Atmospheric Rivers

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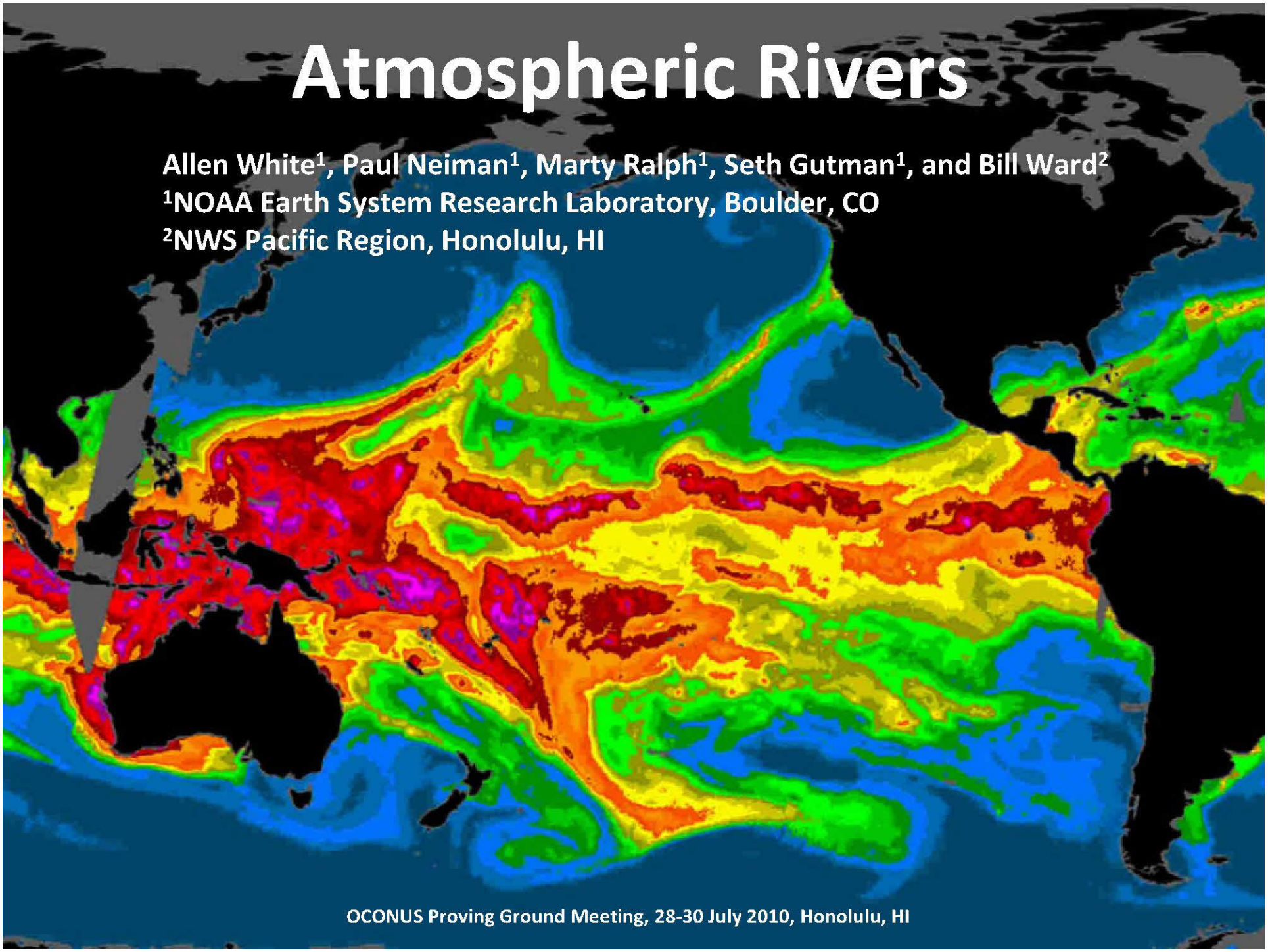


OCONUS Proving Ground Meeting, 28-30 July 2010, Honolulu, HI

Motivation: *Atmospheric rivers (ARs) generate devastating floods, and also replenish snowpacks and reservoirs, across the semi-arid West. Hence, it is crucial to understand this key phenomenon, both as a major weather producer and as one that contributes significantly to climate-scale impacts.*

Outline

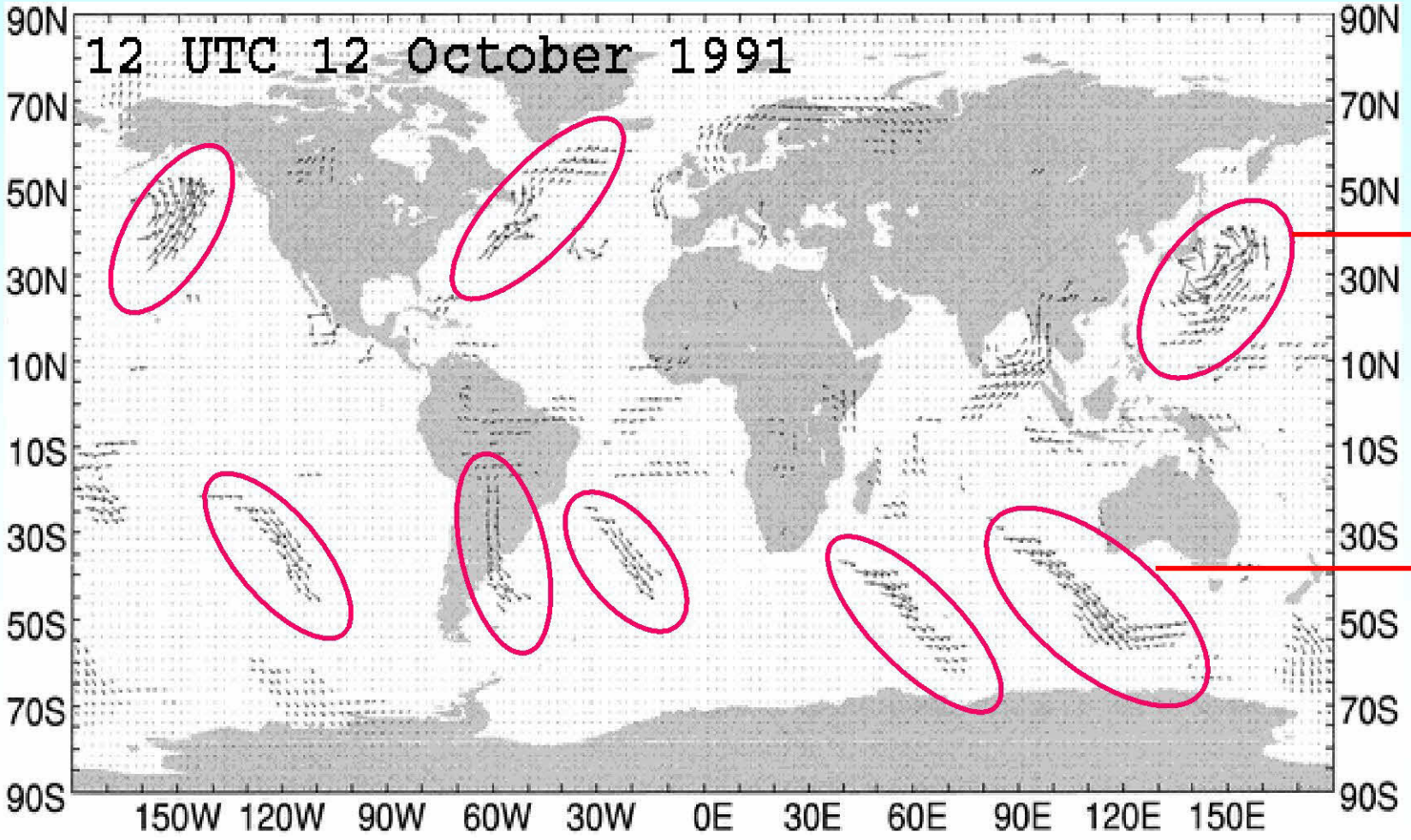
1. Brief review of ARs
2. ARs cause extreme precipitation and flooding
3. GPS-Met and satellite cal/val
4. AR observatories

A few acronym definitions:

AR(O) = atmospheric river (observatory)
APDF = annual peak daily flow
GPS-Met = Global Positioning System Meteorology
LLJ = Low-level jet (airstream)
HMT = NOAA's Hydrometeorology Testbed
IWV = integrated water vapor
NARR = North American Regional Reanalysis
SSM/I = Special Sensor Microwave Imager

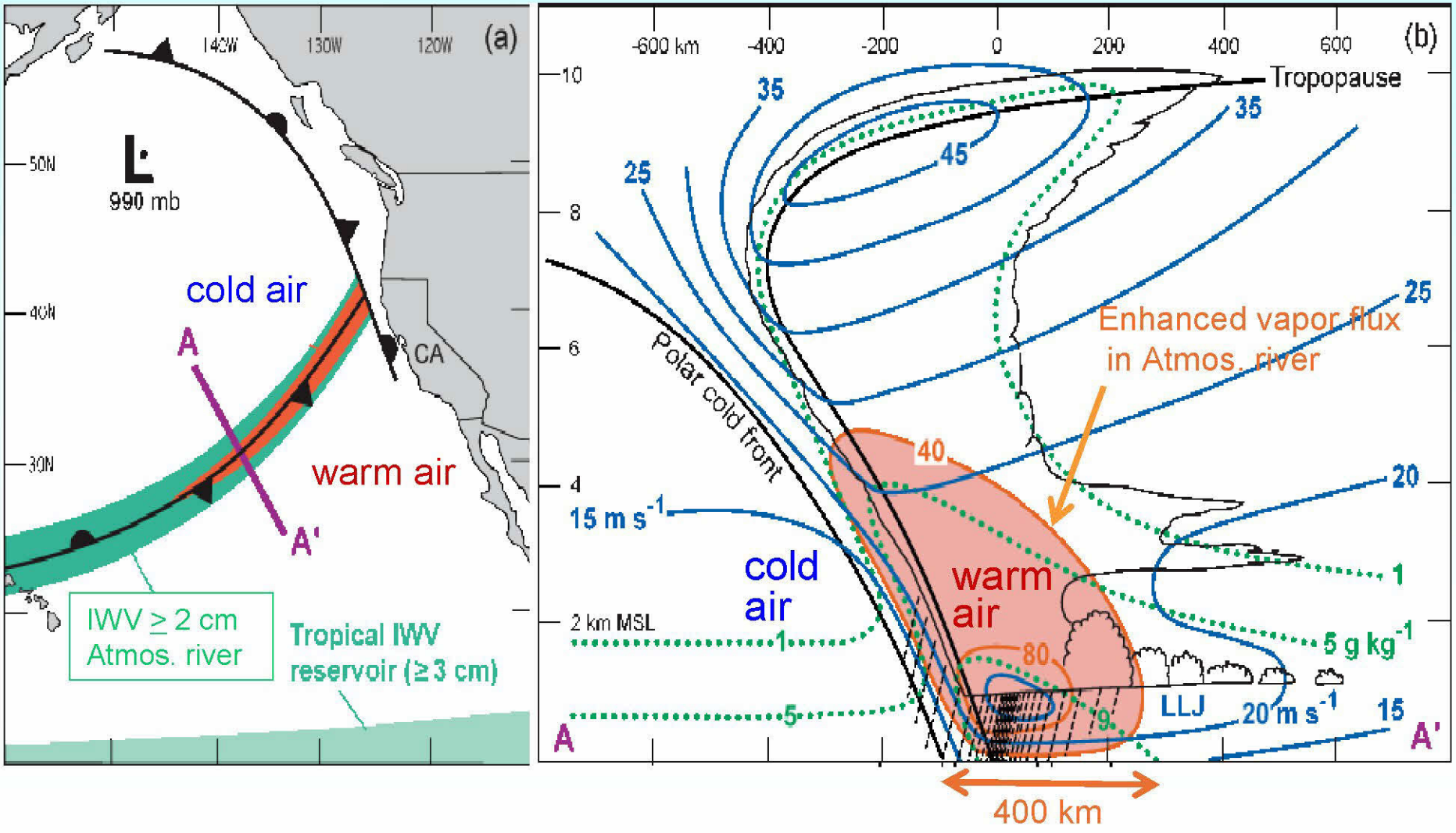
Zhu & Newell (1998) concluded in a 3-year ECMWF model diagnostic study:

1) 95% of meridional water vapor flux occurs in narrow plumes in <10% of zonal circumference.
2) There are typically 3-5 of these narrow plumes within a hemisphere at any one moment.
3) They coined the term “atmospheric river” (AR) to reflect the narrow character of plumes.
4) ARs constitute the moisture component of an extratropical cyclone’s warm conveyor belt.
5) ARs are very important from a global water cycle perspective.

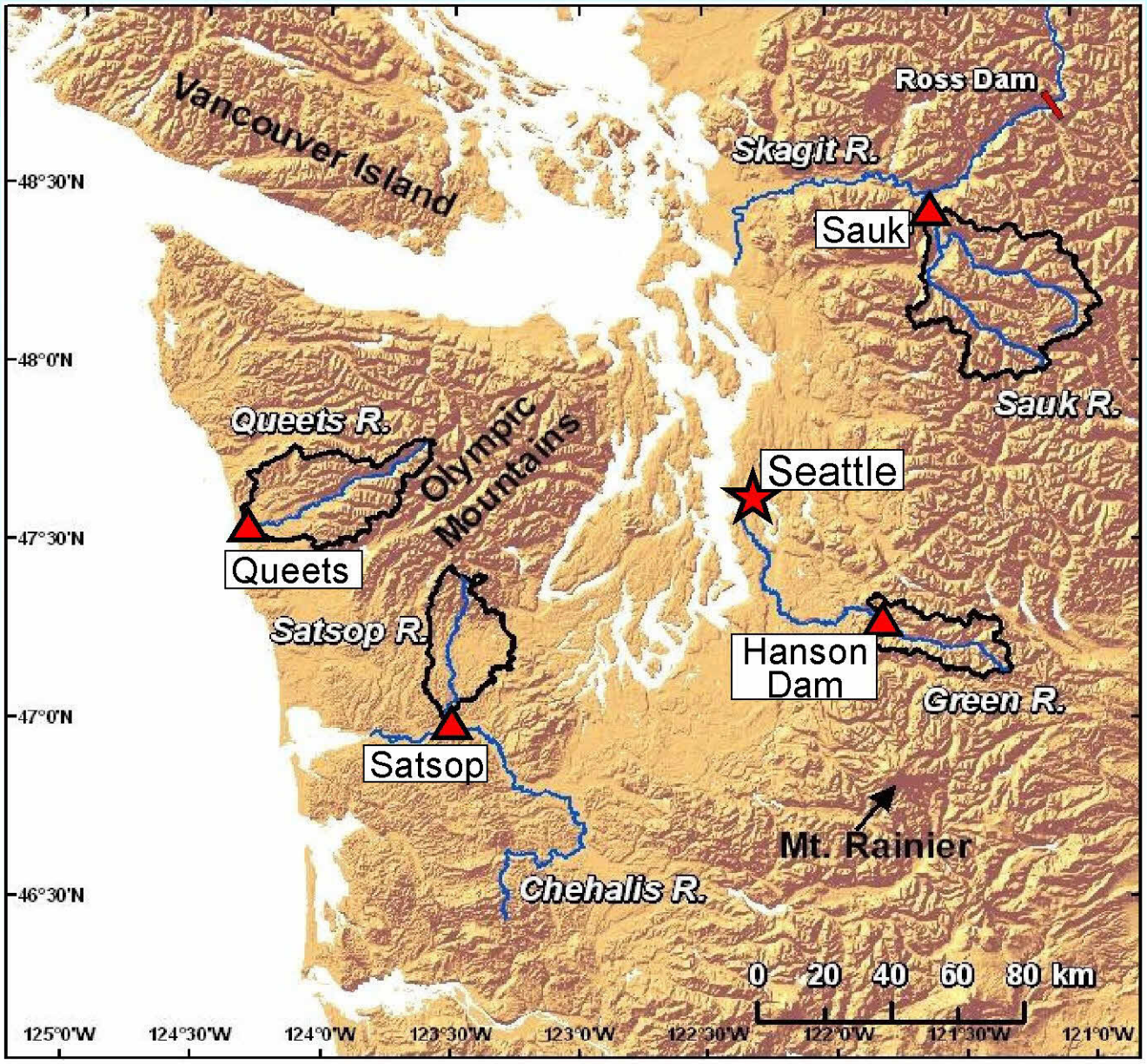


Observational studies by Ralph et al. (2004, 2005, 2006) extend model results:

1) Long, narrow plumes of IWV >2 cm measured by SSM/I satellites considered proxies for ARs.
2) These plumes (darker green) are typically situated near the leading edge of polar cold fronts.
3) P-3 aircraft documented strong water vapor flux in a narrow (400 km-wide) AR; See section AA'.
4) Airborne data also showed 75% of the vapor flux was below 2.5 km MSL in vicinity of LLJ.
5) Moist-neutral stratification <2.8 km MSL, conducive to orographic precip. boost & floods.

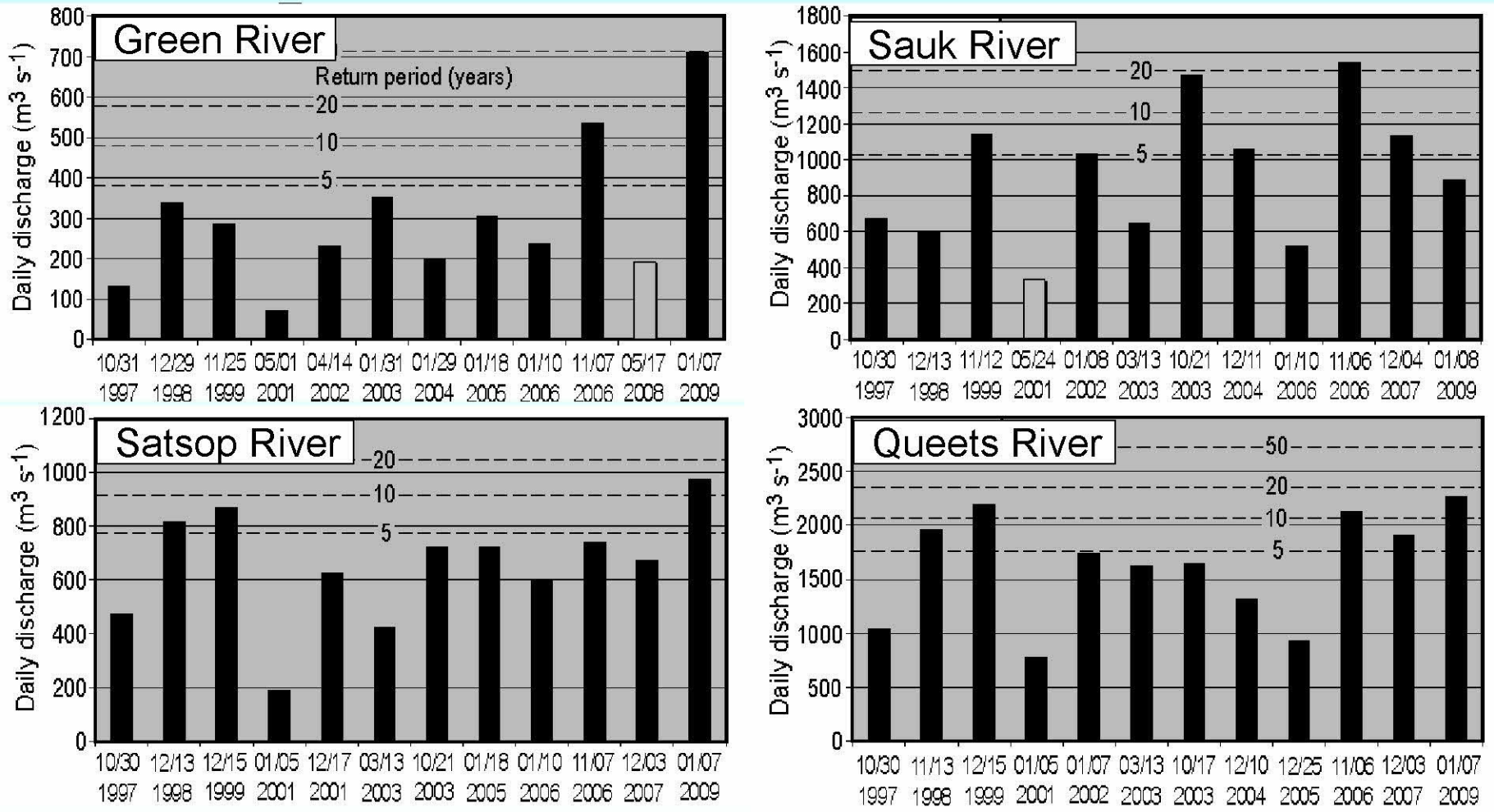


Now let's turn the problem on its head: What causes the largest annual runoffs on major watersheds in western Washington? (Neiman et al. 2010)



APDFs on four key WA watersheds and AR events for WY1998-2009

AR non-AR [determined from 2x-daily SSM/I IWV satellite imagery]

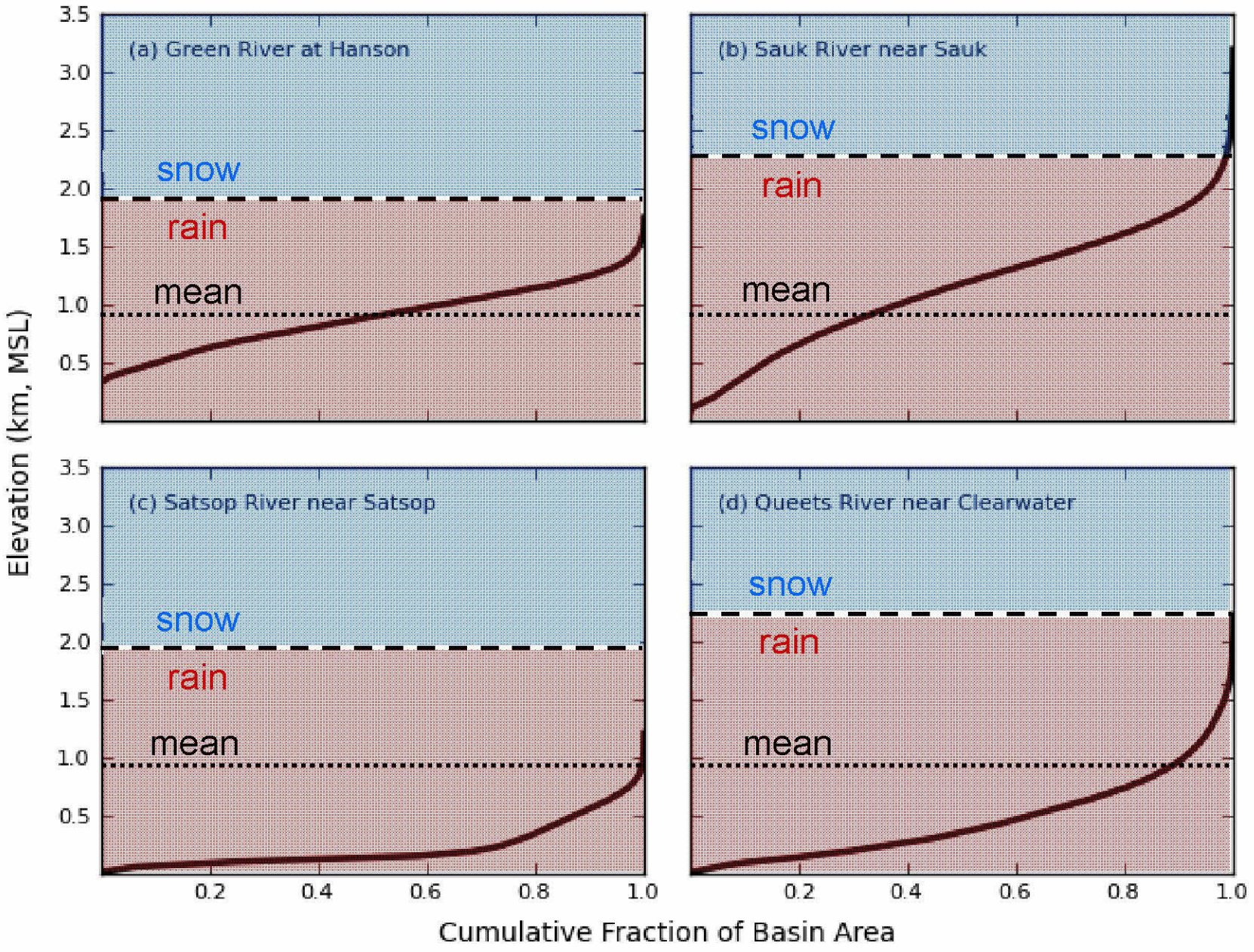


APDF dates for WY 1998-2009

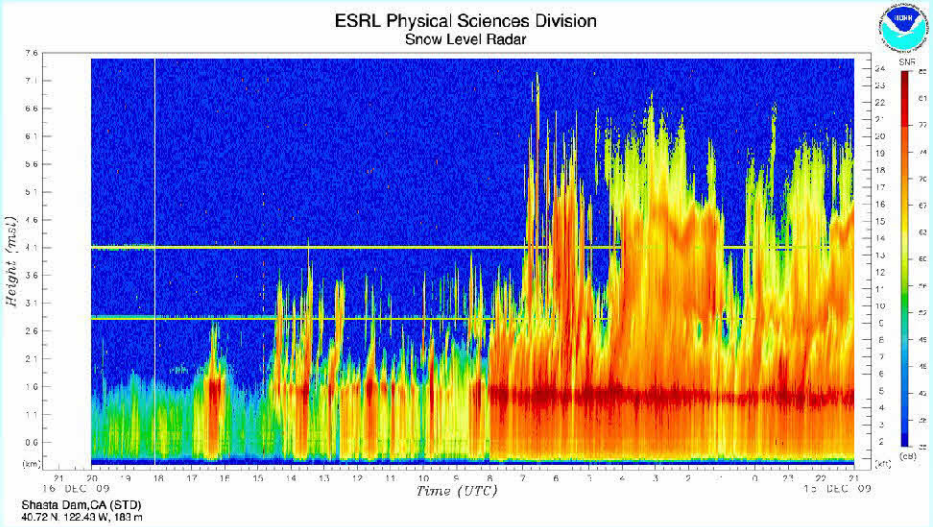
46 of 48 annual peak daily flows in last 12 years at the 4 sites due to AR landfalls

Results consistent with Dettinger (2004) in CA: ARs yield daily increases in streamflow that are an order of magnitude larger than those from non-AR storms

Basin altitude attributes above gauges, and mean melting-level altitudes (300 m below 0°C altitude) for NARR (30 yr inventory) top-10 flood events

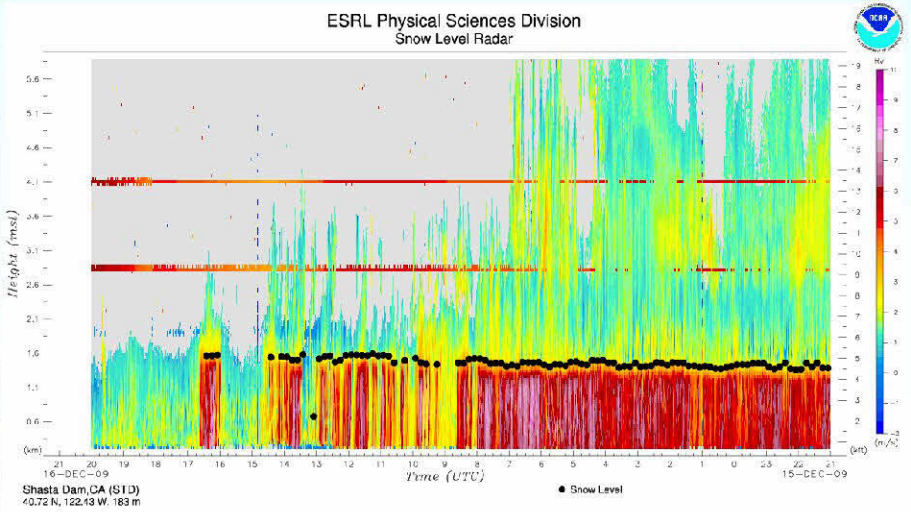


The snow level radar prototype (ca. 2007). A 12-ft trailer is used for the deployments instead of the 10-ft trailer shown here. The 4-ft radar parabolic dish antennas sit down inside the two corrugated aluminum shrouds (culvert piping). The 45-degree angled shroud tops are wrapped with marine and industrial shrink wrap to help shed precipitation. The radar electronics and data communications equipment are rack mounted in the environmentally controlled locker located in the center.



Snow-level Radar at Colfax, CA

Snow-level Radar at Shasta Dam, CA



GPS-Met in NOAA

NOAA Mission:
To understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social, and environmental needs

GPS-Met supports NOAA's Mission by providing reliable and accurate refractivity & moisture observations at low cost under all weather conditions.

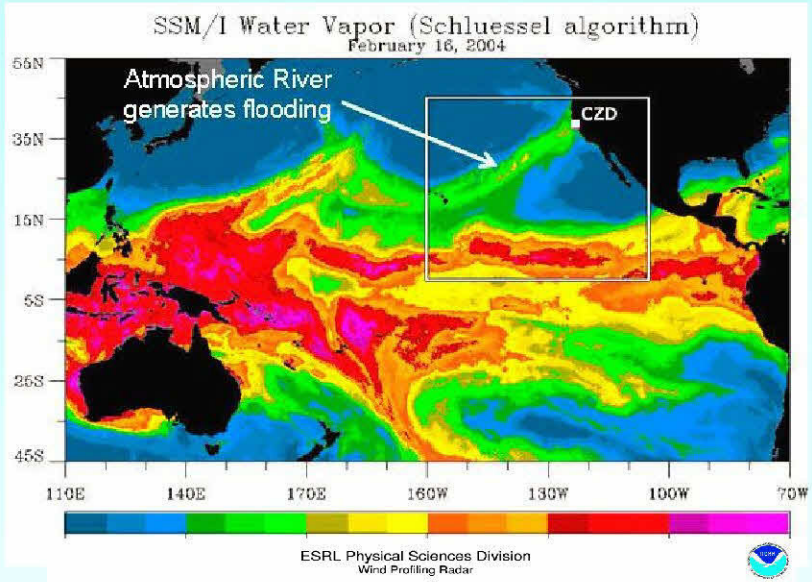
Climate Goal:

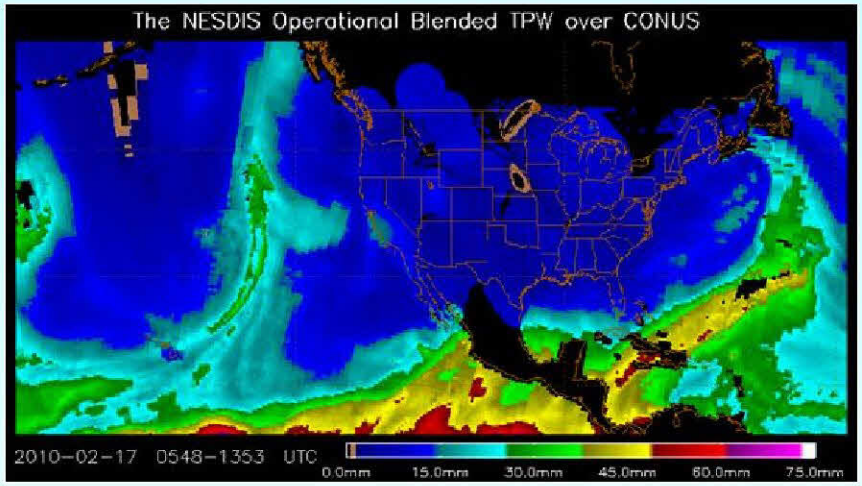
Weather & Water Goal:

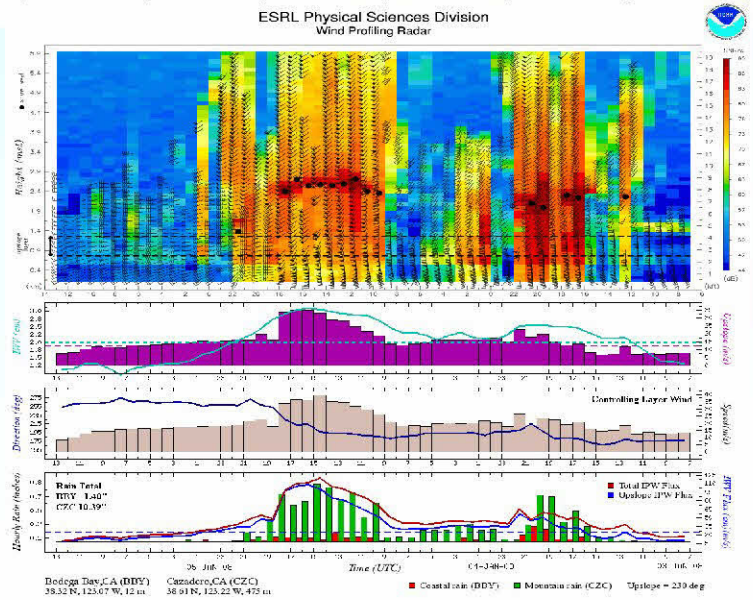
Commerce & Transportation Goal:

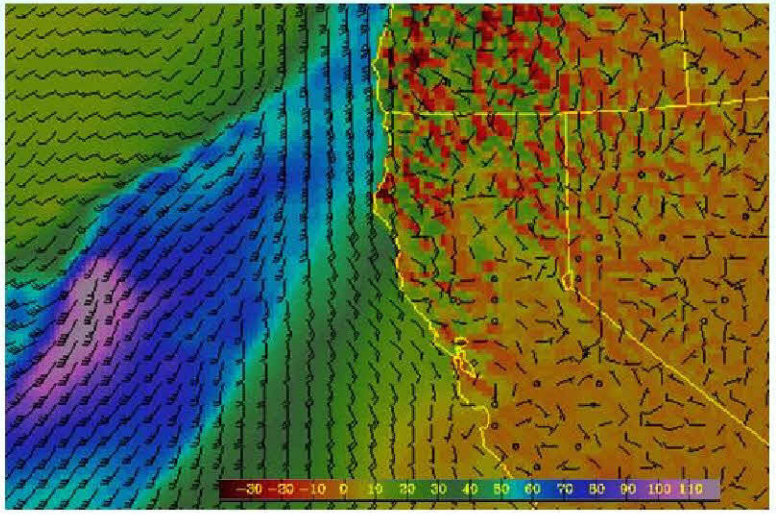
Satellites
Modeling & Observing Systems

Applications of GPS-Met



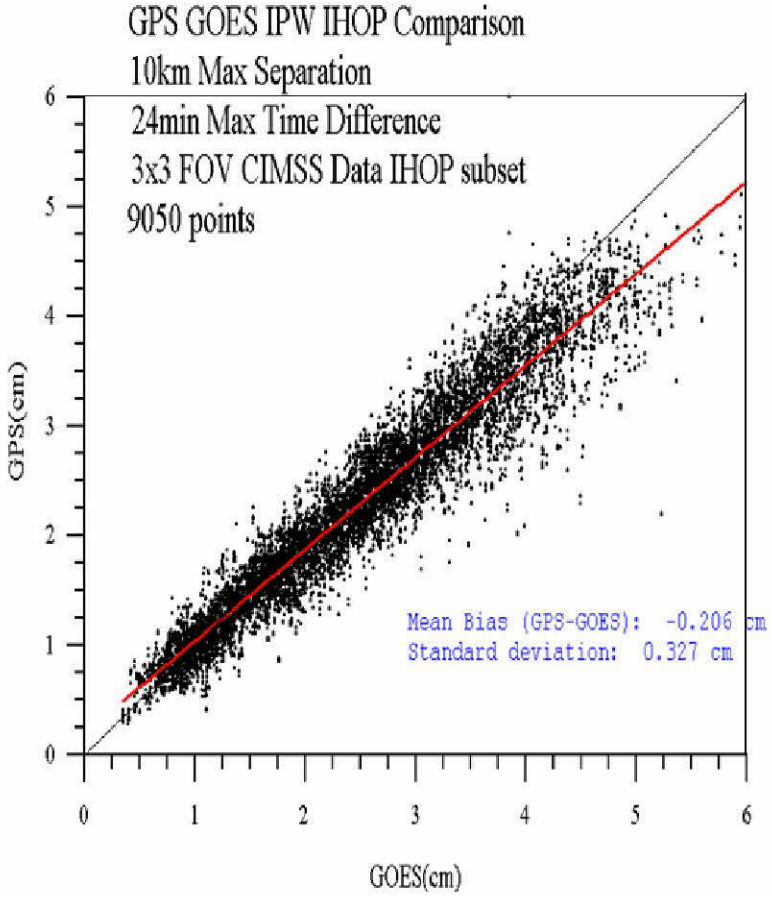


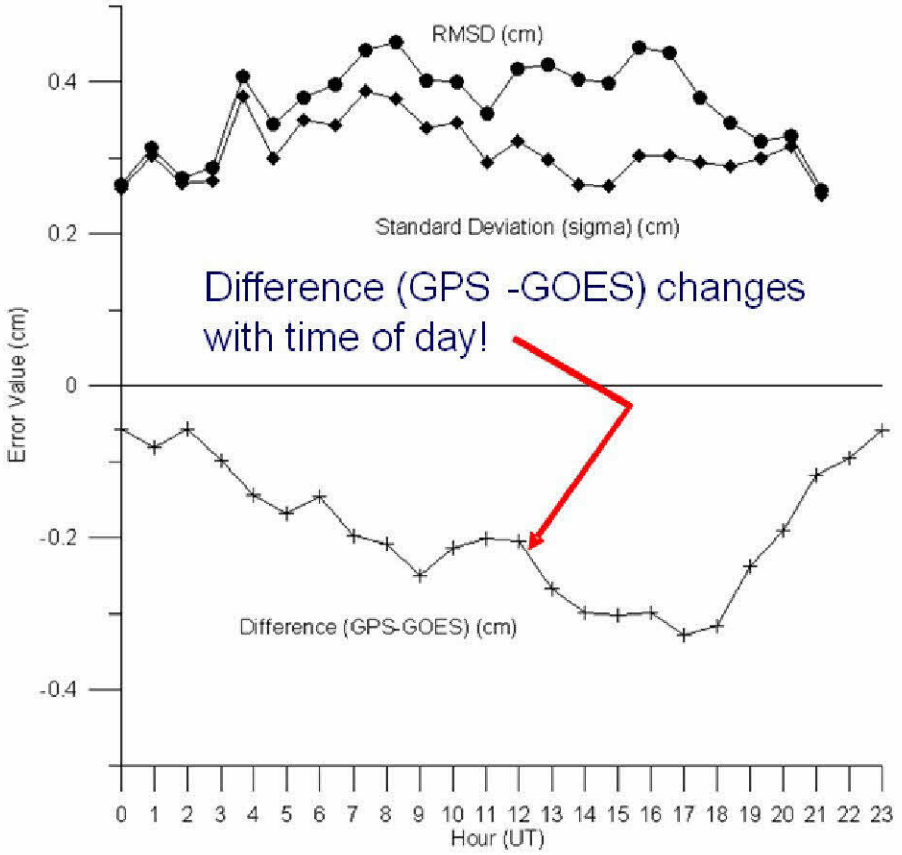




Example: Satellite Cal/Val

Systematic differences between operational GOES East IWV products & GPS were detected in 2002.

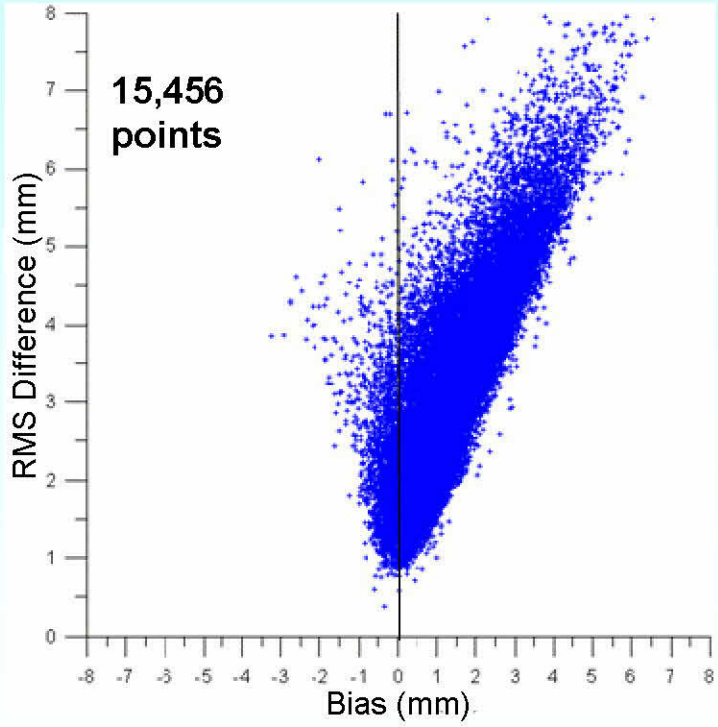




Example: Satellite Cal/Val

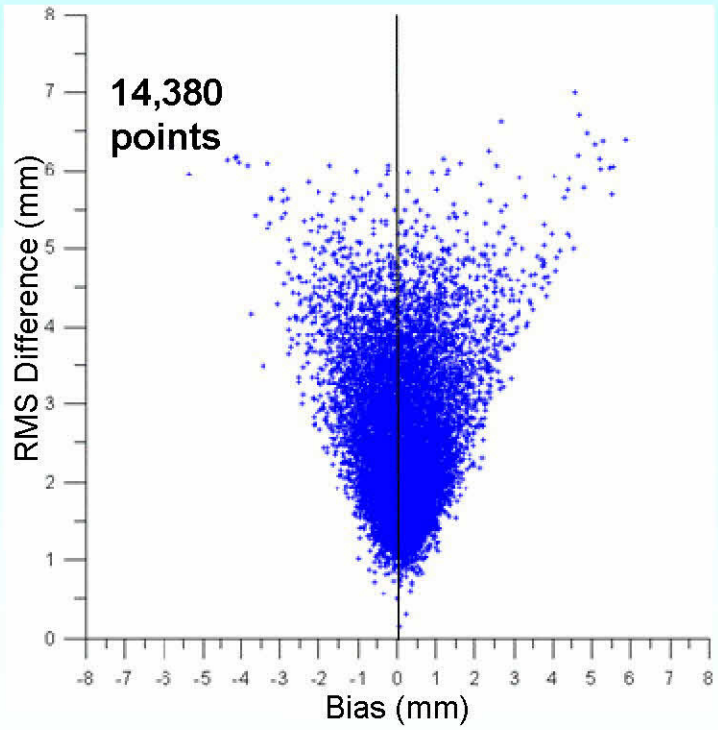
Systematic differences between operational GOES East & GOES West IWV products were detected in 2005.

Operational GOES East - GPS



Bias = 1.452 mm (GOES-East > GPS)
RMS = 3.244 mm

Operational GOES West - GPS

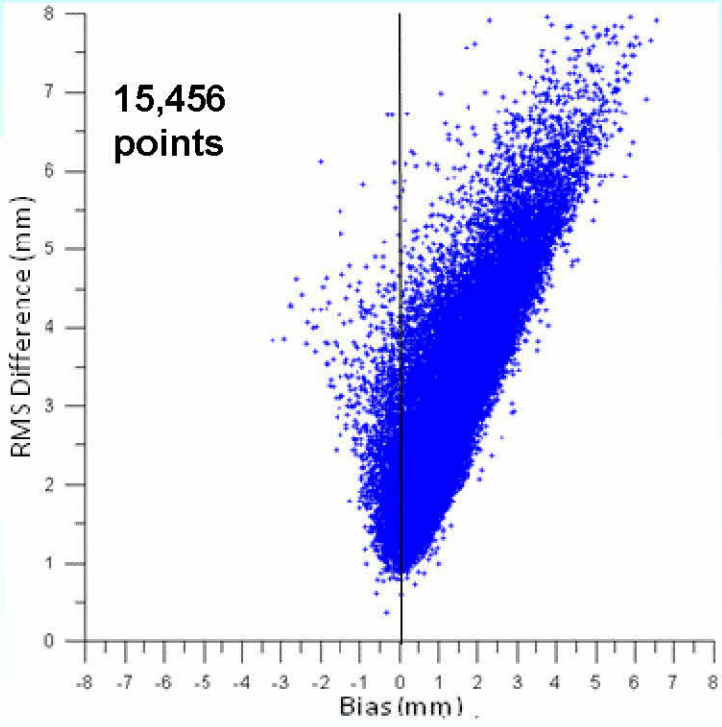


Bias = 0.299 mm (GOES-West > GPS)
RMS = 2.522 mm

Example: Satellite Cal/Val

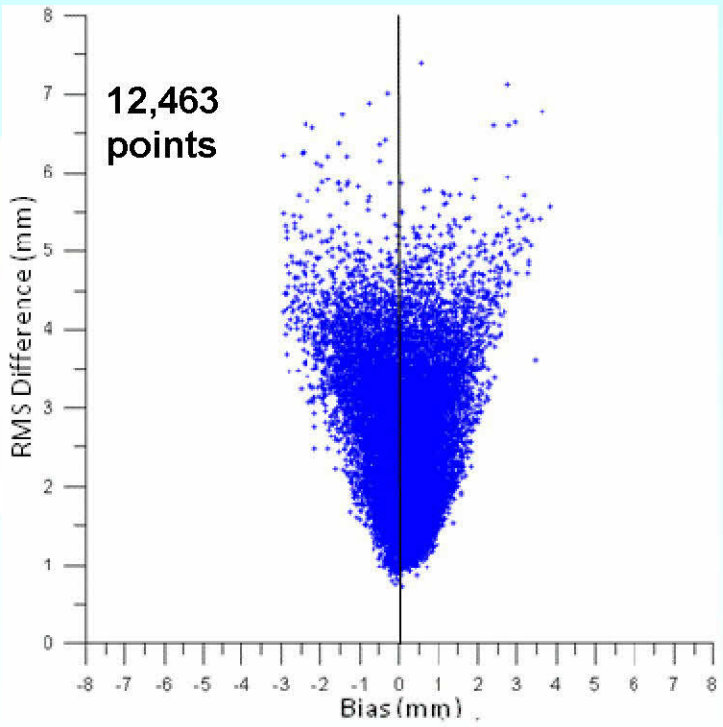
Significant improvements in experimental GOES East IWV products were demonstrated in 2008.

Operational GOES-East



Bias = 1.452 mm (GOES-East > GPS)
RMS = 3.244 mm

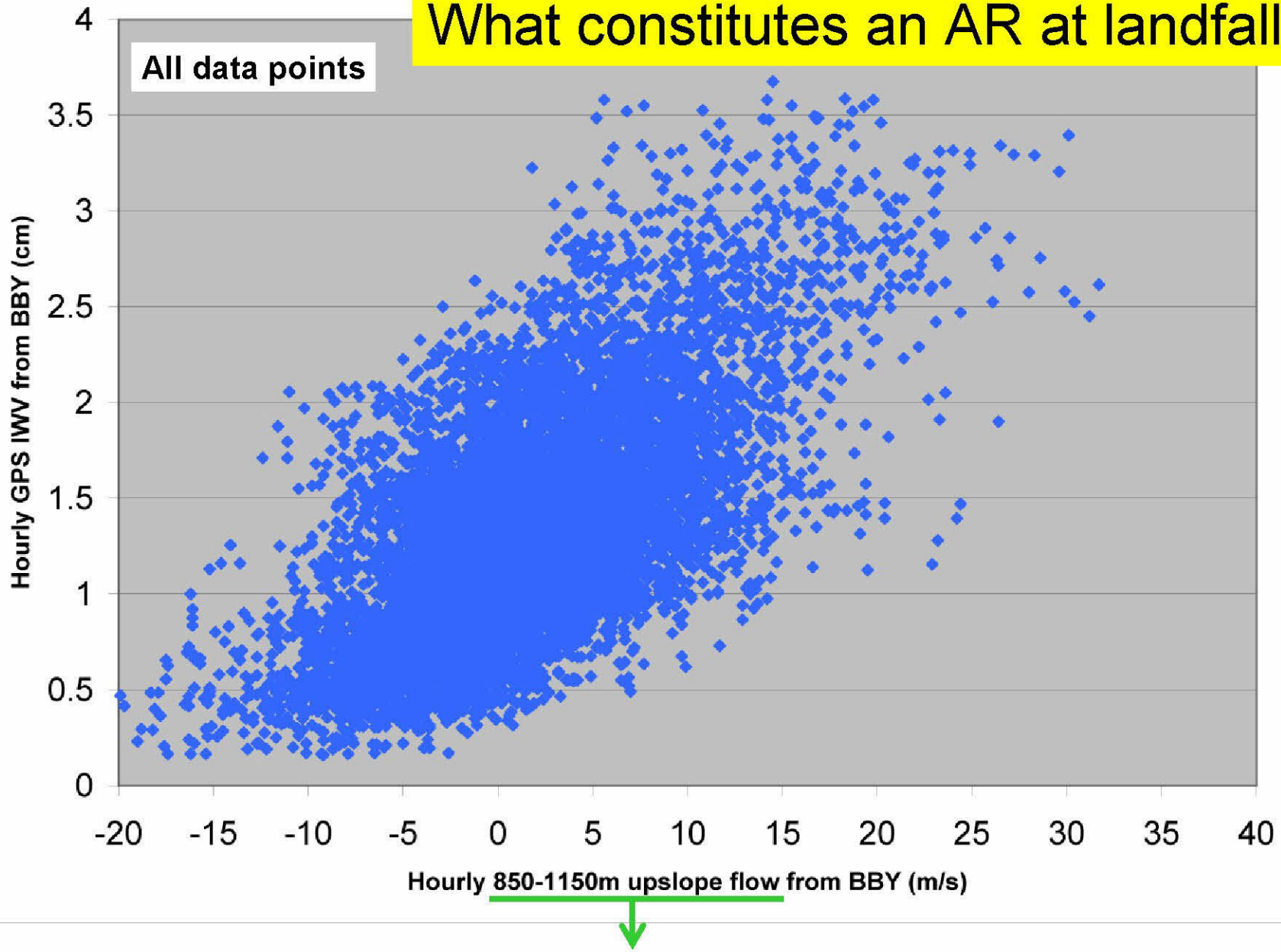
Experimental GOES-East



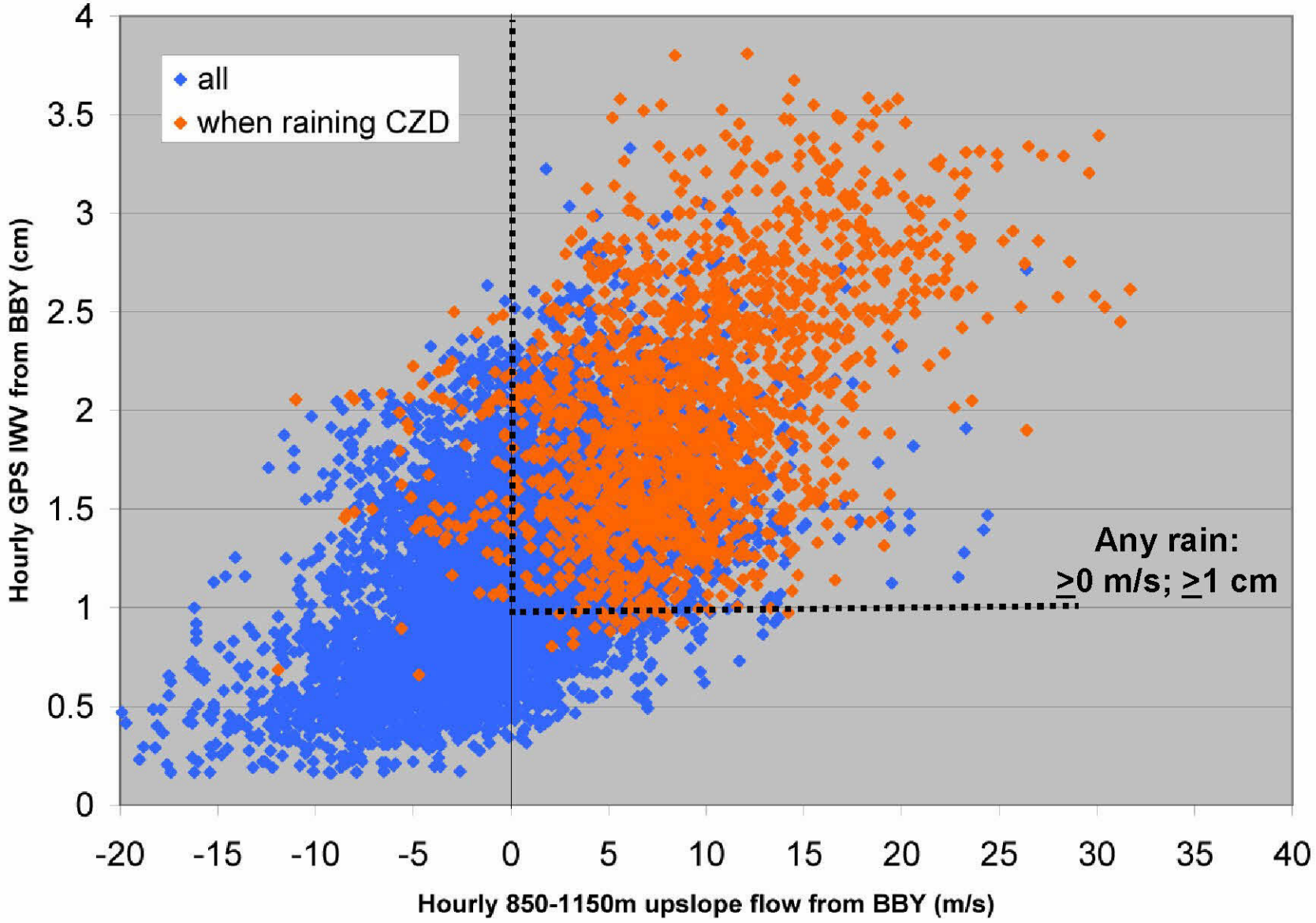
Bias = 0.149 mm (GOES-East > GPS)
RMS = 2.681 mm

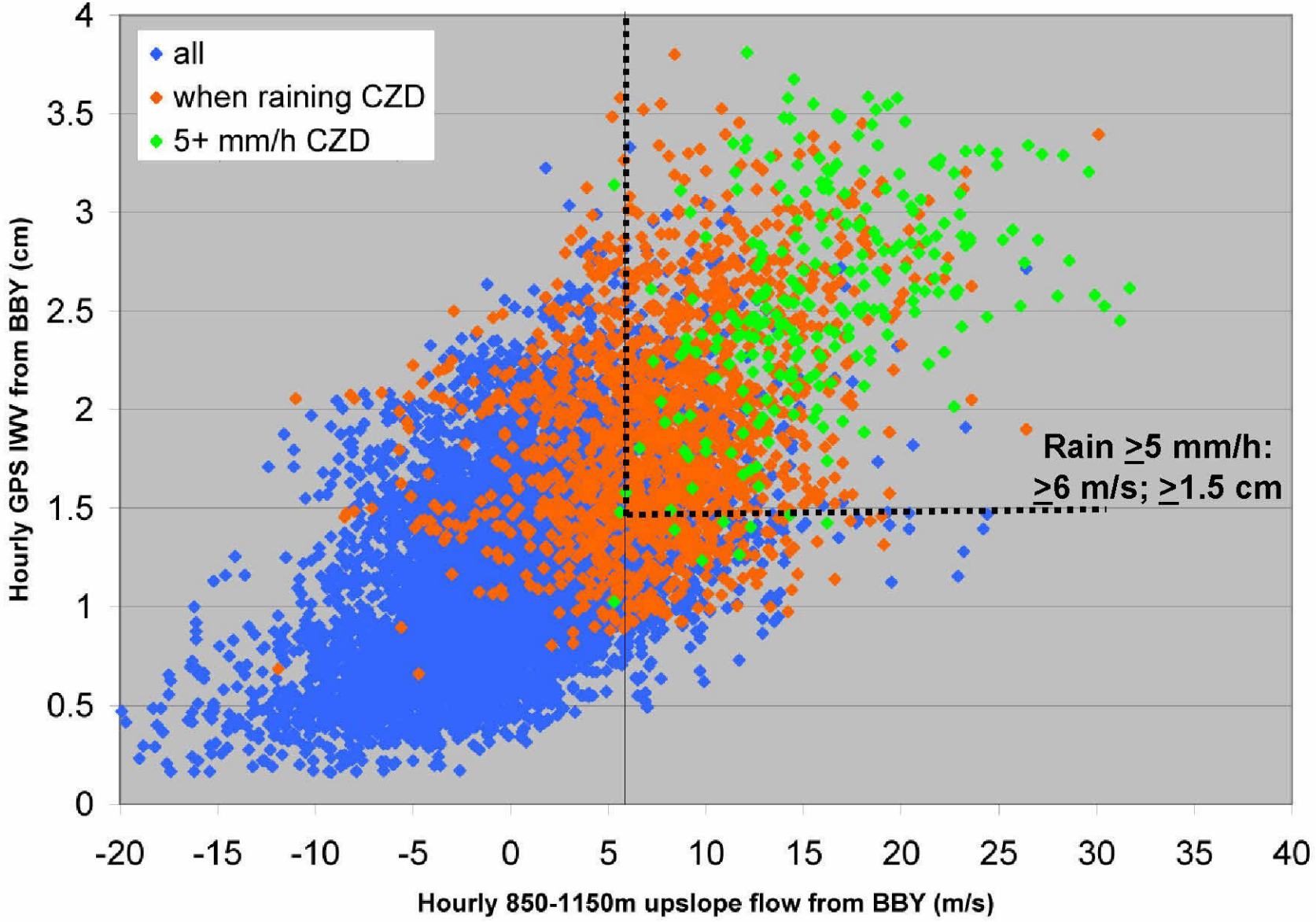
HMT-2004 Microphysics Array

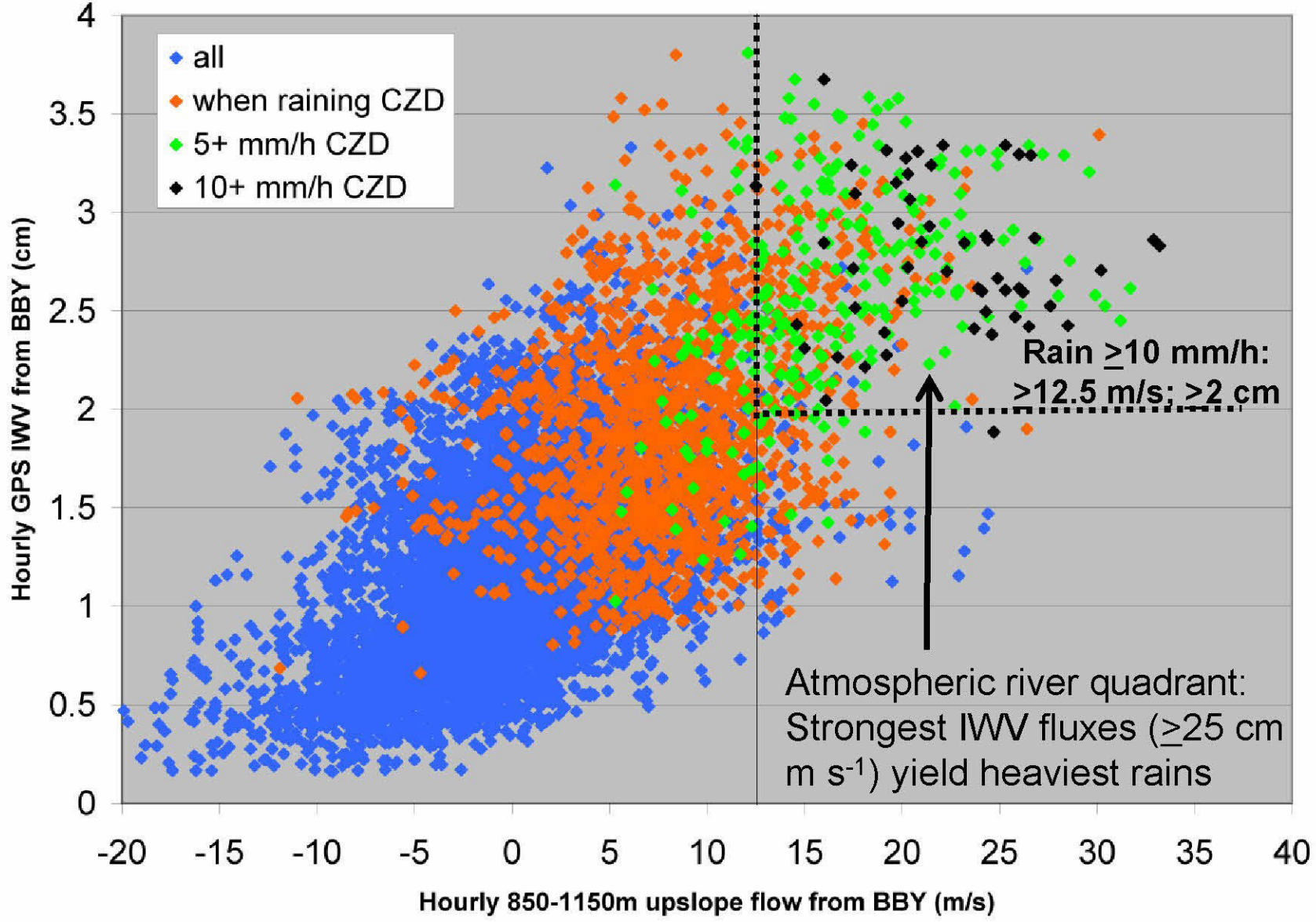
What constitutes an AR at landfall?



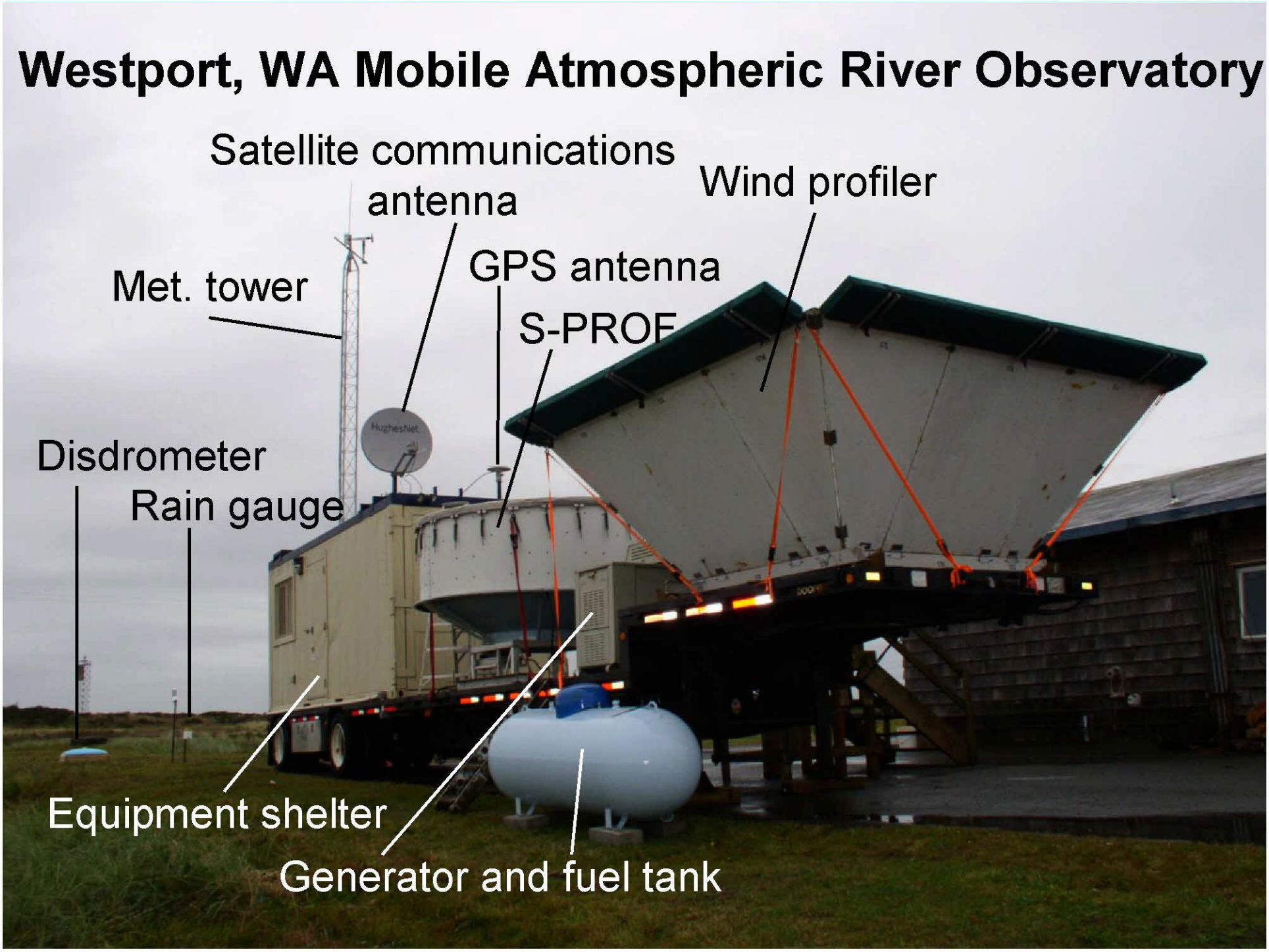
Component of the flow in the orographic controlling layer directed from 230°, i.e., orthogonal to the axis of the coastal mtns

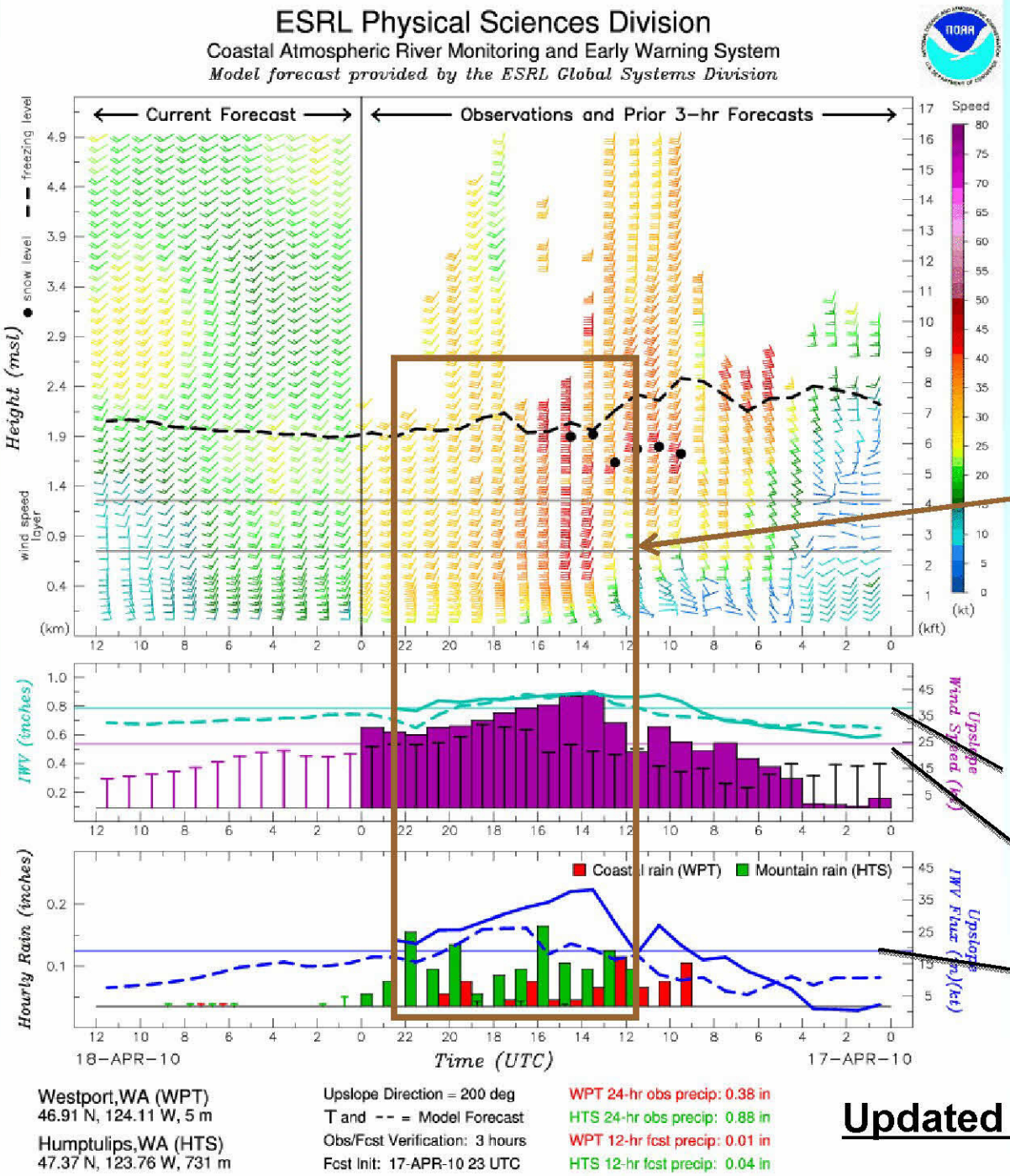

all
when raining CZD
Any rain:
≥0 m/s; ≥1 cm
Hourly GPS IWV from BBY (cm)
Hourly 850-1150m upslope flow from BBY (m/s)
4
3.5
3
2.5
2
1.5
1
0.5
0
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40


all
when raining CZD
5+ mm/h CZD
Rain ≥5 mm/h:
≥6 m/s; ≥1.5 cm
Hourly GPS IWV from BBY (cm)
Hourly 850-1150m upslope flow from BBY (m/s)
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


all
when raining CZD
5+ mm/h CZD
10+ mm/h CZD
Rain ≥10 mm/h:
≥12.5 m/s; ≥2 cm
Atmospheric river quadrant:
Strongest IWV fluxes (≥25 cm
m s-1) yield heaviest rains
Hourly GPS IWV from BBY (cm)
Hourly 850-1150m upslope flow from BBY (m/s)
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

Westport, WA Mobile Atmospheric River Observatory





Westport,WA (WPT)
46.91 N, 124.11 W, 5 m

Humptulips,WA (HTS)
47.37 N, 123.76 W, 731 m

Upslope Direction = 200 deg
T and -- = Model Forecast
Obs/Fcst Verification: 3 hours
Fcst Init: 17-APR-10 23 UTC

WPT 24-hr obs precip: 0.38 in
HTS 24-hr obs precip: 0.88 in
WPT 12-hr fcst precip: 0.01 in
HTS 12-hr fcst precip: 0.04 in

ARO flux tool measures water vapor transport and compares it with forecasts from a high resolution numerical forecast model.

AR conditions detected at Westport by ARO:
GPS-Met IWV > 2 cm,
Low-level jet >40 kt
Light to moderate orographic rain >0.1 in/hr

IWV

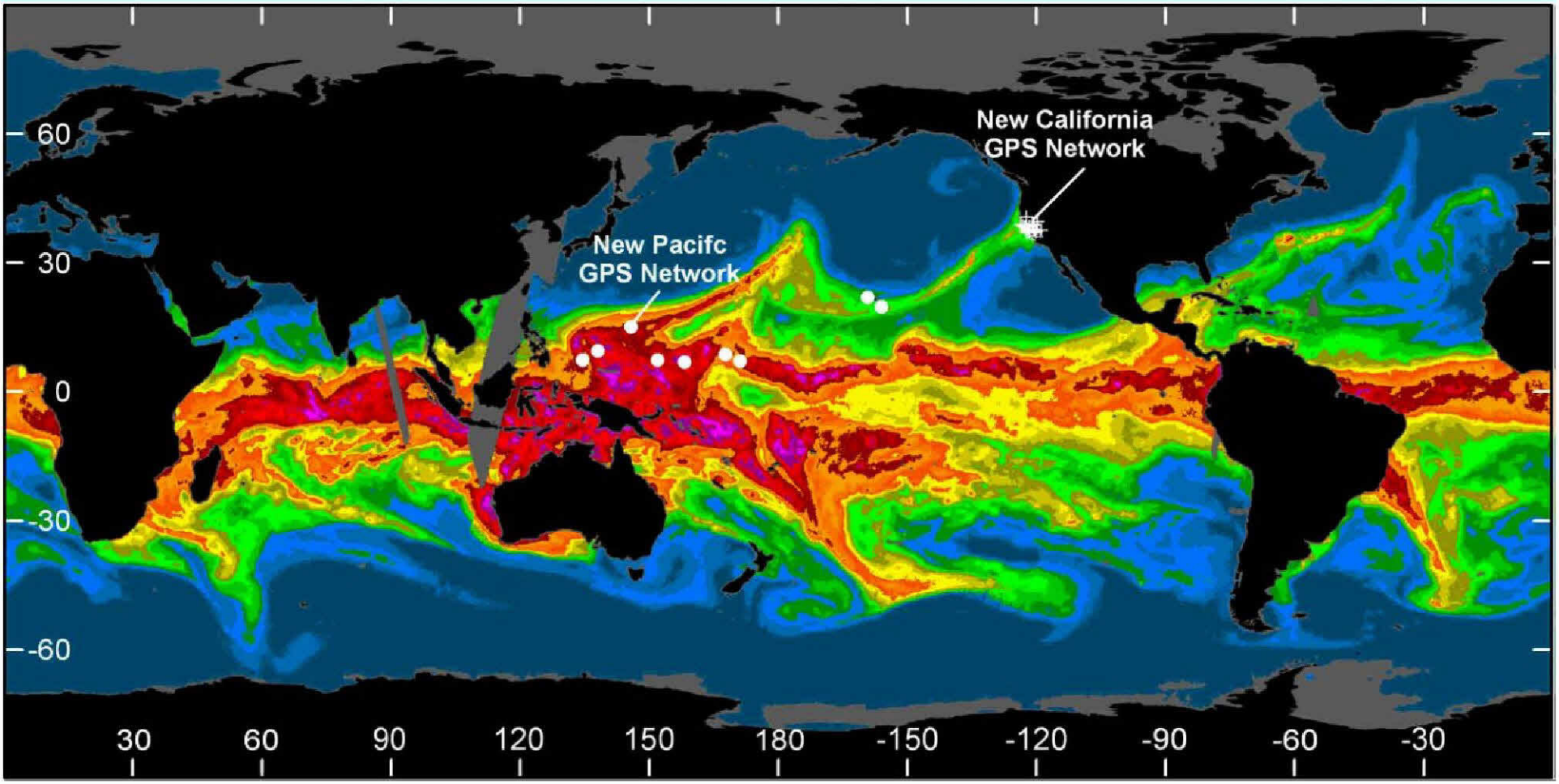
Upslope wind

Uses objective thresholds

"Bulk" Vapor transport

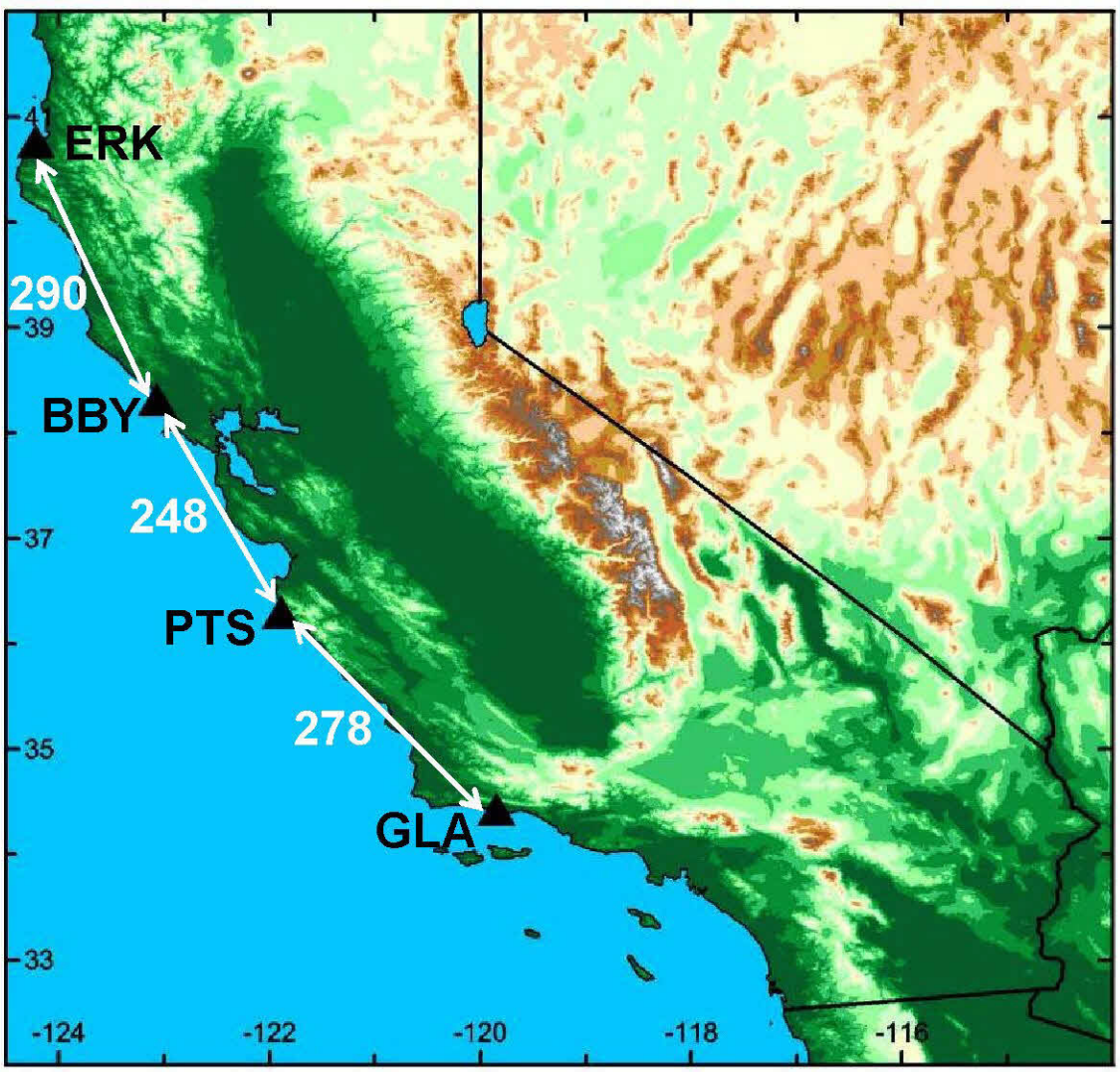
Updated every hour in near real time!

New GPS-Met networks across Pacific Basin (NOAA Coastal Storms Program) and in California (CA Dept. of Water Resources) will help with satellite cal/val and AR monitoring. . .



. . . although wind profilers strategically located across the Pacific Basin to measure the lower tropospheric winds (low-level jets) responsible for transporting the water vapor poleward would be extremely beneficial.

HMT Legacy Project with CA Dept. of Water Resources will install four coastal AROs with these horizontal spacings (km), i.e., sufficient to monitor landfalling ARs across much of the State.



Concluding Remarks

- Atmospheric rivers (ARs) are long, narrow corridors of enhanced water vapor transport responsible for most of the poleward vapor transport at midlatitudes.

- Lower-tropospheric conditions during the landfall of ARs are anomalously warm and moist with weak static stability and strong onshore flow, resulting in orographically enhanced precipitation, high melting levels, and flooding.

- Because ARs contribute significantly to precipitation, reservoir and snowpack replenishment, and flooding in western North America and elsewhere, they represent a key phenomenon linking weather and climate.

- New GPS-Met networks in CA and across the Pacific will aid with cal/val of satellite water vapor retrievals and will monitor atmospheric moisture in the AR breeding grounds. Four ARO's will be installed along the CA coastline to detect and monitor AR conditions at landfall. It would be worthwhile to have a similar wind profile measurement capability at selected sites across the Pacific Basin.

- Next steps include quantifying the role of ARs in the global climate system and estimating the modulation of AR frequency and amplitude (and associated extreme precipitation and flooding upon landfall) due to projected climate change. Mike Dettinger is delving into this research (Dettinger et al. 2009).