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Understanding and Forecasting Atmospheric Rivers

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BIOGRAPHICAL SKETCH

Mr. David Reynolds has held the position of Meteorologist-in-Charge of the National Weather Service (NWS) San Francisco Bay Area Forecast Office since June of 2002. Prior to assuming this position he was Chief of Operations of the Hydrometeorological Prediction Center, one of the service centers of the National Centers of Environmental Prediction in Washington DC. His primary interest is in Quantitative Precipitation Forecasting and in climate change impacts in California.

Mr. Reynolds received a B.S. in Atmospheric Science from the University of California, Davis in 1971, and a M.S. in Atmospheric Science from Colorado State University (CSU) in 1973. He was accepted into the Doctoral Program at CSU in 1982 and completed a year of post-graduate studies. Mr. Reynolds was a Research Assistant Professor at CSU from 1973 to 1980, Chief of the Alaska Avalanche and Fire Weather Forecast Center from 1980 to 1981, a team leader with what is now the NOAA Forecast Systems Laboratory from 1981 to 1983. He was Site Director of the U. S. Bureau of Reclamation's Sierra Cooperative Pilot Project from 1983 until 1988. This cloud seeding research program studied the feasibility of augmenting the snow pack in the central Sierra Nevada. Based on this research, Mr. Reynolds worked for California's Department of Water Resources from 1988 until 1994 to design, implement, and conduct a snow augmentation program for the Feather River above Oroville Reservoir in northern California.

He is a member of the American Meteorological Society, served as Chairman of the AMS Committee on Weather Modification, and is currently on the Committee on Mountain Meteorology. Mr. Reynolds received the National Oceanic and Atmospheric Administration's Administrator Award and has been the recipient of a Department of Commerce group Gold Medal -- the Department's highest honorary award -- in 1999 for HPCs excellent rainfall forecasts associated with Hurricane Floyd. He also received two NOAA group Bronze Medals associated with his participation in the restructuring of the NWS's quantitative precipitation forecasting process.

ABSTRACT

Over the past decade, special observations have been made within northern California, monitoring the strength and location of land-falling Atmospheric Rivers (AR). Atmospheric Rivers are rather narrow plumes (< 400 kilometers width) of high moisture content air that can extend thousands of kilometers across the Pacific Ocean with origins in the subtropics. It is believed these are generated by circulations associated with a strong an extended East Asian jet stream that at times creates a nearly continuous AR across the entire Pacific Basin.

Research, done by NOAA scientist in Boulder, CO, have shown that these strong and sustained land-falling AR's are associated with many if not a majority of floods in California. This presentation will review AR's and discuss how current NWS forecasts offices can recognize and attempt to forecast these phenomena well in advance of landfall. The Columbus Day 2009 event will be used as an example. In addition, the idea of developing an AR threat index or intensity category will be presented. Finally the paper discusses how this knowledge of AR's could be used to prepare state and local officials for a hypothetical, but very believable catastrophic flood event being proposed as part of a statewide emergency response drill in 2011 called ARkStorm.



Understanding and Forecasting Atmospheric Rivers

Dave Reynolds
Meteorologist in Charge
WFO San Francisco Bay Area
June 2010





Acknowledgements

- Paul J. Neiman – NOAA OAR
- Marty Ralph – NOAA OAR
- Wes Junker – Former Lead Forecaster
HPC





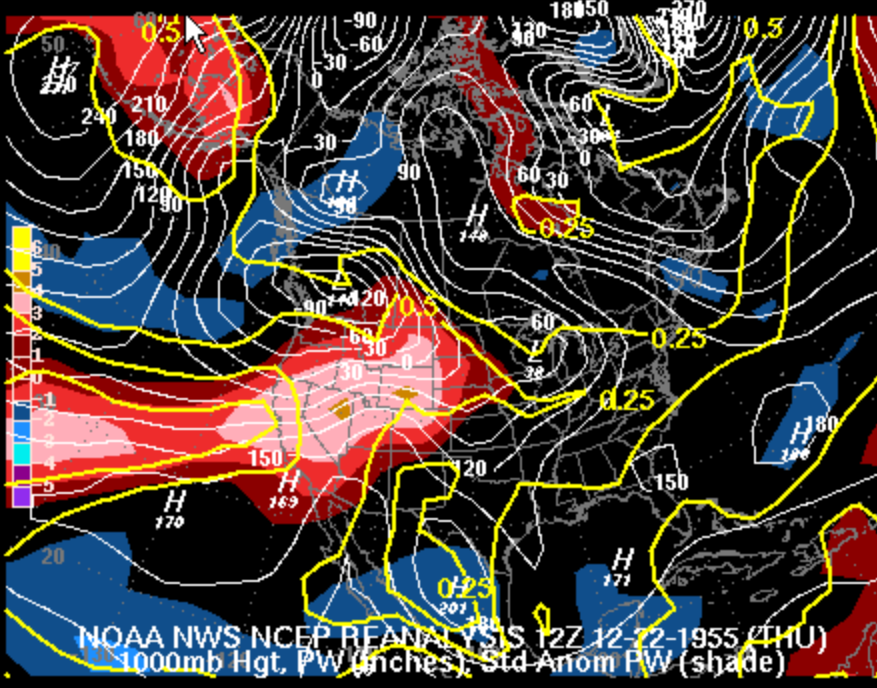
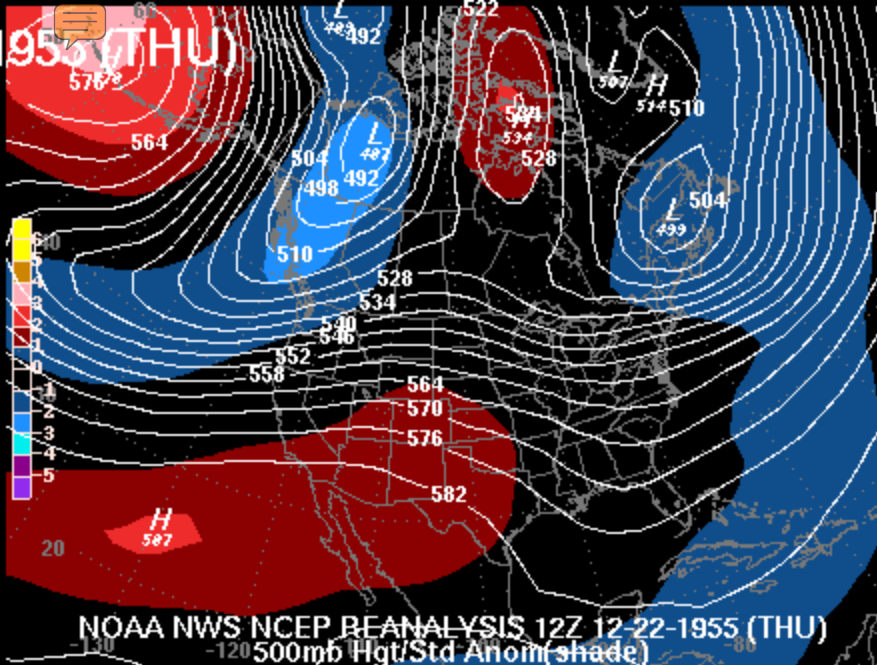
Outline

- Conceptual model of major flood patterns
- What is an atmospheric river
- Forecast tools and methods
- Importance of lead time
- AR Threat or Category Index?
- What might the forecast for a major flood event consist of – ArkStorm Forecast Scenario

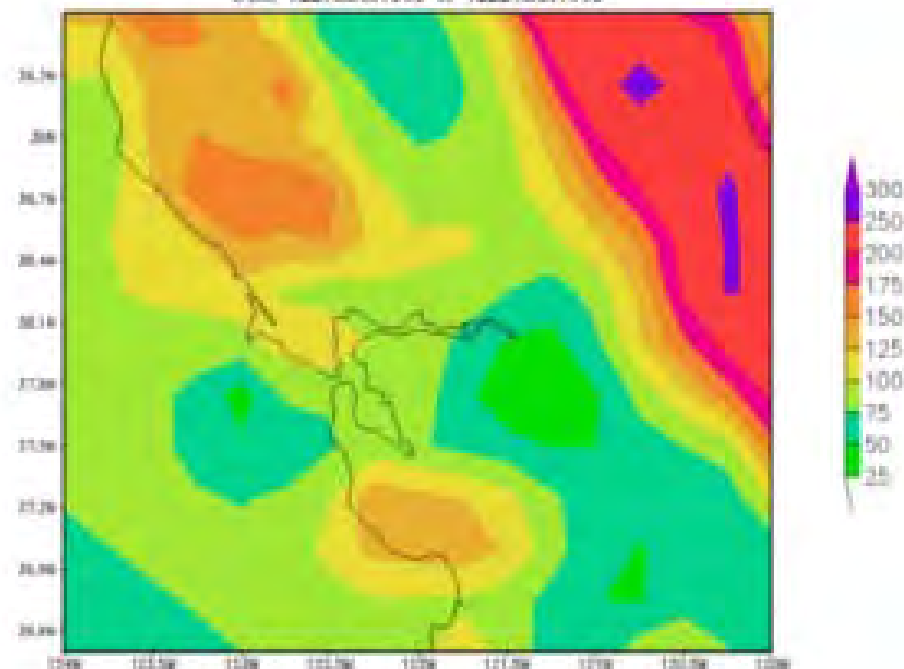


Dec 1955 Synoptic pattern

Ranked #3



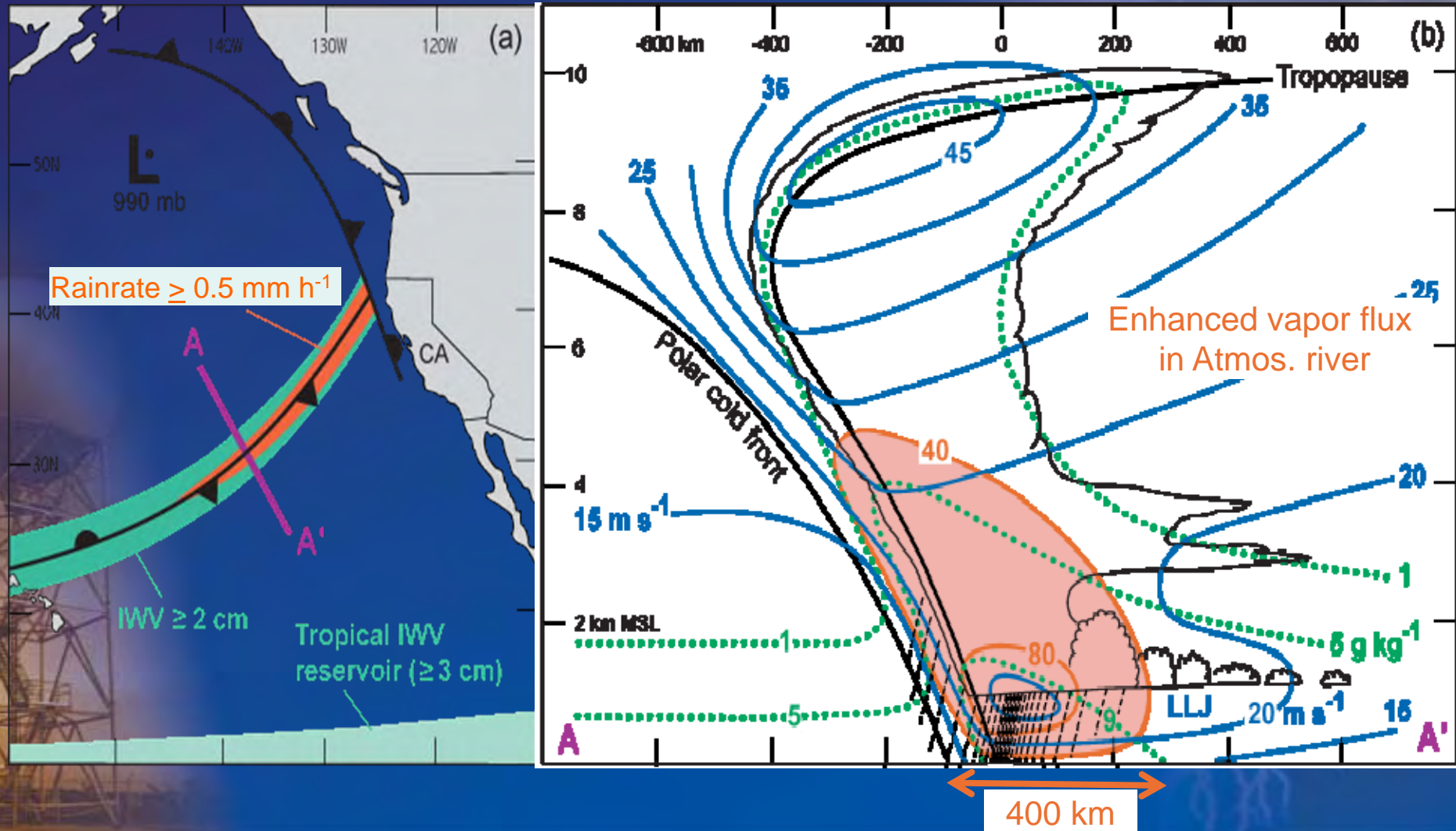
g. Accumulated liquid equivalent precipitation (mm)
from 12Z18JAN1969 to 12Z21JAN1969



Heaviest 3-day rainfall analysis using the CDC .25 deg by .25 deg unified data set ending 1200 UCT 18 Jan 1969-1200 UTC 21 Jan 1969.

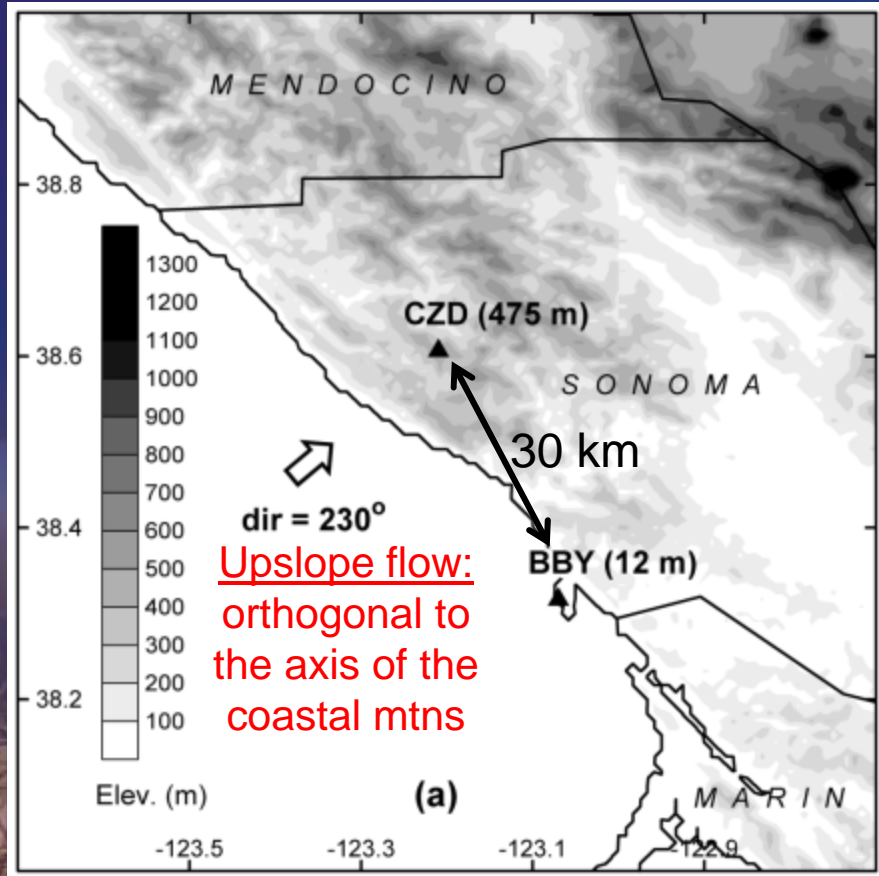
Observational studies by Ralph et al. (2004, 2005, 2006) extend model results:

- 1) Long, narrow plumes of IWV >2 cm measured by SSM/I satellites considered proxies for ARs.
- 2) These plumes 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.





Four-winter study of land-falling ARs along northern California coast



Neiman et al. (2002), *MWR*

- Flood-prone Russian River Basin northwest of San Francisco: 2000/01, 2003/04, 2004/05, 2005/06
- Analyses for when the following observing systems were simultaneously operating –
 - (a) Bodega Bay (BBY): GPS-IWV unit, 915-MHz wind profiler, rain gauge
 - (b) Cazadero (CZD): rain gauge, S-band radar
- Total rainfall: CZD = 4217 mm, BBY = 2016 mm
- 9548 hourly data points

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

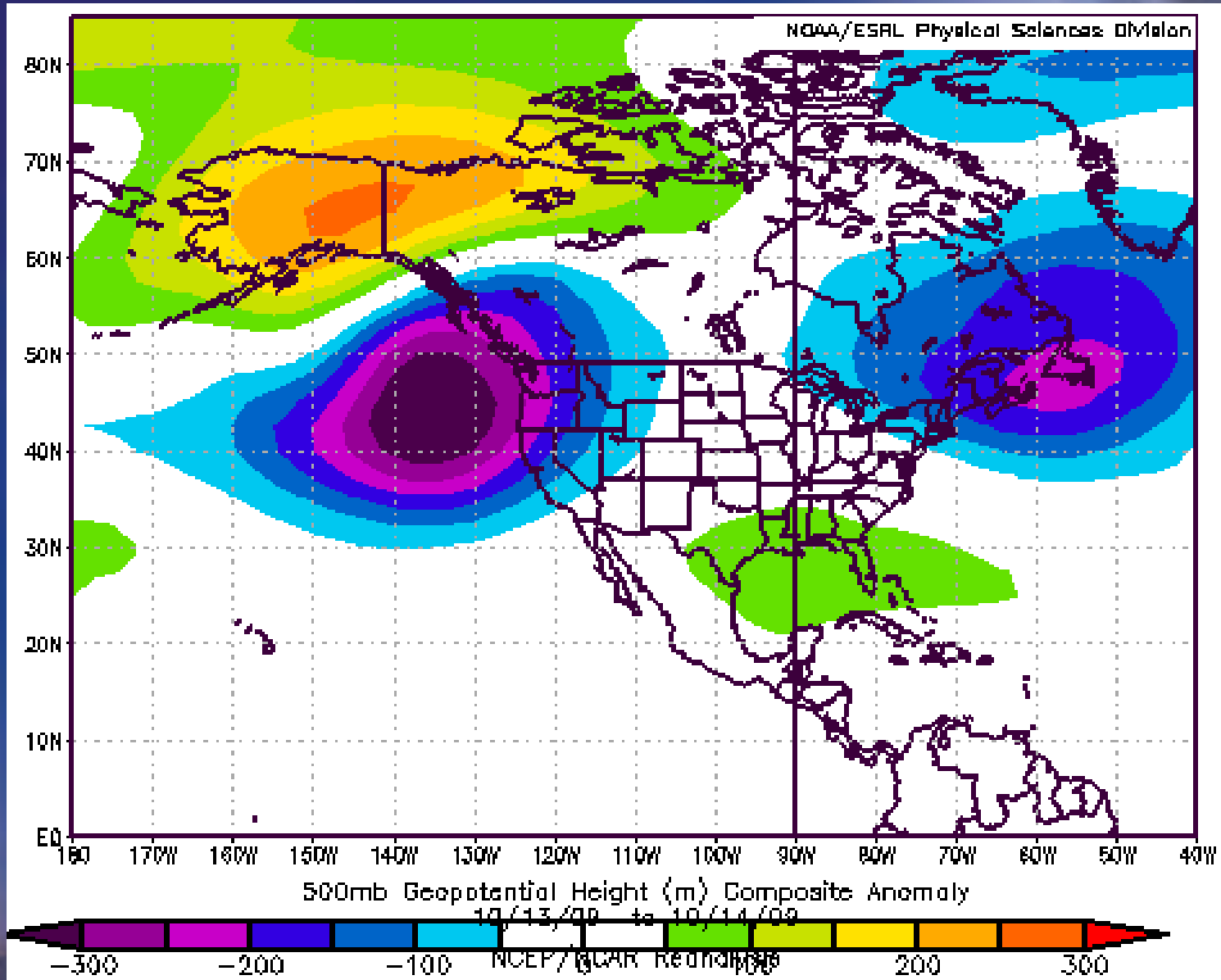


Recent AR Event

- Columbus Day Storm October 13-14, 2009
- Very well forecast a week ahead as a significant high impact event – remnants of ex-typhoon involved
- Analogies made to Columbus Day 1962
- Rather poor QPF forecasts even with 5 to 8 in forecast in 24 hrs. Underestimated by over 10 in for wettest locations. 1500 - 2000% of normal rainy day in October!!



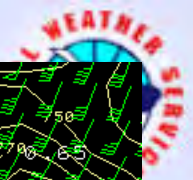
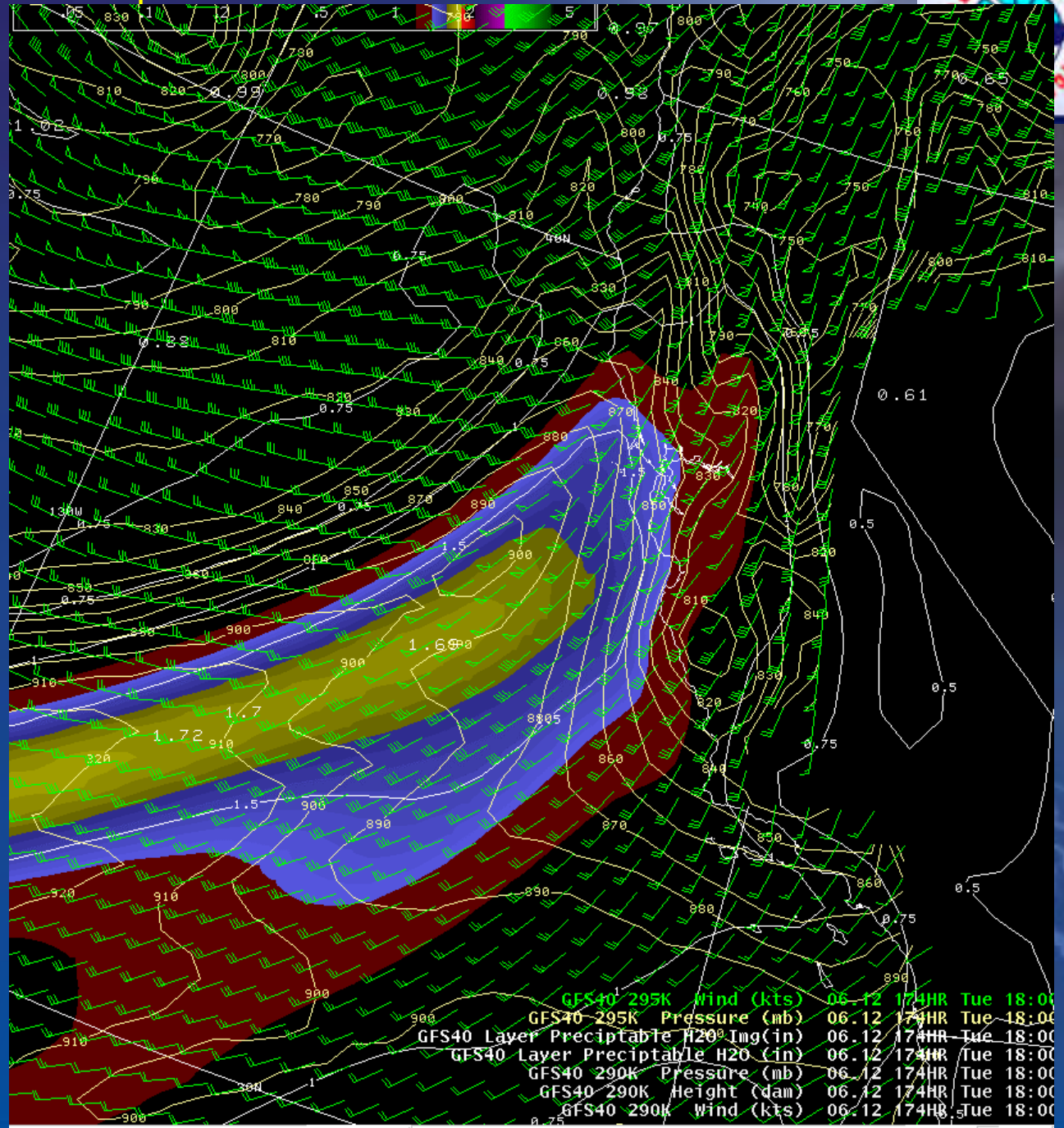
500 mb anomaly chart for Oct 13-14 2009



174 hr 295k Isentropic Forecast with IPW from GFS

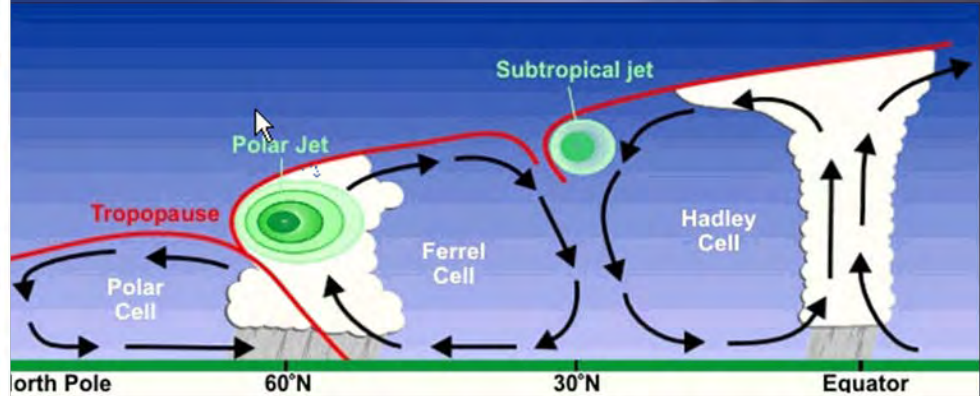
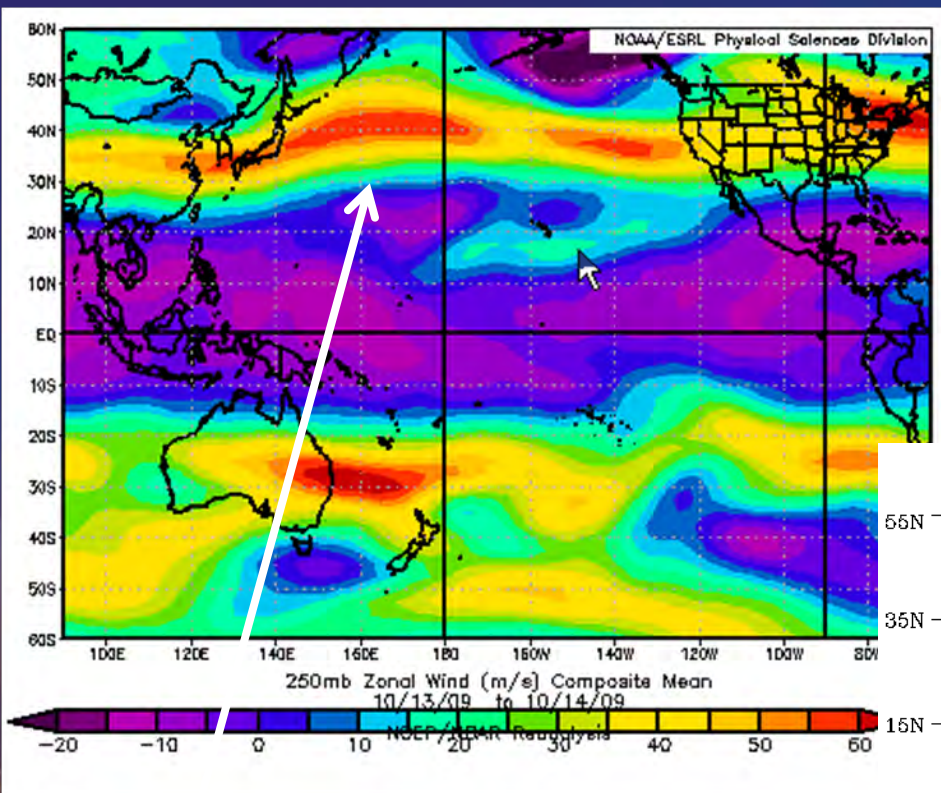
ARs and LLJ occur in warm sector of extratropical cyclones

Model representation of AR

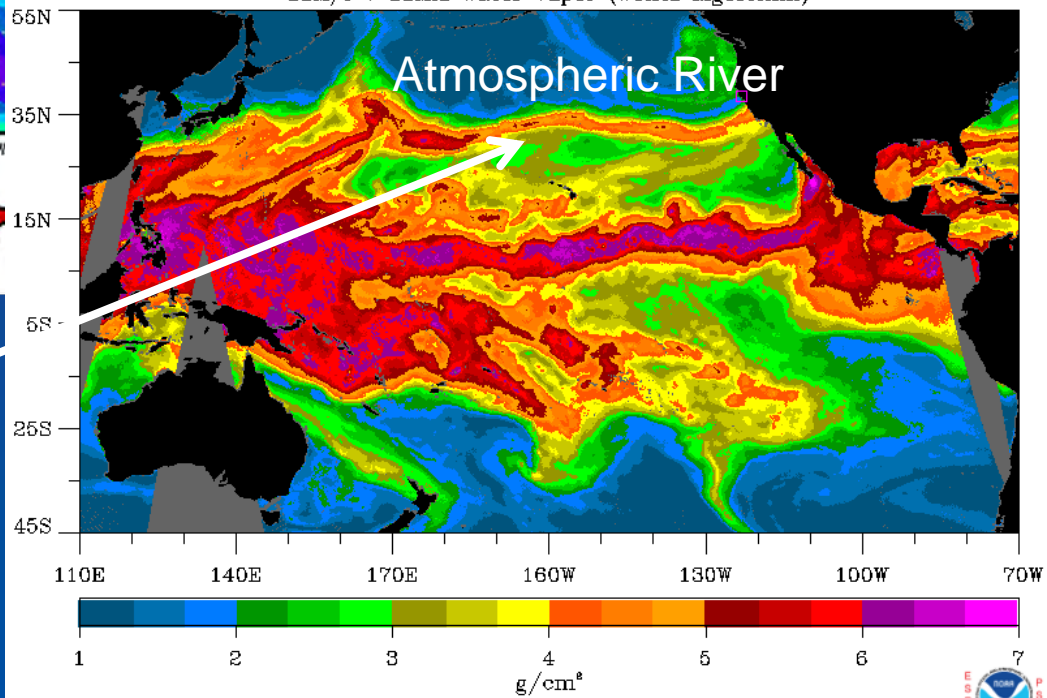




SSM/I shows AR stretching across Pacific to Central California



October 14, 2009 1000 UTC Preceding 12 Hours
SSM/I + SSMIS Water Vapor (Wentz algorithm)

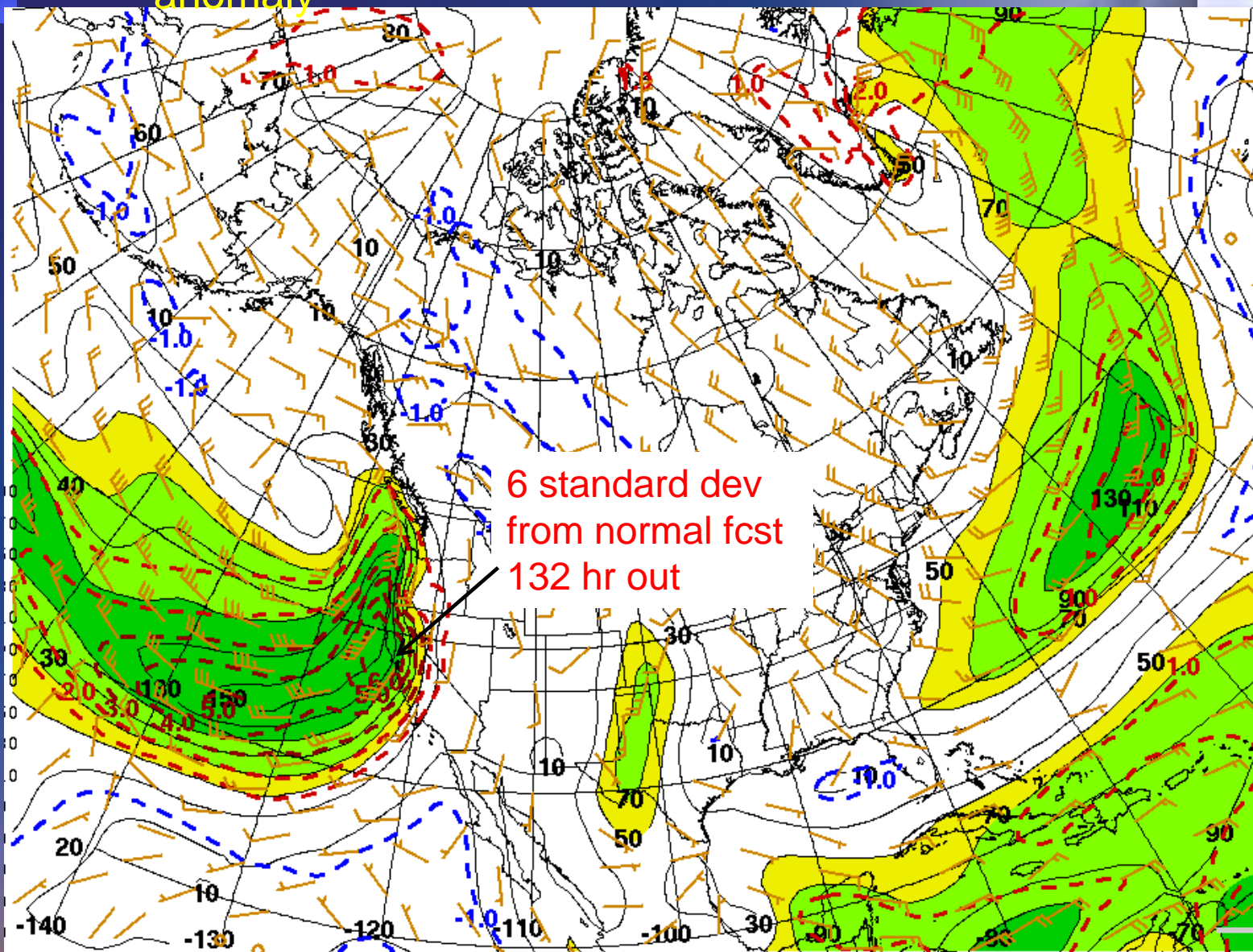


Extended East-Asian Jet





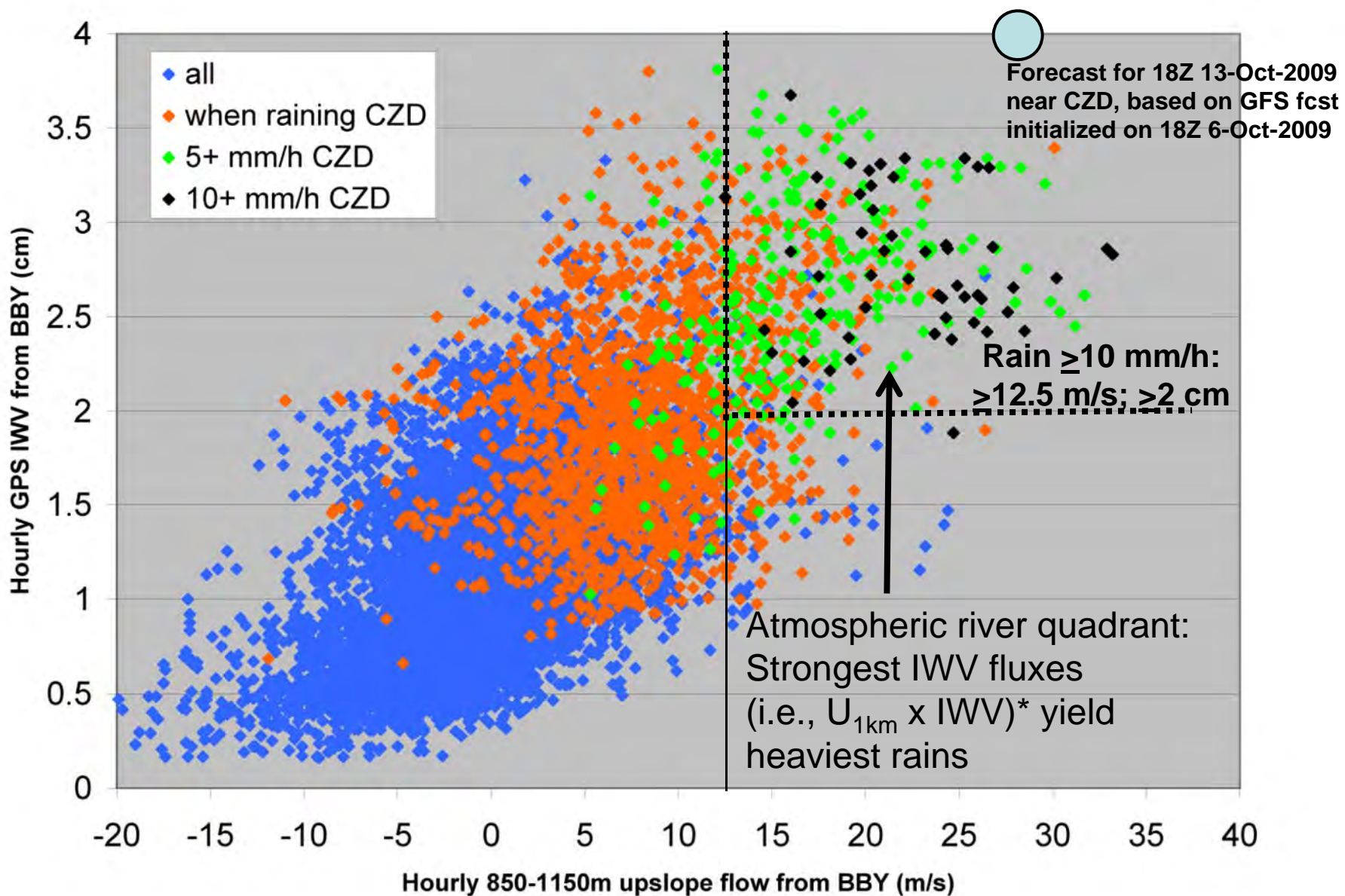
NCEP Global Ensemble Forecast System 132 hr forecast of 850 mb moisture flux and anomaly



6 standard dev
from normal fcst
132 hr out



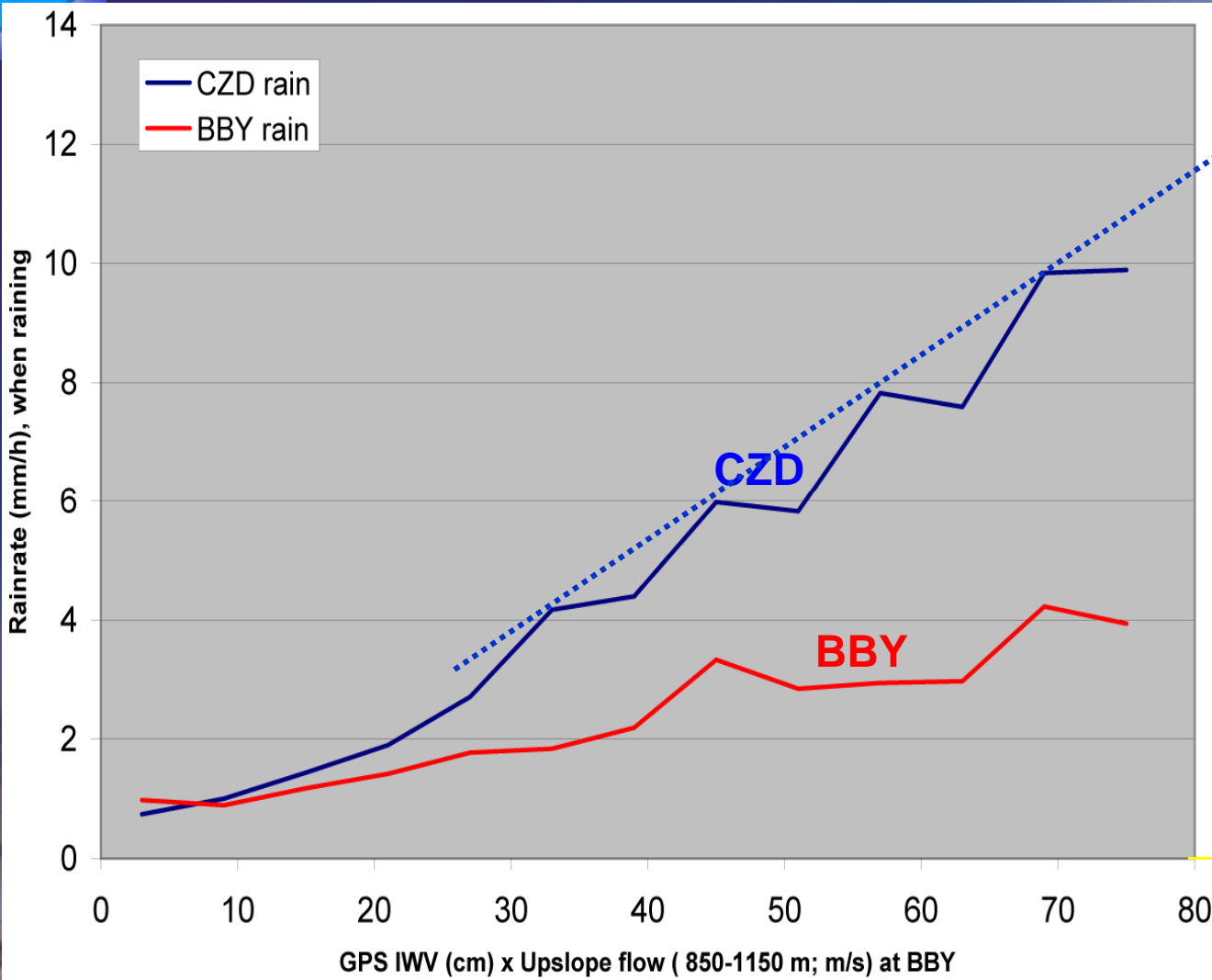
Hourly rain rates associated with land-falling ARs Sonoma Coast





Bulk Upslope IWV Flux vs. Rainrate

Forecast for 18Z 13-Oct-2009 near CZD, based on GFS fcst initialized on 18Z 6-Oct-2009



?

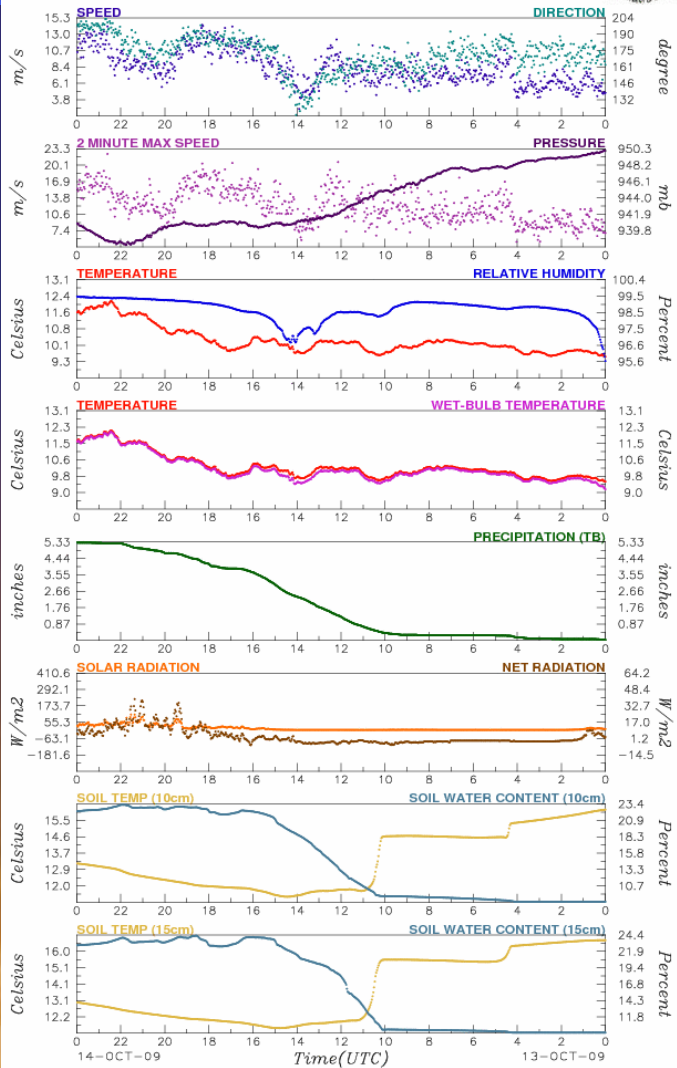
Rainrate and orographic rain enhancement at CZD increases with increasing bulk upslope IWV flux,
i.e., with strengthening AR conditions



Bodega Bay AR Flux Tool

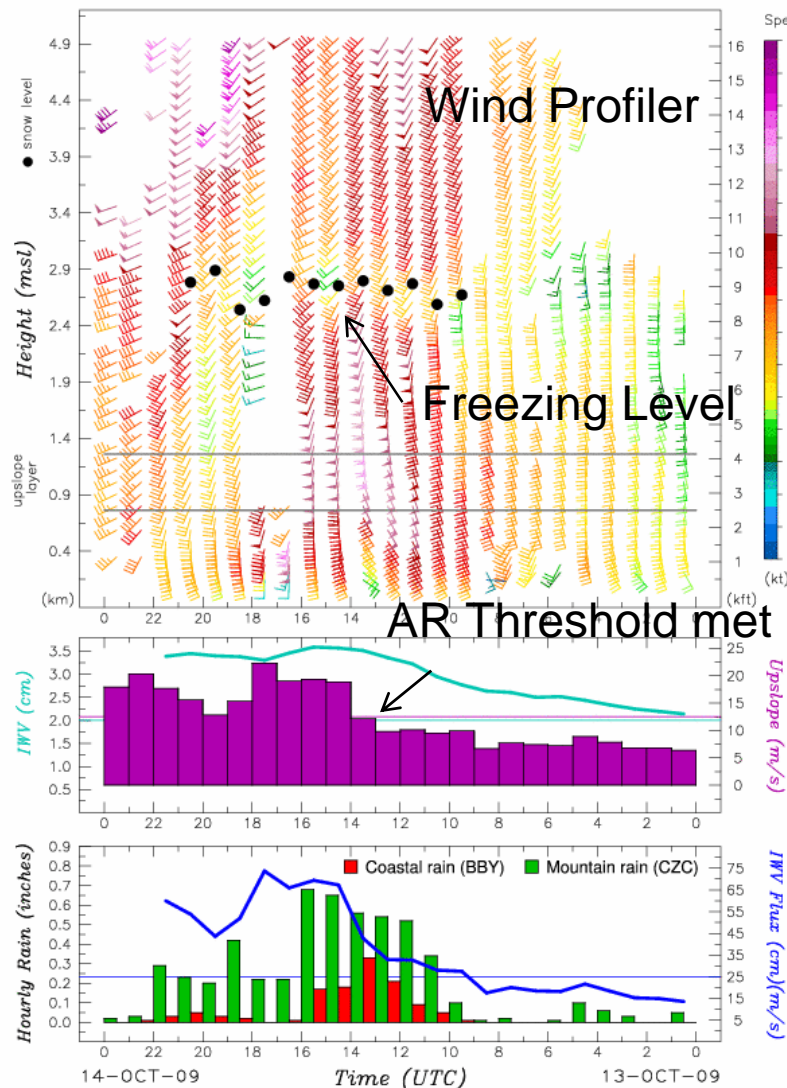


ESRL Physical Sciences Division
Surface Meteorology and Physics



Cazadero, CA (CZC)
38.61 N, 123.22 W, 475 m

ESRL Physical Sciences Division
Wind Profiling Radar

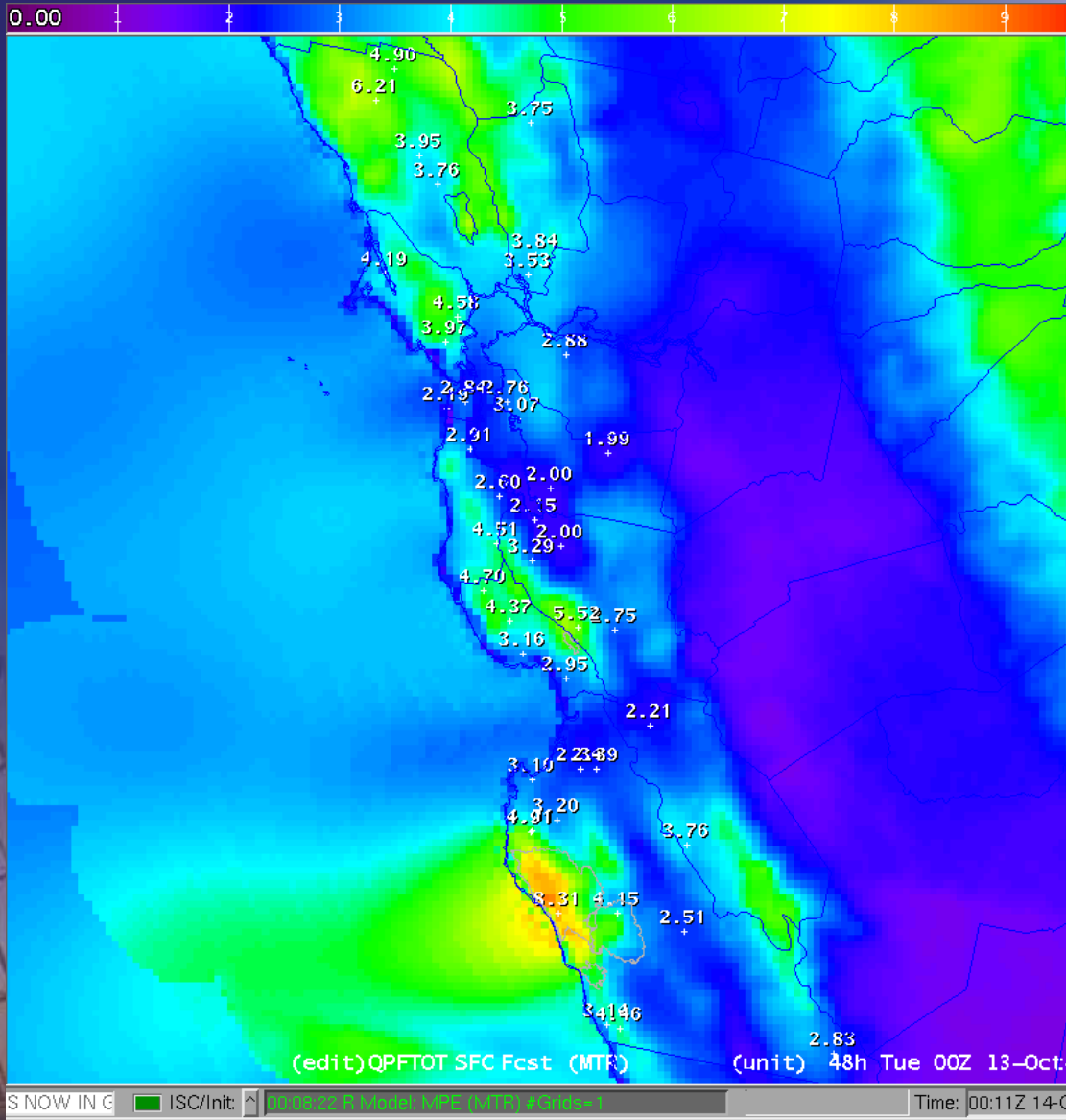


Bodega Bay, CA (BBY)
38.32 N, 123.07 W, 12 m
Cazadero, CA (CZC)
38.61 N, 123.22 W, 475 m

Upslope Direction = 230 deg
BBY 24-hr precip: 1.19 in
CZC 24-hr precip: 5.30 in



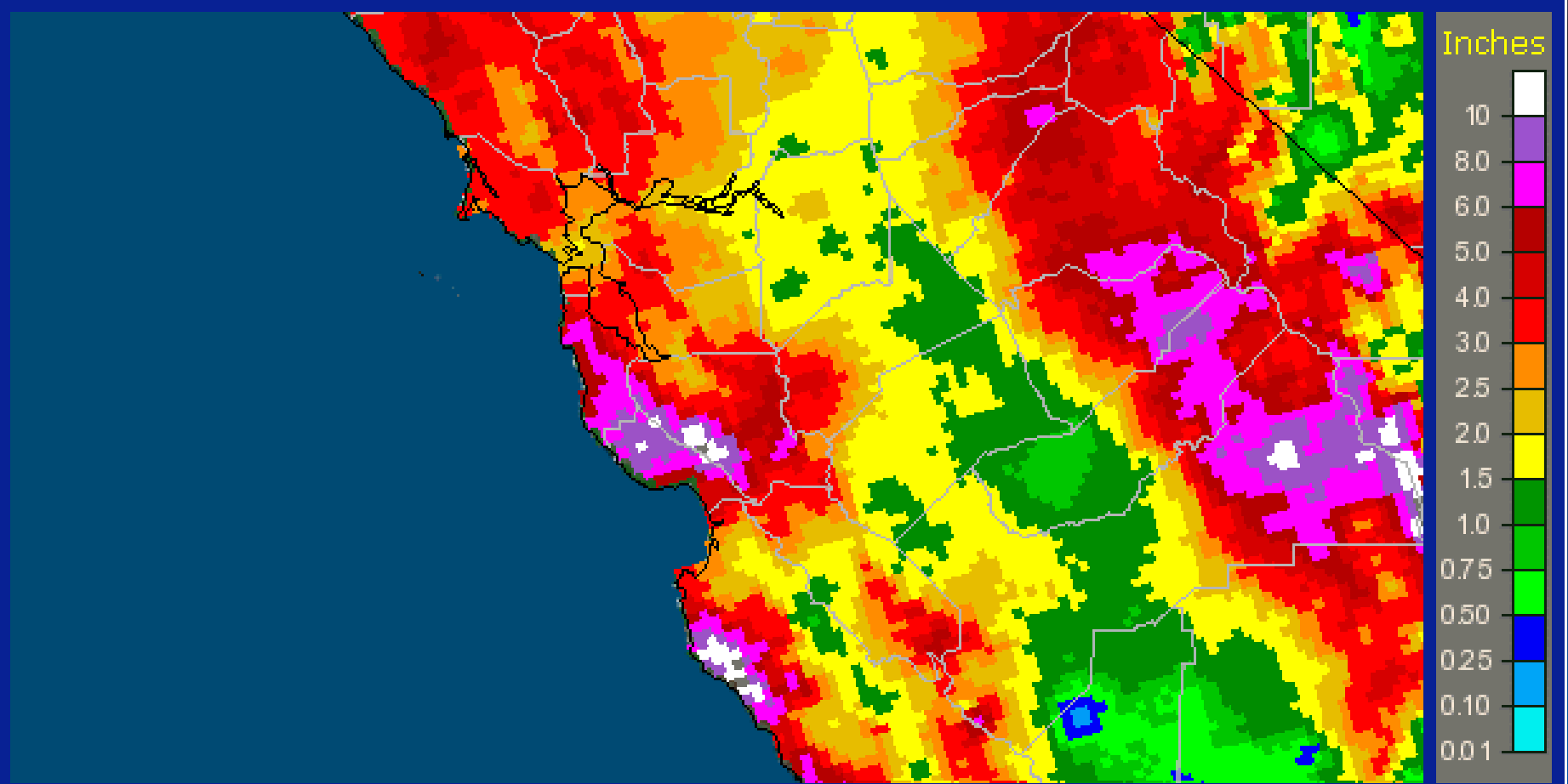
WFO 24 hr QPF Total

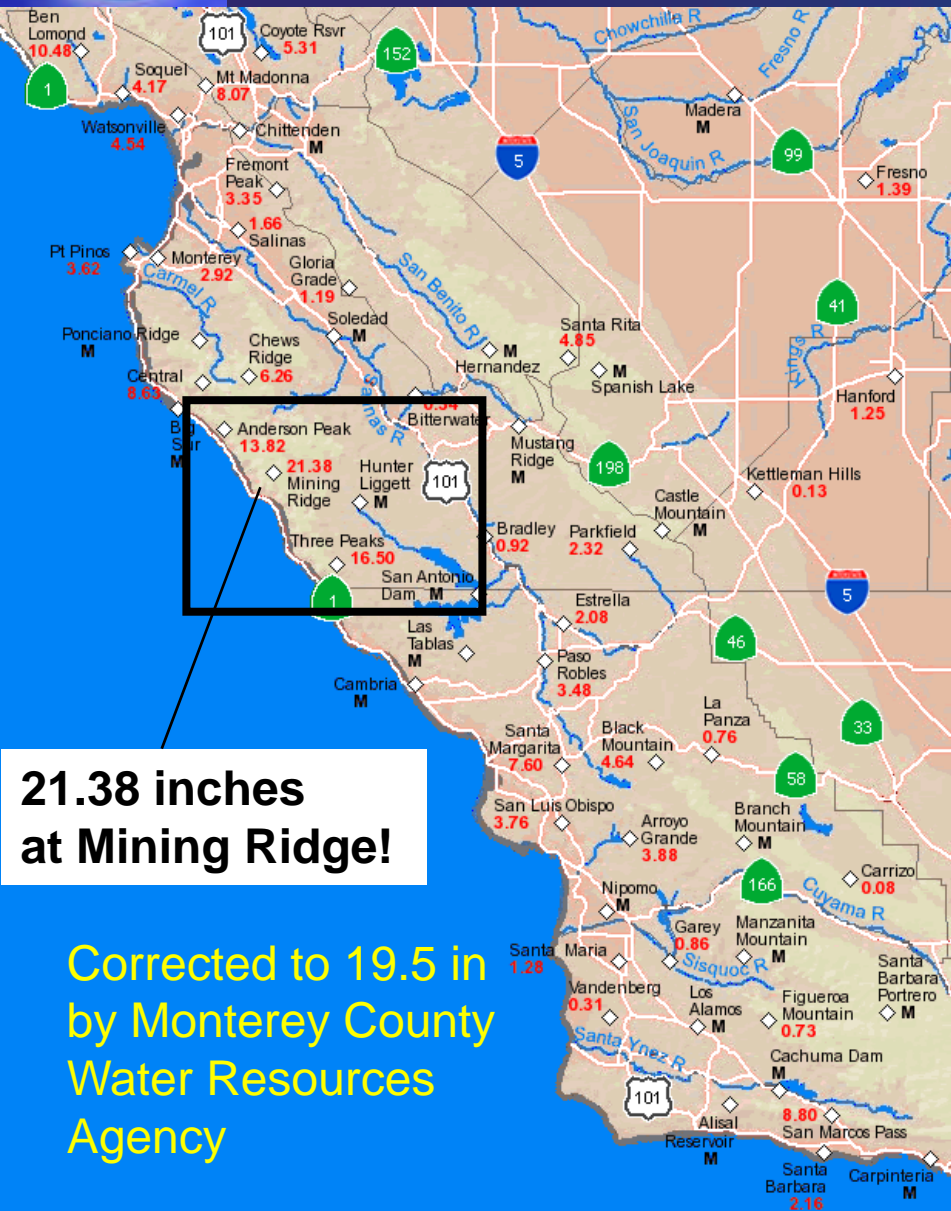




CNRFC 24-hr QPE Ending 12Z 14 Oct 2009

San Francisco Bay Area, CA (MTR): 10/14/2009 1-Day Observed Precipitation
Valid at 10/14/2009 1200 UTC - Created 10/16/09 10:34 UTC





Max 24-h precip from Alert Raingage network as of 1200 UTC 14 October

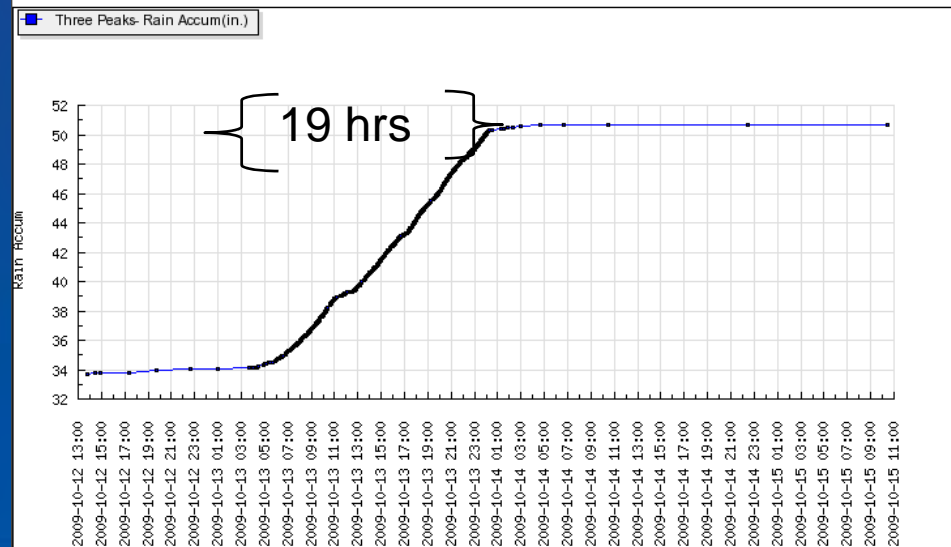
- Three peaks Alert trace

21.38 inches at Mining Ridge!

Corrected to 19.5 in by Monterey County Water Resources Agency

MONTEREY COUNTY Water Resources Agency

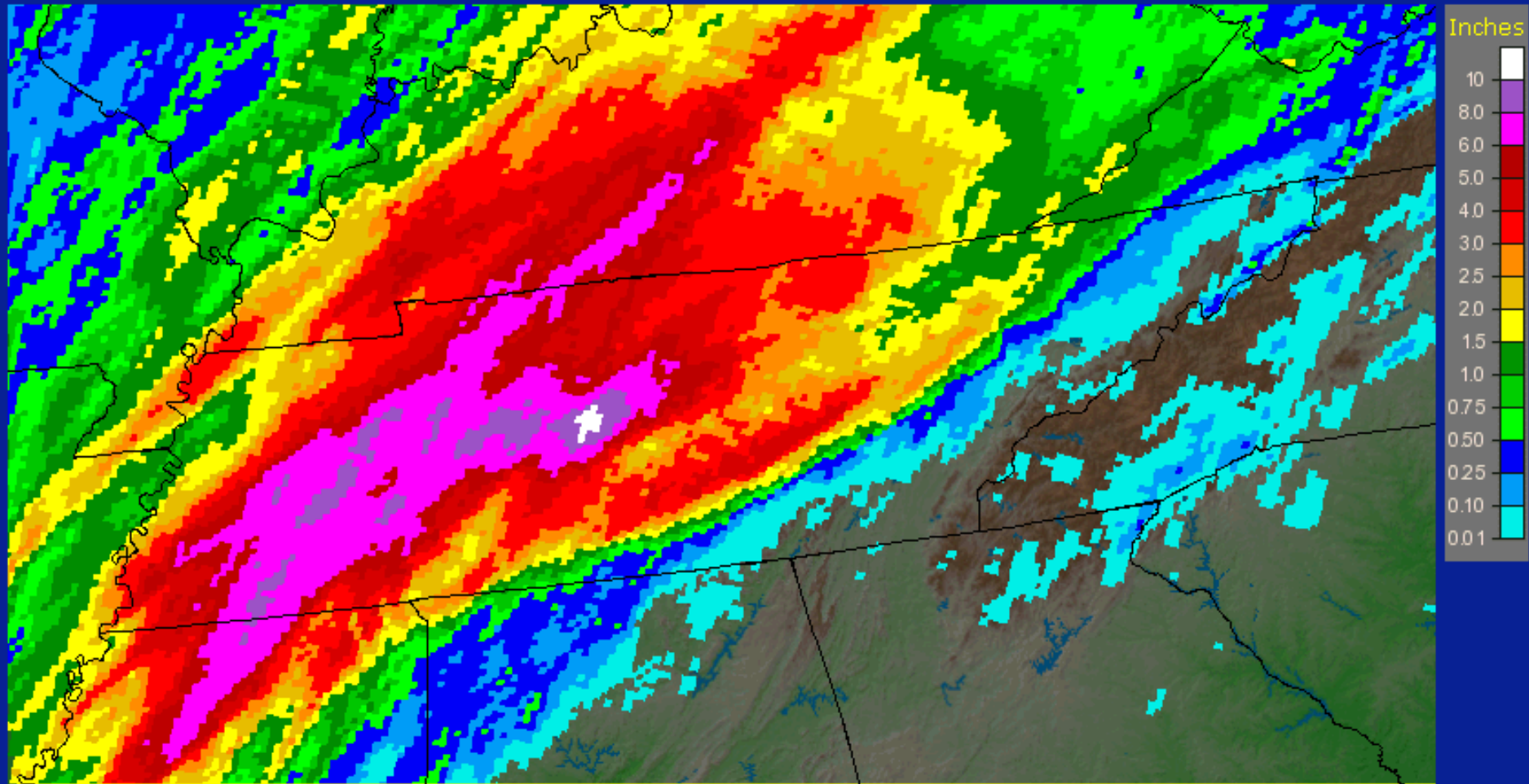
Multiple Graph (2009-10-12 12:31:00 - 2009-10-15 12:31:11) US/Pacific





Comparison to recent Nashville flood

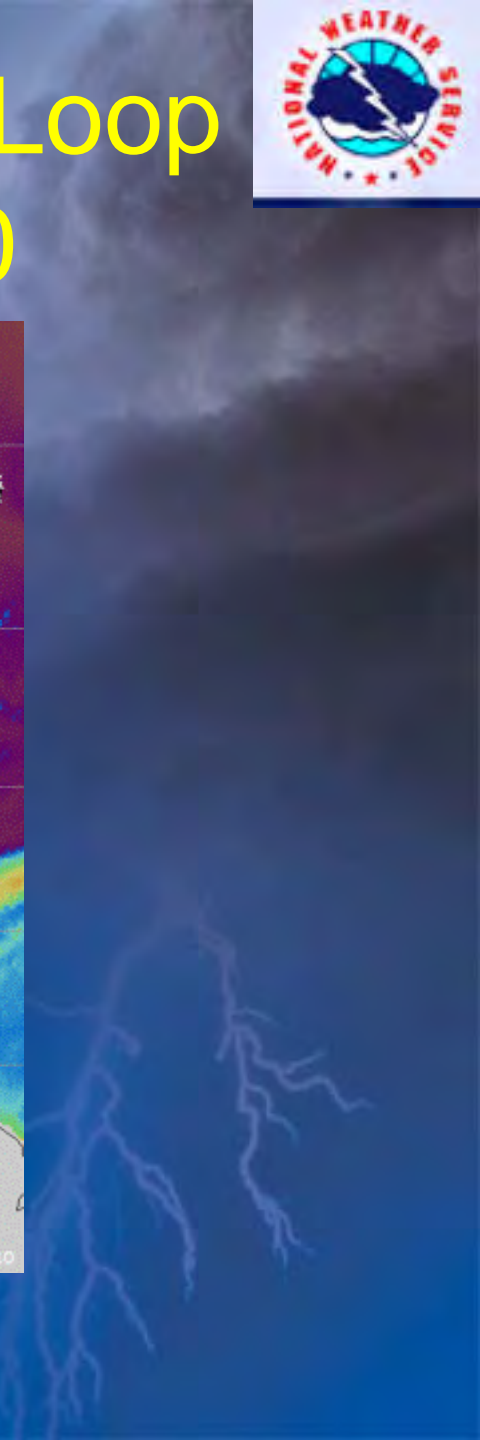
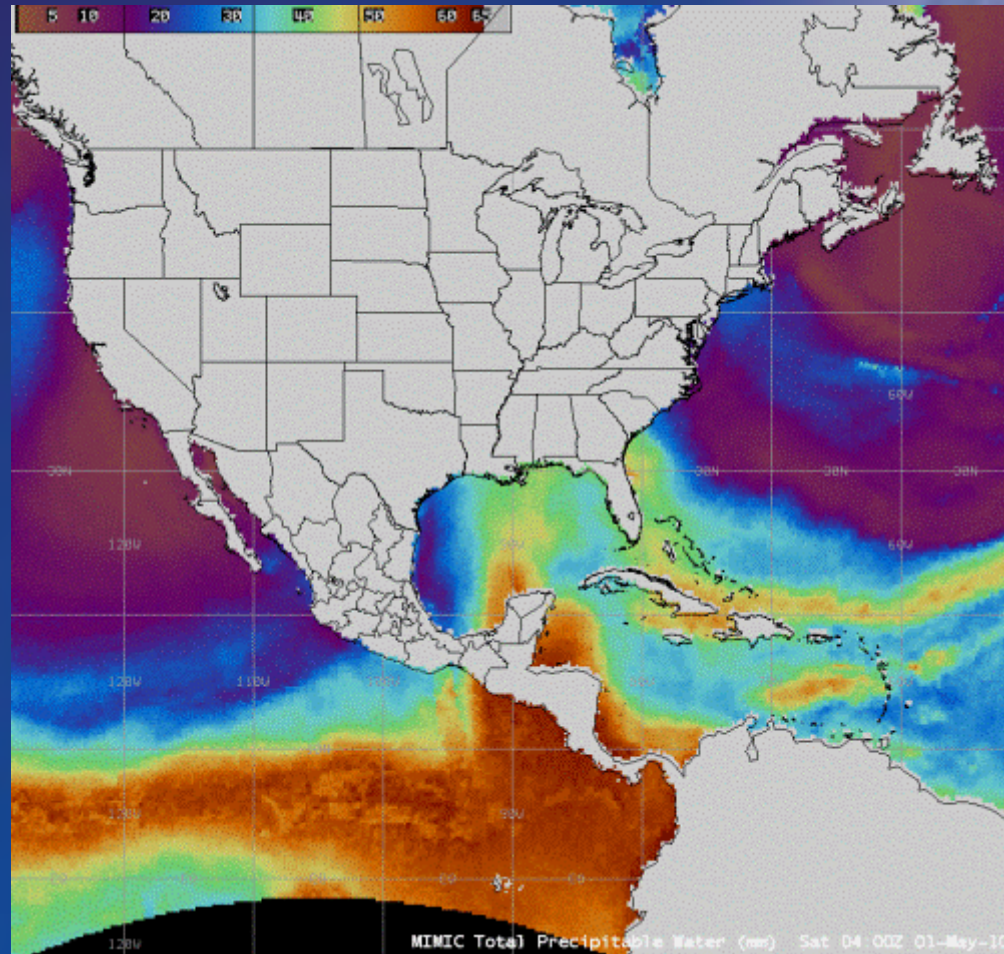
Tennessee: 5/2/2010 1-Day Observed Precipitation
Valid at 5/2/2010 1200 UTC - Created 5/4/10 23:00 UTC



Topo Pcpn Amount Counties Rivers States Highway/City RFC Boundary



Total Precipitable Water Loop Nashville Flood 2010



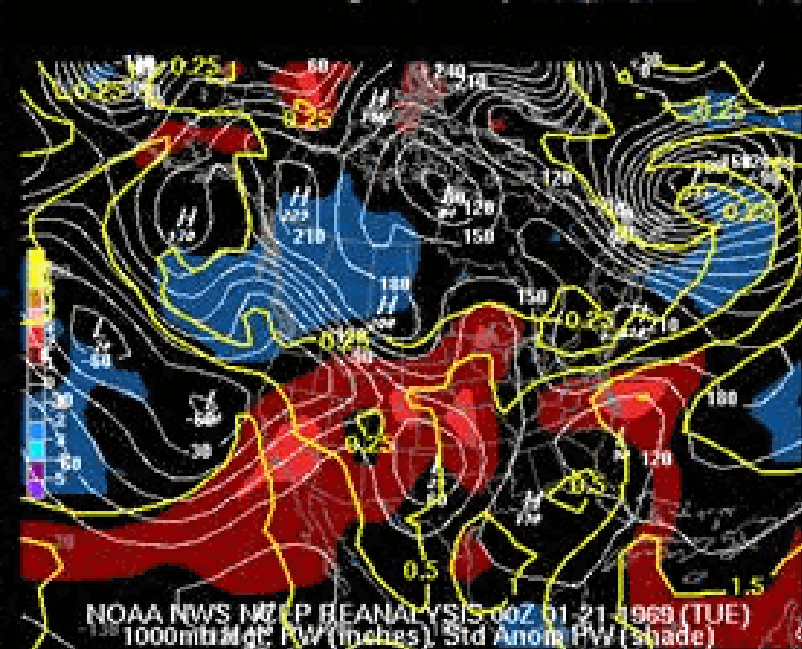
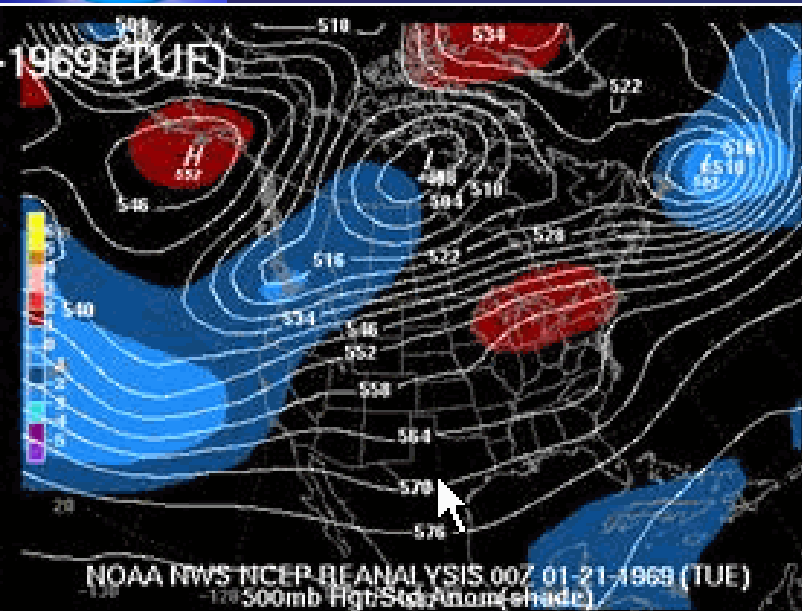


Possible ArkStorm Forecast Scenario

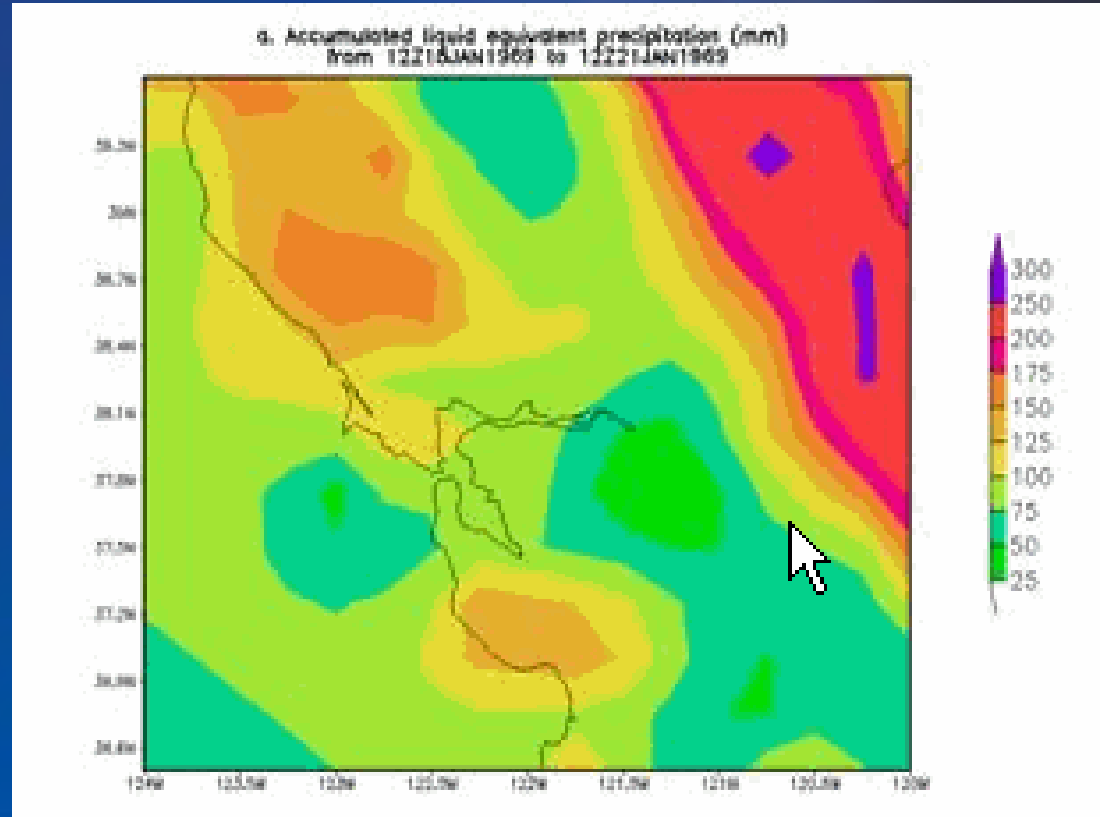
- Pattern forecast 5 to 7 days in advance typical of heavy rain and AR event
- Ensembles show bi-modal solution – warm and very wet or cold brief wet pattern
- Assume pattern preceded by two wet months with now low elevation snowpack
- Reservoirs encroached into flood pool from recent runoff



Jan 1969 Synoptic Pattern

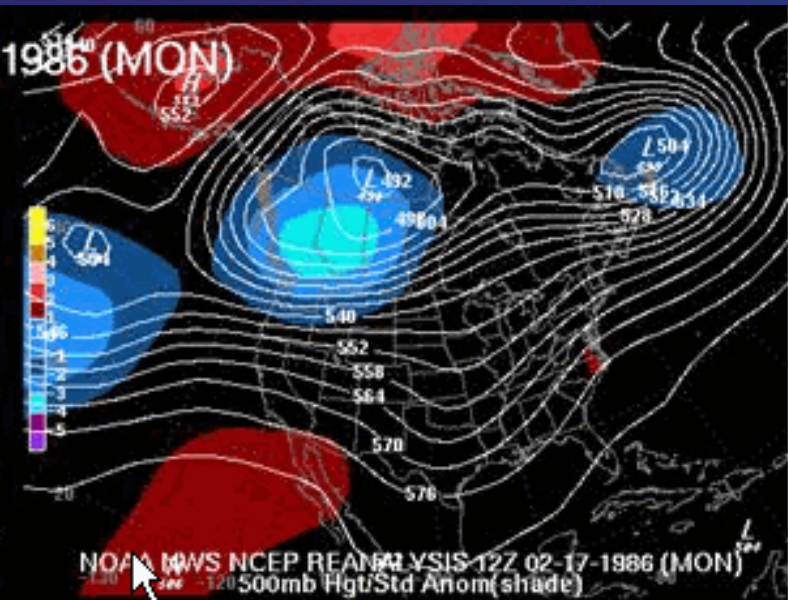


#12

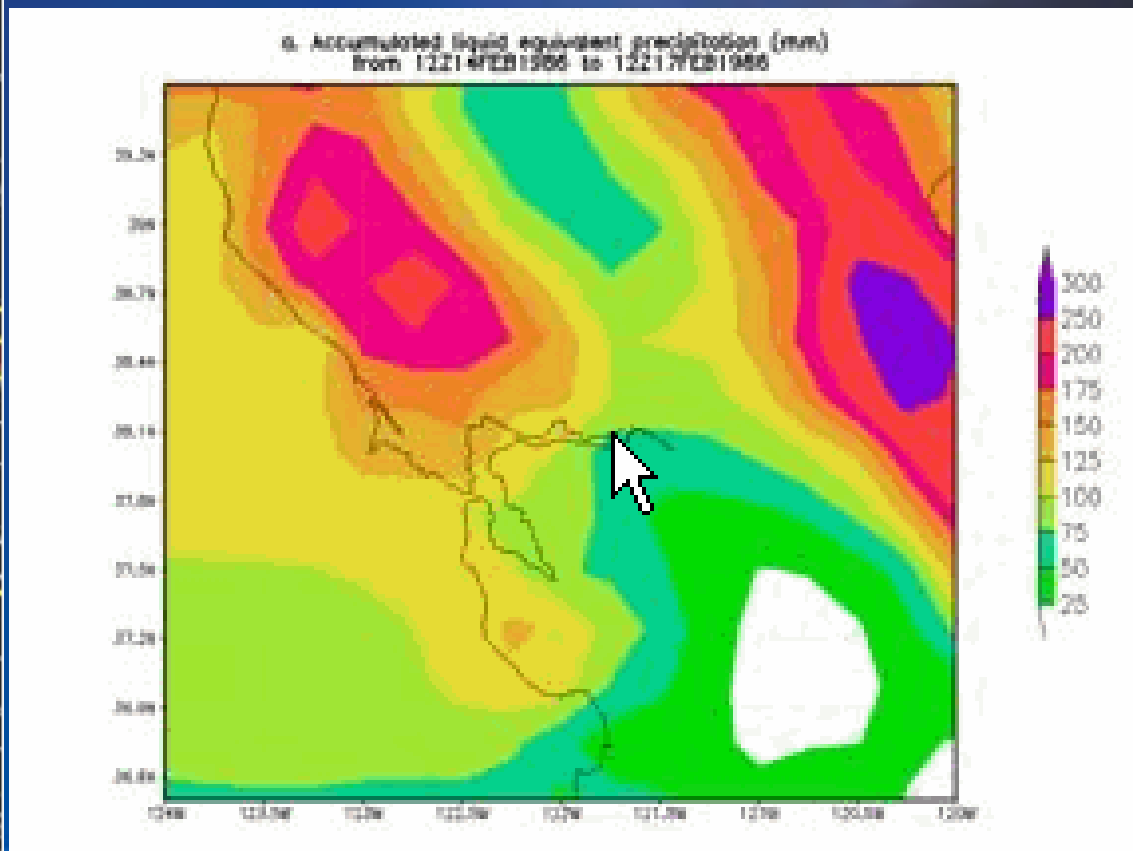
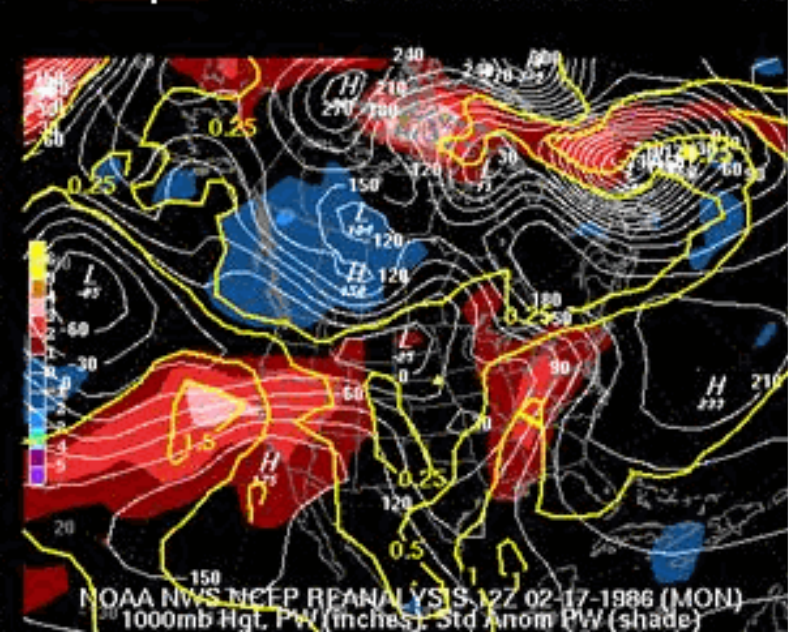




Feb 1986 Synoptic Pattern

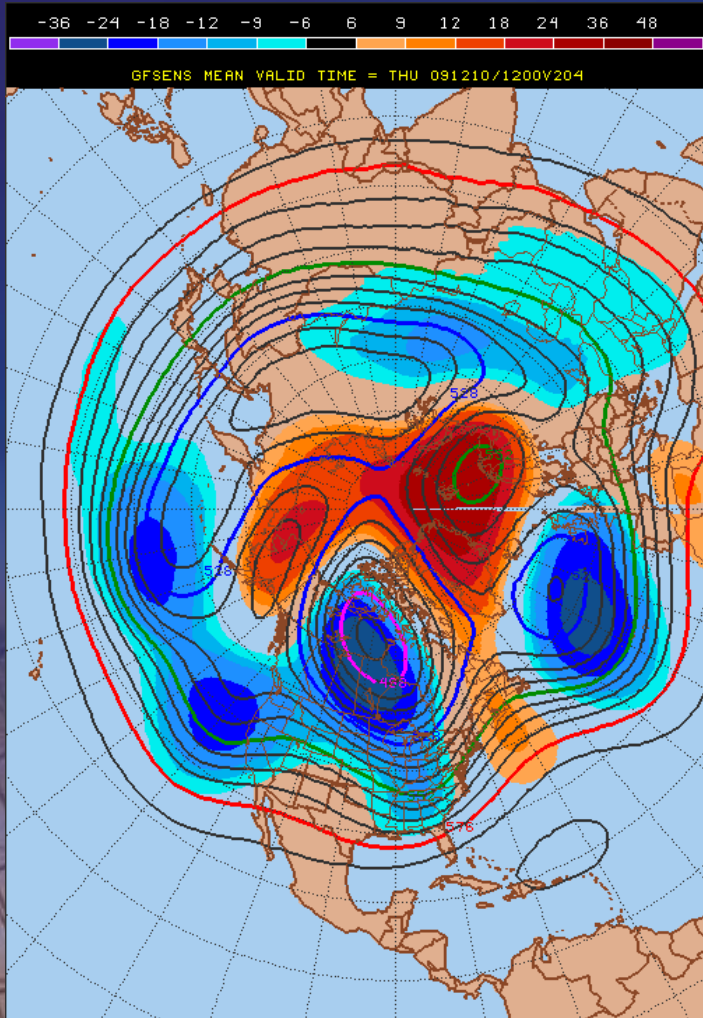


5





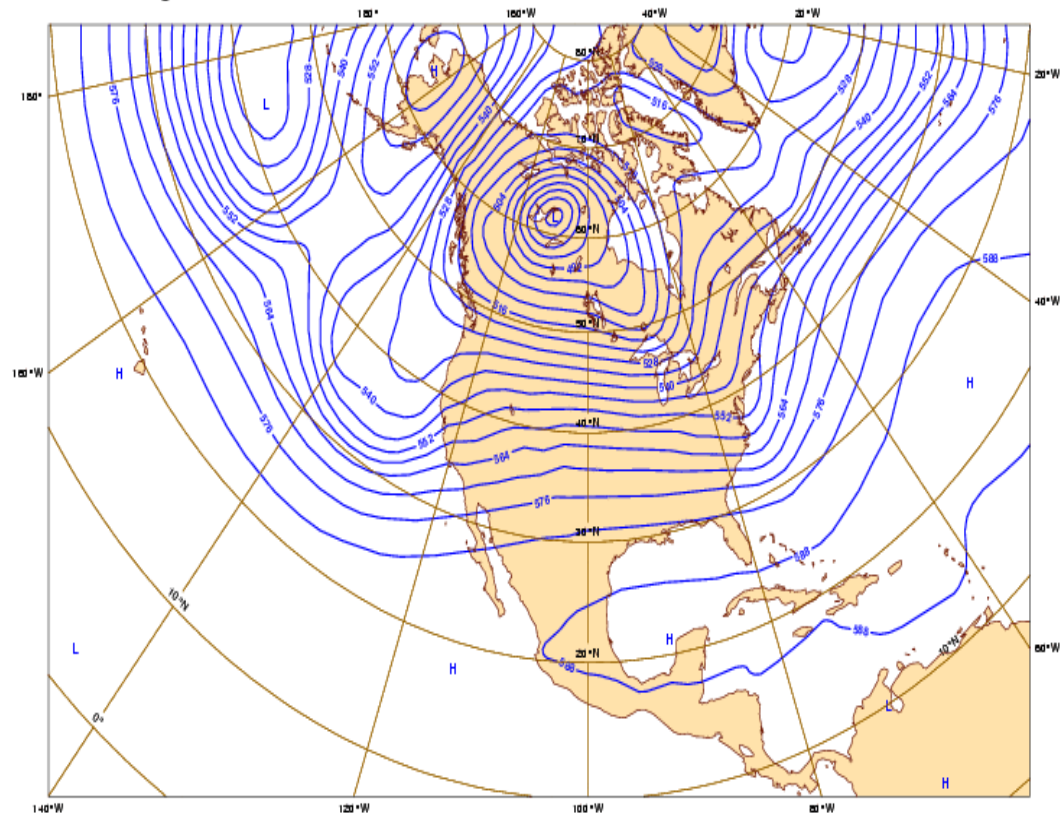
204 hr GFS ensemble forecast and 192 hr ECMWF 500 mb heights



GFS ENSEMBLE MEAN/ANOM 500MB HGT
INIT TIME = 091202/0000F204

PURPLE = 498 DM BLUE = 528 DM GREEN = 552 DM RED = 576 DM
WHITE = OPERATIONAL
SPAGHETTI VALID TIME = THU 091210/1200V204

Wednesday 2 December 2009 00UTC ©ECMWF Forecast t+192 VT: Thursday 10 December 2009 00UTC
500 hPa Height



GFS ENSEMBLE/21 MEMBER 500MB SPAGHETTI
INIT TIME = 091202/0000F204



Northern-Central California Impacts for period Day 5-10



Hazard	Potential Impacts
Heavy Rain	Models and ensembles have begin to trend to a serious and potential subtropical undercutting of west coast ridge beginning mid week next week. This would raise freezing levels to possibly above the crest levels along Hwys 80 and 50 causing a rain on snow event.
Flooding	Flood potential Outlook issued. A series of warm and very wet storms are possible beginning mid –week next week. The snowpack is well above normal and exists to rather low elevations. The combination of heavy rain and melting snow could combine to produce major flooding along all western and northern Sierra rivers downstream from Shasta to Yosemite and Kings Canyon areas.
Heavy Snow	Snow will begin falling mid-week at 6000 to 7000 ft. Snow levels are expected to rise to possibly 8000 ft before lowering to 5000 ft by late in the week. 1 -2 feet of snow is possible above 6000 ft.
High Winds	Another round of high winds are possible especially high elevations of the Sierra, Sacramento Valley and along the northern Ca coast.
Coastal and Marine	Gale warnings may be needed by mid-week next week. Large coastal swells are possible by late in the week.



Northern-Central California

Impacts for period Day 1-7

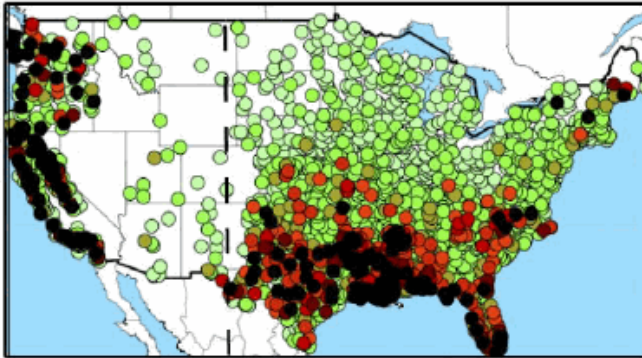


Hazard	Potential Impacts
Heavy Rain	Major warm rain event on tap for Northern /Central Ca over the next 7 days. Rainfall amounts of 10 to 20 inches with locally 30 in possible in preferred sw facing slopes along the coast range and in the Sierra and Siskiyou. Lower elevation sites could experience 4 to 8 in of rain. Warm tropical air from the mid-Pacific crossing over the equator is moving directly toward northern and Central Ca.
Flooding	Rainfall amounts along with some melting snows at elevations below 5000 ft will lead to the potential for major flooding along the main rivers from the Sacramento to the north to the Kings and Kaweah to the south. Also coastal rivers that are still running high will most likely exceed the flood levels set last week. This is a potentially very dangerous and life threatening event for a widespread area of northern and Central Ca. Record flood levels are possible. Persons living along rivers and streams or near or behind levees in the central Valley should pay close attention to the forecast over the next few days.
Heavy Snow	Heavy snow warnings for elevations above 7000 ft. through Saturday. Snow levels are expected to rise above 8000 ft before lowering to 5000 ft by late in the week. 1 -3 feet of snow is possible above 8000 ft.
High Winds	High wind watch for the Sierra and northern Sac Valley and foothills beginning Thursday. Winds over 100 mph possible higher elevations of the Sierra with 40 to 50 mph lower elevations. Widespread power outages are likely
Landslides in Coastal Areas	Combination of completely saturated ground and more very heavy rain could lead to major landslides along steep terrain especially coastal locations. Some landslides have already occurred in the Bay Area from the last series of storms.

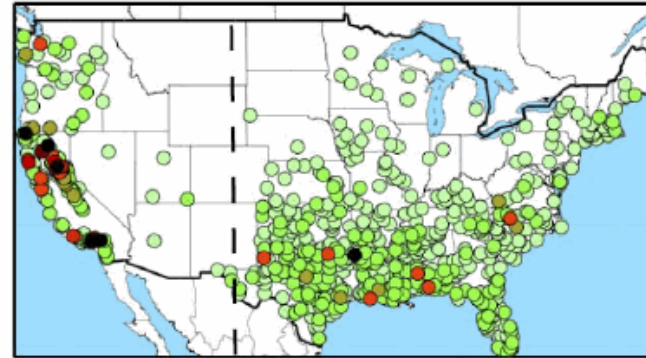


AR Intensity Category?

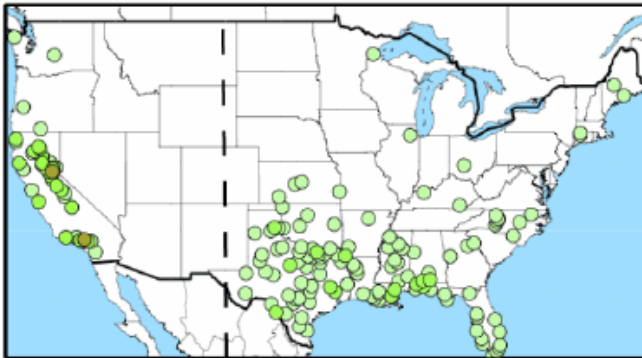
NUMBER OF EXTREME 3-DAY PRECIPITATION EVENTS AT US COOP STATIONS, 1950–2008



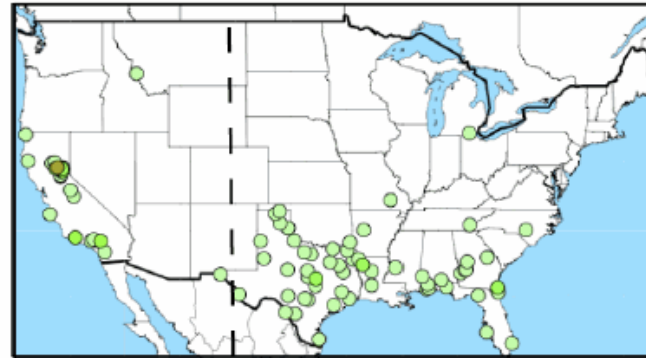
R-Cat 1 (200 < P < 300 mm)



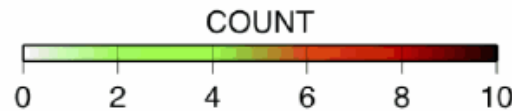
R-Cat 2 (300 < P < 400 mm)



R-Cat 3 (400 < P < 500 mm)



R-Cat 4 (P > 500 mm)





Conclusions

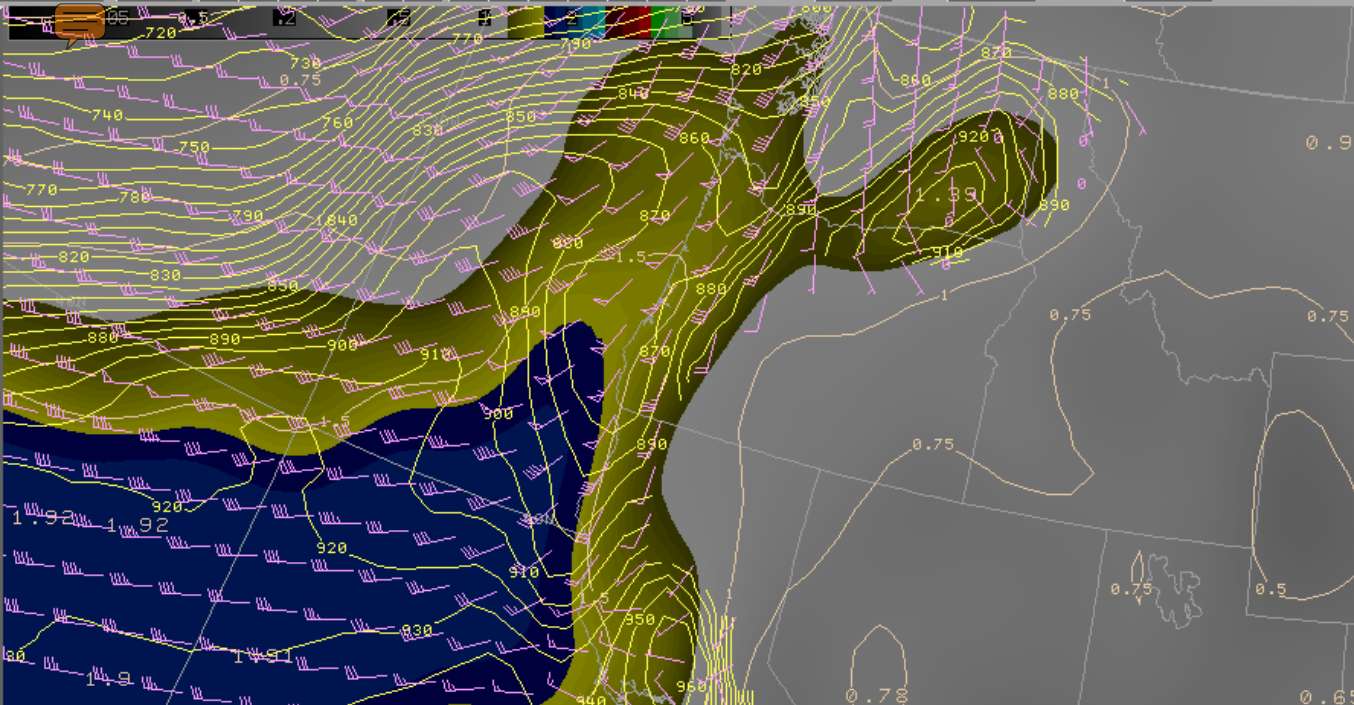


- Land-falling Atmospheric Rivers play a major role in producing extreme rainfall events in CA.
- Forecasters now have a much better understanding of what these phenomena are, how they form, and how to diagnose them in model output.
- This knowledge allows forecasters to provide up to 10 days lead-time in alerting state and local emergency officials and water resource agencies to the potential flood threat. This is critical if forecast based reservoir operations are to be successful.
- It is proposed that an objective scheme for categorizing the potential strength of land-falling ARs be created much like is done for land-falling tropical cyclones. This could be based on model forecast QPF (Ralph and Dettinger) or projected rain rates using model forecasts of IPW and LLJ magnitudes aka Neiman.
- The knowledge and information presented here will be used as part of the states Golden Guardian drill in 2011 called ArkStorm.

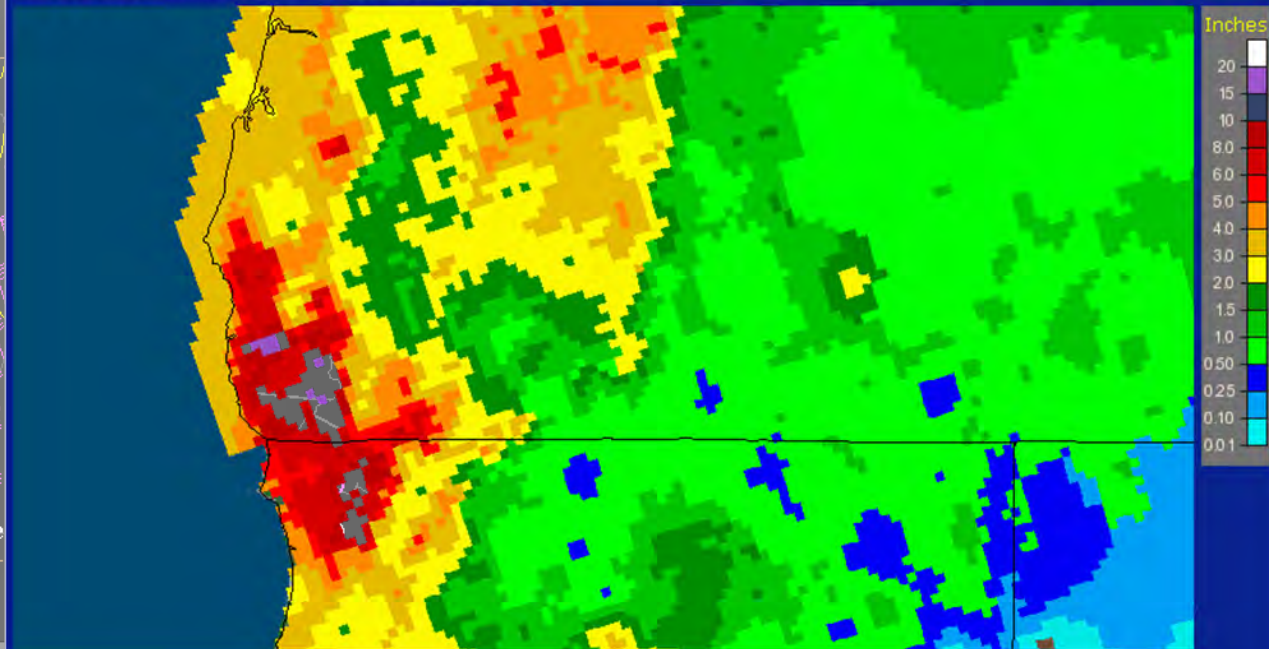


AR forecast 8 days out valid 06Z June 4 2010

7 Day rainfall totals June 1-7, 2010



Medford, OR (MFR): Current 7-Day Observed Precipitation Valid at 6/6/2010 1200 UTC - Created 6/7/10 0:03 UTC



GFS40 Lave
GFS40 L

Radar: [dropdown menu]

- Topo
- Pcpn Amount
- Counties
- Rivers
- States
- Highway/City
- RFC Boundary