A Multi-scale Observational Case Study of a Pacific Atmospheric River Exhibiting Tropical-Extratropical Connections and a Mesoscale Frontal Wave

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*Center for Multi-scale Modeling of Atmospheric Processes (CMMAP)

Motivation

- Extreme precipitation events represent both a hazard (floods) and a benefit (water supply, etc.), and yet are challenging to predict and to represent in climate models.

- For the U.S. West Coast atmospheric rivers (AR) have been identified as a major source of extreme precipitation events and water supply through their role in focusing water vapor transport and orographic precipitation within the context of their parent extratropical cyclones.
  - **How well to climate models represent ARs?**

Key science gaps

- A key question has emerged about whether some extreme precipitation events on the U.S. West Coast are partly a result of direct entrainment and transport of large water vapor contents from the tropics into ARs

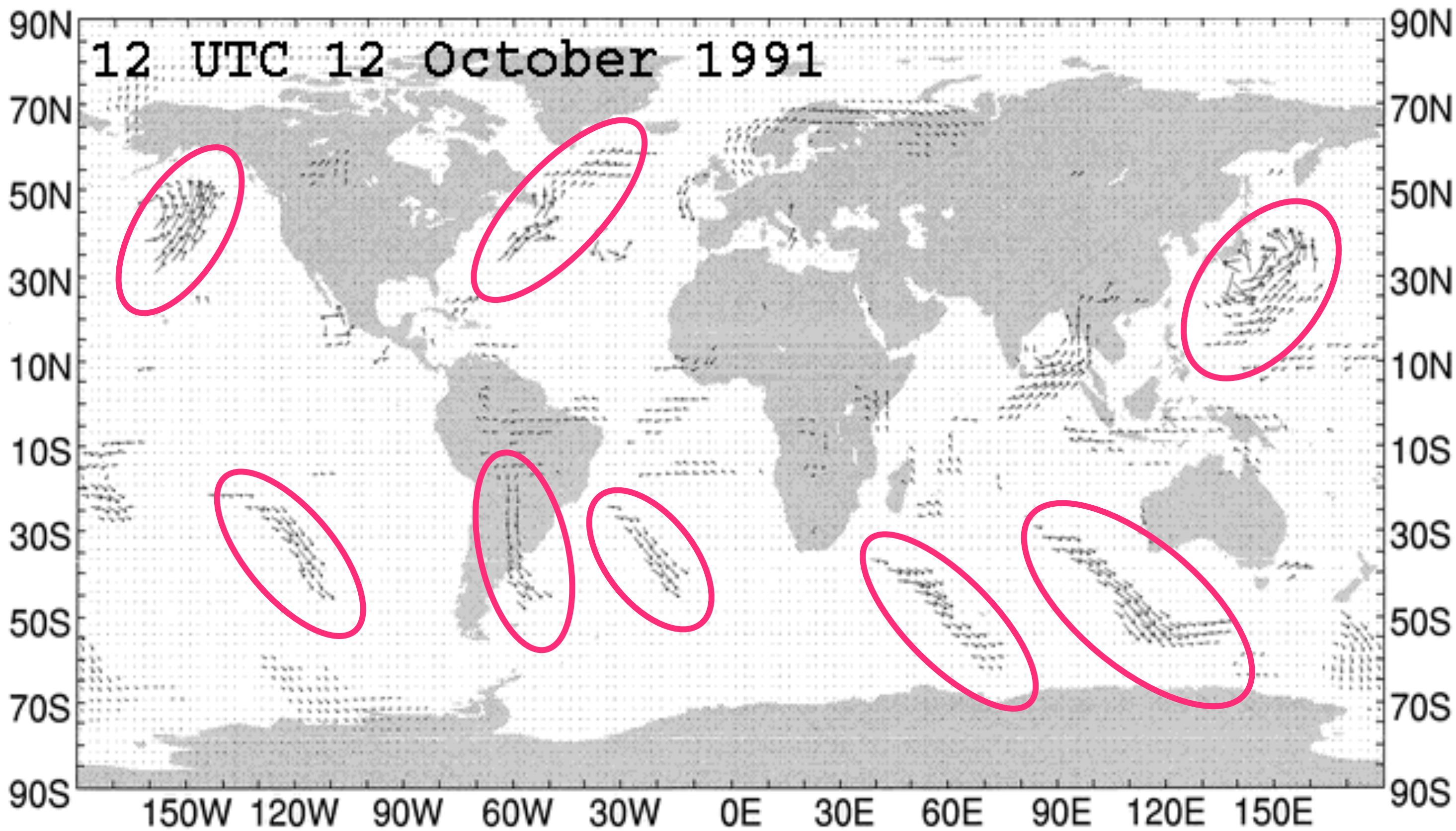
- Does MJO forcing of the extratropics influence the development of strong atmospheric rivers and possibly favor the direct entrainment of tropical water vapor?

- What processes can extend the duration of heavy rain in landfalling ARs?

Background: Water vapor transport and the role of ARs

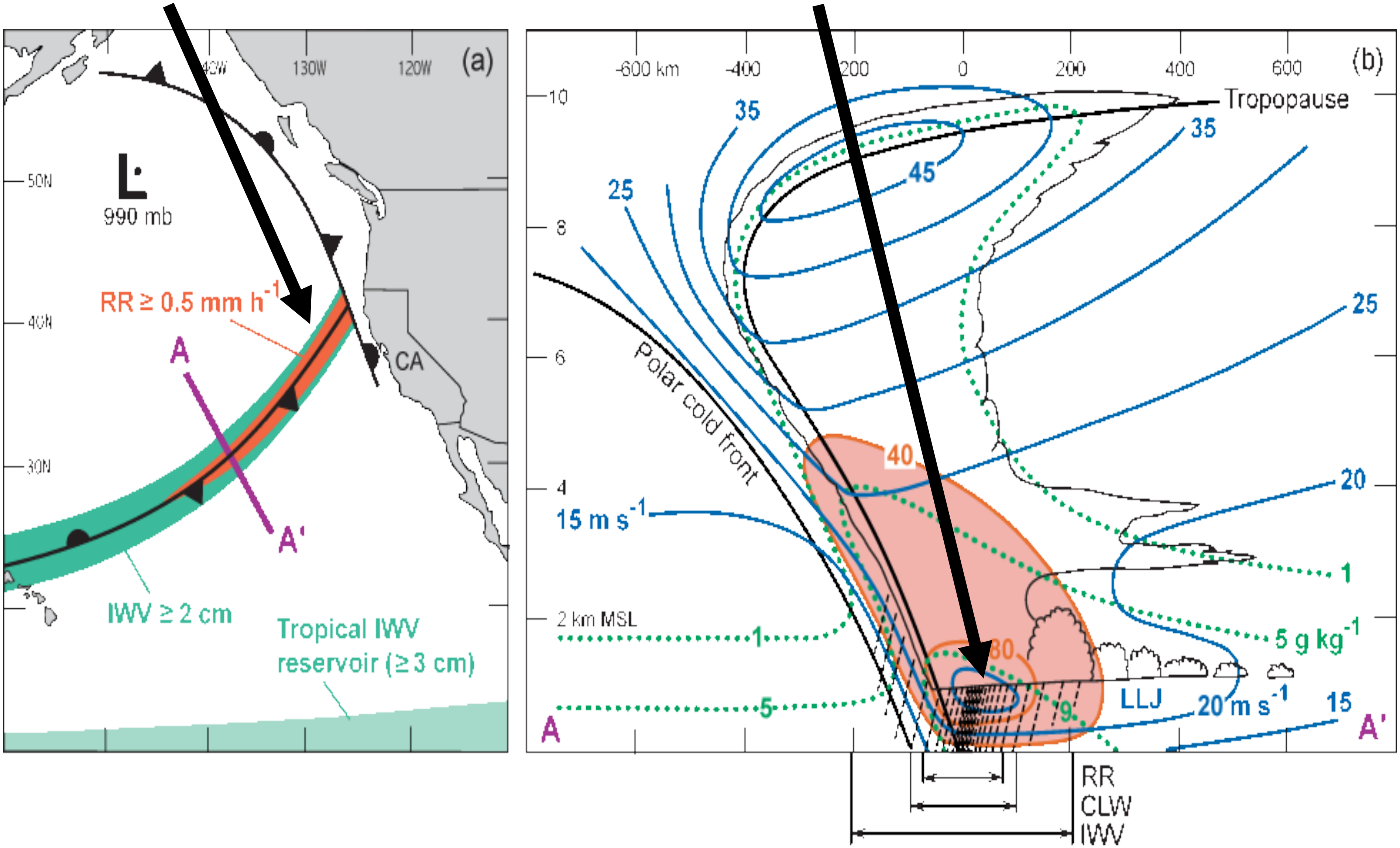
Zhu & Newell (MWR 1998) coined the term AR and concluded:

1) Most water vapor transport occurs in only a few narrow regions
2) >90% of meridional water vapor transport occurs in < 10% of earth's circumference
3) There are 4-5 ARs within a hemisphere at any one moment
4) ARs are part of extratropical cyclones and move with the "storm track"



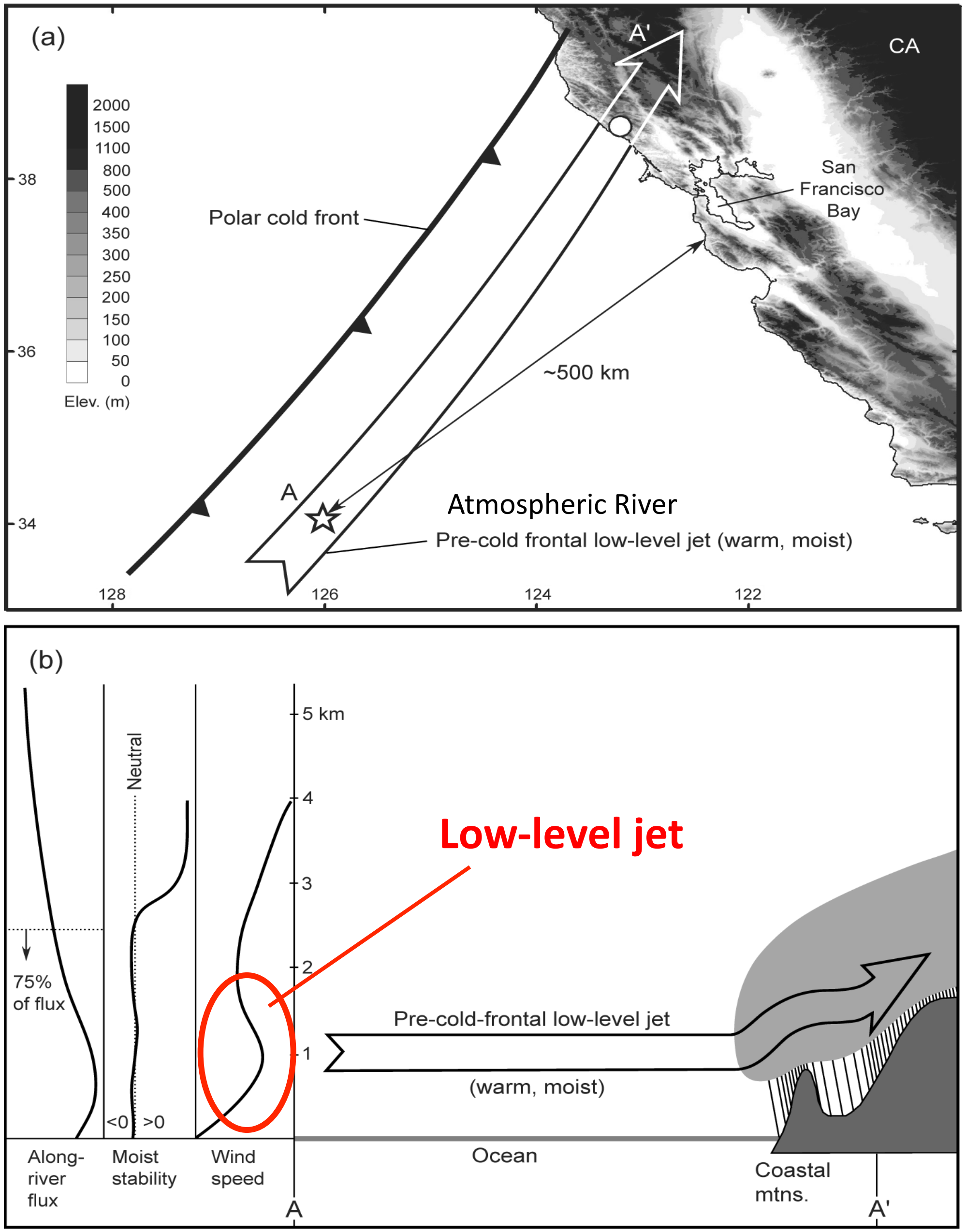
SSM/I Satellite data provide mean location

Aircraft data quantify intensity and structure



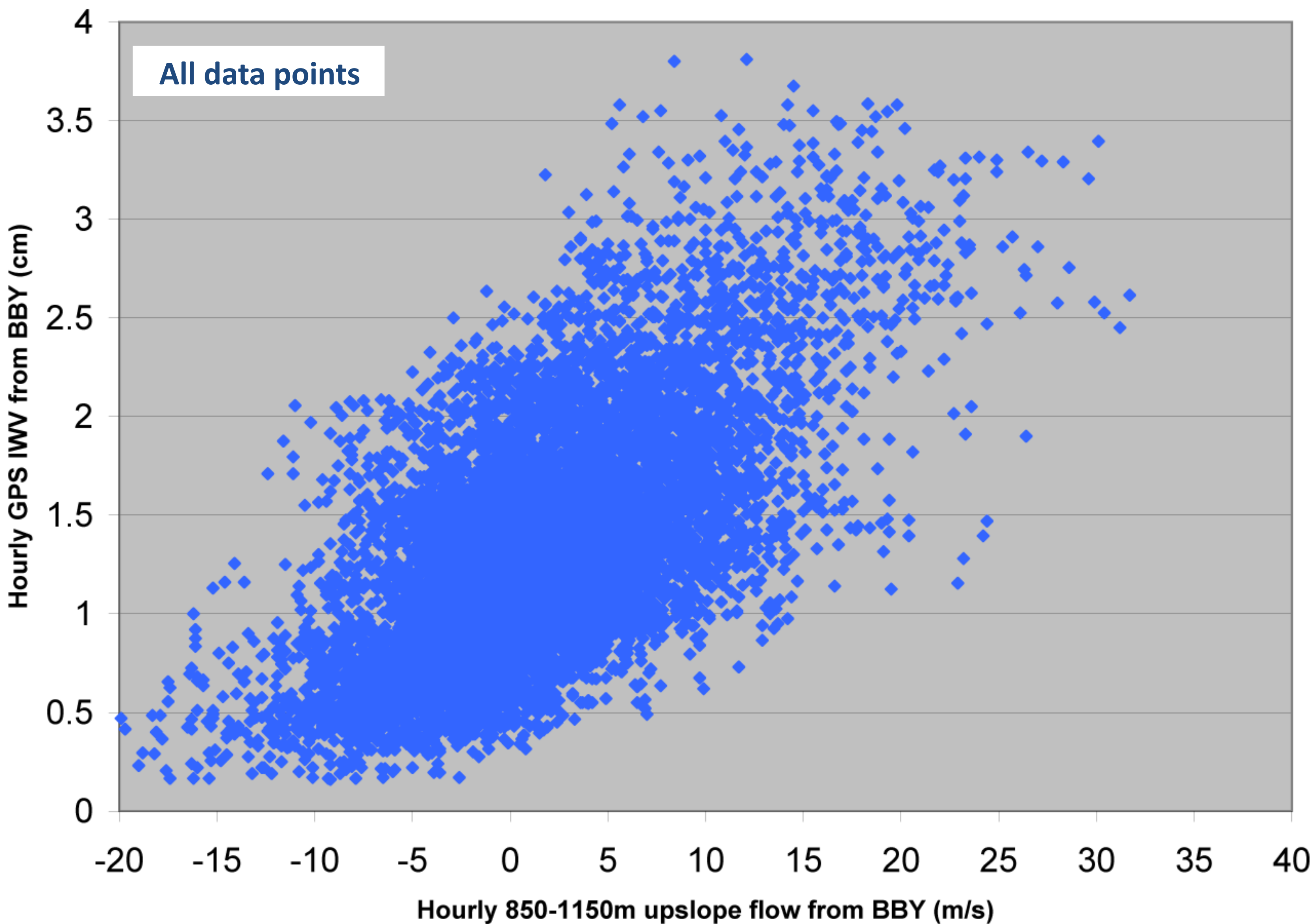
Ralph, Neiman and Wick (2004), *Mon. Wea. Rev.*

Vertical structure documented offshore

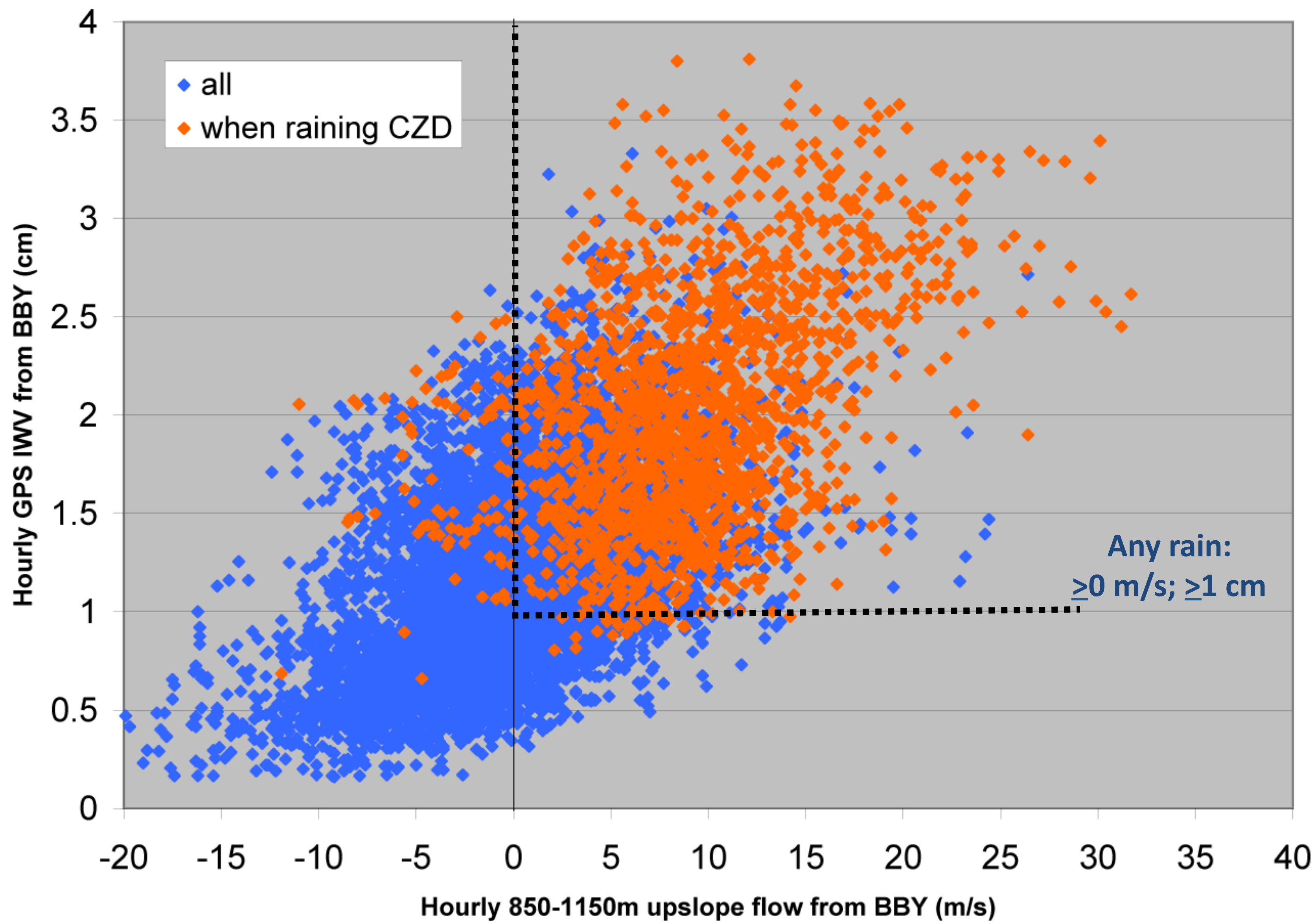


- 17 research aircraft missions offshore of CA documented atmospheric river structure.
- Wind, water vapor and static stability within atmospheric rivers are ideal for creation of heavy rainfall when they strike coastal mountains.

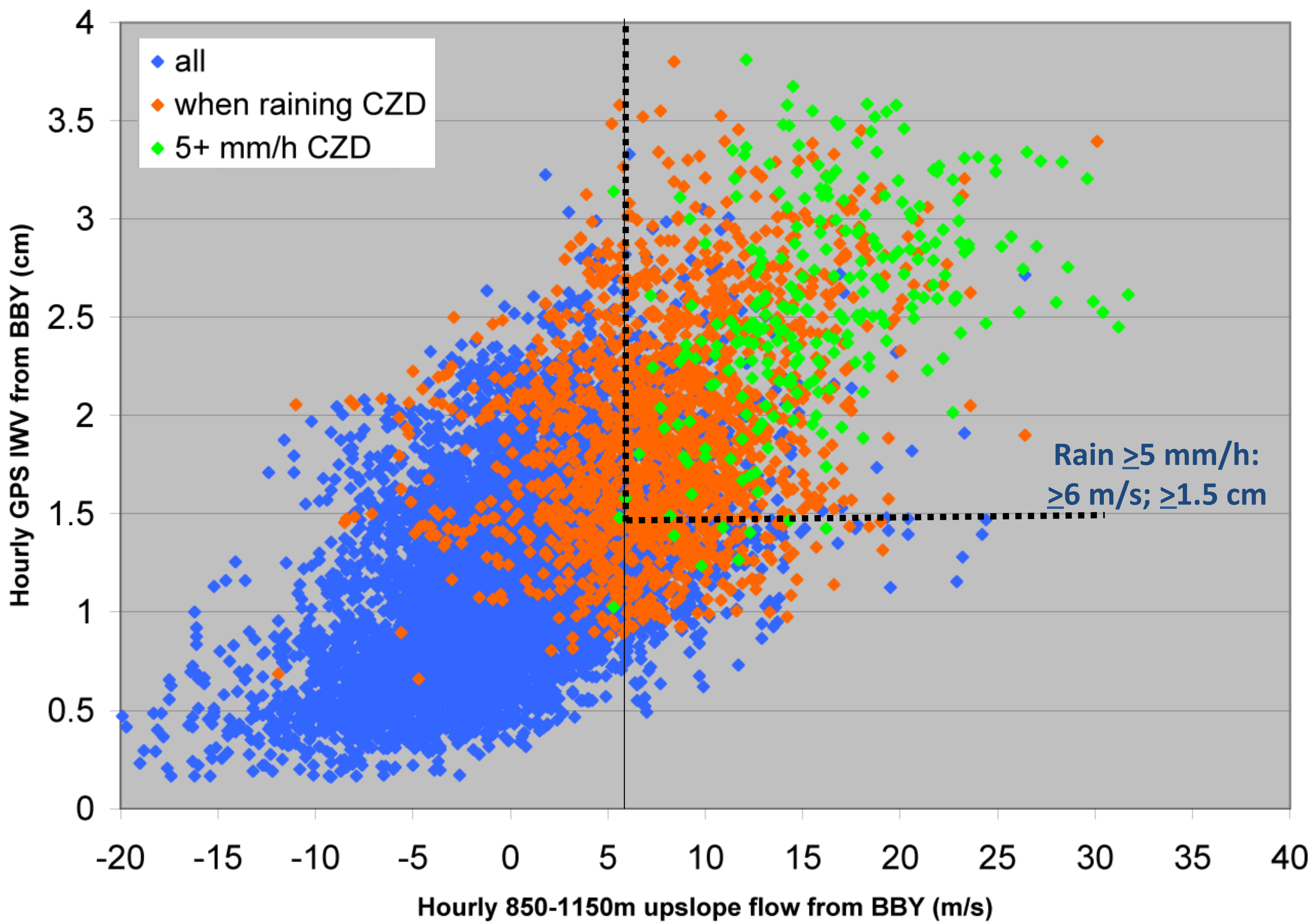
Ralph, Neiman and Rotunno (2005), *Mon. Wea. Rev*.



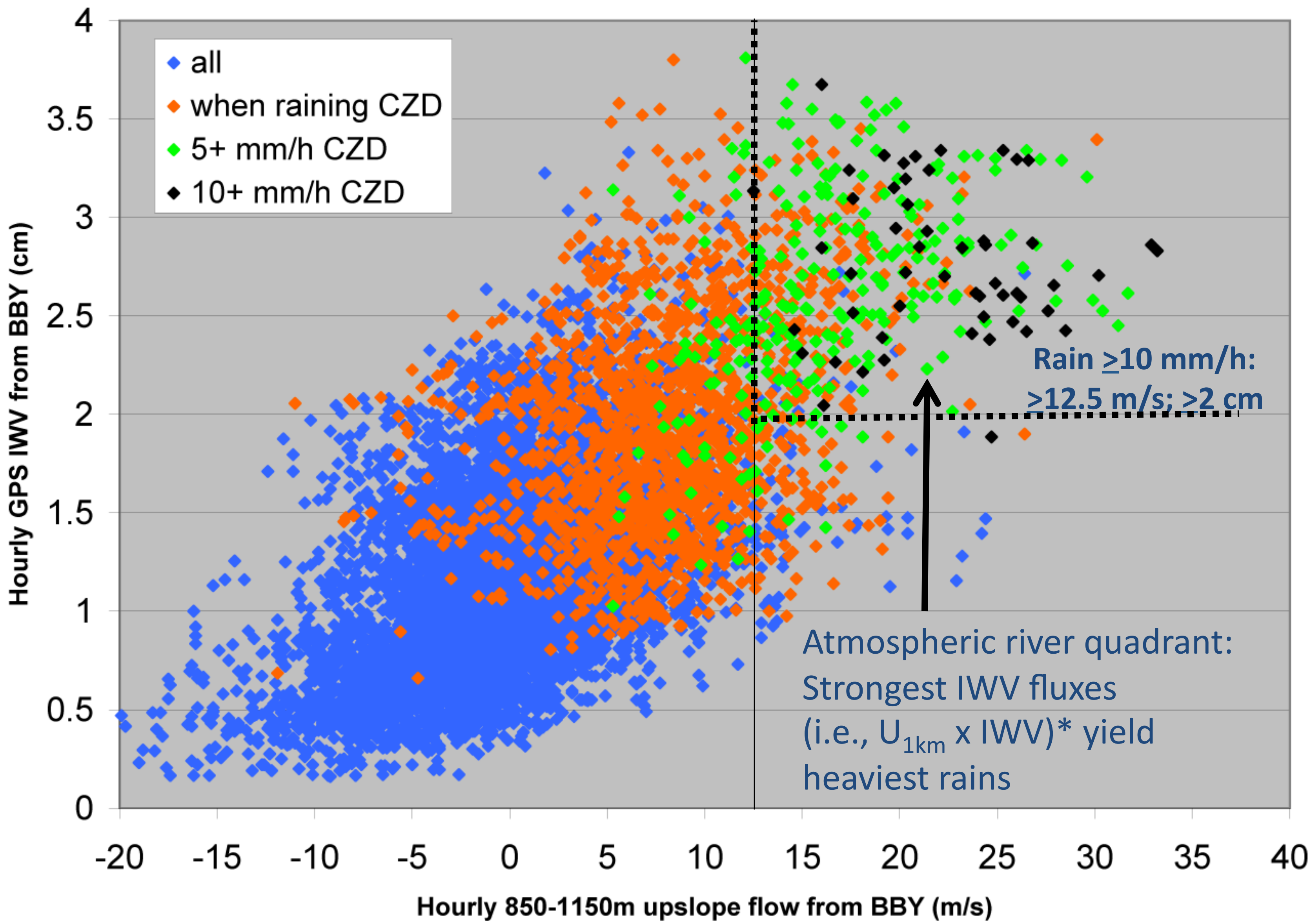
Component of the flow in the orographic controlling layer directed along 230°, i.e., orthogonal to the axis of the coastal mtns



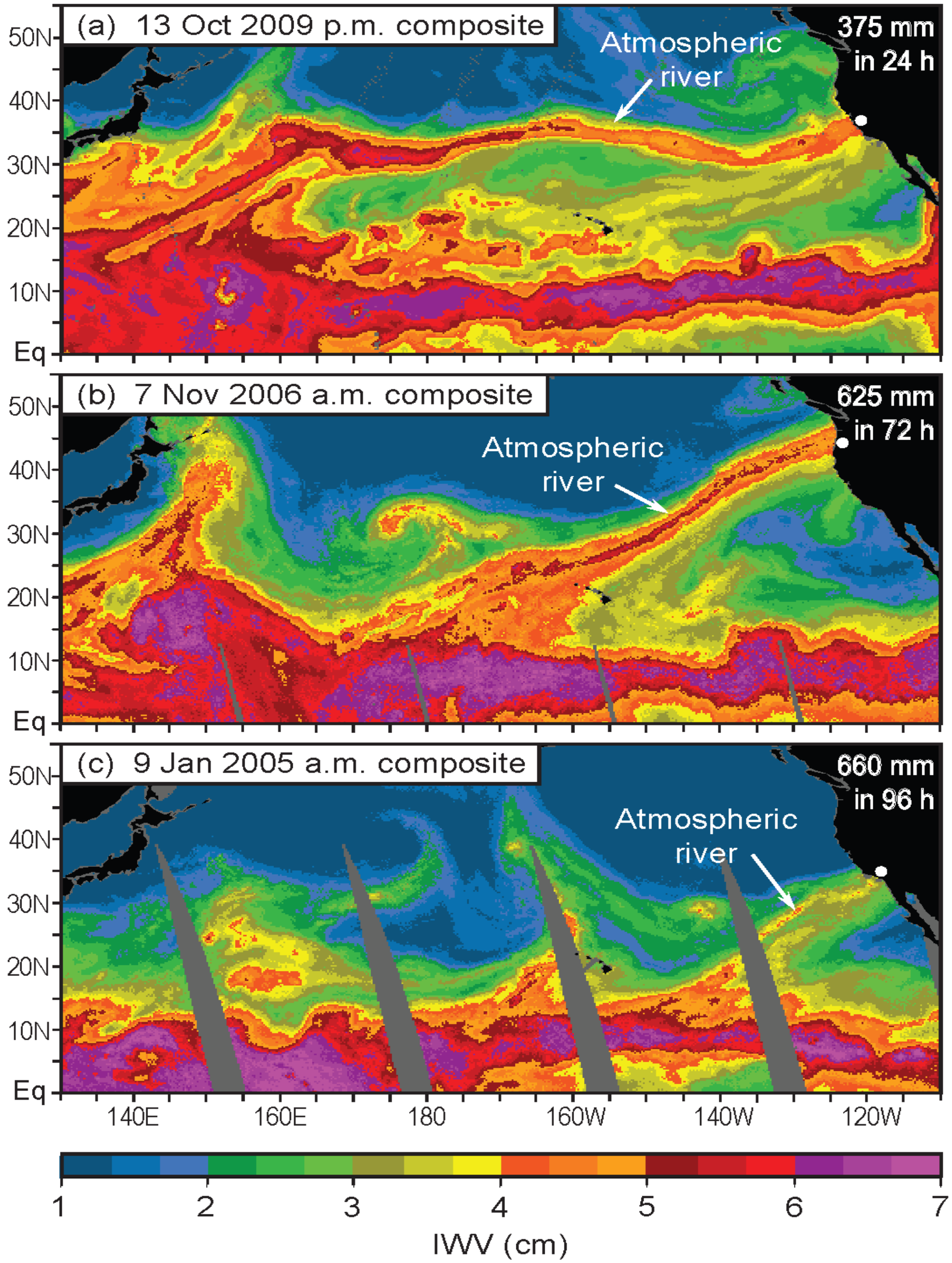
all
when raining CZD
Any rain:
≥0 m/s; ≥1 cm
Hourly GPS IWV from BBY (cm)
Hourly 850-1150m upslope flow from BBY (m/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40



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)



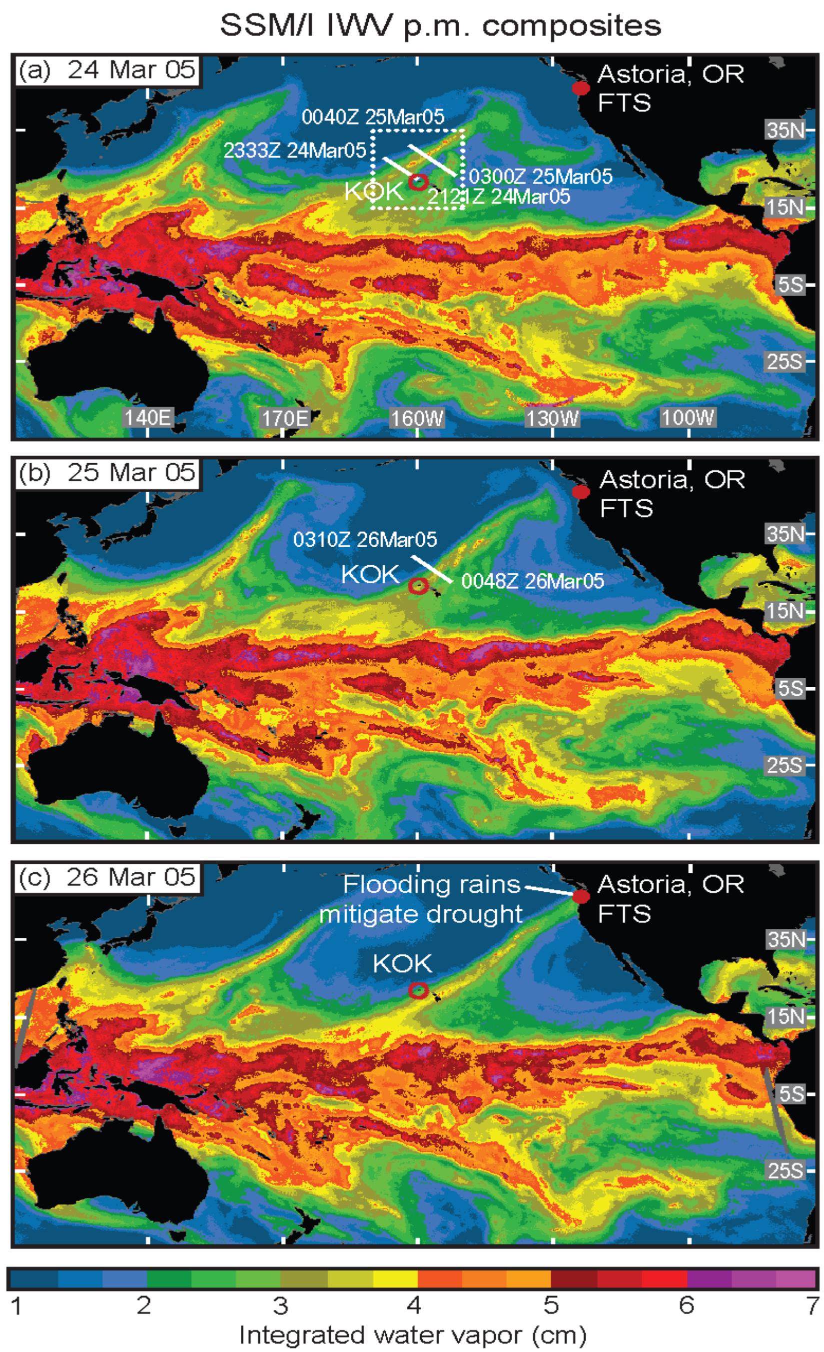
all
when raining CZD
5+ mm/h CZD
10+ mm/h CZD
Hourly GPS IWV from BBY (cm)
Hourly 850-1150m upslope flow from BBY (m/s)
Rain ≥10 mm/h:
≥12.5 m/s; ≥2 cm
Atmospheric river quadrant:
Strongest IWV fluxes
(i.e., U_{1km} x IWV)* yield
heaviest rains



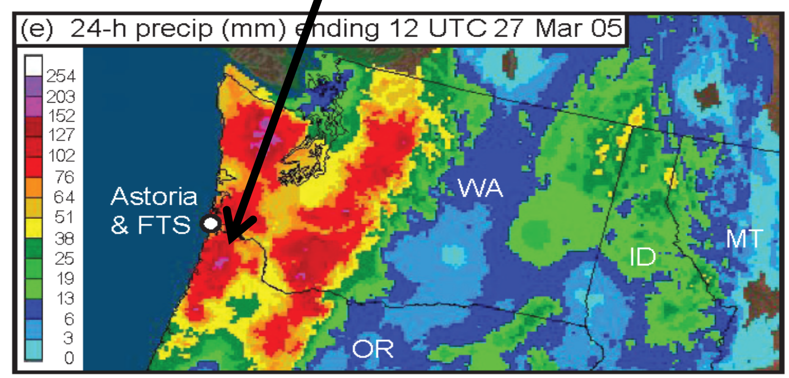
Three examples suggestive of entrainment of tropical water vapor

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.

March 2005 Case Study

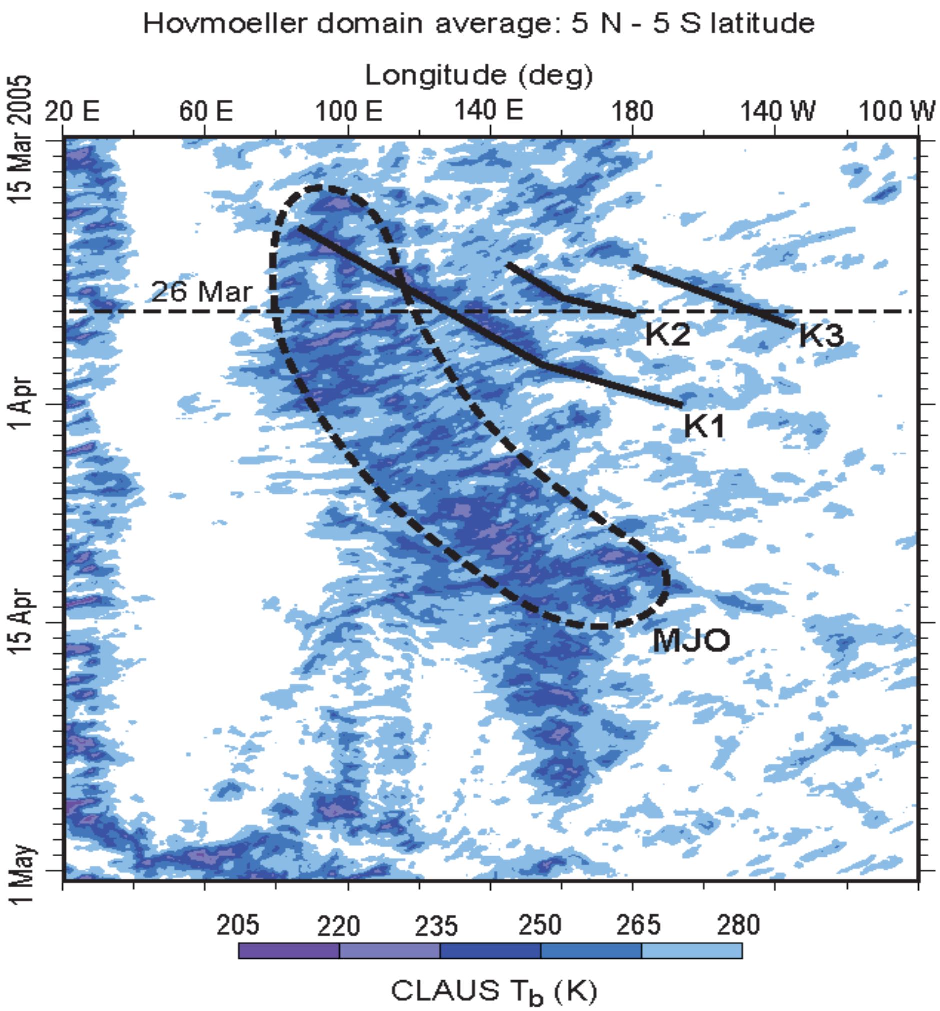


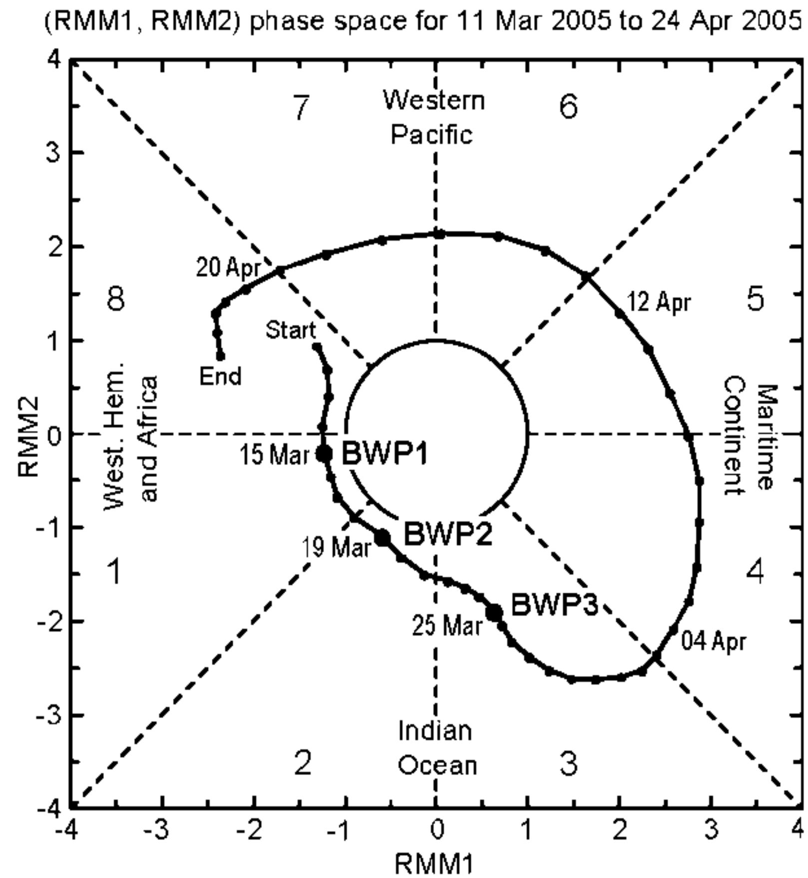
Max Rainfall: 8 inches in 30 h



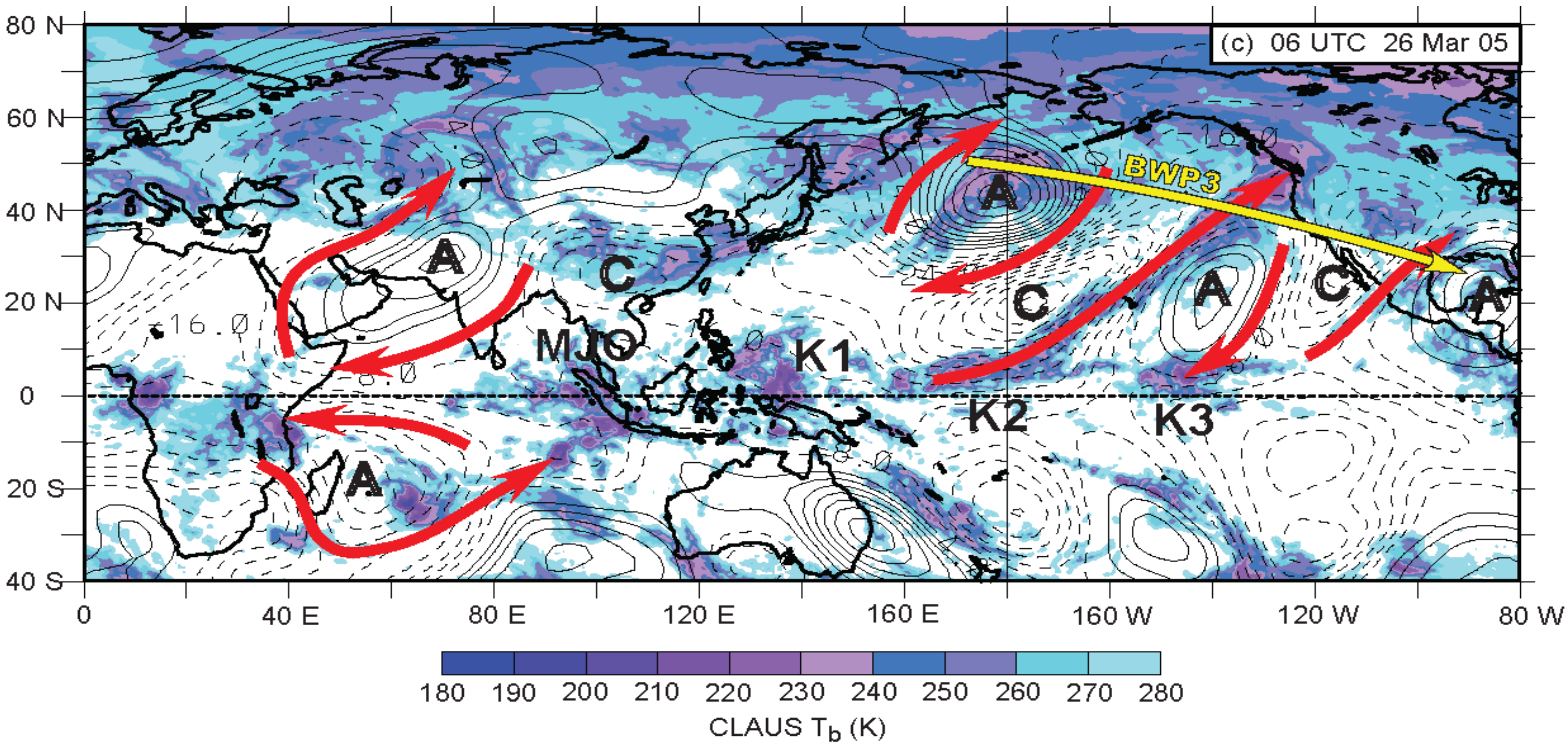
Overview of the March 2005 event studied here

An MJO and Equatorial Kelvin waves were present



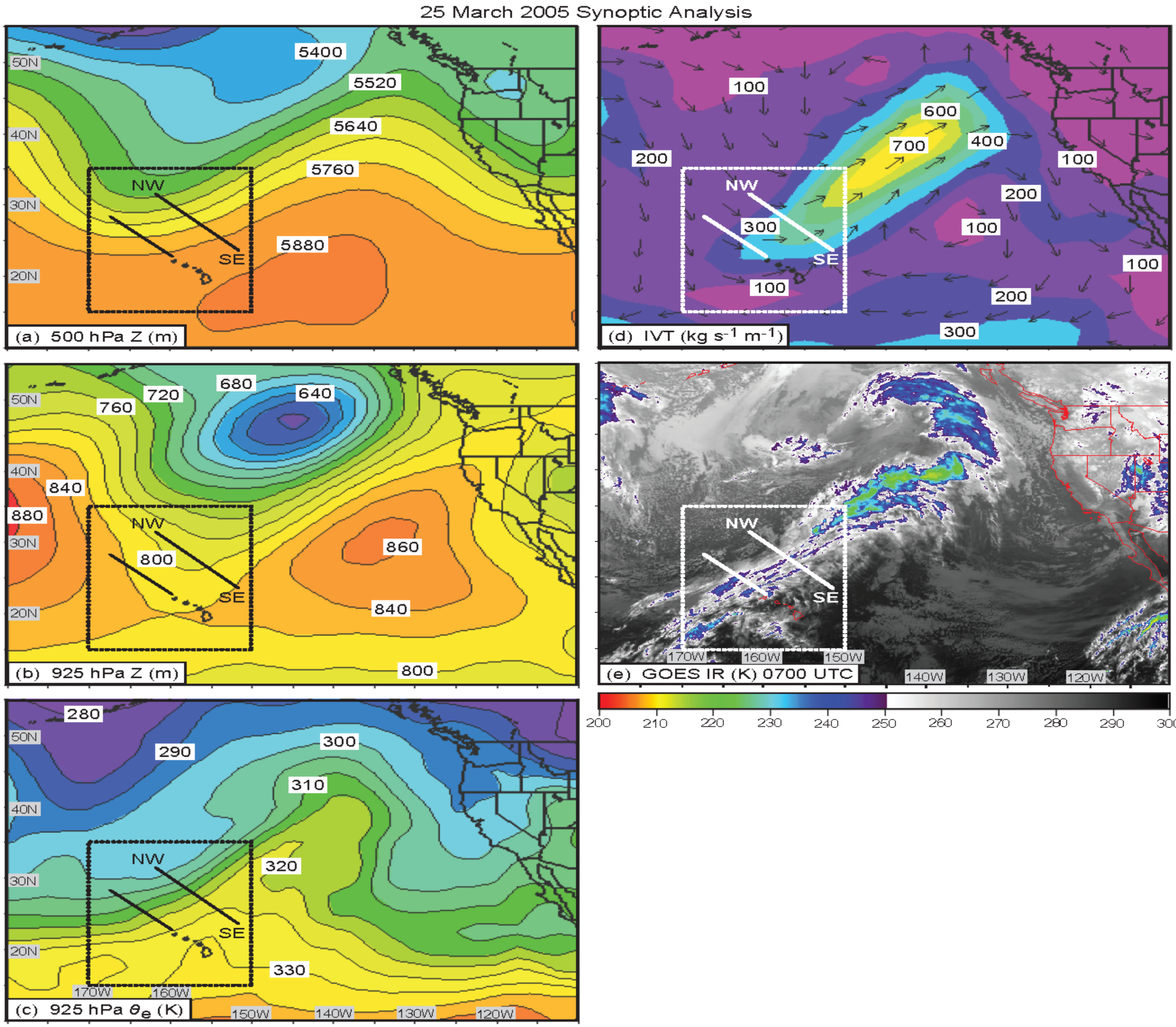


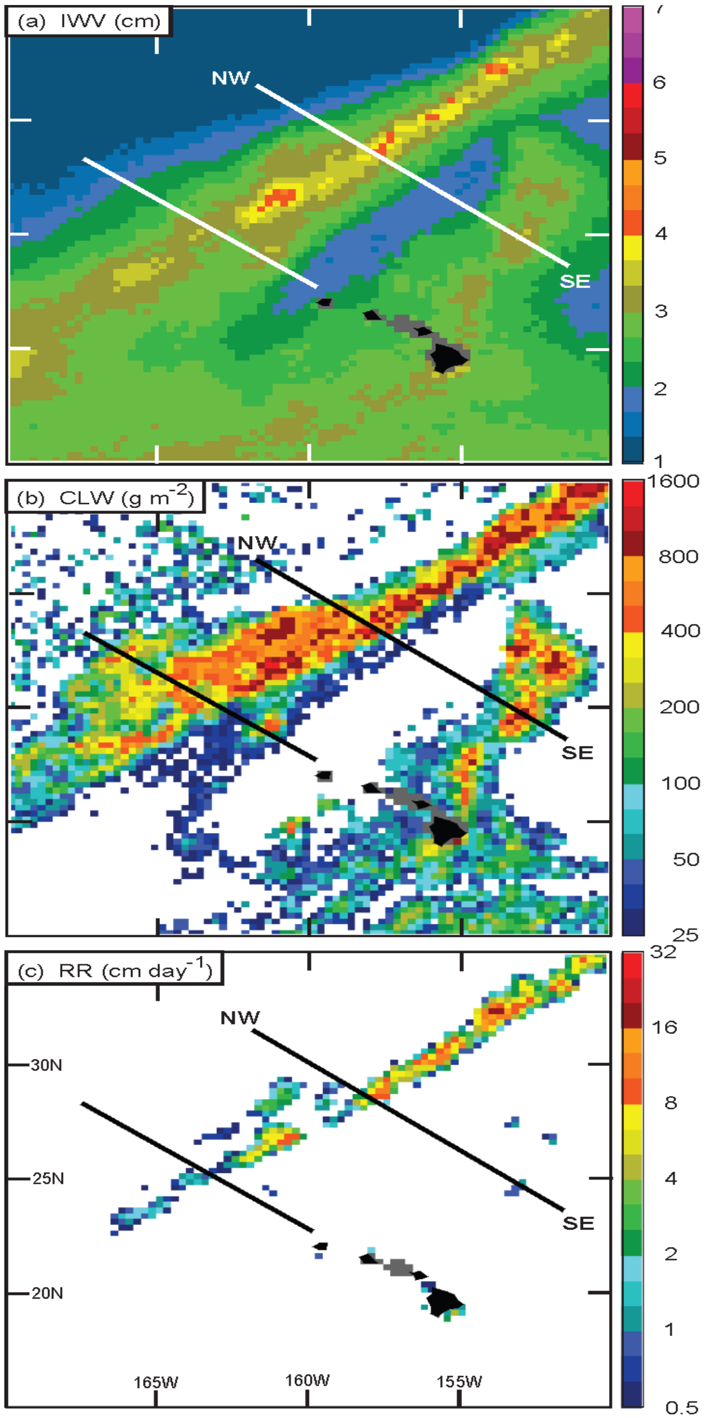
Summary of large-scale circulation patterns and key phenomena derived from stream function anomalies filtered to remove the first three harmonics of the mean seasonal cycle and from cloud patterns



150 hPa stream function perturbation and CLAUS Tb

Composite analyses derived from the NCEP–NCAR reanalysis dataset for 25 March 2005





SSM/I satellite imagery centered on 1744 UTC 24 March 2005, with P-3 flight tracks

Integrated water vapor

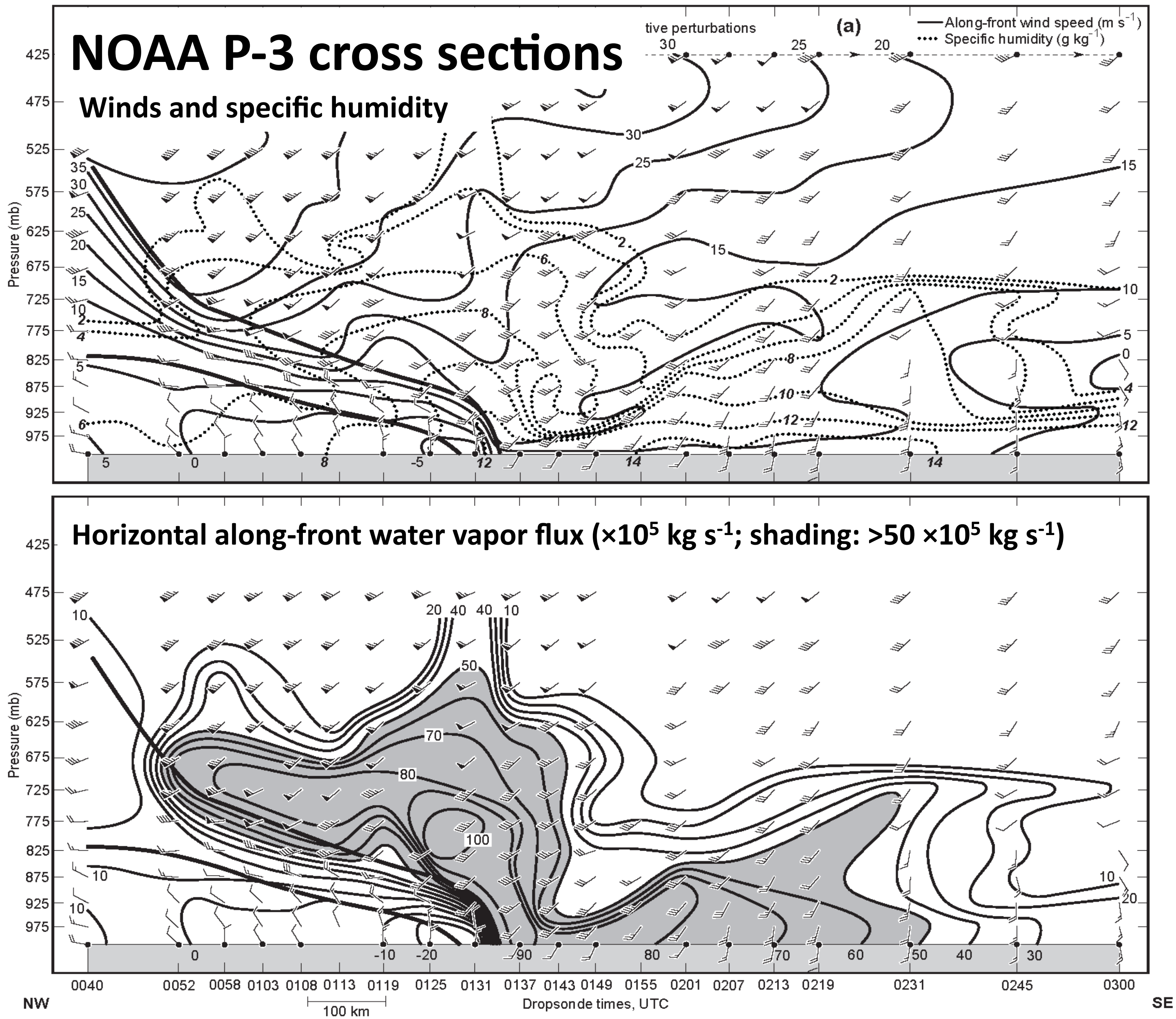
Cloud liquid water

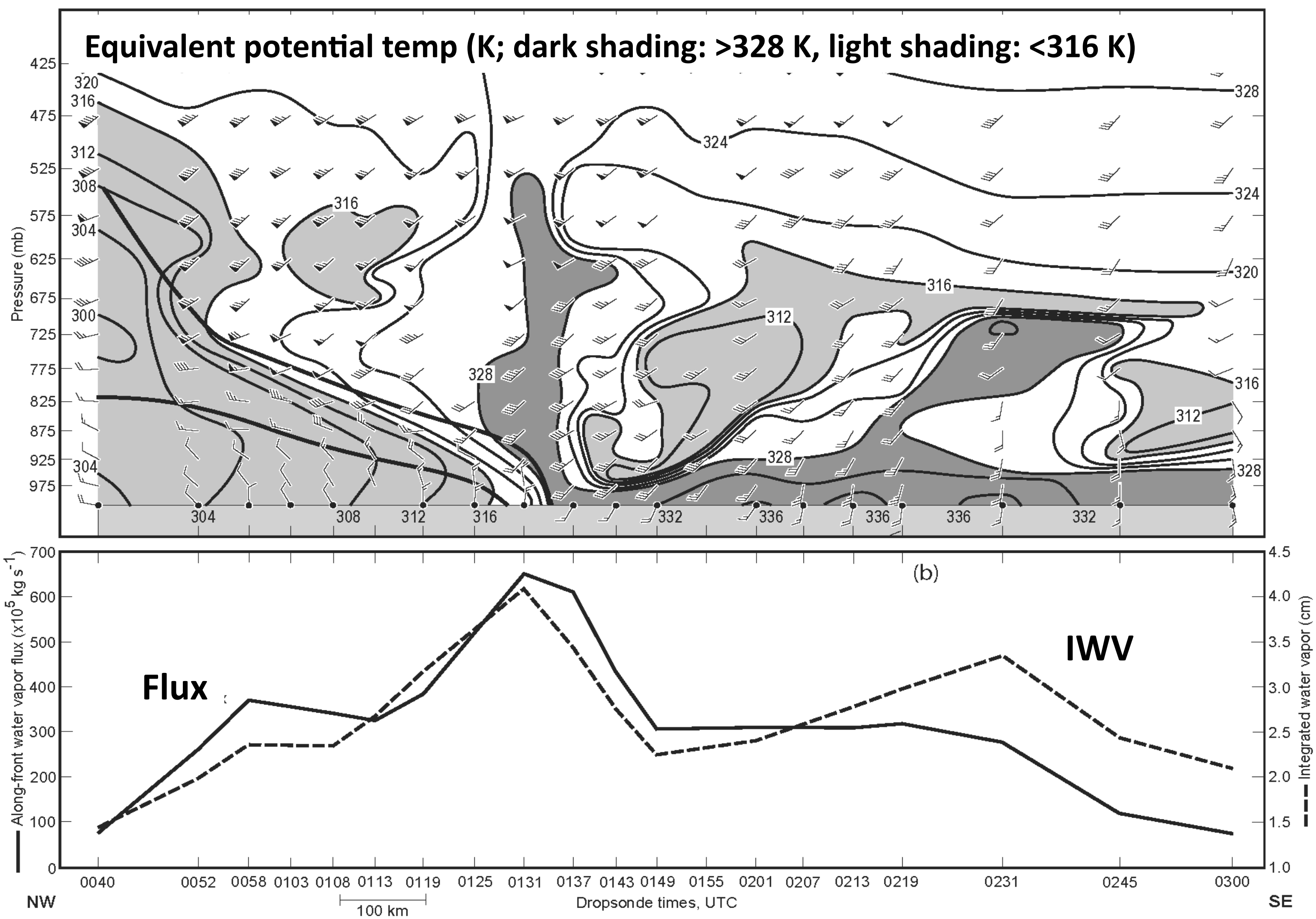
Rain rate

NOAA P-3 cross sections

Winds and specific humidity

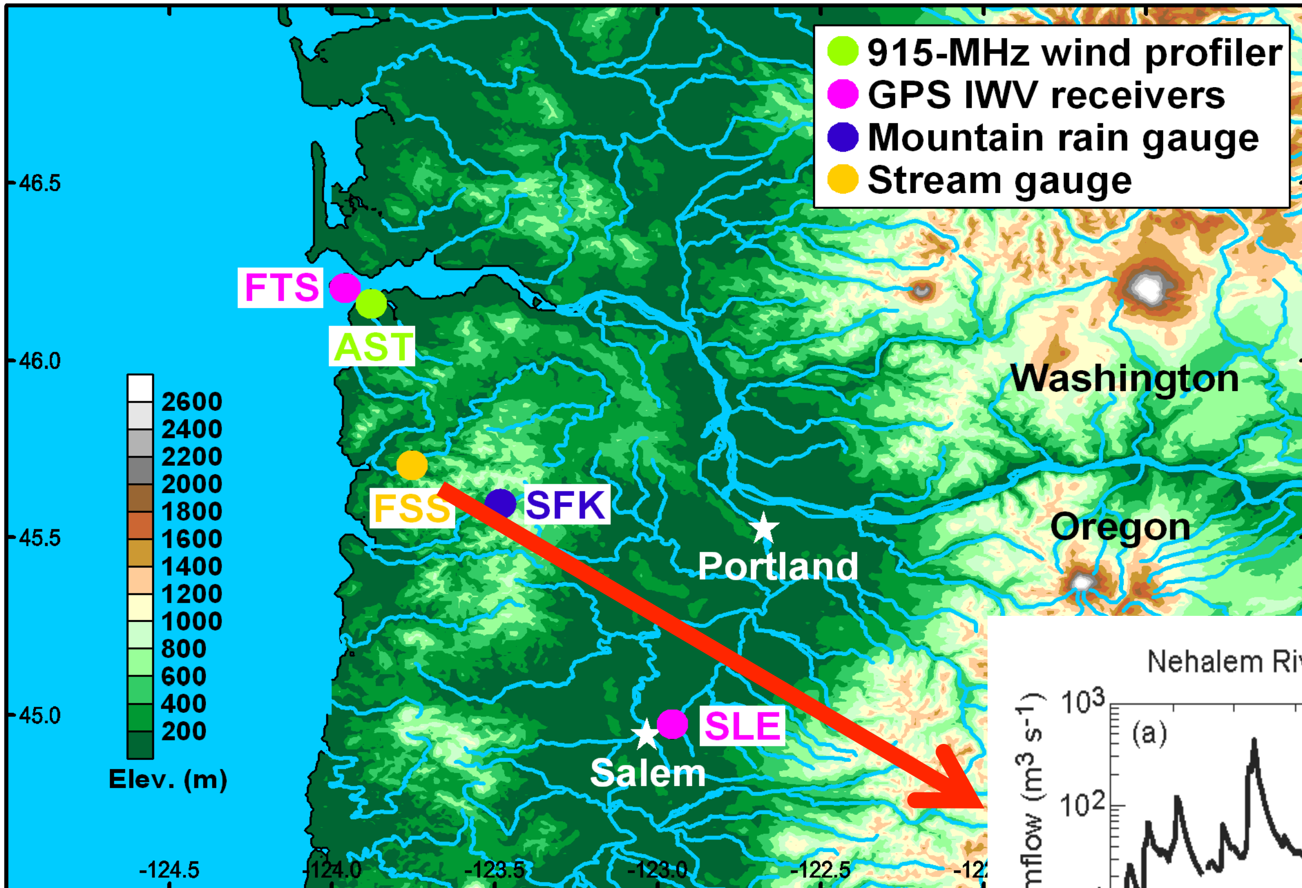
Horizontal along-front water vapor flux (×10^5 kg s^{-1}; shading: >50 ×10^5 kg s^{-1})

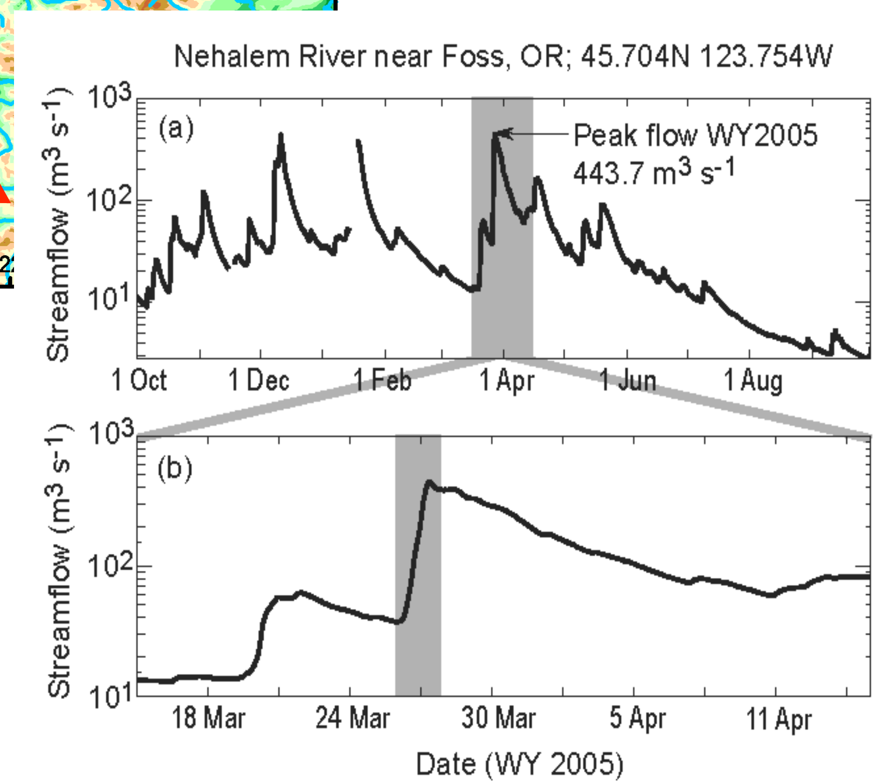




Equivalent potential temp (K; dark shading: >328 K, light shading: <316 K)
Pressure (mb)
(b)
Flux
IWV
Along-front water vapor flux (x10^5 kg s^-1)
Integrated water vapor (cm)
Dropsonde times, UTC
100 km
NW
SE

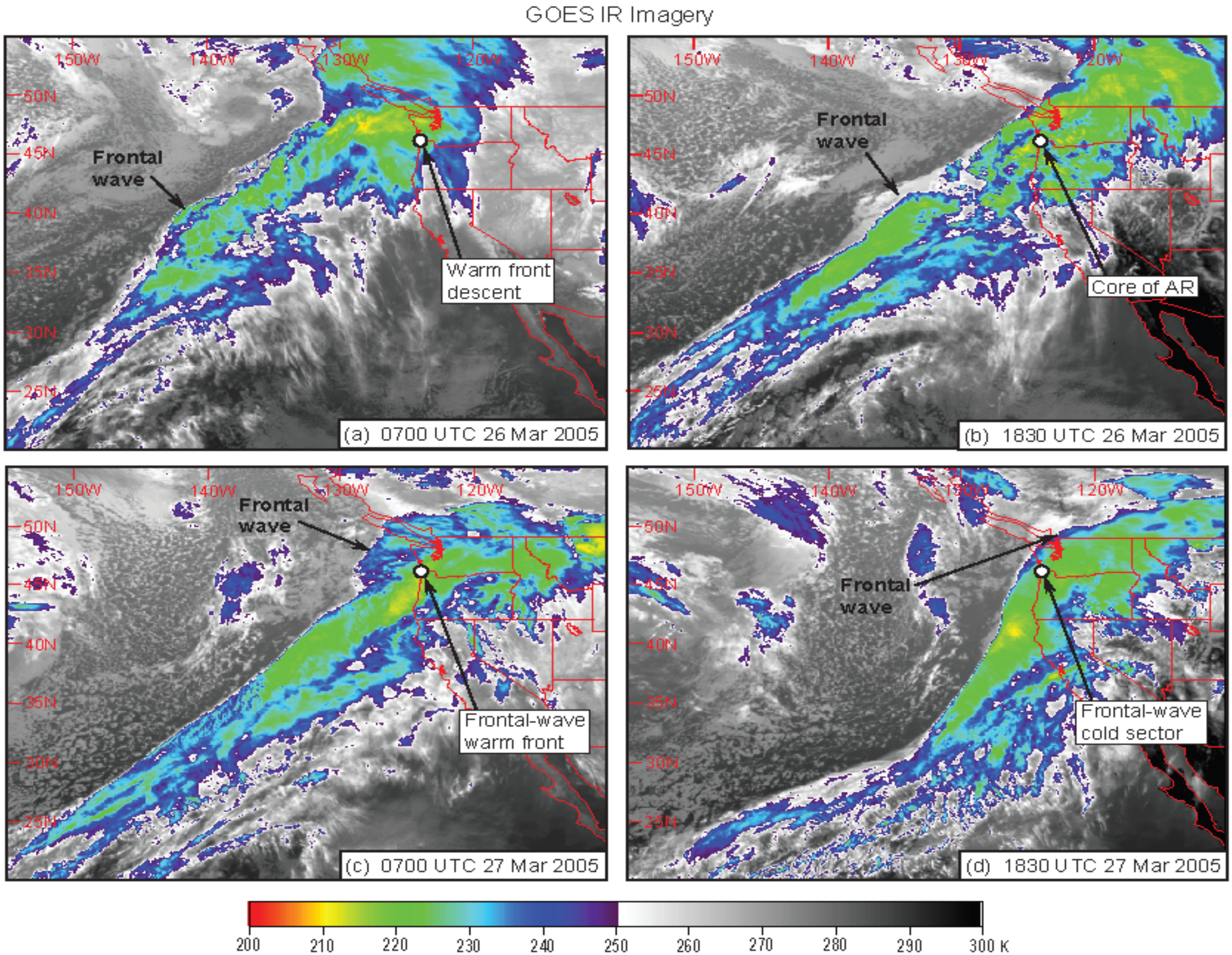
Region affected by AR landfall and extreme precip.

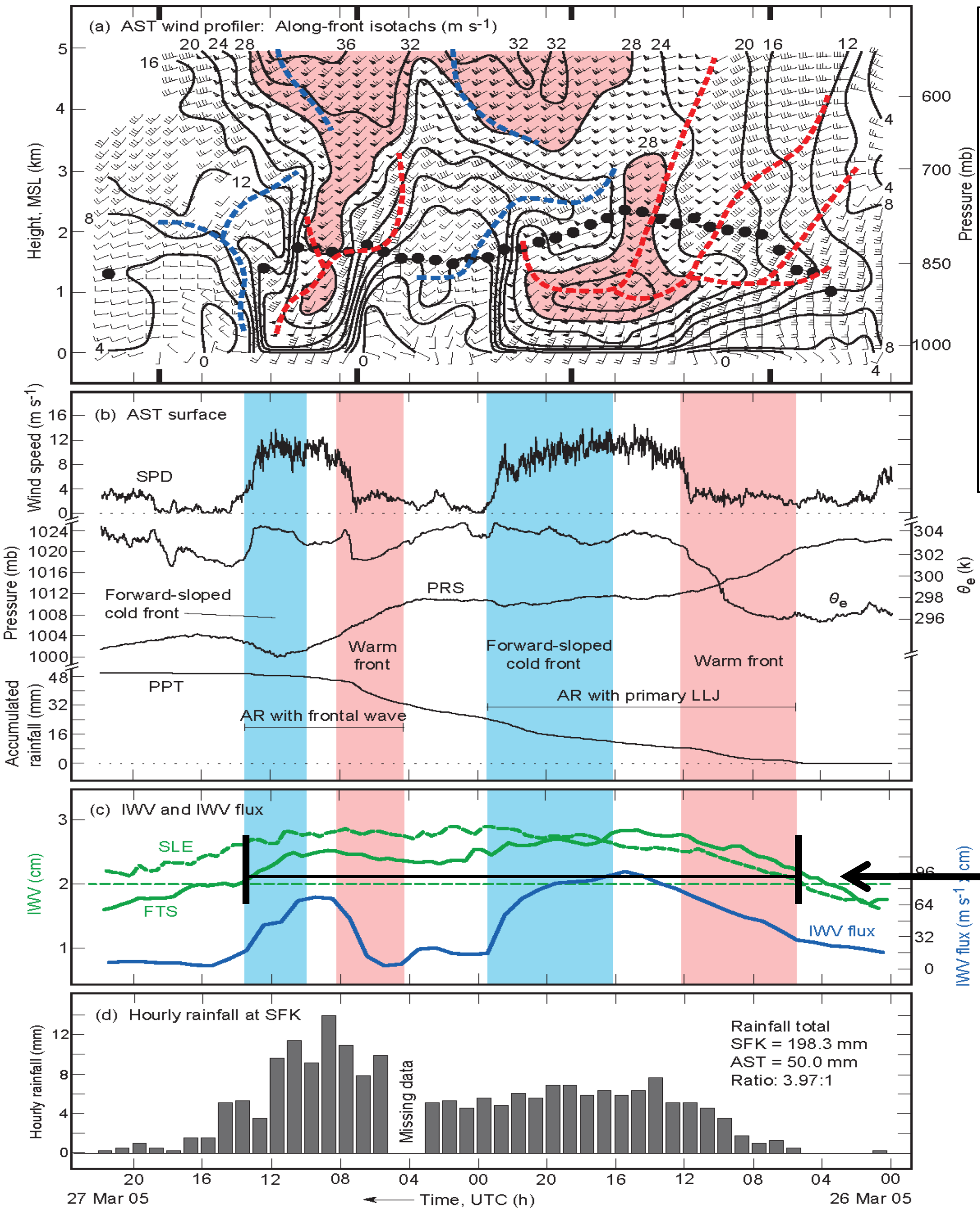




The 27 March storm created the maximum runoff for water year 2005

IR satellite image sequence showing development of a frontal wave



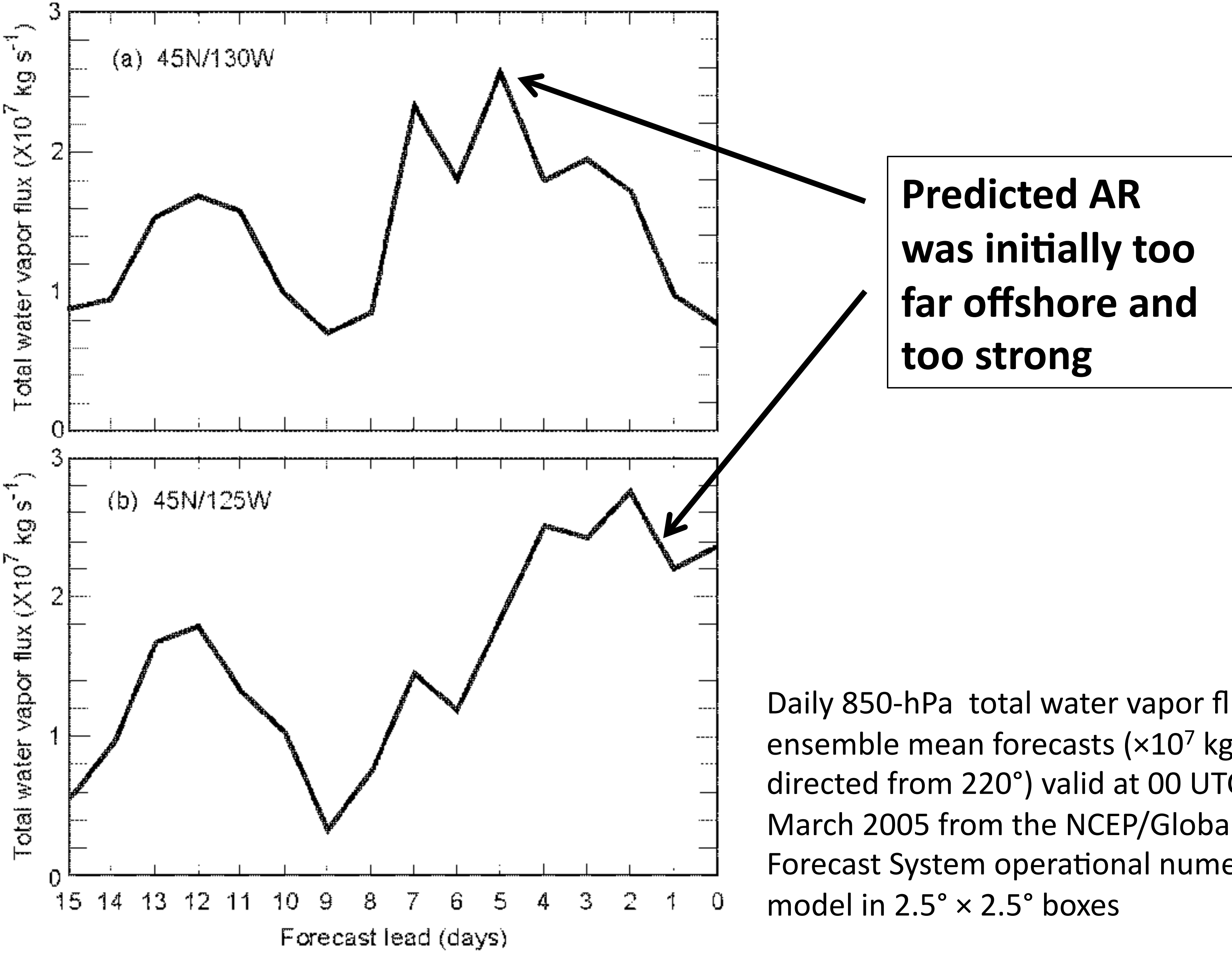


Wind profiler, GPS-met and surface observations on the NW Oregon coast showing:

- AR conditions and

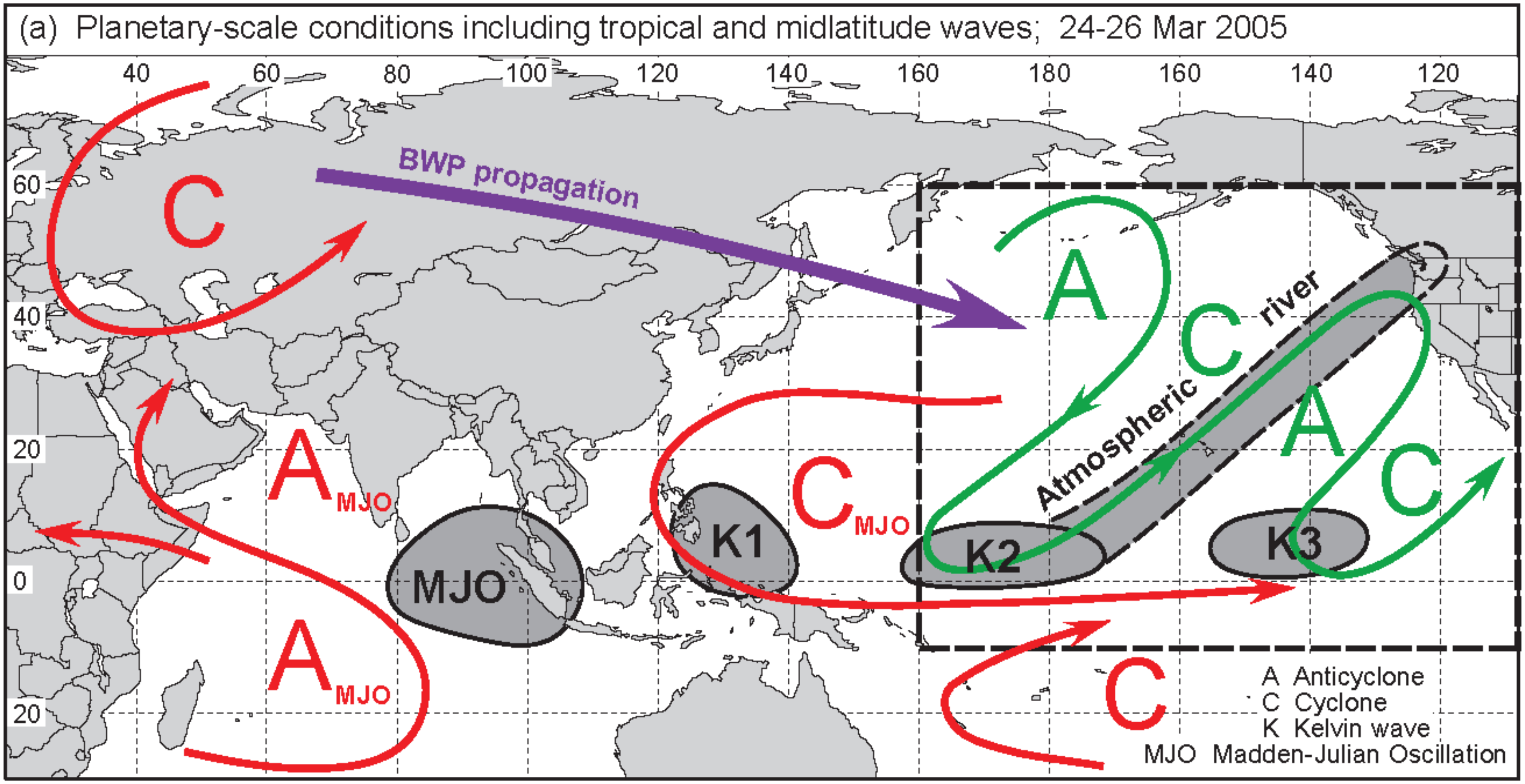
- passage of a frontal wave.

AR conditions persisted for >28 hours.



Daily 850-hPa total water vapor flux ensemble mean forecasts ($\times 10^{7}$ kg s^{-1}; directed from 220°) valid at 00 UTC 27 March 2005 from the NCEP/Global Forecast System operational numerical model in 2.5° × 2.5° boxes

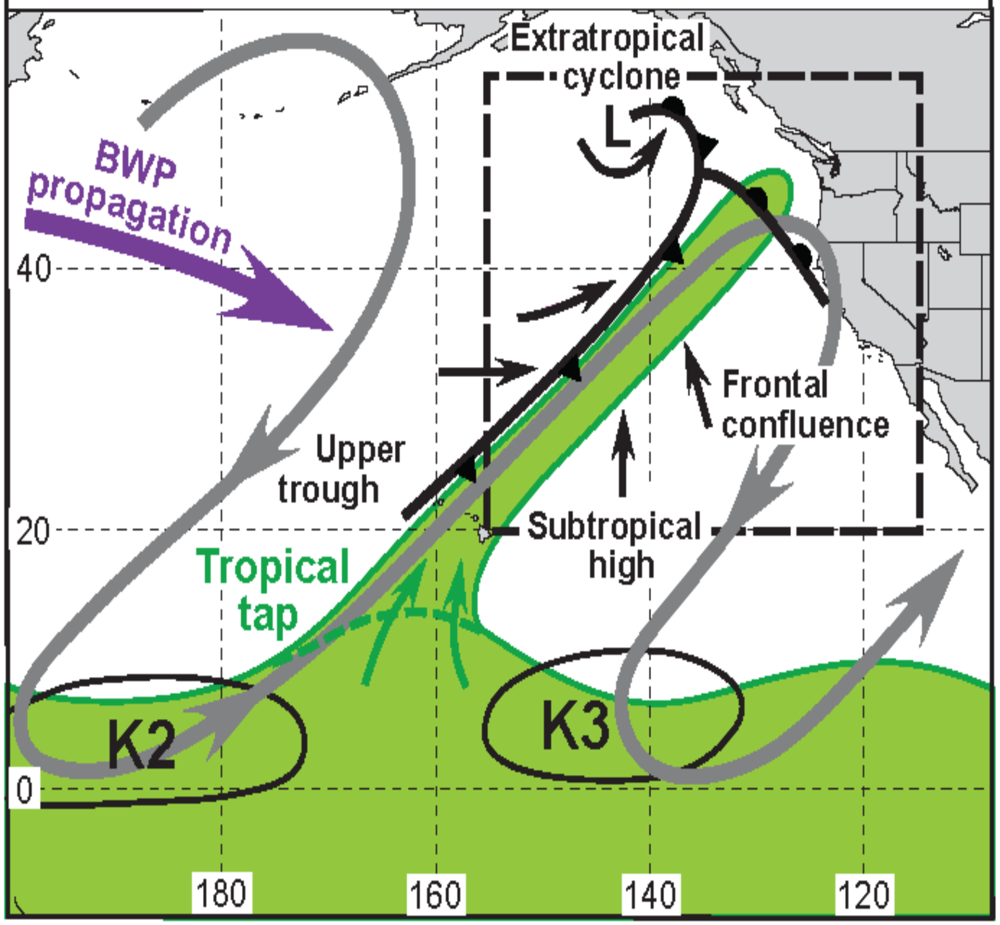
Planetary- and synoptic-scale conditions in the March 2005 case



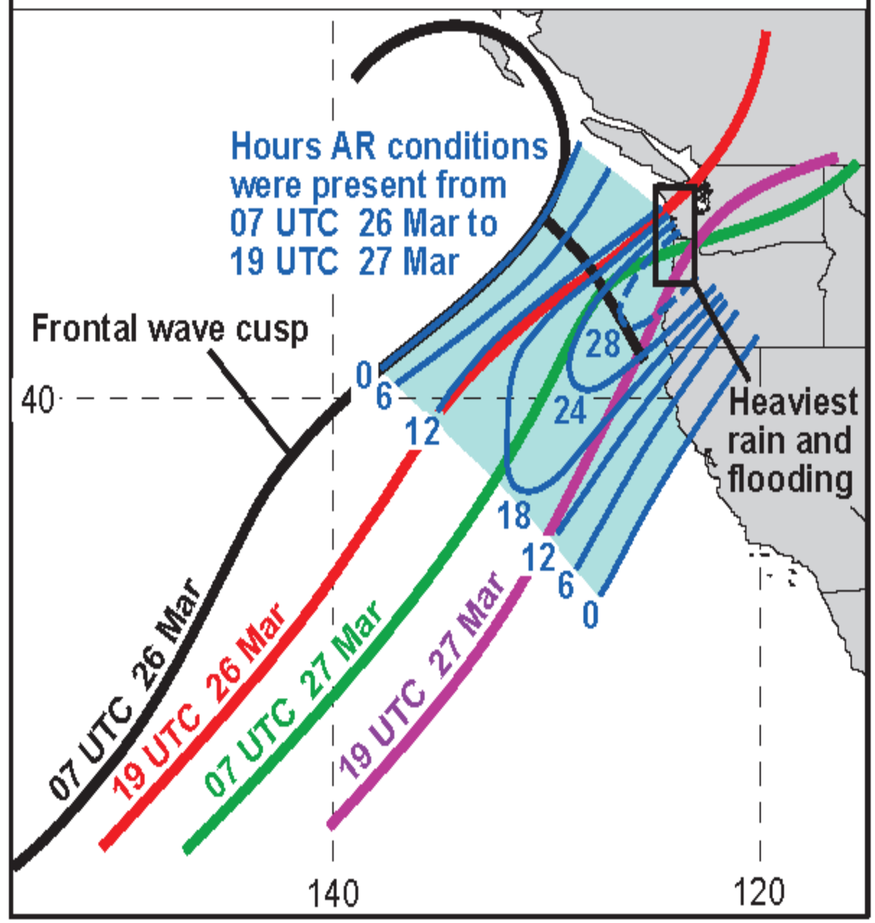
Phasing of tropical and extratropical conditions leading to entrainment of tropical water vapor into the AR

The frontal wave increased the duration of AR conditions where the extreme precipitation occured

(b) Synoptic-scale conditions including baroclinic wave packet; 24-26 Mar 2005



(c) Mesoscale conditions including frontal wave; 26-27 Mar 2005



Conclusions

- Moving from larger scales to smaller scales, the primary findings of this study are:
  - phasing of several major planetary-scale phenomena influenced by tropical-extratropical interactions led to the direct entrainment of tropical water vapor into the AR near Hawai'i,
  - dropsonde observations documented the northward advection of tropical water vapor into the subtropical extension of the midlatitude AR, and
  - a mesoscale frontal wave increased the duration of AR conditions at landfall in the Pacific Northwest.

Related modeling challenges

- Simulate the key processes from the MJO to Equatorial Kelvin waves to Baroclinic wave packets, AR and a mesoscale frontal wave.
- Accurately represent the terms in the water vapor budget in ARs, from frontal convergence, to surface energy fluxes, condensation, rainout and evaporation.
- Phasing and amplitudes of MJOs, ARs and mesoscale frontal waves are important on time scales from days to weeks.
- Extreme precipitation event predictions and climate projections depend upon getting these right.

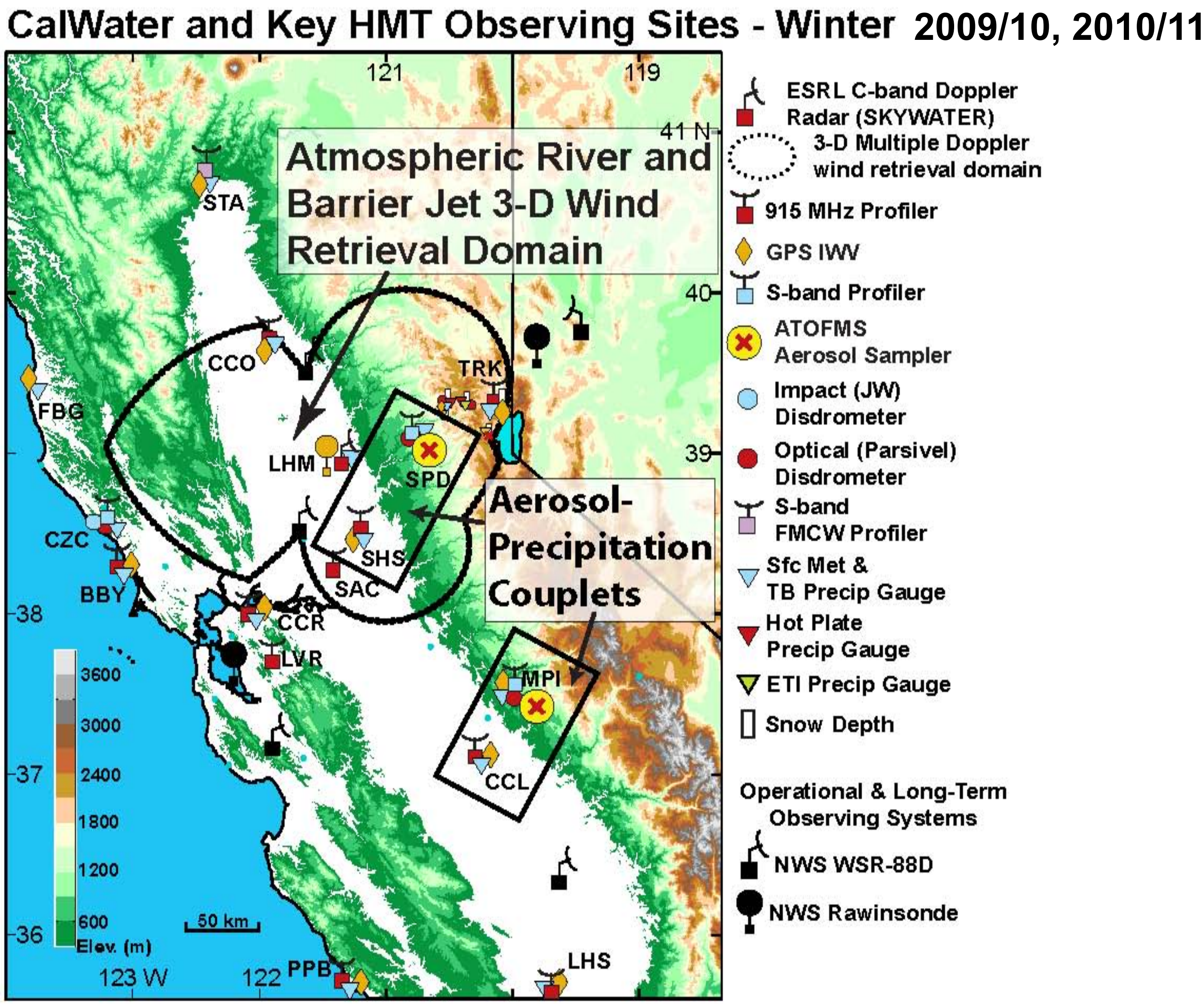
CalWater Experiment

Major Sponsors/Partners

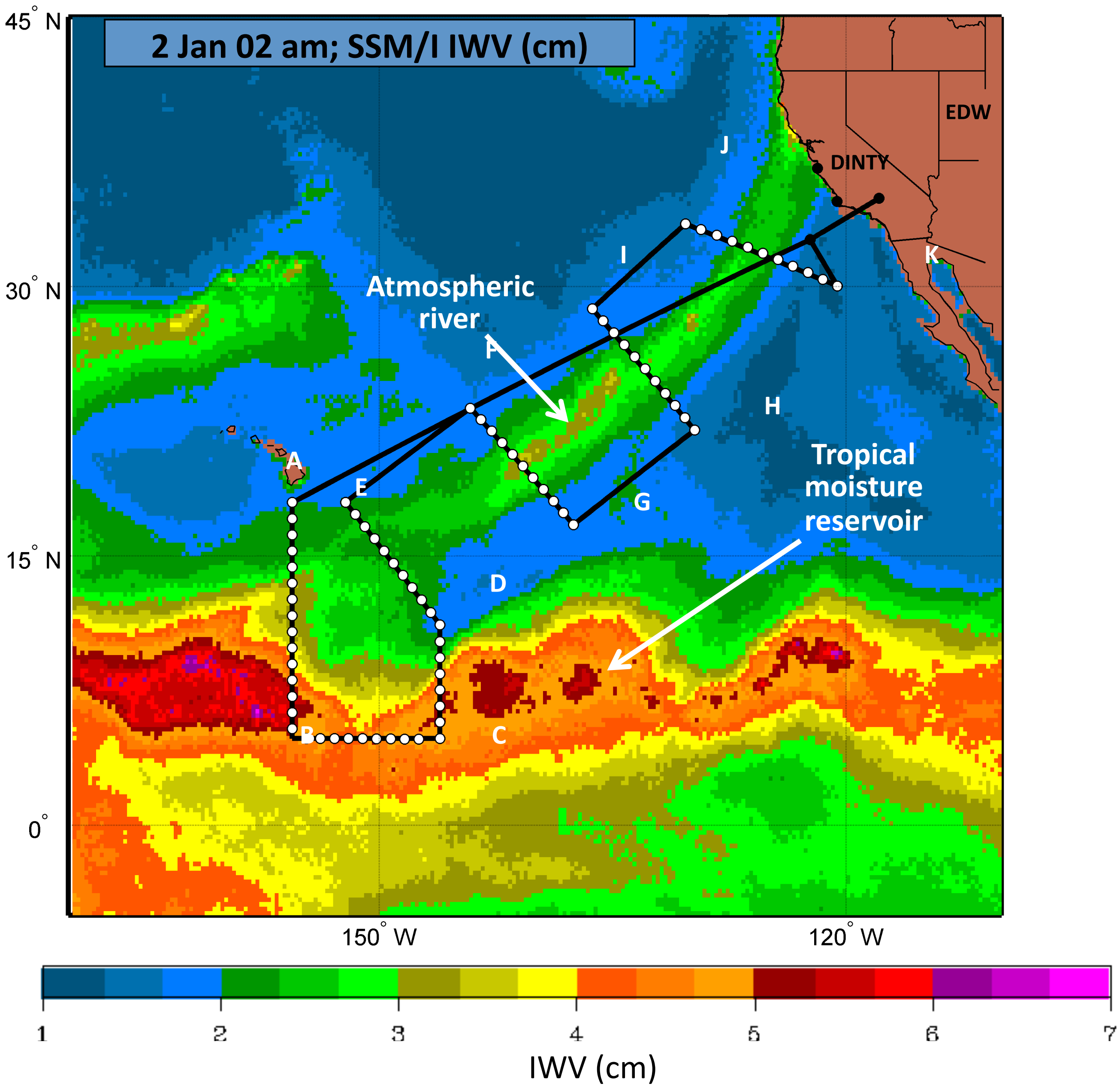
California Energy Commission, NOAA, Scripps

- Two primary science themes
  - Assessing uncertainties in climate projections of ARs and their influence on uncertainties in projections of extreme precipitation events and water supply
  - Assessing potential aerosol impacts on orographic precipitation
- Phase 1 is underway (2009-2011)
  - Focused on impacts of the Sierra Nevada on ARs, including the role of the Sierra Barrier Jet in modulating precipitation distributions and aerosol transports
- Phase 2 is being planned
  - Focuses on the water vapor transport budget in ARs over the ocean, and the potential role of tropical processes
- **Potential for collaborations between CMMAP and CalWater**

CalWater Phase I



CalWater Phase II



Global Hawk Atmospheric River/ Tropical Tap Flight Plan

Distance (DINTY-DINTY):
- ~7600 nmi or ~14,000 km

Assumed Speed:
- 335 knots or 172.4 m/s

Cruising Altitude:
- ~18 km (~60kft)

Flight Duration:
- EDW-DINTY RT: ~4.5 hours
- DINTY-DINTY: ~22.7 hours

Sampling Legs
- A-B: 1460 km
- B-C: 1000 km
- C-D: 700 km
- D-E: 1000 km
- F-G: 1000 km
- H-I: 1000 km
- J-K: 1000 km

Dropsonde spacing: 100 km

75 total dropsondes