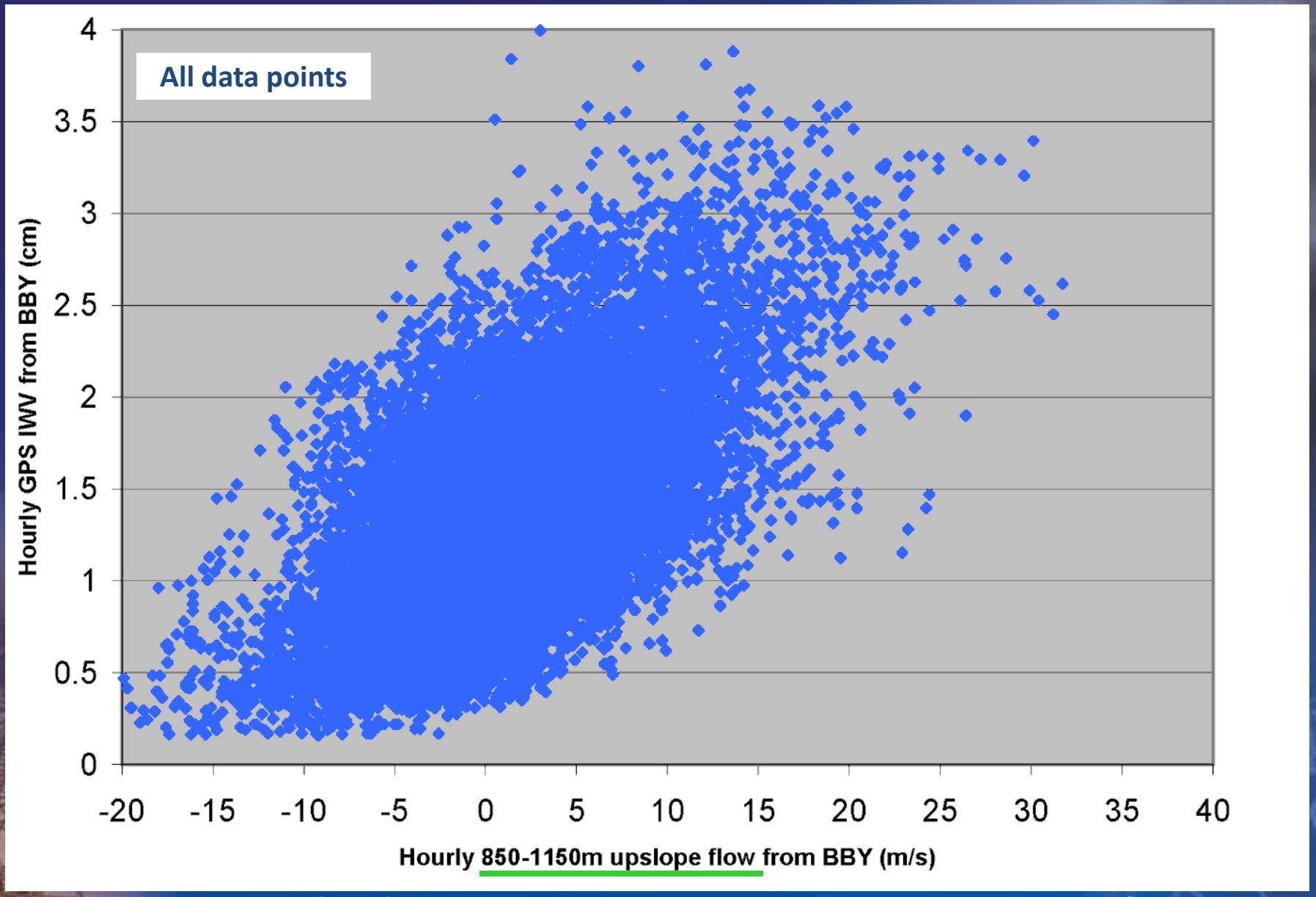
Global reanalysis melting-level anomaly (hPa; rel. to 30-y mean)



Melting level ~4000 ft (1.2 km) above normal across much of the PacNW during the landfall of this AR

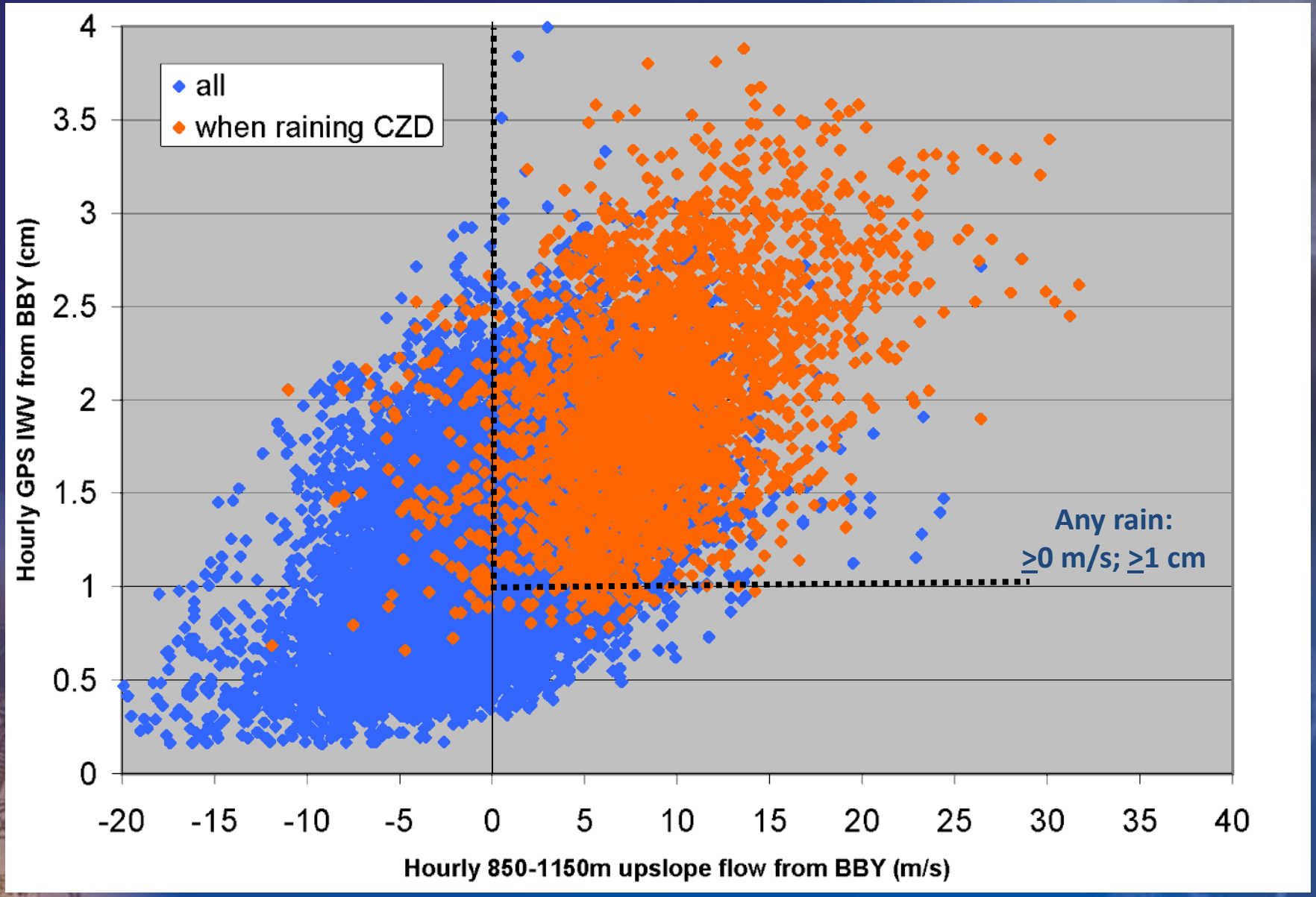
Thresholds in water vapor and wind are key in determining heavy hourly rainfall

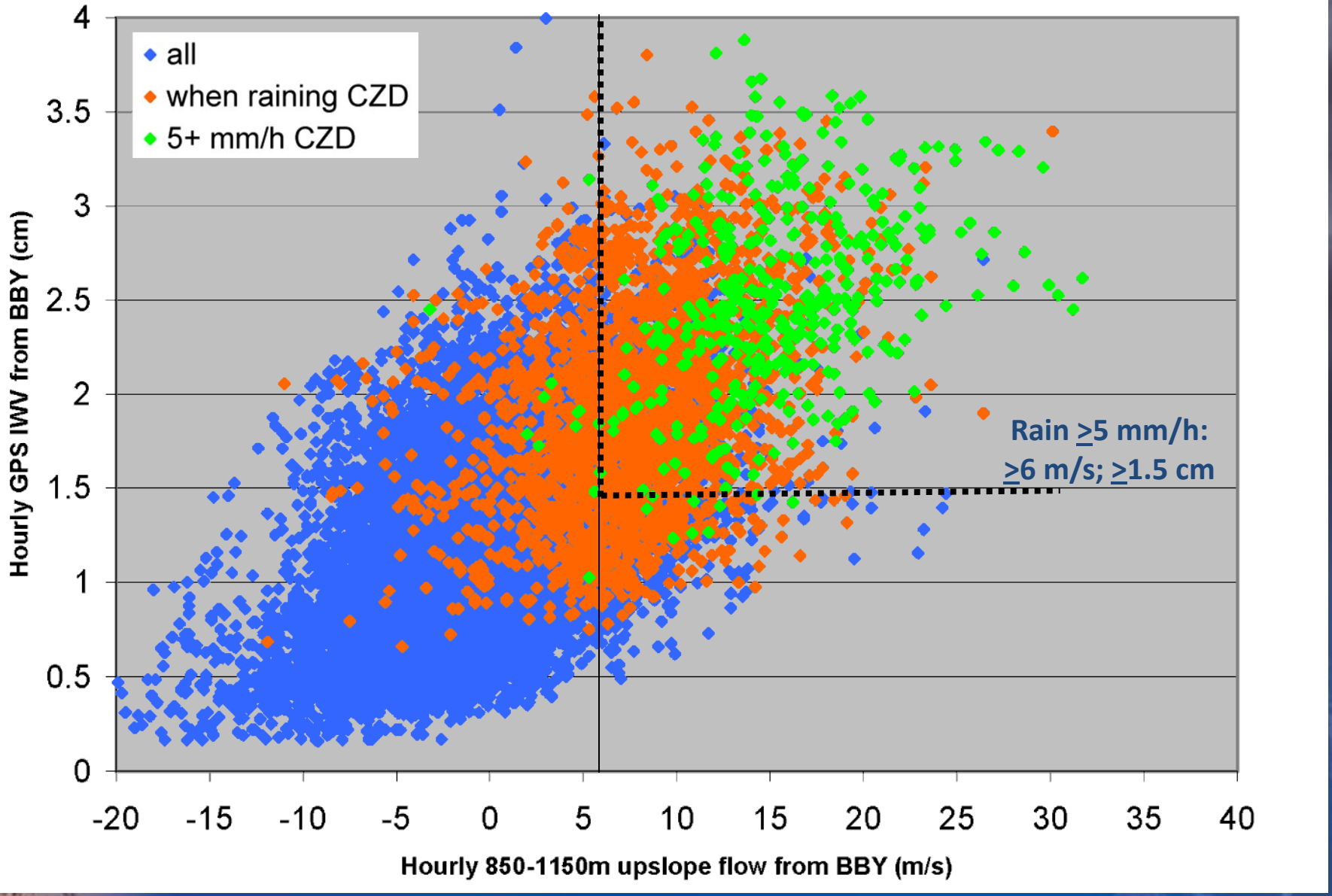
- The next 4 graphs each show 8 winters of hourly observations from an atmospheric river observatory near Bodega Bay operated in HMT.
- Over 18,000 hourly measurements of
  - Water vapor
  - Winds at 1 km above sea level
  - Coastal mountain rainfall
- Conclusions are that the heaviest hourly rain rates occur when
  - Water vapor (IWV) exceeds 2 cm, and
  - Upslope winds at 1 km altitude exceed 12 m/s

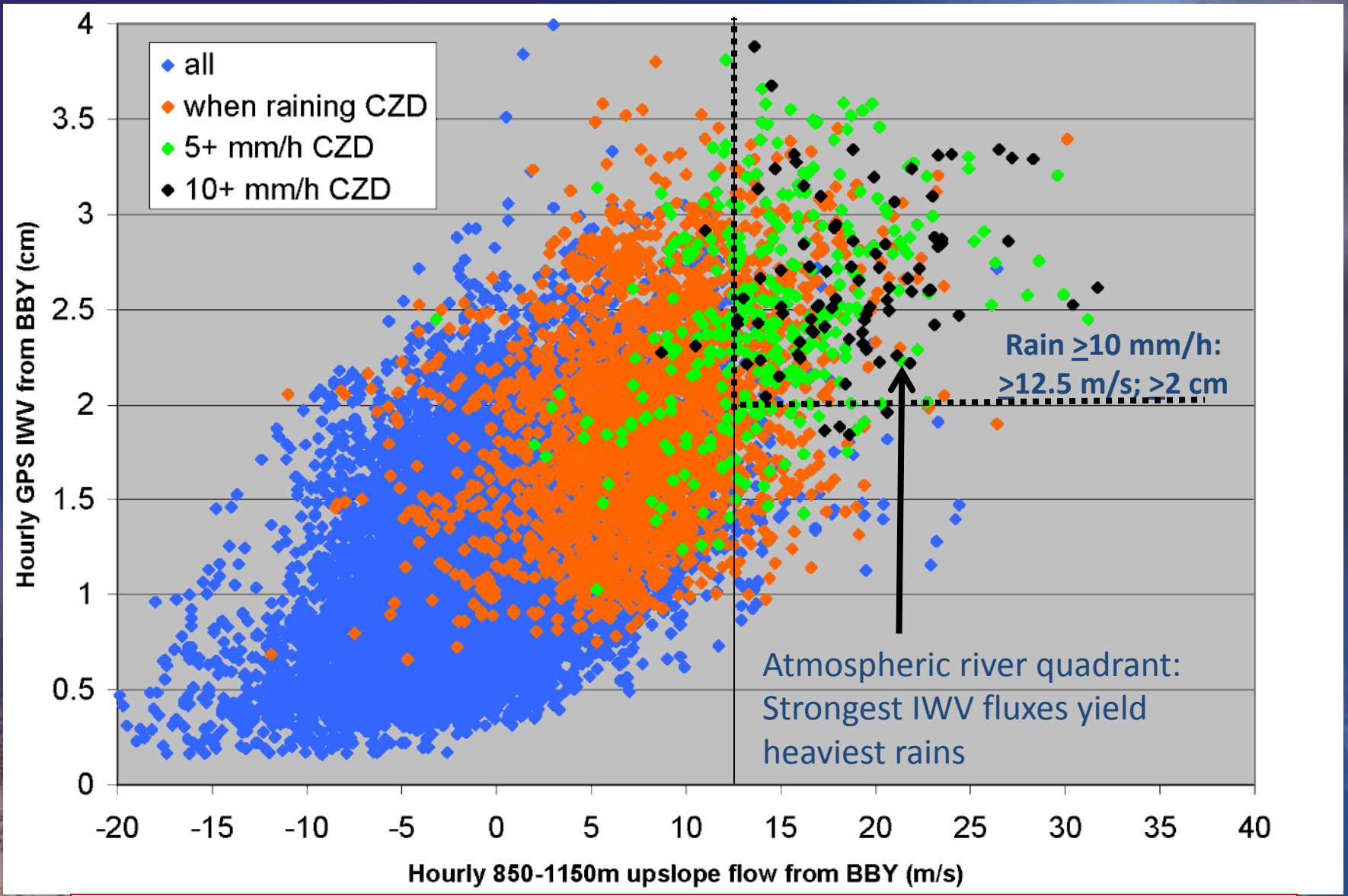


Component of the flow in the orographic controlling layer directed from 230°, i.e., orthogonal to the axis of the coastal mtns

Neiman et al. (2008), *Water Management*


all
when raining CZD
Hourly GPS IWV from BBY (cm)
4
3.5
3
2.5
2
1.5
1
0.5
0
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
Hourly 850-1150m upslope flow from BBY (m/s)
Any rain:
≥0 m/s; ≥1 cm


all
when raining CZD
5+ mm/h CZD
Hourly GPS IWV from BBY (cm)
Hourly 850-1150m upslope flow from BBY (m/s)
Rain ≥5 mm/h:
≥6 m/s; ≥1.5 cm
4
3.5
3
2.5
2
1.5
1
0.5
0
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40

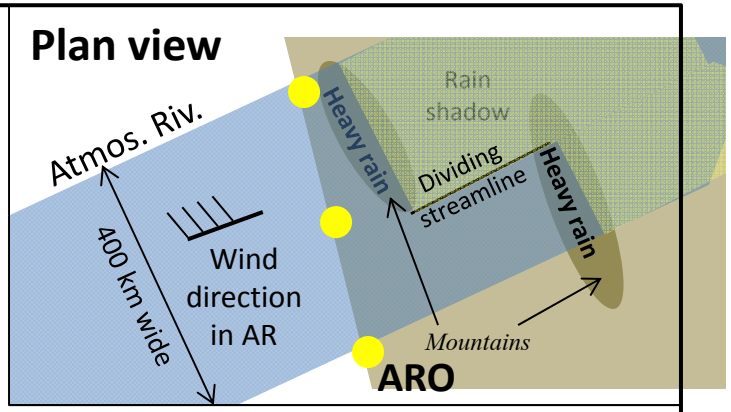


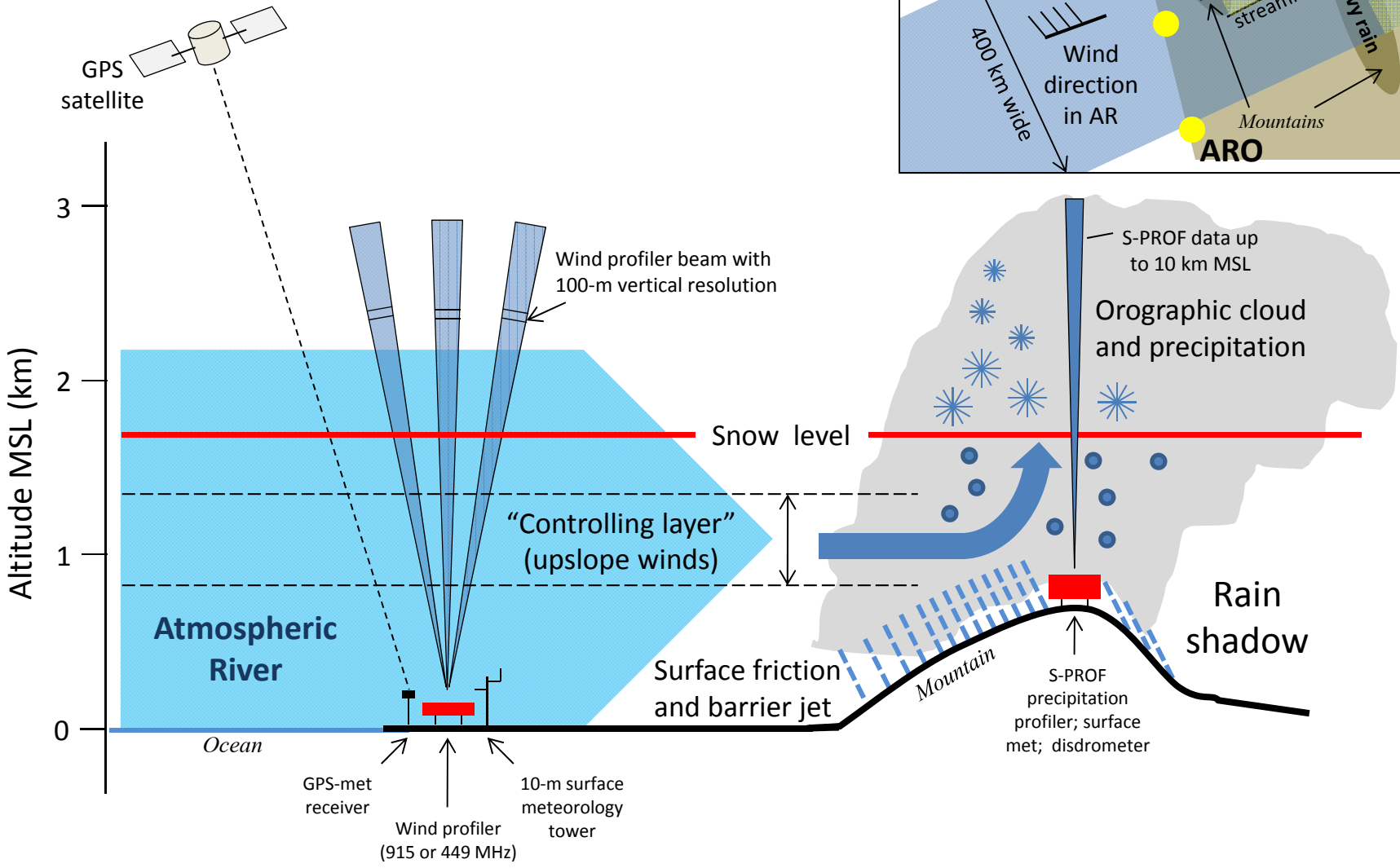
*Nearly 2/3 of tropospheric water vapor is in the lowest 2 km MSL.
Hence, to first order, the IWV flux provides a close estimate
of the low-level water-vapor transport into the coastal mountains.

Physical variables required for extreme precipitation (including AR conditions)

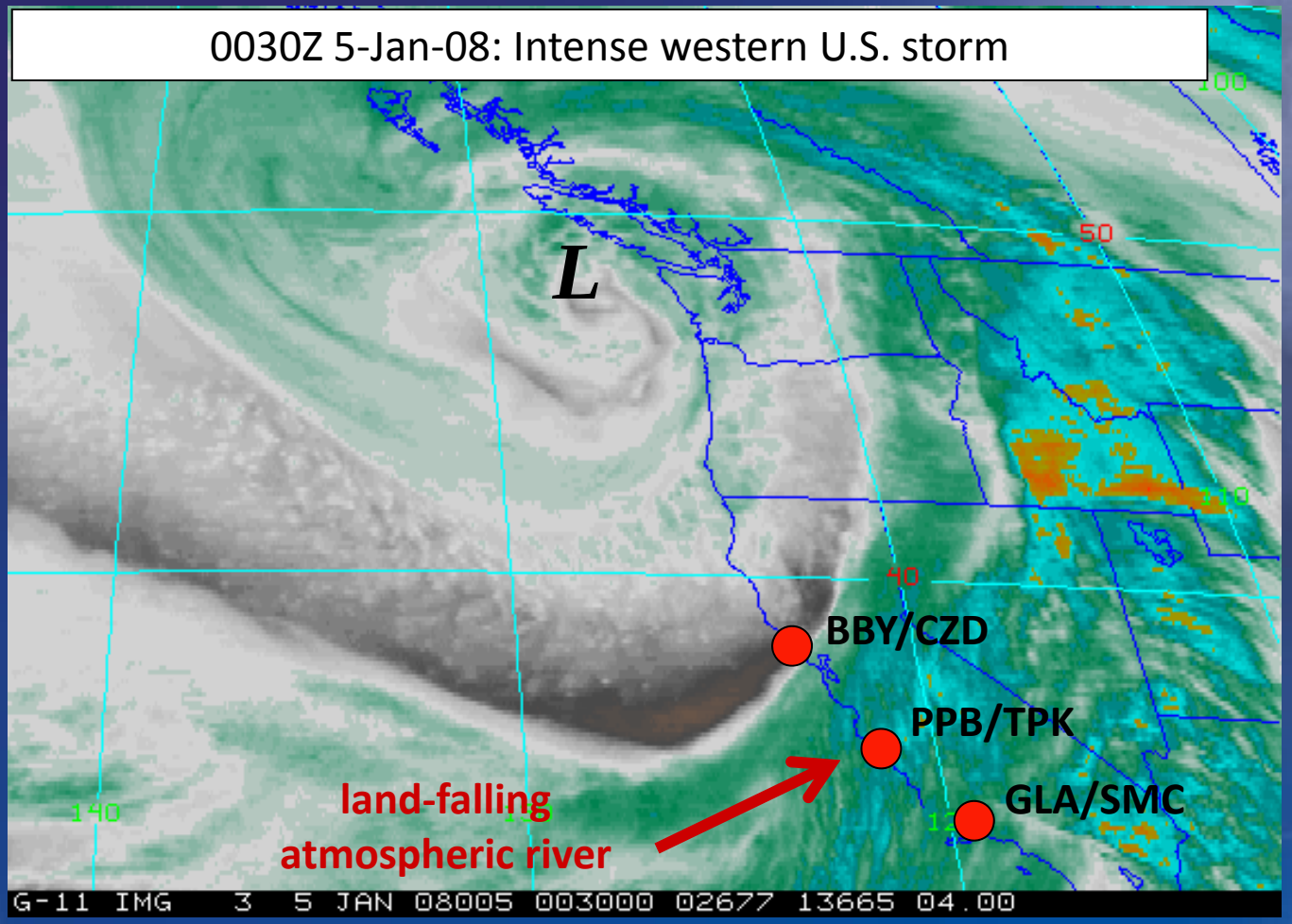
- Wind in the controlling layer near 1 km MSL
  - speed > 12.5 m/s
  - direction (determines location of rain shadow)
- Water vapor content
  - vertically integrated water vapor (IWV) > 2 cm
- Snow level
  - Above top of watershed

Coastal Atmospheric River Observatory





Prototype forecast tool tested at 3 CA couplets during NOAA's HMTs



Couplet

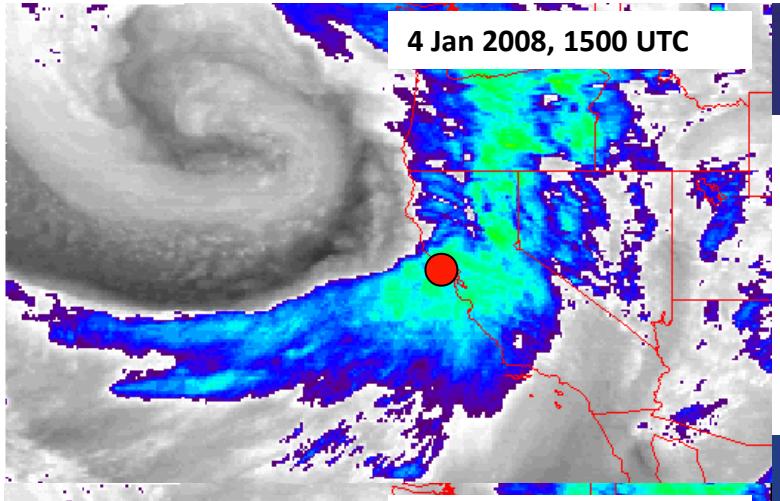
North:
Central:
South:

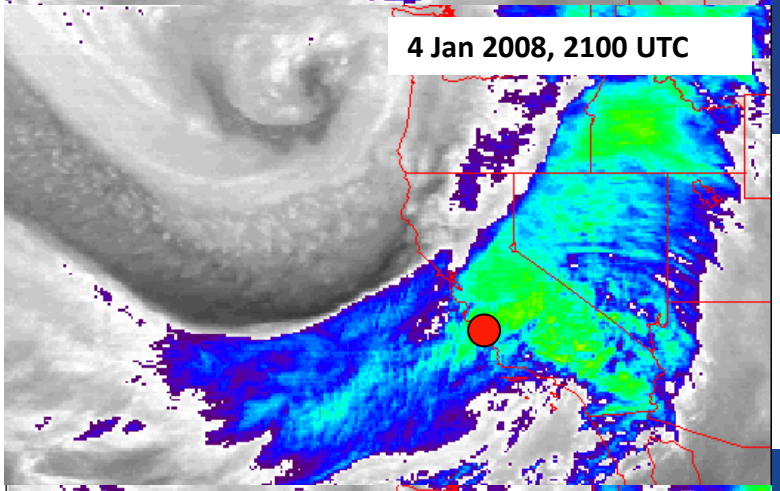
Coast (*profiler, GPS, rain gauge*):

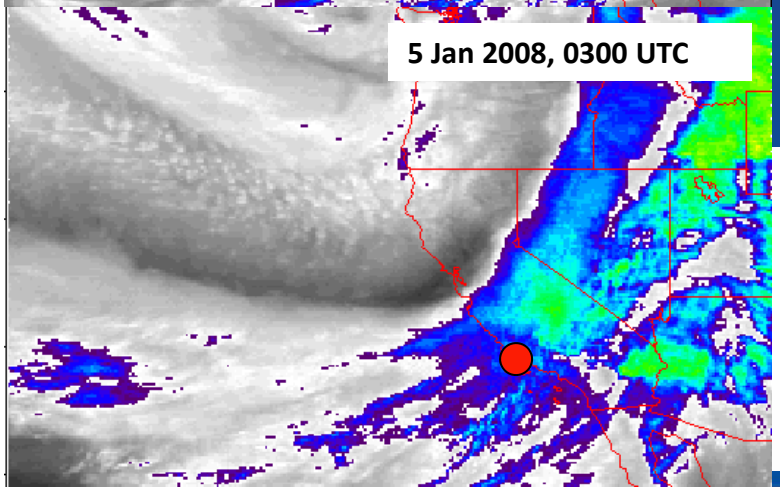
Bodega Bay (BBY; 12 m MSL)
Piedras Blancas (PPB; 11 m MSL)
Goleta (GLA; 3 m MSL)

Mountains (*rain gauge*):

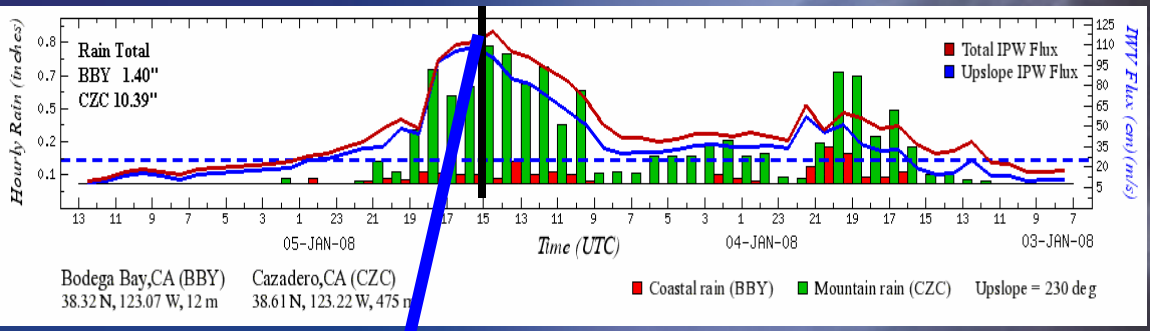
Cazadero (CZD; 475 m MSL)
Three Peaks (TPK; 1021 m MSL)
San Marcos Pass (SMC; 701 m MSL)



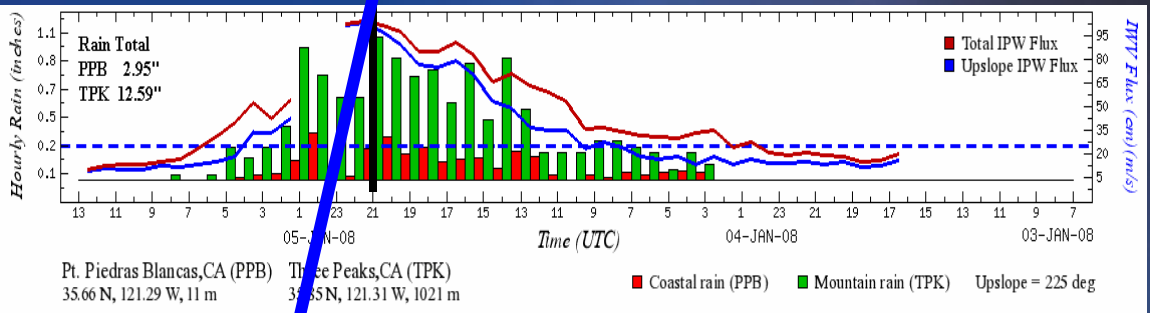




Time of max AR bulk flux at BBY: 1500 UTC 4 Jan

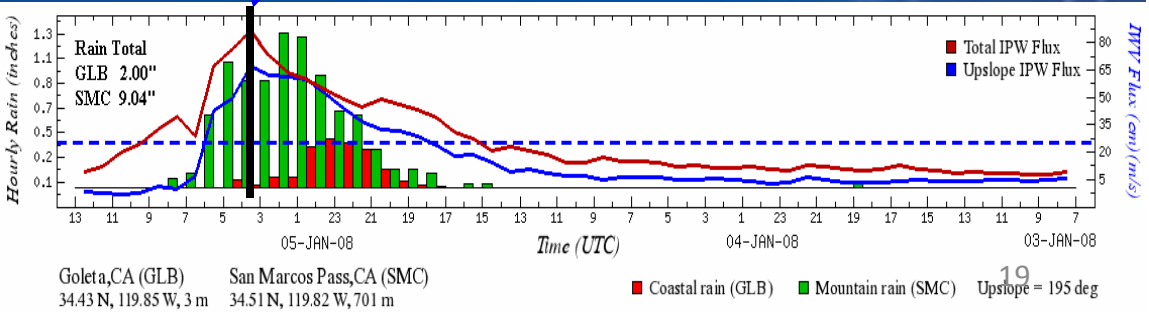


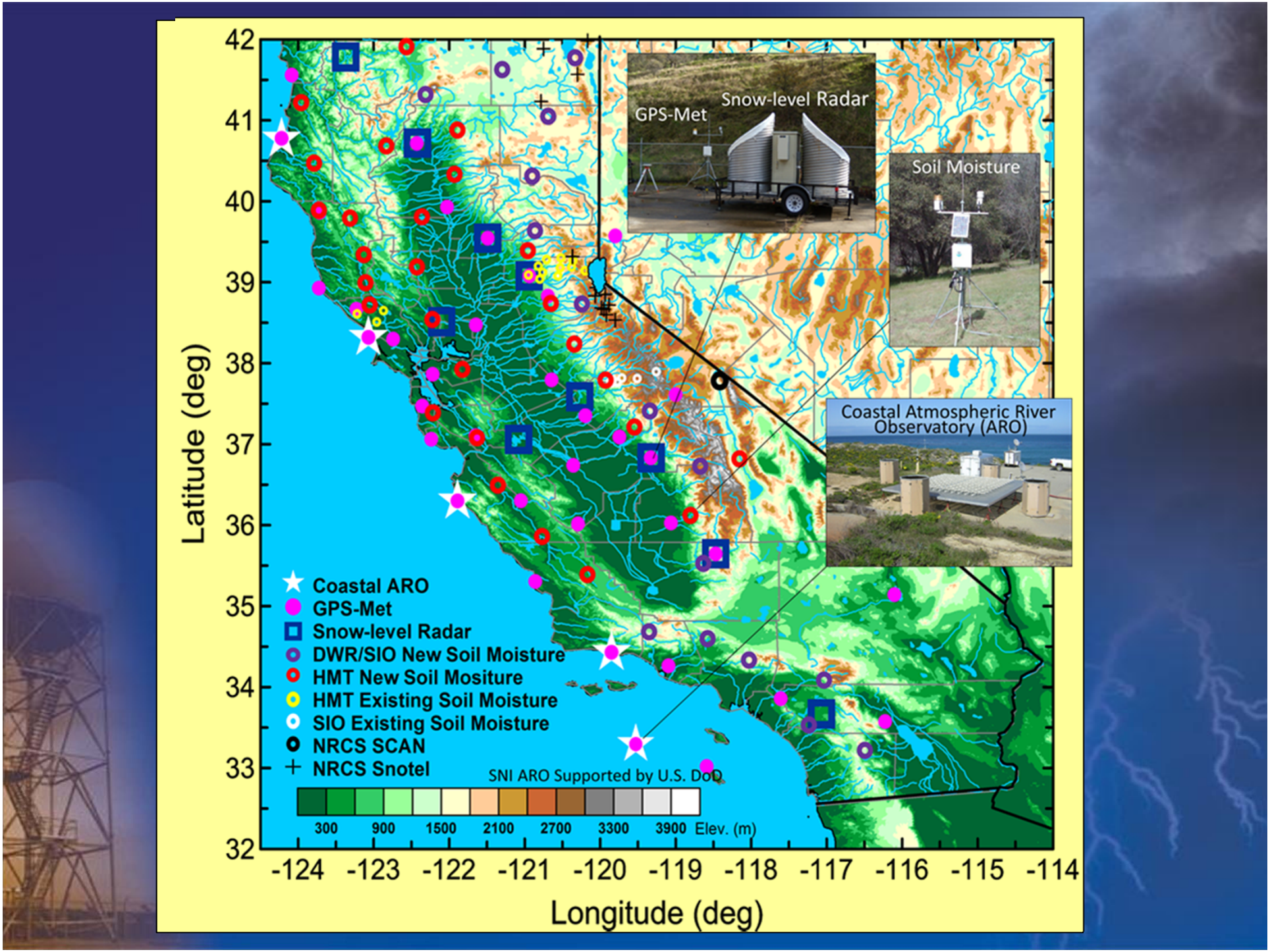
Time of max AR bulk flux at PPB: 2100 UTC 4 Jan



AR Propagation: ~12 m s^{-1}.
½-day lead time for SoCal

Time of max AR bulk flux at GLA: 0300 UTC 5 Jan




GPS-Met
Snow-level Radar
Soil Moisture
Coastal Atmospheric River Observatory (ARO)
Coastal ARO
GPS-Met
Snow-level Radar
DWR/SIO New Soil Moisture
HMT New Soil Mositure
HMT Existing Soil Moisture
SIO Existing Soil Moisture
NRCS SCAN
NRCS Snotel
SNI ARO Supported by U.S. DoD
300 900 1500 2100 2700 3300 3900 Elev. (m)
Latitude (deg)
Longitude (deg)
42 41 40 39 38 37 36 35 34 33 32
-124 -123 -122 -121 -120 -119 -118 -117 -116 -115 -114

Summary

- Weather Issues Surrounding Ars:
  - Lead time and preparation for emergency managers key to saving lives and property
    - 7-10 day outlook desired for high impact hydrologic events
    - Forecast-coordinated reservoir operations a possible outcome
  - Knowing when MJO will or will not provide forcing mechanism for AR's and how to determine impact locations.
    - Minimize false alarm rates
- How well are ARs and the major precipitation events associated with them, represented in global and regional simulation and forecast models?
  - Timing, location and duration beyond 12-hrs poor
- QPF for land-falling ARs still very problematic
  - Models in short term seem to handle thermodynamics and kinematics within the AR OK but very poor in getting condensate to the ground
  - Clouds much more efficient at forming precipitation than models understand
    - Role of aerosols

Thank You

- For more information, please see:
  - http://hmt.noaa.gov/
  - http://www.esrl.noaa.gov/psd/atmrivers/