A Local Area QPF and Analysis System for Atmospheric Rivers

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International Conference on Atmospheric Rivers
Scripps Institution of Oceanography,
La Jolla, California, USA
August 8, 2016

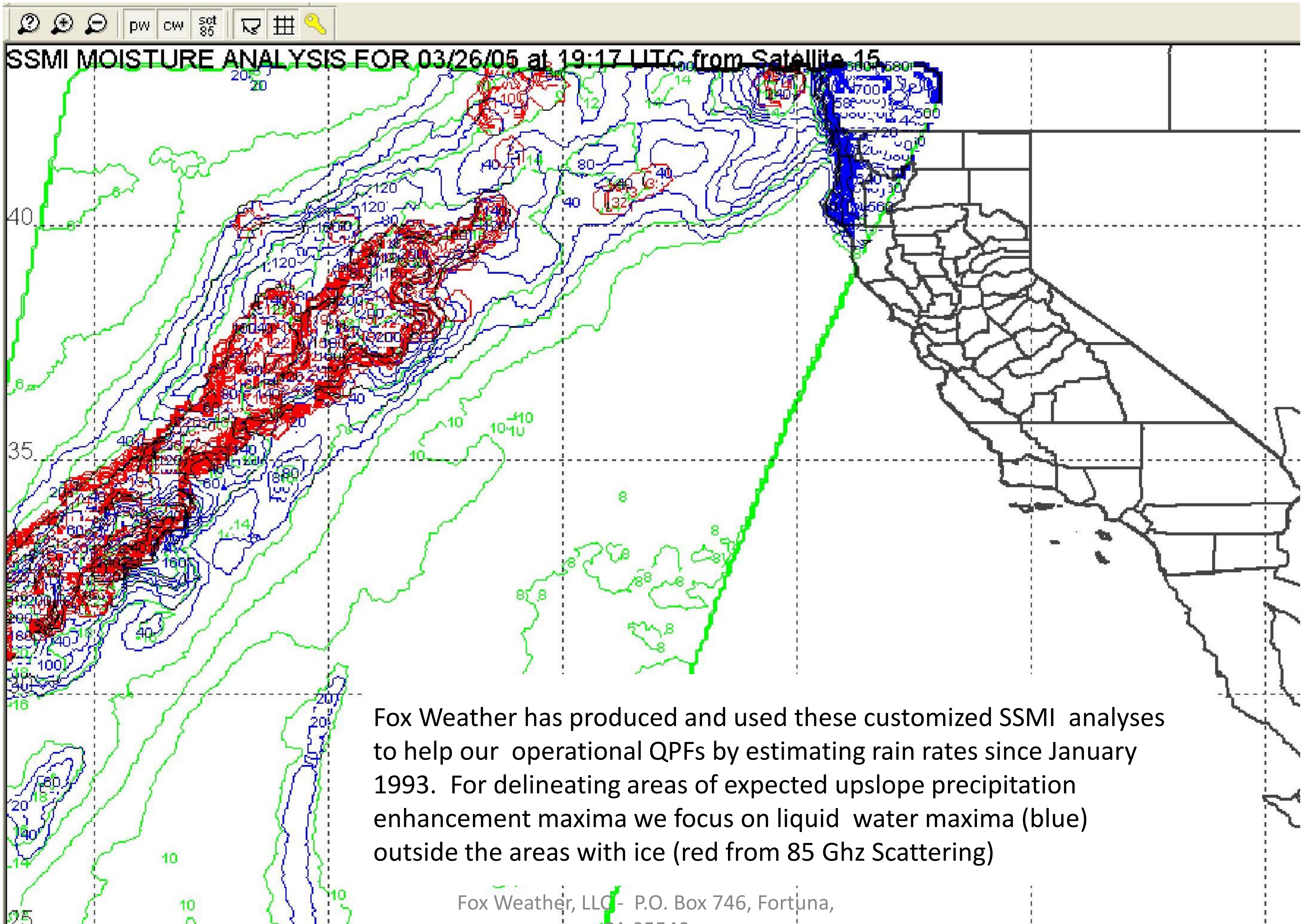
FOX WEATHER LLC

Overview

- How we approach Atmospheric Rivers….Local Focus
  – Early work in 1990s and early 2000's (SSMI)
  – Clients … interested in local effects
  – Local Forecast Modeling: WRF and MtnRT®
- MtnRT ®   Overview
  – Who uses MtnRT? Where is it implemented?
    - QPFs…gridded, text, animations.
    - Diagnostics and wind studies.
  – Communicating 'on-the-ground' effects of Atmospheric Rivers
  – Other uses: Forestry/Fire Weather, and Fruit Frost.

Our Early Work Relating to Atmospheric Rivers Perspective of SSMI Microwave Satellite Imagery

- 1988-1990: Joint paper with Frank Wentz (Remote Sensing Systems): *SSMI as a forecasting tool in west coast winter storm rainfall* (Wentz and Fox, 1990)
- To distinguish areas of warm rain, we used IWV, LWC, and 85 GHz Ice Scatter Index from SSMI microwave imagery.
- From observed (raingauges): Largest orographic enhancement occurred in fronts having high columnar liquid contents (LWC) and lacking ice phase "warm rain".
- Operationally we looked for frontal bands with LWC>=100mg/cm^2 as an indicator of potential for heavy rains.
- Developed an heuristic satellite rain estimation algorithm based on LWC, drop size distributions and their variability in warm clouds
  - Helpful in operationally forecasting heavy orographic rain events since 1992.



Fox Weather has produced and used these customized SSMI analyses to help our operational QPFs by estimating rain rates since January 1993. For delineating areas of expected upslope precipitation enhancement maxima we focus on liquid water maxima (blue) outside the areas with ice (red from 85 Ghz Scattering)

Warm Rain: Significant Contributor to Total Rain

- Rain rate at coastal point not much different from brightband rain within main front.
- Rain rate briefly higher in convective bands than in warm rain.
- Includes coast and coastal hill points (Sonoma Co, Calif)

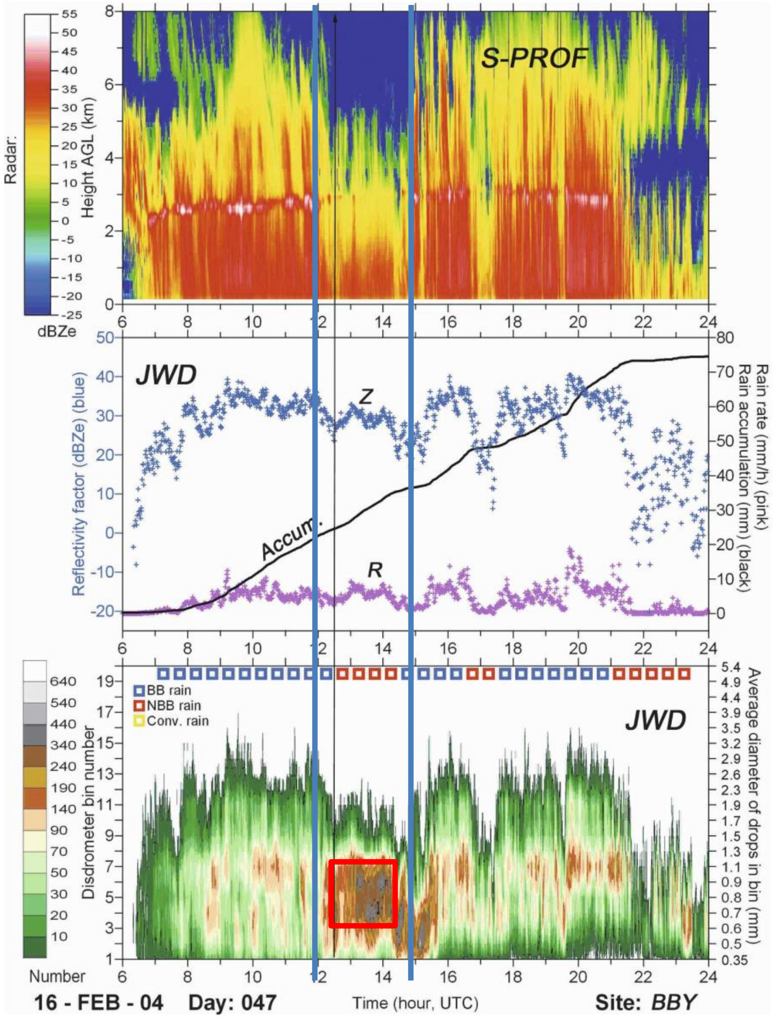


FIG. 2. S-PROF and JWD data from BBY for an 18-h period. (top) A time–height display of reflectivity. (middle) Parameters *R*, *A*, and *Z* computed from the raw DSD data of the JWD. (bottom) Contoured numbers of drops (min^{-1}) as a function of time and *D*. Open squares indicate objective classification of half hours as (blue) BB or (red) NBB rain.

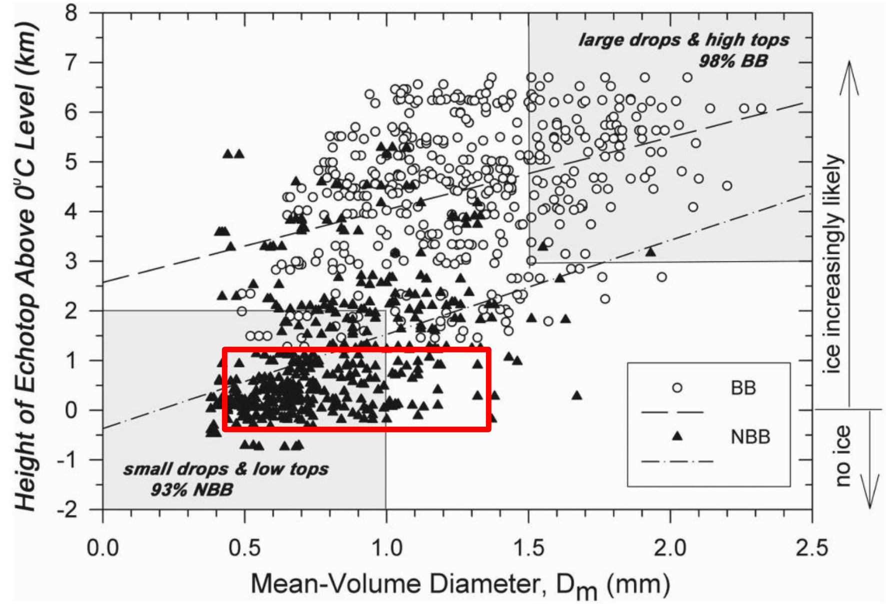


FIG. 8. Mean-volume drop diameter measured by the disdrometers as a function of height of the S-PROF echo top above the 0°C level. Data from Cazadero and Bodega Bay for BB (open circles) and NBB (triangles) periods are included. Each point represents one 10-min disdrometer sample. Dashed lines are least squares best fits to the data.

Outlined in red areas of high liquid content.

Martner B. E., **S. E. Yuter**, **A. B. White**, **S. Y. Matrosov**, **D. E. Kingsmill** and **F. M. Ralph** (June 2008): Raindrop Size Distributions and Rain Characteristics in California Coastal Rainfall for Periods with and without a Radar Bright Band. *J. Hydrometeor.*, **9** (3), 408-425

The MtnRT® Forecasting and Analysis Utility

- What Is MtnRT®?
  - The elegant description: "Expert System"
  - Another elegant description: *"Collection of heuristic models"*
  - What is in MtnRT? *Thumb Rules, Empirical Utilities, Adaptable Architecture*
- Processing: GFS -> WRF arw (12 or 4km) -> MtnRT® (1.5 km), using DEM terrain
- Effective Resolution of Rain: *closer to 3-4 km even if mapped to a 1.5 km grid*.
  - *Reason: Propagation speed of collection of drops versus growth time of drops can alias the resolution of cell sizes and rain rate*.
- MtnRT provides inputs for our QPFs
- Types of Midlatitude Rains Forecasted by MtnRT
  - *Fronts (no AR), Single cyclone (2-3 fronts w/subtrop influence), Conveyor belt w/4 or more fronts or mesoscale waves, subtropical influence.*
- MtnRT Forecast of Convective systems
  - *Inputs from 4km WRF preferred*

MtnRT development and Use:

- Crop Disease Forecasts over Complex Terrain - USDA/NIFA: CSREES, AFRI, ARDP, thru OSU/IPPC
- USDA/ARS wind studies for disease spore movement. Publications in *Phytopathology*
- Crop Disease Weather forecasts - thru Oregon State Univ/IPPC
- Main driver for Fox Weather's QPF System
  - Since 2011
  - QPFs for rain and snow
    - Text, maps; animations thru 168 hours via FoxQPFserve™
  - Gridded QPFs formatted for USACE Los Angeles
    - Since 2014
  - Gridded QPFS for Santa Clara Valley Water District
    - Since 2012
  - MtnRT® Atmospheric River Module:
    - Written in 2011
    - Updated in 2013 and 2015.
- Other Clients/Agencies
  - Fire Weather Forecasts for Forestry companies
  - Frost and Freeze Guidance for agriculture…winegrapes

MtnRT Forecast Regions

- Coastal Washington and Oregon - Fox Weather
- California and Nevada -Fox Weather
- All of Western Mexico and Arizona –Fox Weather
- Midwestern US/Great Lakes – Fox Weather
- Southern Mexico to Yucatan – Fox Weather
- Western US Rockies westward – Oregon State Univ/IPPC

Basic Concepts for Atmospheric River Module in MtnRT®

- Integrated vapor transport (IVT) : Standard measure is 1000-250 hPa.
- Low level IVT (LIVT) in MtnRT is 1000-750 hPa.
- Warm Rain ("Non-bright-band")
  - Input model resolution either 12 or 4 km. Self –adjusting for upstream model resolution.
  - Input model temporal resolution either 6 or 3 hours.
  - Collision-coalescence is the primary growth mechanism.
  - Assumes a Marshall-Palmer DSD, with large variation in N(0) .
  - Vertical depth of moist layer: Deeper moist layer allows more droplets to collide and coalesce
  - Relationship between T, Td, Wind Speed within a forecasted rain area over ocean
    - Indicator of probable low-level jet and implied LIVT below resolution of the WRF 12km input.
    - Provides estimate of enhanced rain rate in the LLJ and barrier jet.
    - Existence of LLJ or barrier jet implies moisture convergence, which is parameterized in MtnRT.
- Upslope Enhancement
  1. Mean dew point in airmass at low levels …within 2 km of the surface
  2. Upslope component wind speed of air in (1) to calculate upslope-enhanced rain amounts for a particular slope and aspect, given a particular wind vector.
  3. Terrain-enhanced rain is added to the WRF rain forecast

Some Background References

- **Martner B. E.**, **S. E. Yuter**, **A. B. White**, **S. Y. Matrosov**, **D. E. Kingsmill** and **F. M. Ralph** (June 2008): Raindrop Size Distributions and Rain Characteristics in California Coastal Rainfall for Periods with and without a Radar Bright Band. *J. Hydrometeor.*, **9** (3), 408-425. – Illustrates nicely the differences in DSD between BB and NBB rains.

- **Neiman, P. J., F. M. Ralph, A. B. White**, **D. A. Kingsmill**, and **P. O. G. Persson,** 2002: The statistical relationship between upslope flow and rainfall in California's coastal mountains: Observations during CALJET. Mon. Wea. Rev., 130, 1468– 1492. - A good basic paper for our application.

- **Neiman, P. J., A. B. White, F. M. Ralph**, **D. J. Gottas**, and **S. I. Gutman** (2009). A Water Vapor Flux Tool for Precipitation Forecasting. *U.K. Journal of Water Management* , 83-94 .

- **Pruppacher, H.R., and Klett**, J.D. 1980: Microphysics of Clouds and Precipitation , D. Riedel, Boston, pp. 23-26. (Differences in DSD in warm rain and effects on rain rate).

- **Waldvogel, A.,** 1974: The N_0 jump of raindrop spectra. J. Atmos. Sci., 31, 1067–1078. – Short period variability in drop size distribution that contribute to variation in rain rates.

- **Wentz, F.J., A.D. Fox,** 1990: Using SSM/I as a forecasting tool for extratropical cyclones in the eastern North Pacific Ocean and California. 5th Conference on Satellite Meteorology and Oceanography, London, England, Sept 3-7, 1990, Preprints (A92-22526 08-47). Boston, MA, Amer. Meteor. Soc., 1990, pp. 265-271 - Focused on rain rates associated with different types of rains (warm rains versus rain with ice phase, as determined from SSMI imagery).

- **Fox, A.** (2014). MtnRT® White Paper: Summary of the MtnRT® system – providing weather inputs for plant disease models. Published by Fox Weather, LLC, Fortuna, CA, USA at www.foxweather2.com/MtnRT_WhitePaper140502.pdf, 54 pp.

Atmospheric River (AR) Basic

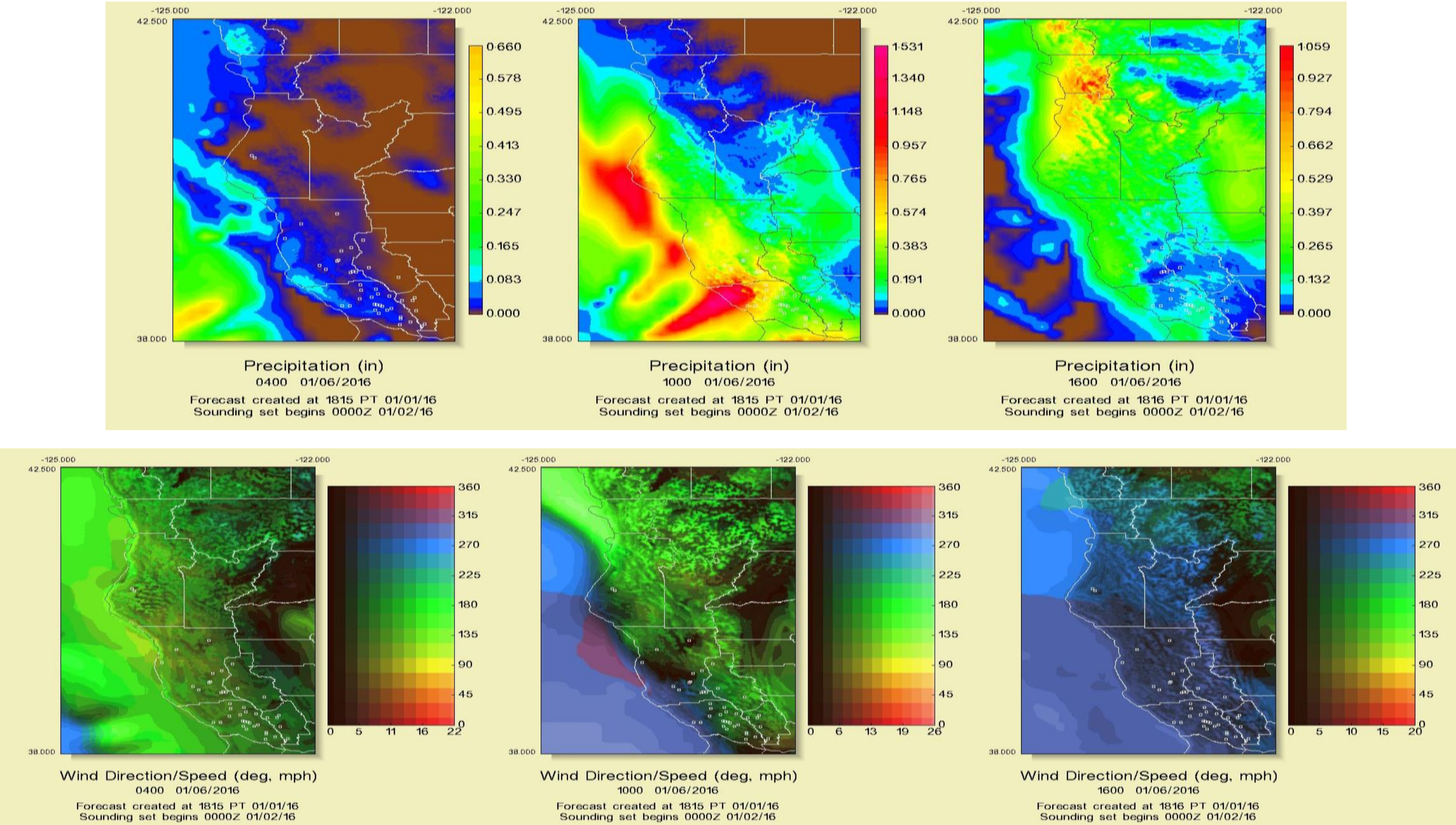
- A long and moist conveyor belt – classical definition.
- Using MtnRT: Perspective of daily QPF, sub-daily time scales with terrain forcing.
- Basic questions:
  - Subtropical jet or flow present plus a long, well defined IWV zone?
    - Is an IVT or LIVT present?
  - Are mesoscale wave signatures present or expected within a larger AR pattern?
  - Can MtnRT add local scale insight to forecasters to describe AR-influenced rains locally?
  - Can MtnRT help us to better communicate expected effects to our clients?
- *Communicating local scale AR effects to clients using MtnRT:*
  - *Pictures and Animations!*

MtnRT for Atmospheric Rivers: Diagnostics and Illustration

- Concept:
  - AR influence : continuous function from weak to strong
  - Some type of AR influence occurs whenever the westerlies are active.
- Diagnostics:
  1) Typical appearance of AR and non-AR rains in MtnRT forecast
  2) AR rains show strong upslope enhancement of rainfall over low foothills <0.8 km as well as at 2km. (Figure 6)
  3) Non-AR type rains show minimal upslope enhancement. (Figure 4)
  4) AR rains often show heavy rain over ocean in strong LLJ (Figure 5)
- MtnRT Wind Vector Detail
  - Illustration of dry wind detail over ocean/coastal zone. (Figure 7).
  - The ability of MtnRT to resolve coastal wind circulations below the resolution of input WRF enables resolution of other wind features, e.g. barrier jet.

Figures

- Atmospheric River (AR)
  - Basic Characteristics-
    - Warm sector rainfall (warm rain)
    - Includes low level jet (LLJ) - higher water vapor (IWV, implied LIVT), and LWC within the lowest ~2.0 km above ocean
  - Illustrations
    - Non-AR: Heavy rains but minimal upslope enhancement. (Figure 4)
    - Heavy rain over ocean due to moisture convergence (LIVT) in the low level jet within a larger rain area (Figures 5a)
    - Heavy Upslope Rain (Figures 5b)
- Forecast Verifications (Figures 6a-b)
- Local Wind illustration, coastal zone (Figure 7)



Classification: Cold front, no AR or low AR influence due to low wind speed over coast-inland

Figure 4

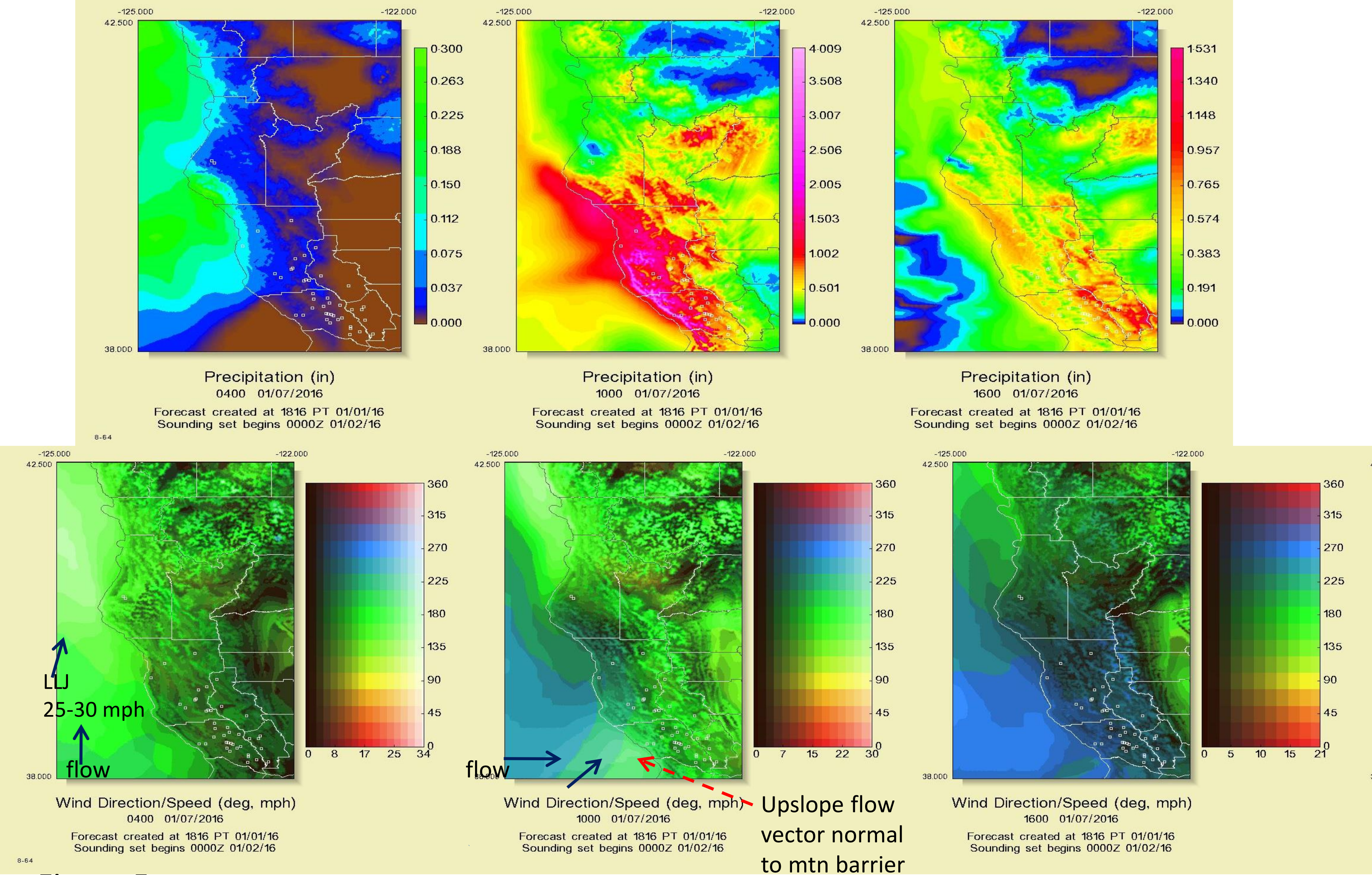


Figure 5a.

Classification: Cold front, weak to moderate AR, AR focusing in Sonoma Co. AR characteristics absent north of Cape Mendocino due to colder airmass 1000-800 hPa.

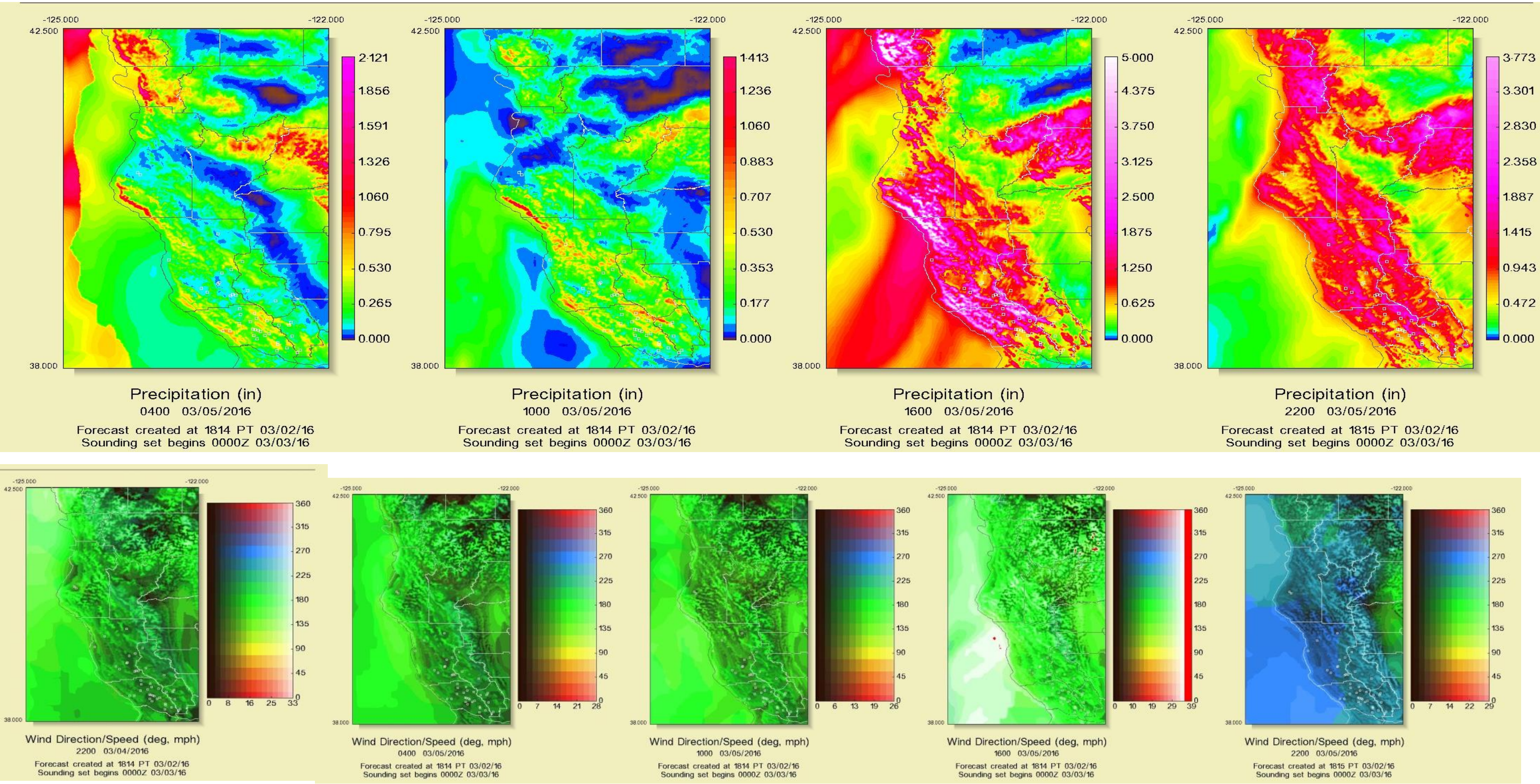


Figure 5b. Classification: Cold front with moderate AR, AR focuses Mendocino-Sonoma Co's. AR characteristics small to the north of Cape Mendocino until second front arrives ~1600.

Forecasted versus Observed Rainfall from 46 station network - Santa Clara Valley Water District for 24 hours ending at 2400 PST 8 Mar 2016.

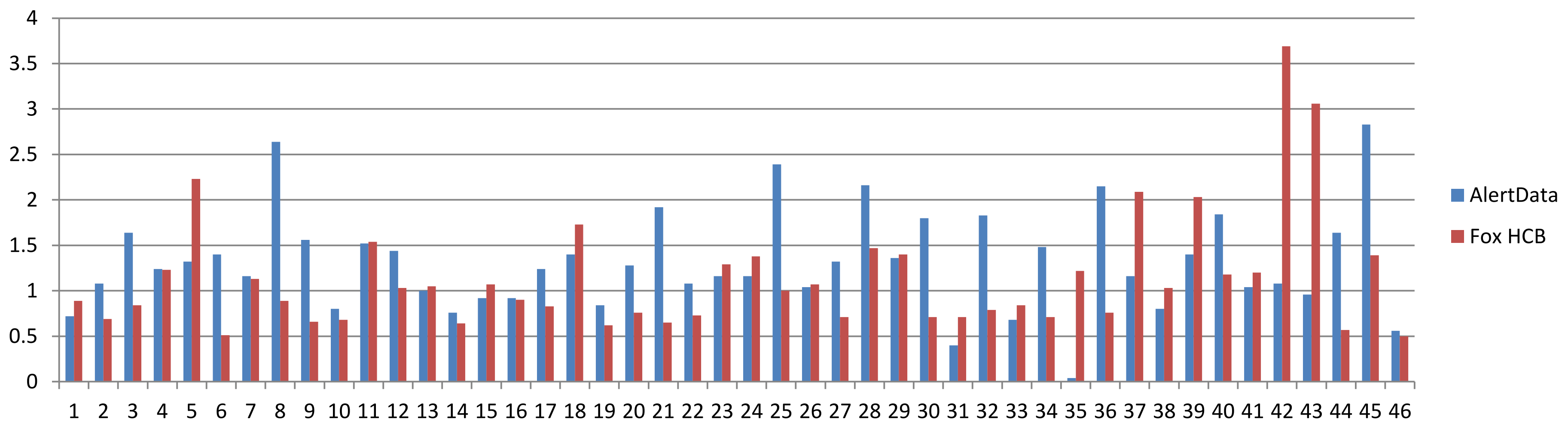
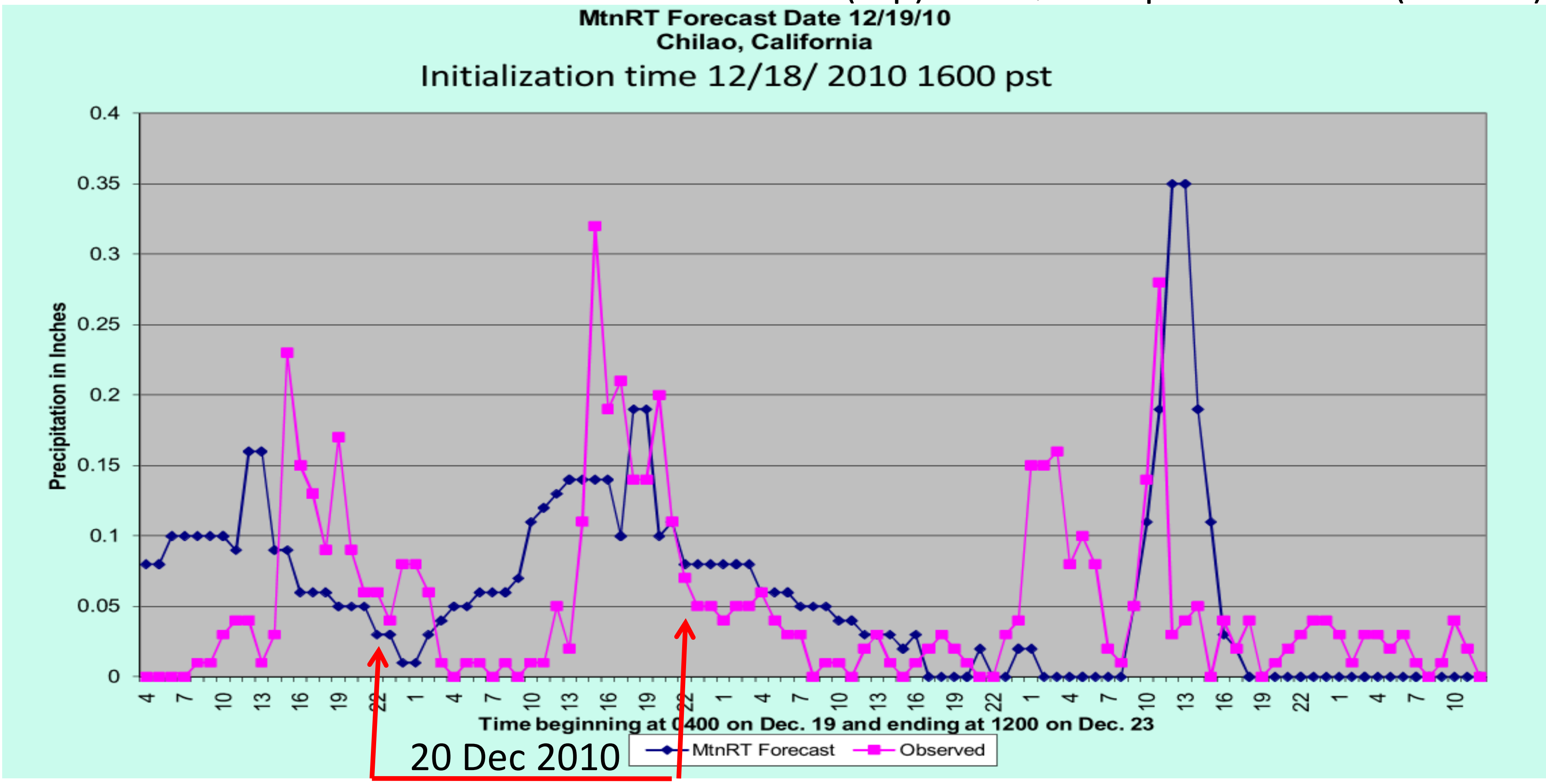


Figure 6a.

MtnRT® Forecast versus Observed (top) and QPF Maps for the 20th (bottom)



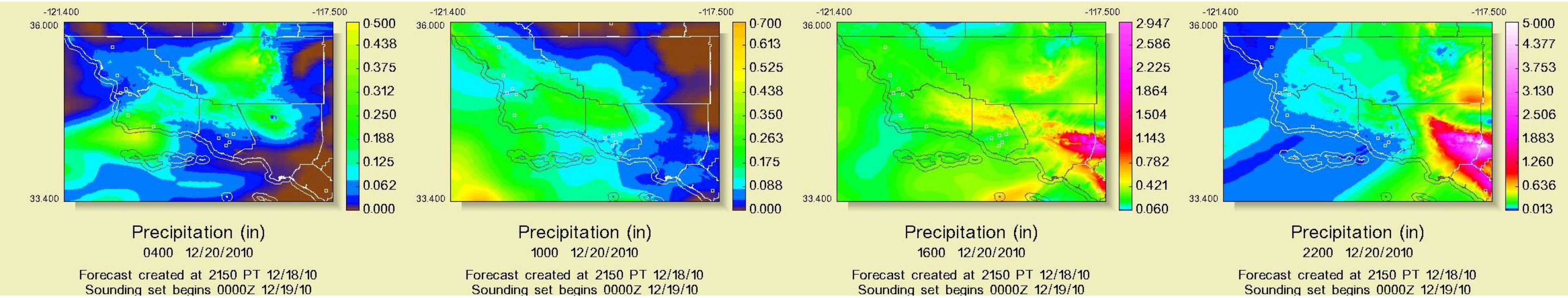
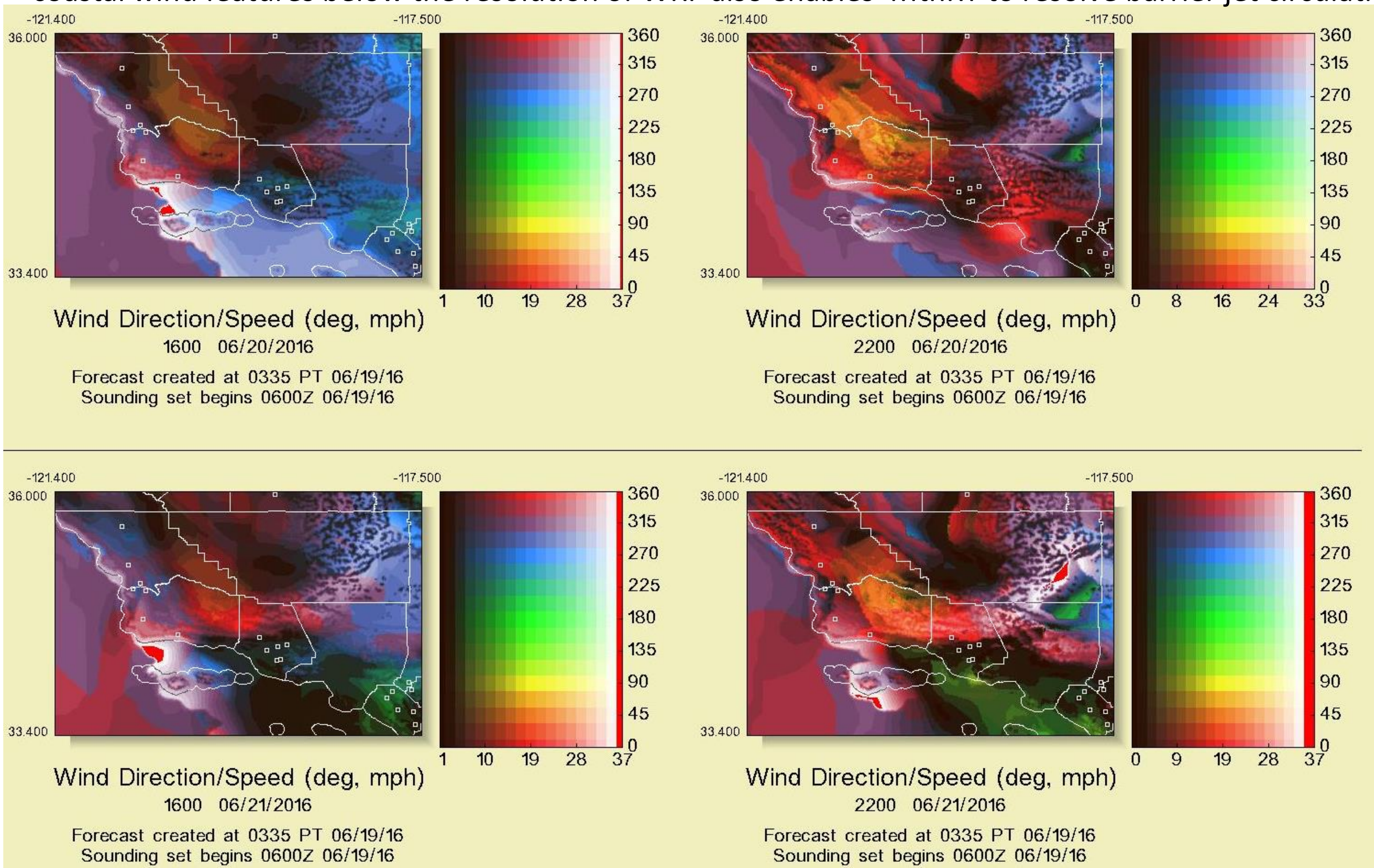


Figure 6b. Classification: Strong cold front, moderate to strong AR for Los Angeles County. Used the 2010 version of MtnRT®. (Courtesy IPPC/OSU).

Figure 7. Resolution of coastal wind circulations.

Example of "sundowner" wind event forecasted by MtnRT® for June 20-21, 2016. This shows a characteristic strong wind event around the Channel Islands in NW-N flow. This ability to resolve coastal wind features below the resolution of WRF also enables MtnRT to resolve barrier jet circulations.



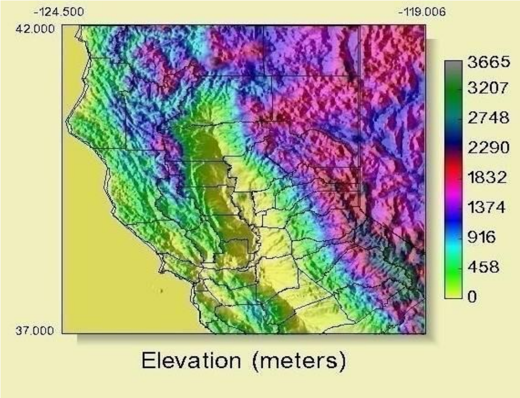
Summary

From perspective of operational forecasting in California:

1. "Atmospheric River" (AR) appears in MtnRT as a basic characteristic of rain-bearing extratropical cyclones affecting the US west coast.
2. There is similarity in basic local-scale AR signatures occur on MtnRT 's QPF maps whether the AR is strong or weak, differing primarily in rain amount, wind speed and orographic enhancement ratio.
3. Elements of AR we have observed on smaller scale:
    a) Subtropical jet with synoptic or mesoscale waves.
    b) Low level jet in warm sector portion of cyclone and abundant low level moisture in the 0-2 km layer (implied LIVT maximum).
    c) Upslope flow and enhanced rain rates over coastal mountains, e.g. 200-1500m above sea level.
    d) In many cases, characteristic AR patterns of orographic precipitation are identifiable by behavior of rain on the local scale.
    e) Presented on a 1.5 km grid, resolution of rain in ARs is realistically ~3-4 km due to propagation speed and time required for droplet growth to occur.

4. Typical AR signatures in MtnRT's QPFs.
    a) Rainfall maximum over ocean upstream, associated with combined high mean moisture content and wind speed in the defined area of the LLJ. (note: 3b above)
    b) Well-defined maxima in 3 or 6 hour rainfall in coastal hills at 200-1000m above sea level.

5. The basic AR pattern in U.S. West Coast and California
    a) Many different forms and intensities
    b) The smaller AR-type systems, though perhaps not spectacular, are important for QPF.



Thank You!!

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