

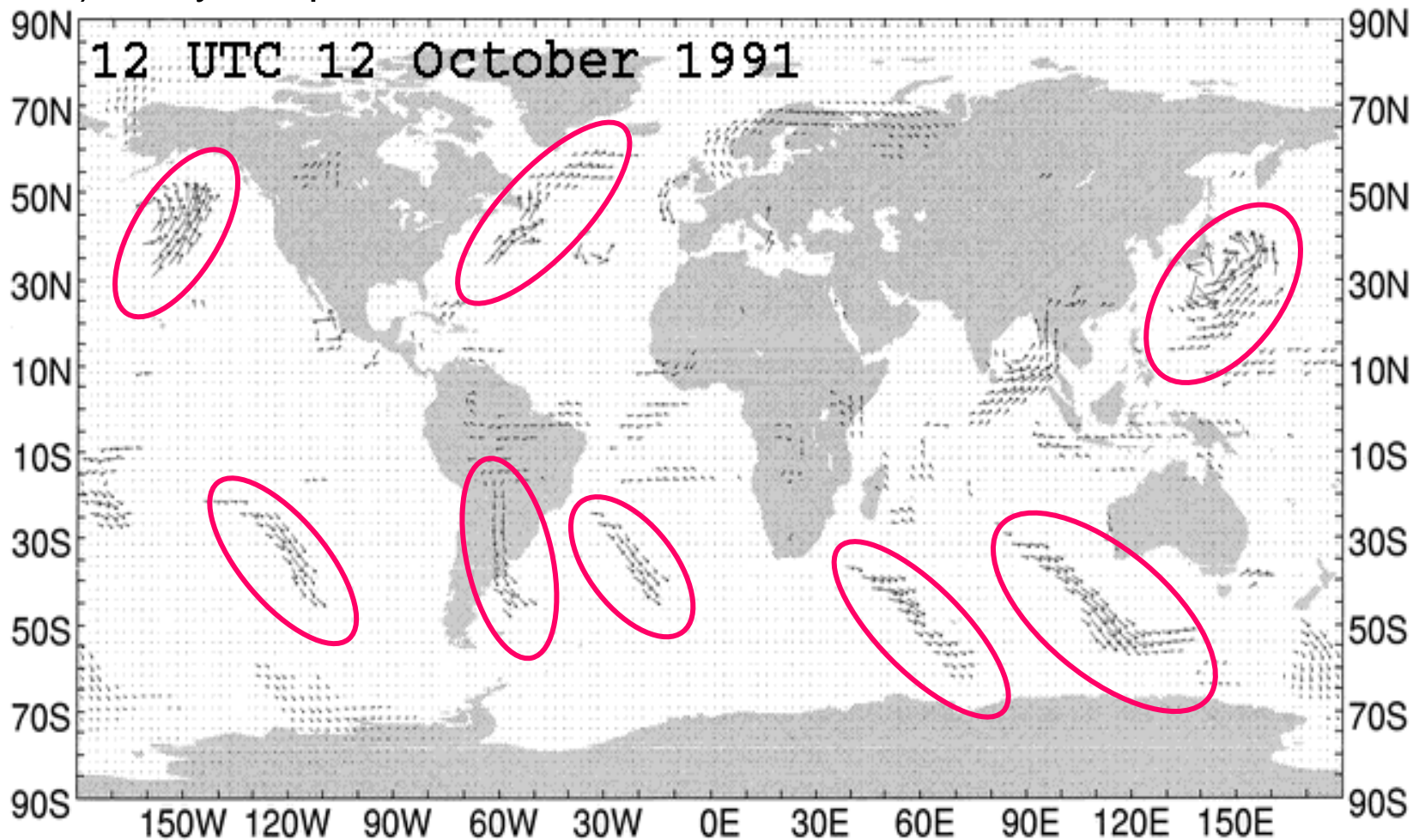
***Atmospheric Rivers:  
A Key to Understanding California  
Extreme Precipitation Events***

**Dr. F. Martin Ralph  
NOAA/Earth Systems Research Laboratory**

**2006 California Extreme Precipitation Symposium  
23 June 2006, Sacramento, California**

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

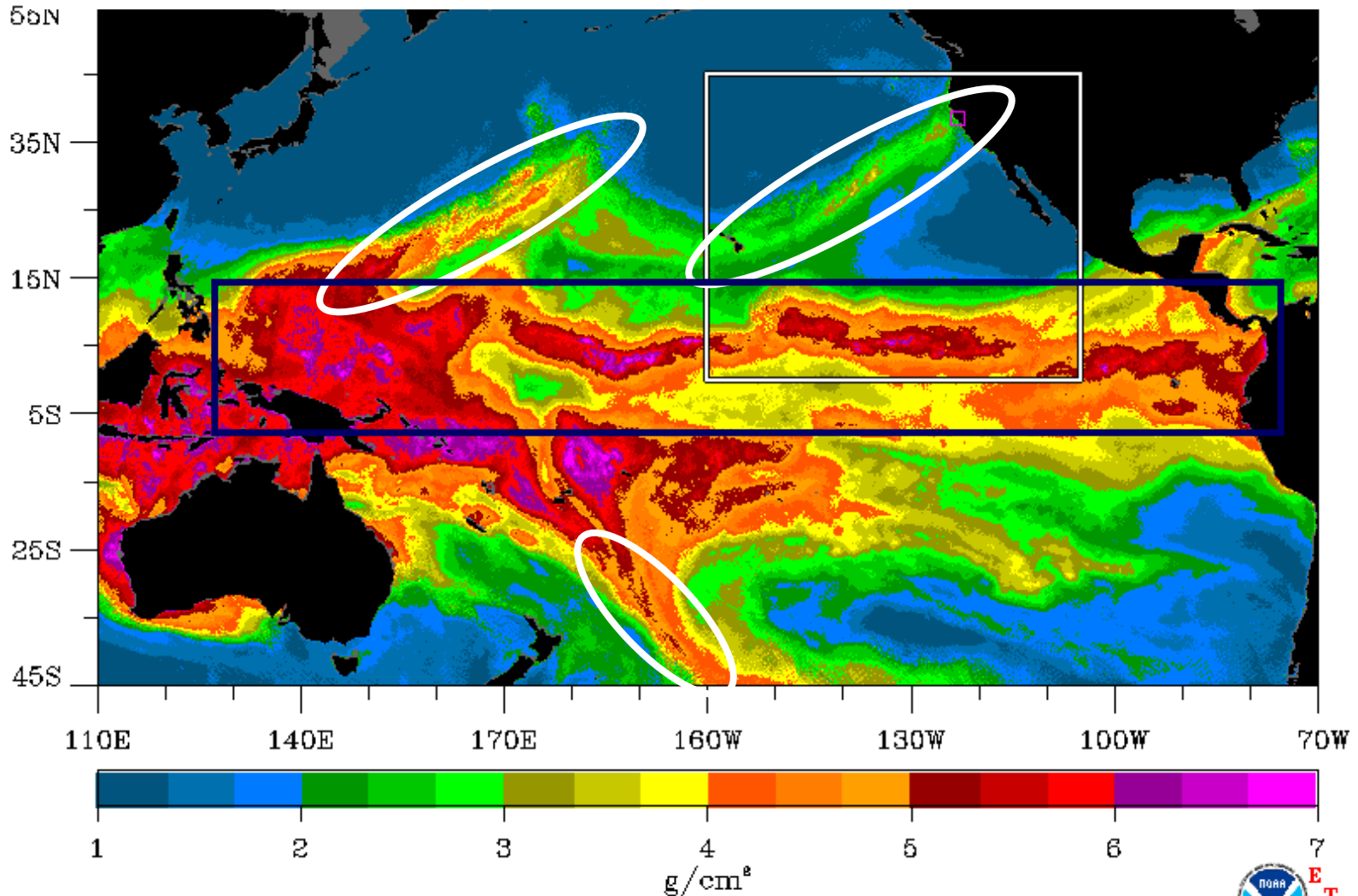
- 1) Most water vapor transport occurs in only a few narrow regions
- 2) There are 4-5 of these within a hemisphere at any one moment
- 3) They are part of storms and move with the “storm track”



**They coined the term “atmospheric river”**

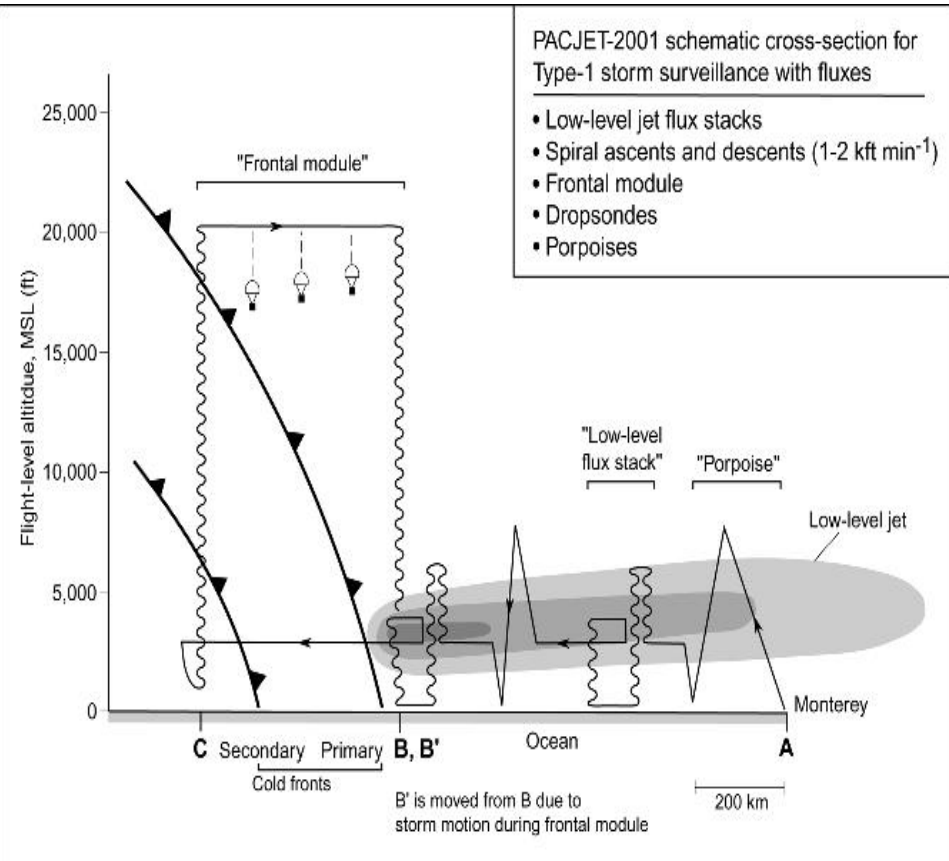
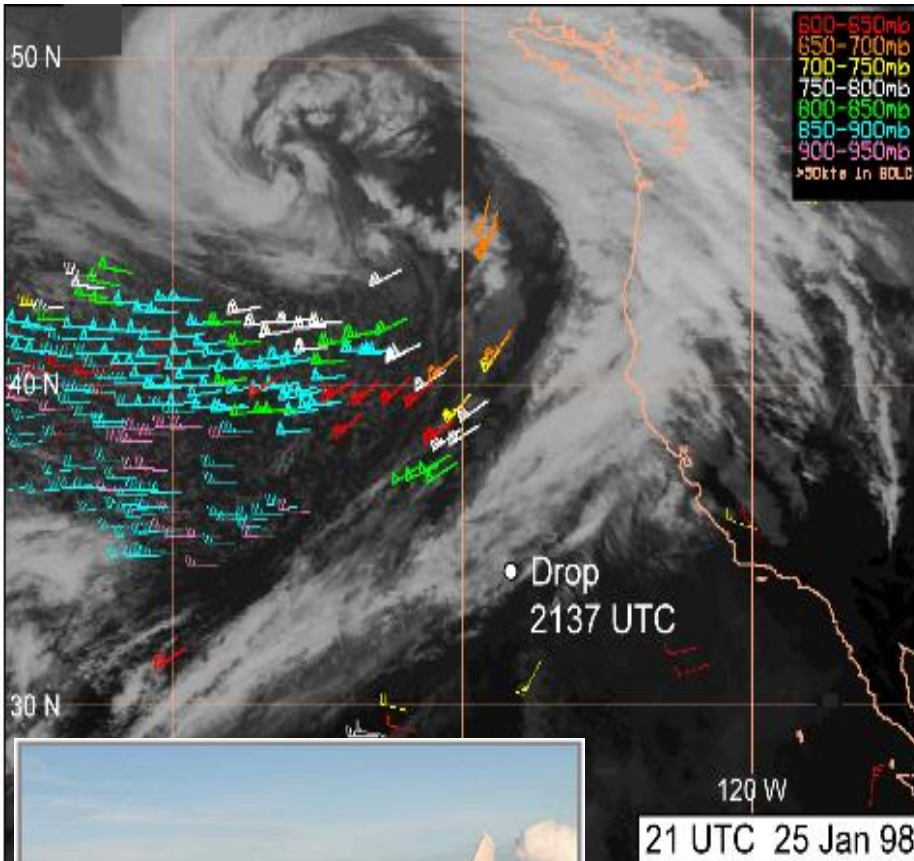
# Atmospheric Rivers

- Ralph et al. (2004) developed a method to use satellite observations of water vapor to identify the location, width and water vapor content in atmospheric rivers



# Representative storm-relative position

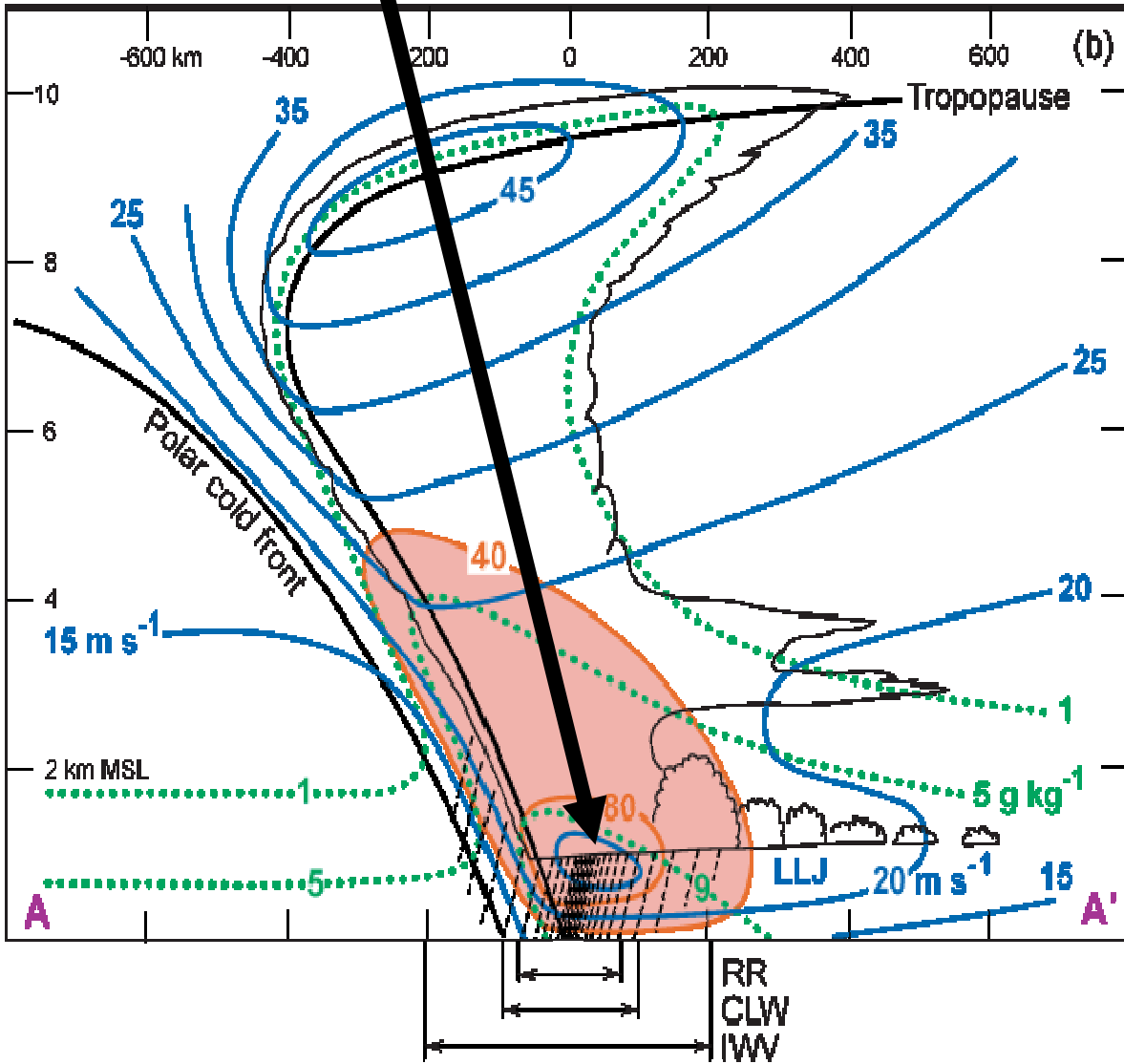
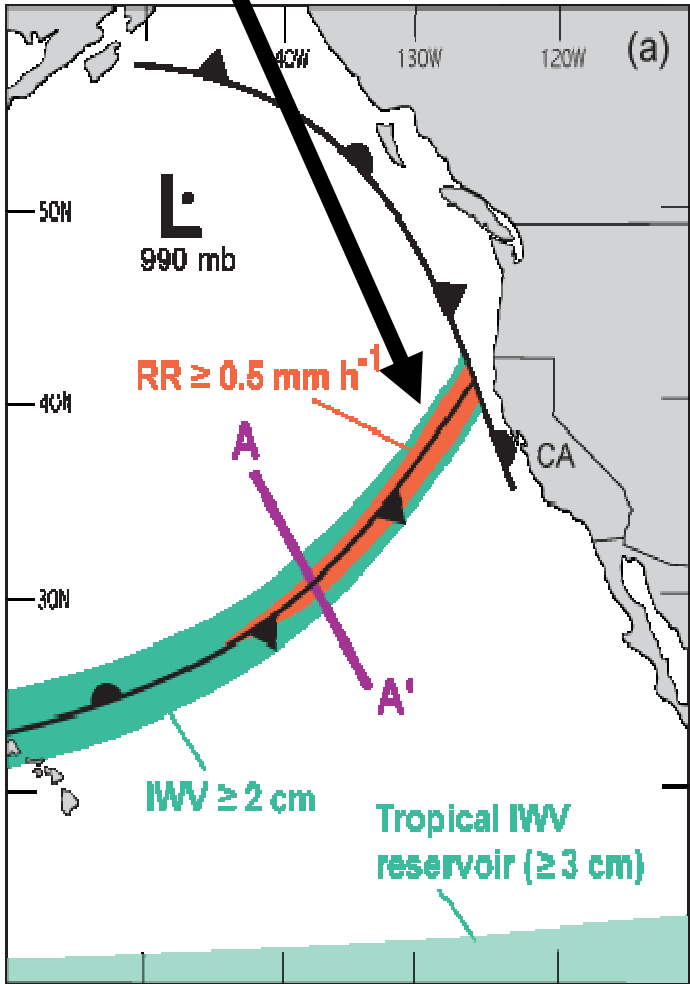
# Low-level jet (LLJ) airborne observing strategy



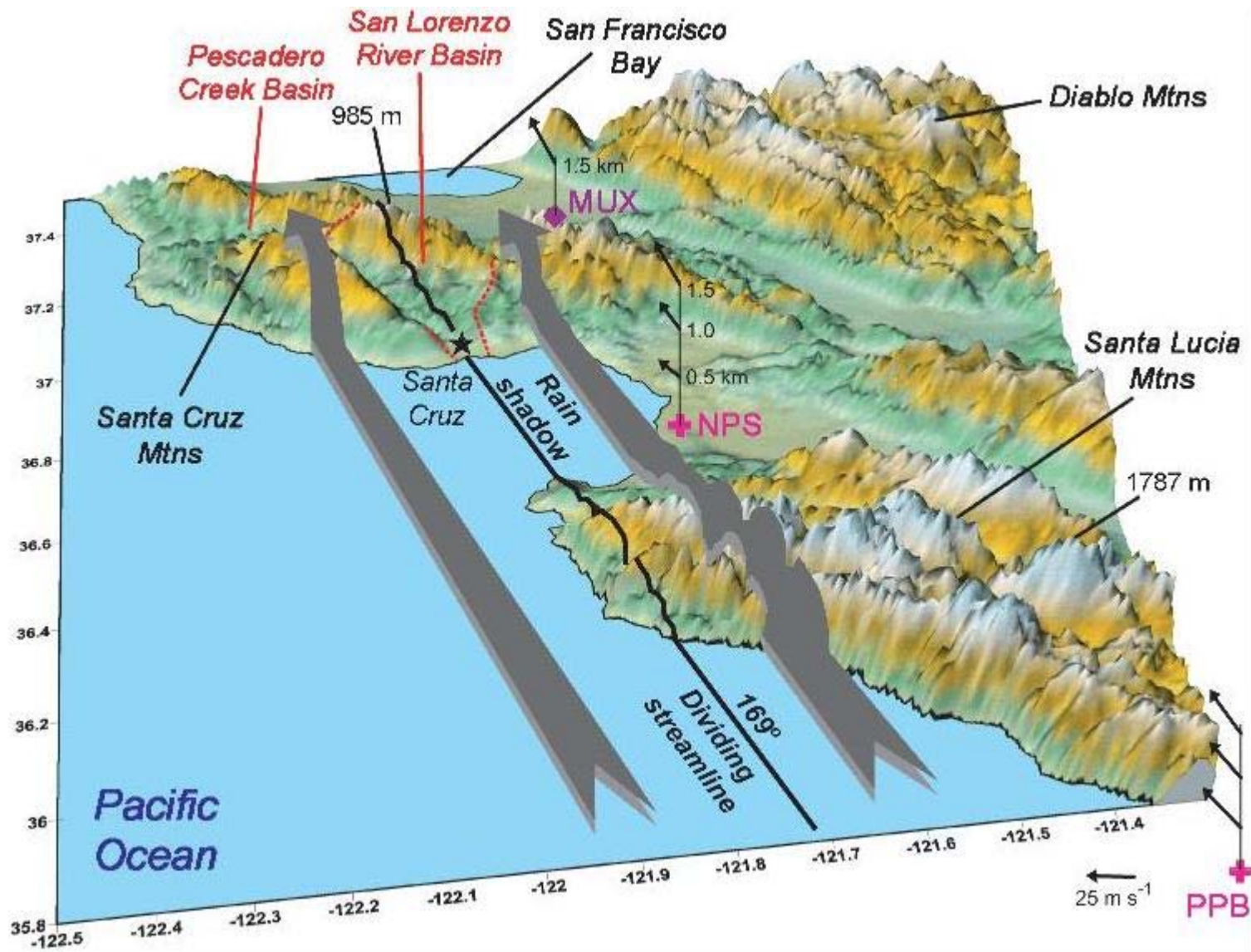
In each case, satellite imagery shows the location of the dropsonde in the vicinity of the cold-frontal comma-cloud tail.

Satellite data provide mean location

Aircraft data quantify intensity and structure



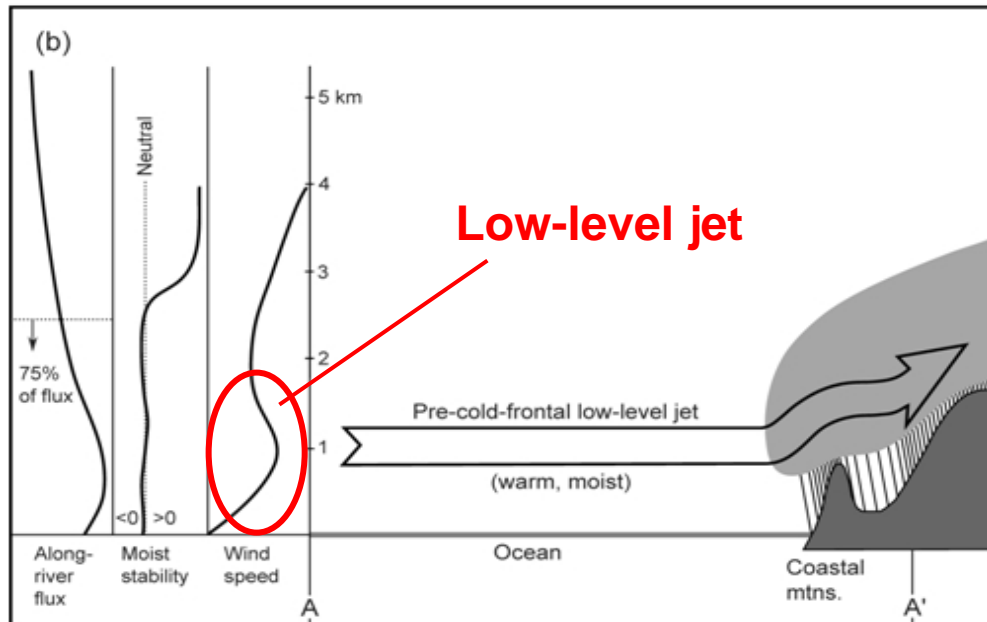
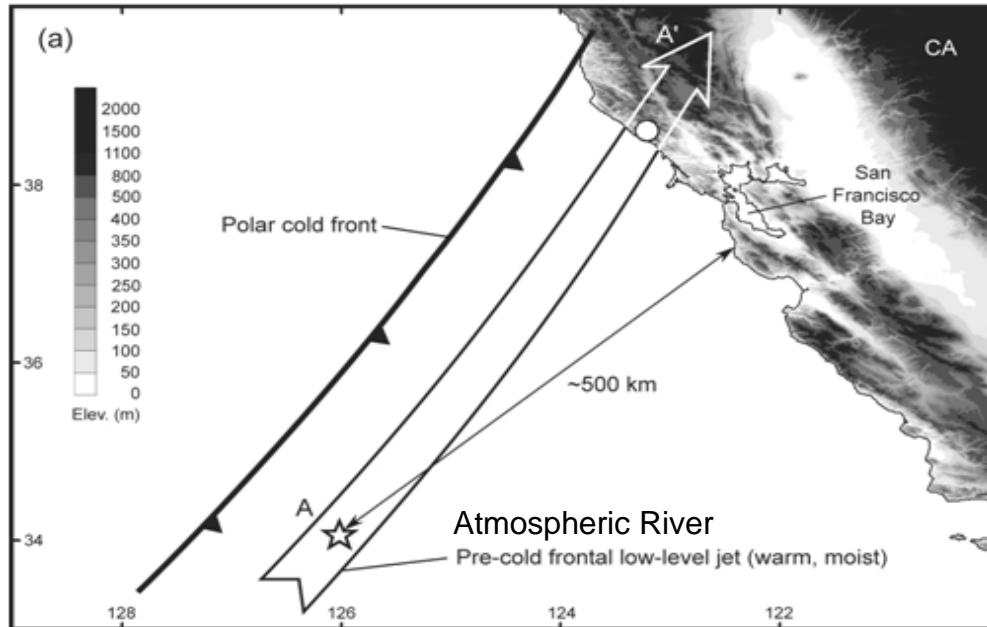
Ralph et al. (2004), *Mon. Wea. Rev.*



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

- Air ascends coastal mountains, water vapor condenses, heavy rainfall occurs
- Details of the atmospheric river determine which watersheds flood

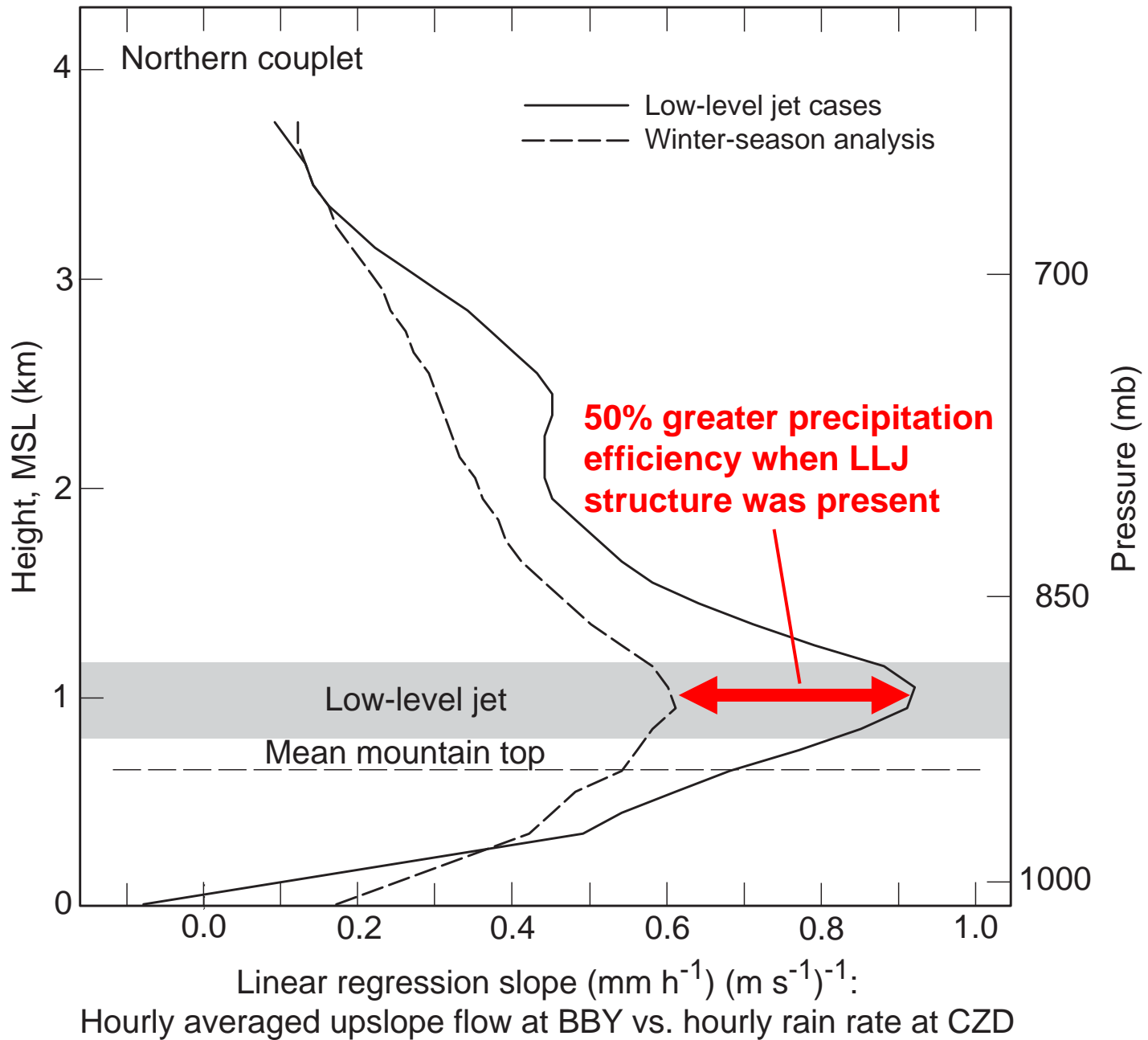
# When an Atmospheric River Strikes Coastal Mountains, it causes heavy rainfall



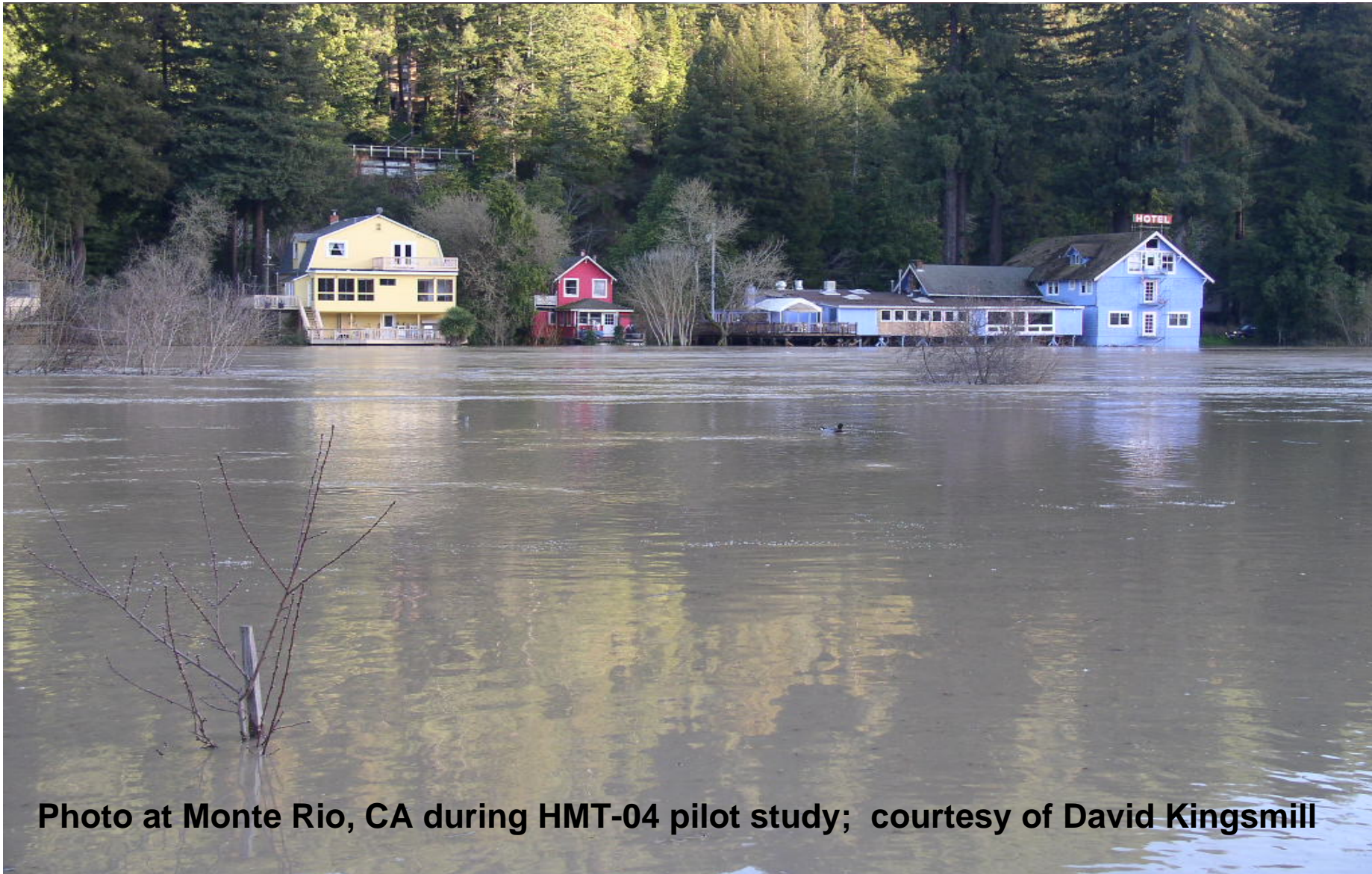
➤ 17 research aircraft missions offshore of CA documented atmospheric river structure.

➤ Wind, water vapor and static stability within atmospheric rivers are ideal for creation of heavy rainfall when they strike coastal mountains.

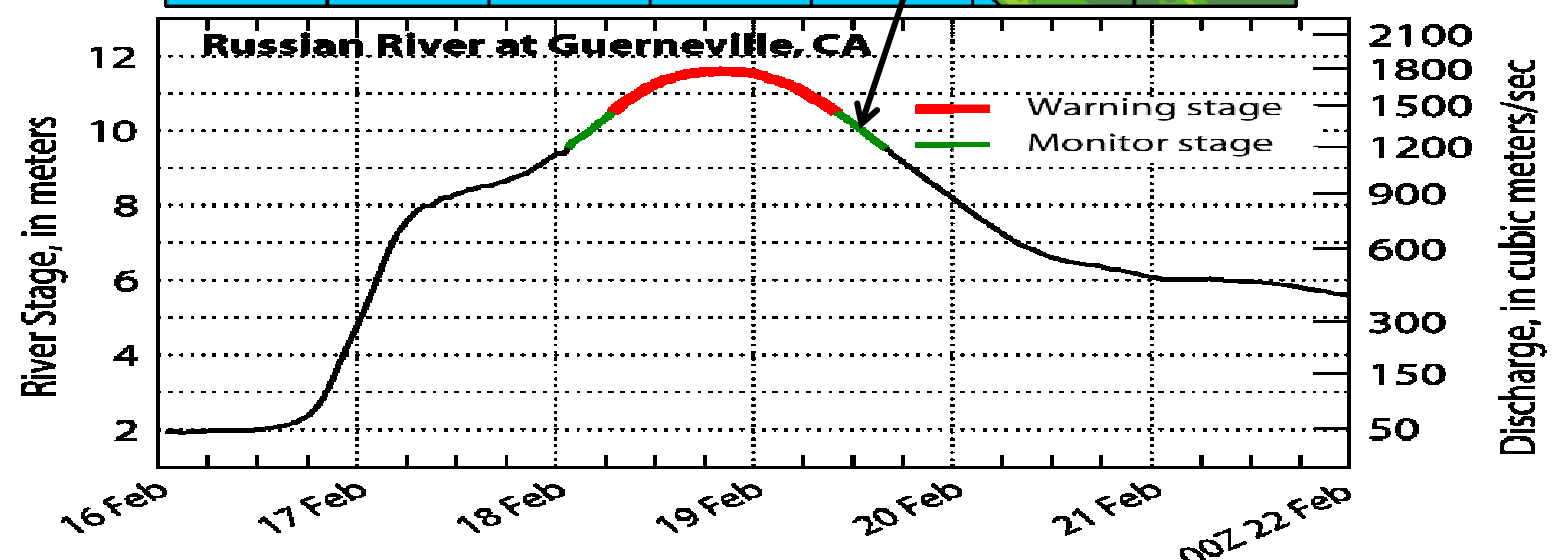
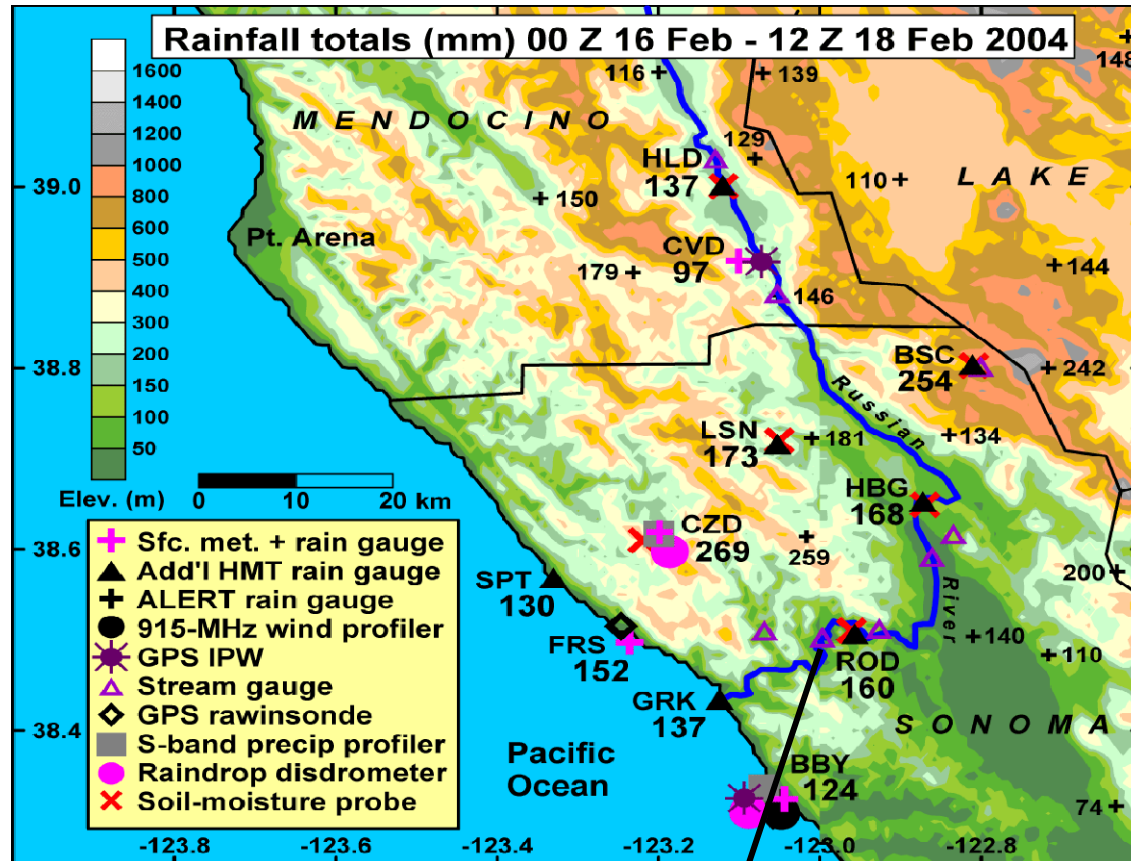
➤ These characteristics were present in both El Nino and Neutral winters

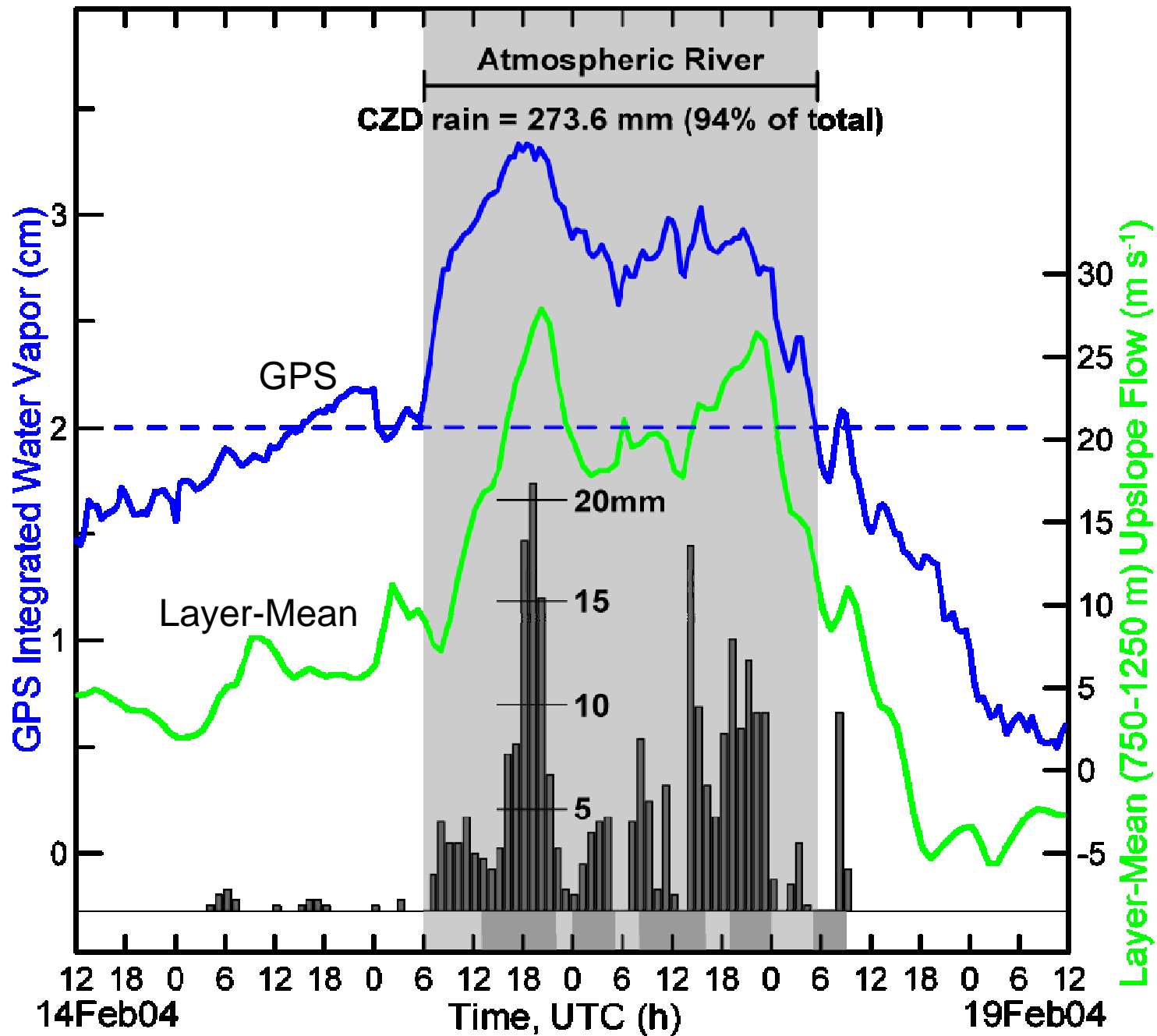


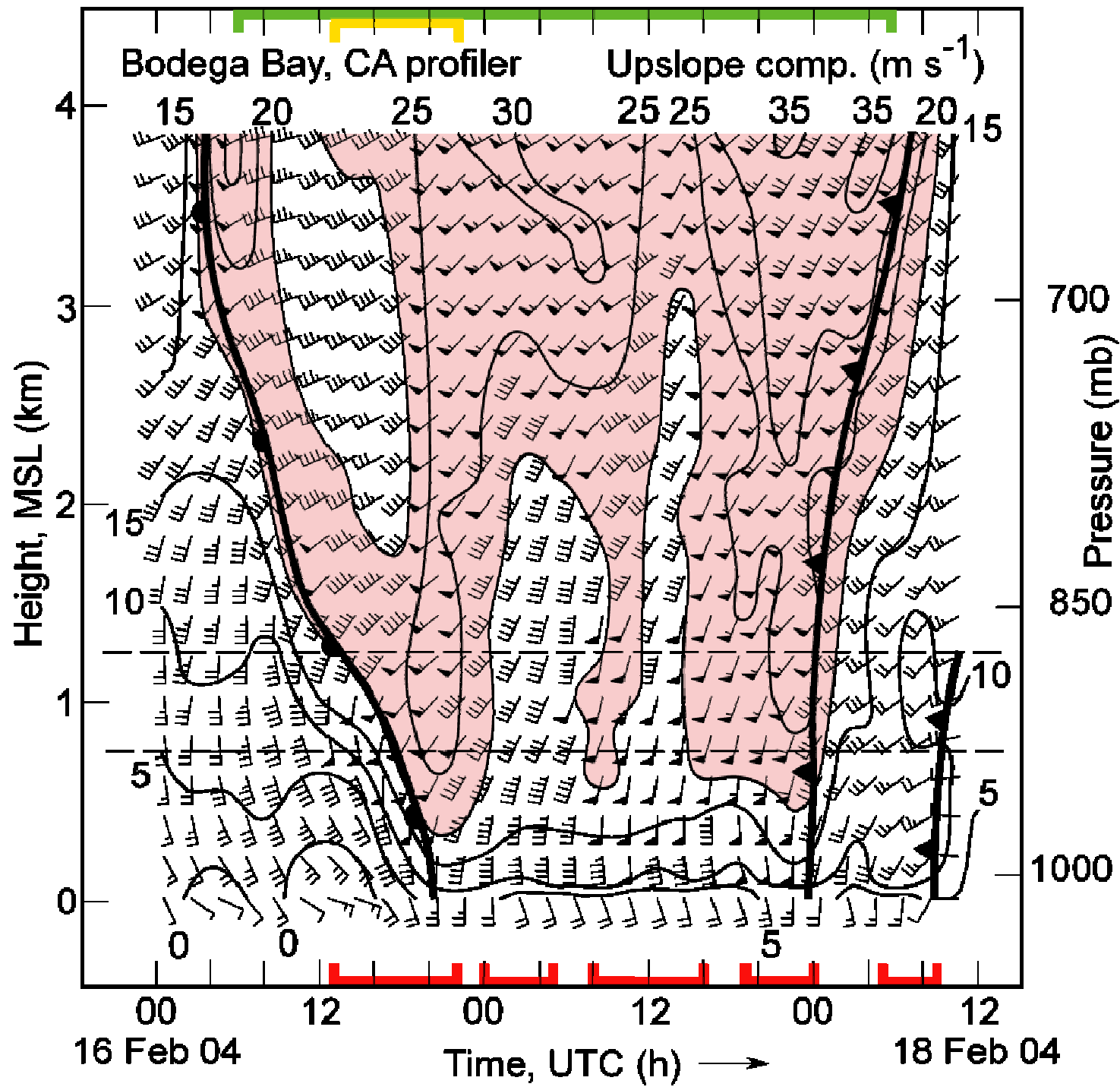
# Russian River Flood on 18 February 2004

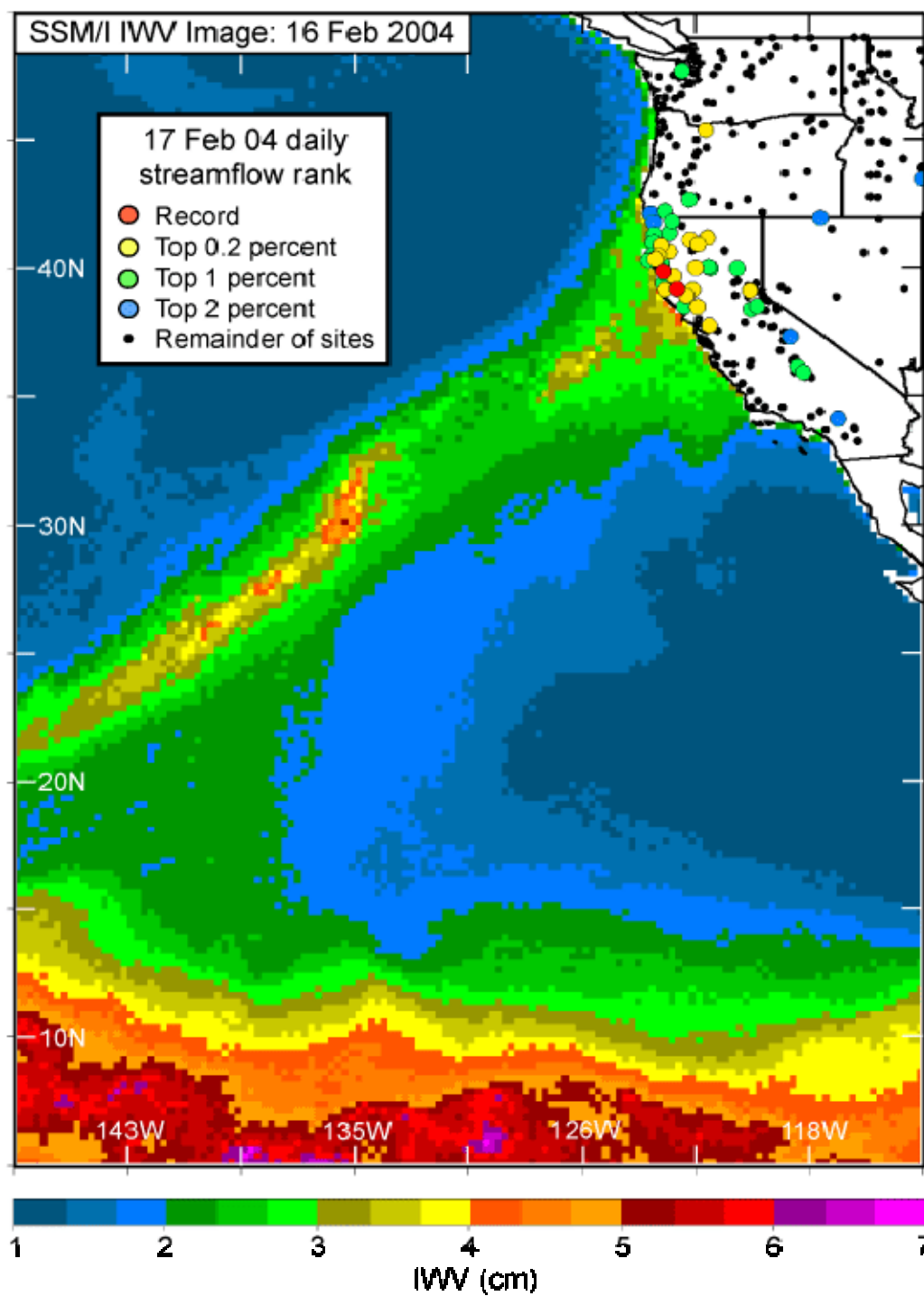


**Photo at Monte Rio, CA during HMT-04 pilot study; courtesy of David Kingsmill**







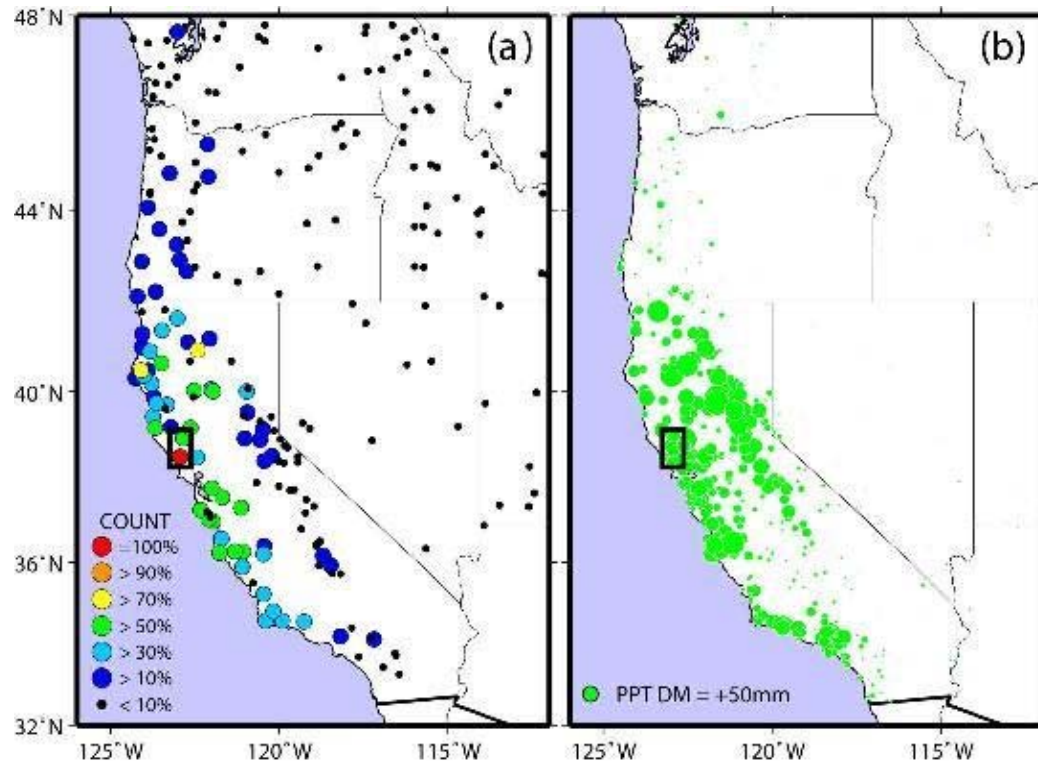


- SSM/I satellite image shows atmospheric river
- Streamgauge data show regional extent of high streamflow  
Covering roughly 500 km of coast

Ralph et al. (2006), *Geophys. Res. Lett.*

# The 7 Flood/Monitor Events on Russian River at Guerneville, CA since 01Oct97

Event rank since 10/97	Date of peak stage and mean flow mm/dd/yyyy#	Days in event	Peak Daily mean flow ( $\text{m}^3 \text{s}^{-1}$ )	Max hourly stage (m)*	Flood or Monitor Stage for daily mean	Atmos. River structure in SSM/I**	GPS IPW > 2cm? (max IPW, cm)	BBY profiler LLJ? (max speed m/s)	Atmos. river conditions near or at coast in previous 2 days?
1	01/01/2006	3	2320	13.4	Flood	Yes	Yes (3.4?)	Yes (30)	Yes
2	02/18/2004	2	1700	11.6	Flood	Yes	Yes (3.3)	Yes (30)	Yes
3	02/07/1998	3	1460	11.4	Flood	Yes***	NA	Yes (26)	Yes
4	02/03/1998	2	1350	11.8	Flood	Yes***	NA	Yes (32)	Yes
5	12/16/2002	2	1240	11.1	Monitor	Yes	Yes (mm)	Yes (30)	Yes
6	02/20/1998	1	1130	10.7	Monitor	No***@	NA	Yes (22)	Yes
7	12/29/2005	1	1110	9.8	Monitor	Yes	Yes (3.6)	Yes (20)	Yes



# Conclusions of Russian River Study

- The major flood of 16-18 Feb 2004 resulted from the land-fall of an atmospheric river, which caused heavy orographic rainfall (>250 mm in 60 hr)
  - Wind profiler observed LLJ structure
  - GPS IWV data showed >2 cm
  - SSM/I showed AR structure offshore
- All 7 floods since experimental data became available AR conditions were present and caused heavy rainfall
- Along-shore extent of heavy rain and flooding was ~400 km

# How representative are the Russian River results?

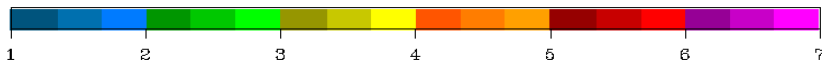
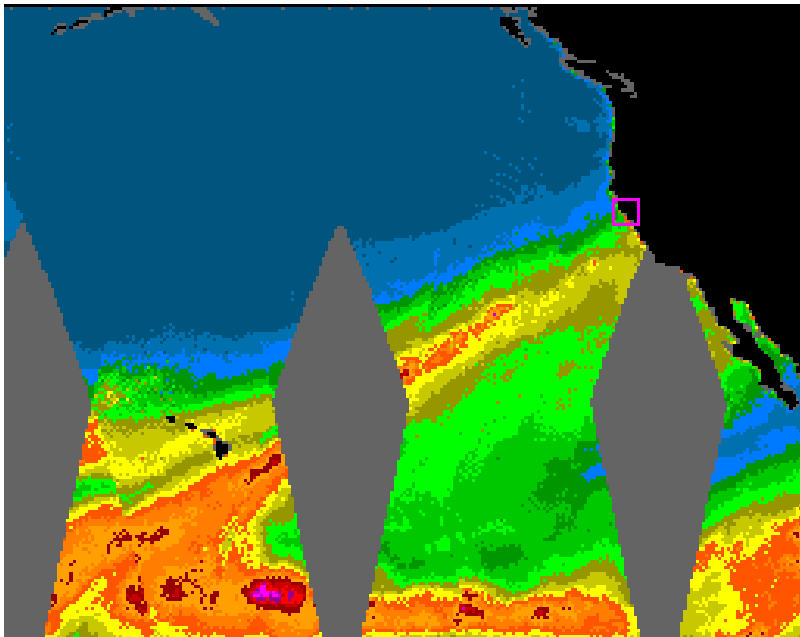
- Are the results found for the Russian River representative of other CA watersheds and other extreme precipitation events?
- Although a thorough study is required to answer this, the following examples of recent extreme events suggest it is so.

# Modeling study assessed 4 major CA storms

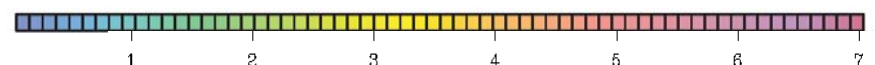
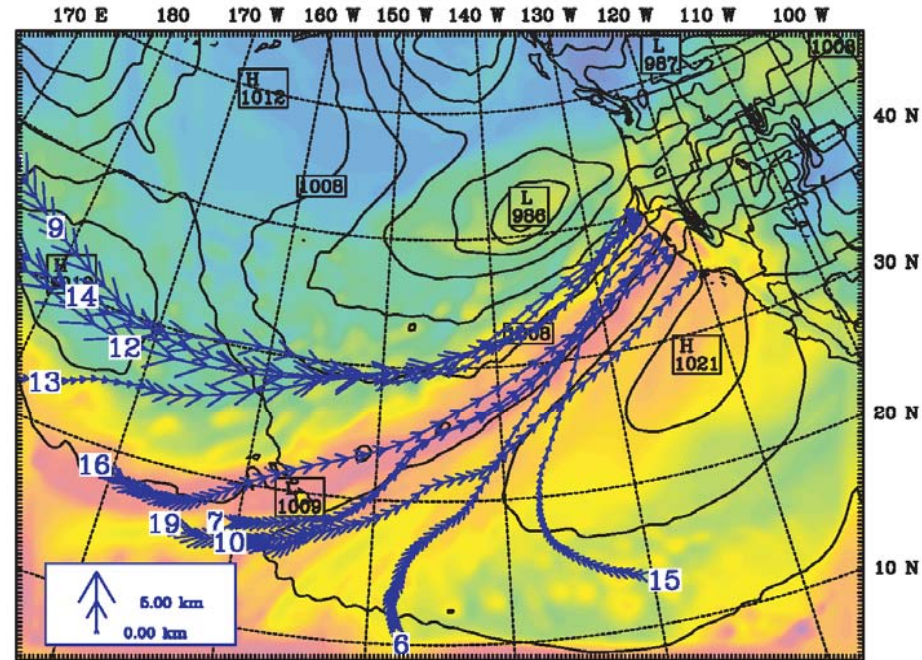
- 4 historically strong cases all had AR conditions
- Results indicate that the Jan 1997 storm directly tapped the tropics
- ENSO neutral conditions seem to favor the tapping of the tropical water vapor reservoir

# SSM/I IWV and MM5 Simulation: SLP & backward trajectories

## 2 Jan 1997 SSM/I Observations



## 00UTC 01Jan97 Model results



Color coding is of integrated water vapor (cm)

# 25 Feb 2004 storm

## SSM/I IWV Composite Satellite Image

Feb 25, 2004 SSM/I-Derived Total Column Water Vapor  
Descending Passes 6:30–11:00 PST

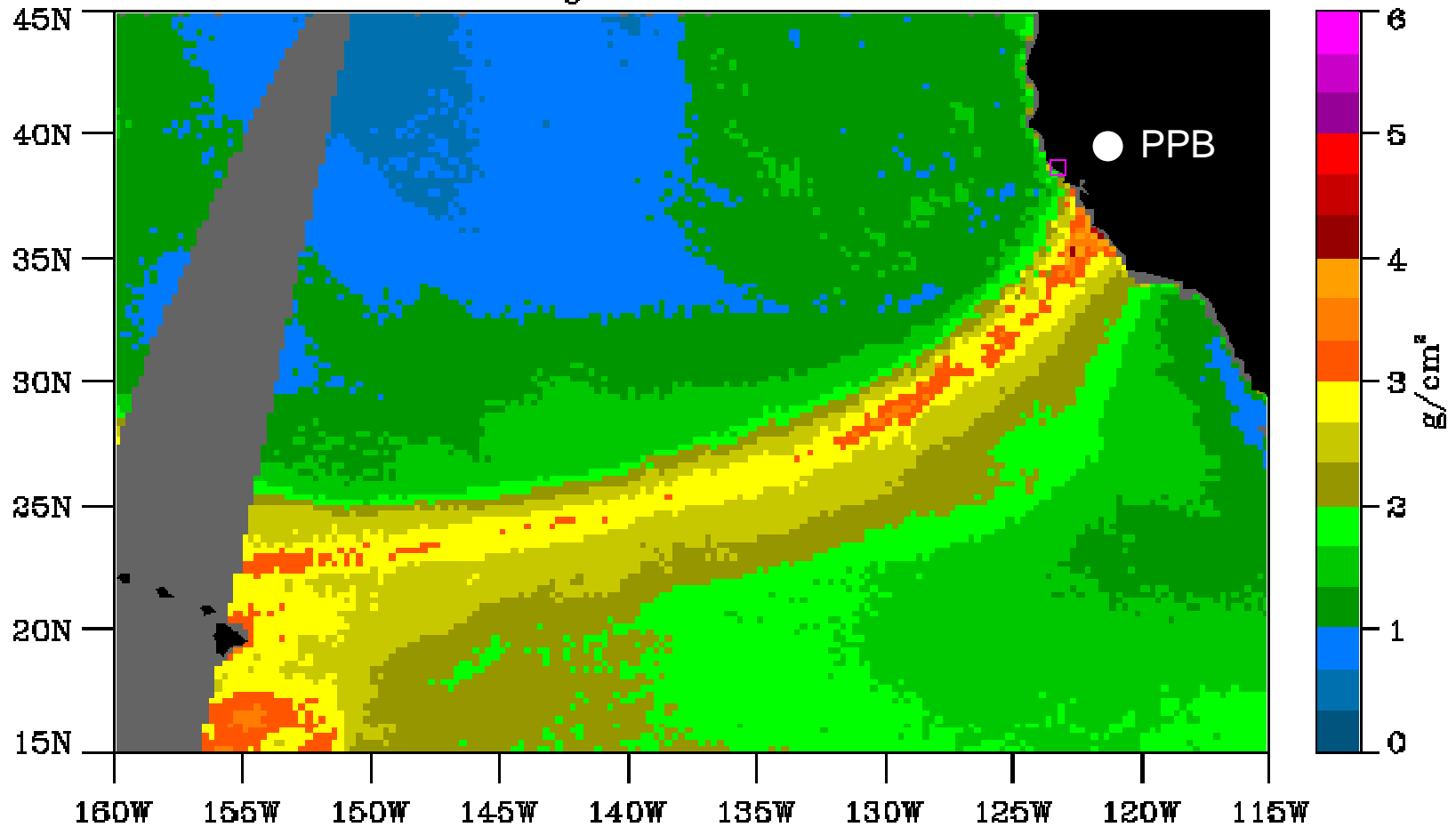
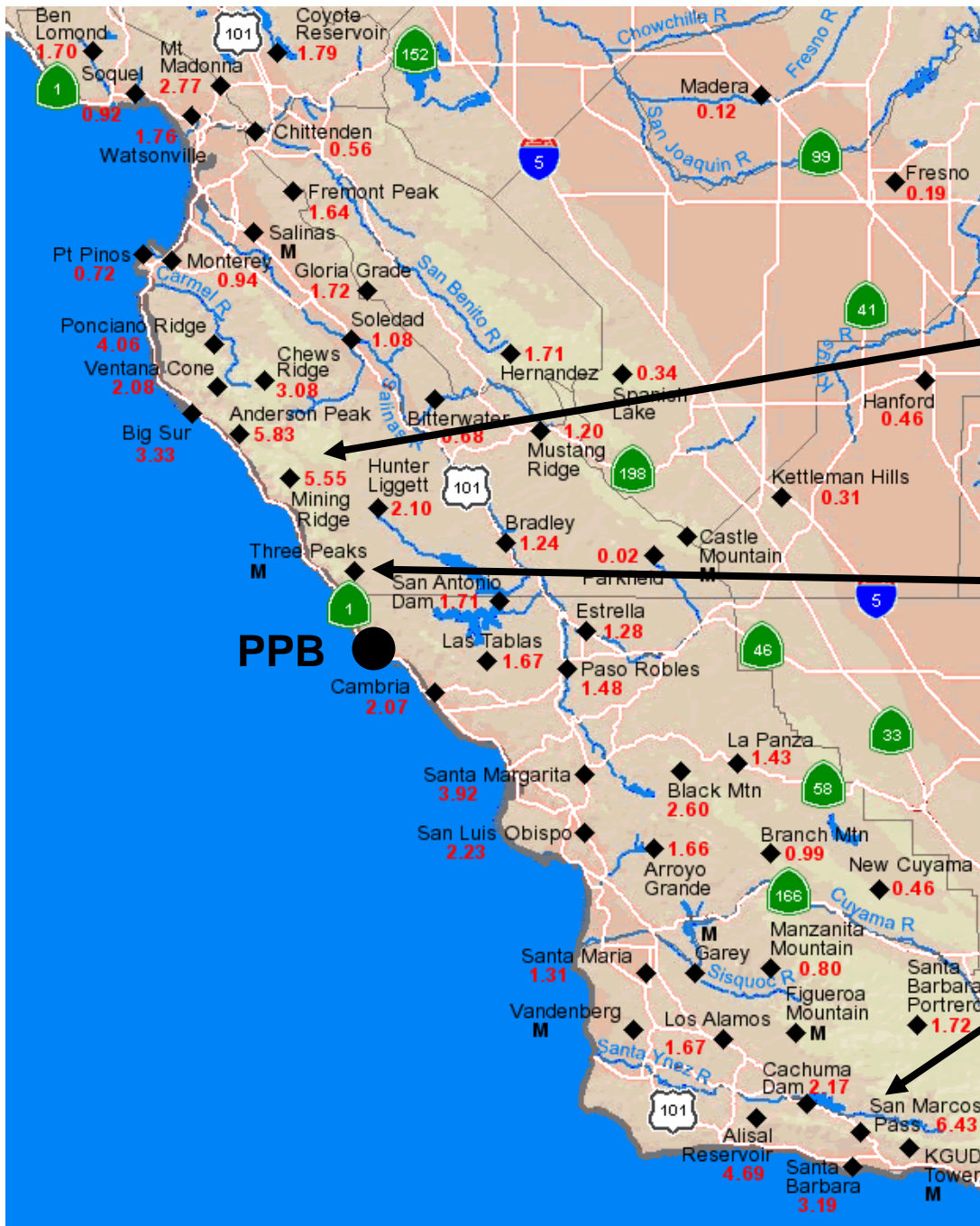


Image Courtesy Gary Wick, NOAA ETL



25-26 February  
2004

5-6 inches of  
rain in 24 hrs

10-11 inches  
at TPK

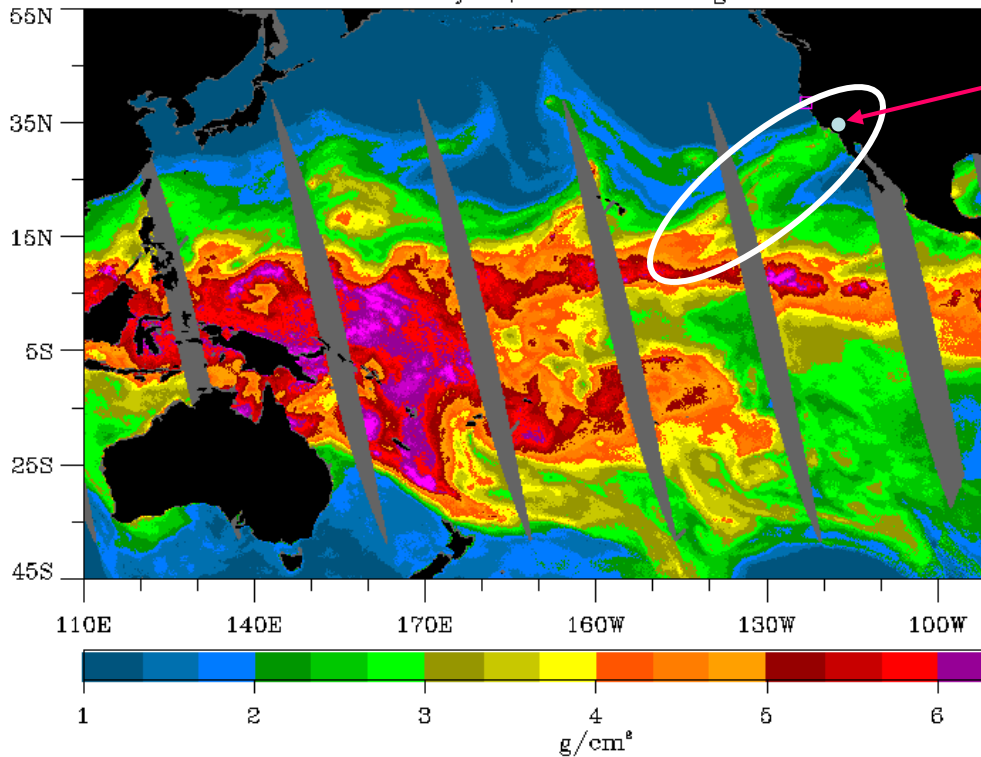
6.43 inches

# 7-11 January 2005

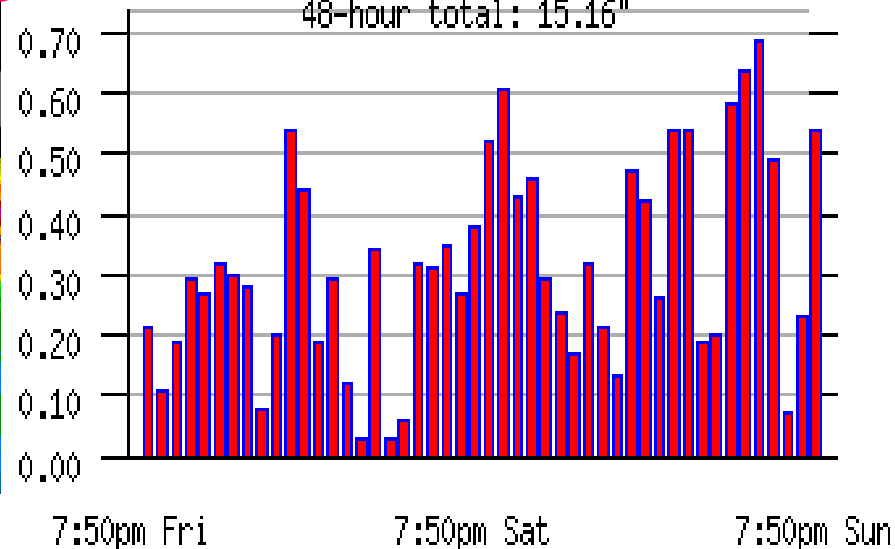
- Up to 30 inches of rain, floods, and debris flows strike S. CA
- SSM/I IPW data indicative of atmospheric river conditions
- Evidence of connection to tropical water vapor reservoir

*Supported by NOAA's Weather-Climate Connection Program*

SSM/I Water Vapor (Schuessel algorithm)  
January 09, 2005 Ascending Passes

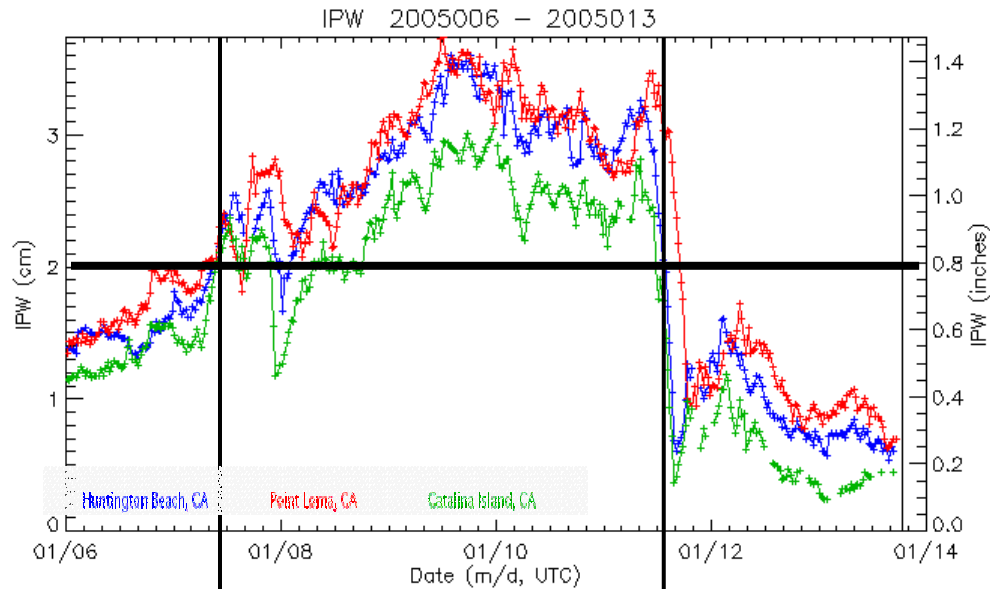


CLEAR CREEK - RAWS  
Precipitation (inches)  
48-hour total: 15.16"



ETI

# January 2005 CA Flooding: IPW > 2cm during Rainfall

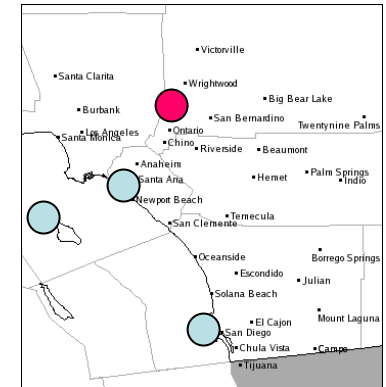


Integrated Water Vapor (IWW)  
Data from 3 GPS sites

(courtesy of NOAA/FSL)

3 coastal sites

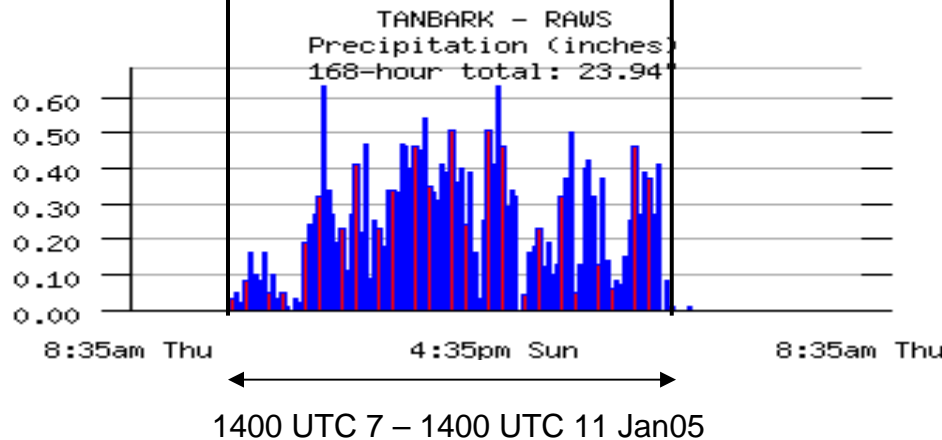
IPW > 2 cm



RAWS hourly rain guage data  
~24 inches fell in 96 h

“Tanbark” site is at 2600 ft  
MSL in the San Gabriel  
Mountains above Los Angeles

Hourly rainfall  
(inches)



# Debris Flow in La Conchita, CA, on 10 Jan 2005

## 10 Fatalities



# Many atmospheric rivers do not cause floods

- Not all ARs are equally intense
- Some storms move quickly over an area
- Floods are favored by strong ARs that stall over a particular watershed
- Several cases show that this occurs when a meso-alpha scale frontal wave develops on a pre-existing polar cold front

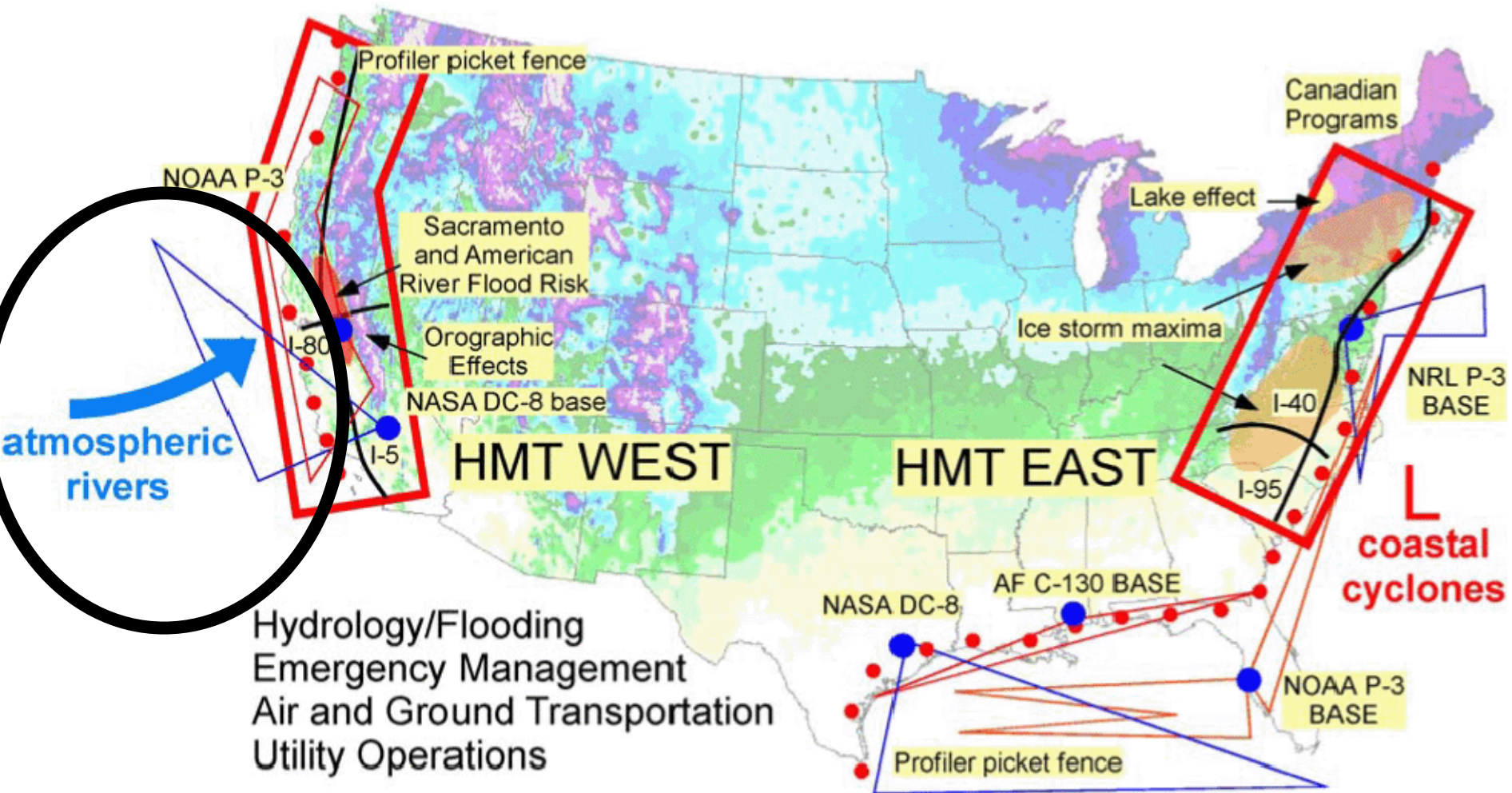
# Conclusions

- Atmospheric rivers contain the atmospheric conditions that can create extreme precipitation when they strike the coastal mountains
- ARs likely act as a link between tropical forcing (e.g., MJOs) and extreme CA precipitation events
- The most extreme events may result partly from direct tapping of tropical water vapor

# Future work

- GPS and profiler analysis
- Climatology of land-falling ARs from SSM/I
- P-3 missions from HI to study tropical tap
- Assess if UAS can help fill observational gap for water vapor transport over the Eastern Pacific
- What is the role of “frontal waves?”
- How do ARs evolve as they cross the coastal ranges and then how do they respond to the Sierras
  - HMT-08 planned
  - SHARE experiment proposed

# Overarching Recommendation: Use a National Hydrometeorological Testbed (HMT) approach to improve cool season QPF



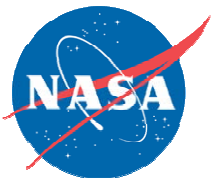
Cool-season QPF multi-agency workshop report, BAMS 2005

# The NOAA Unmanned Aircraft System (UAS) Altair Demonstration Project

David W. Fahey  
NOAA ESRL Chemical Sciences Division  
Boulder, Colorado USA



Channel Islands National Marine Sanctuary, 16 Nov. 2005



Nov 2005 18.4 hour demo flight up to 45 kft

