Center for Western Weather and Water Extremes

SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Mesoscale Frontal Waves Associated with Landfalling Atmospheric Rivers

FIRO Science Task Group Workshop

May 30, 2017

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Study Goals

1. Establish a non-exhaustive case list of AR impacting the ARO that were also associated with MFW (AR+MFW).
2. Report on the relative frequency of MFW+AR, and differences in AR strength, duration, precipitation in these cases.
3. Identify synoptic scale weather regimes that support MFW formation and secondary cyclone development when there is a landfalling AR.
4. Estimate the impact of MFW on AR precipitation forecast skill during landfalling AR
5. Investigate the growth mechanisms that allow development of MFW into a secondary cyclone when an AR is present.

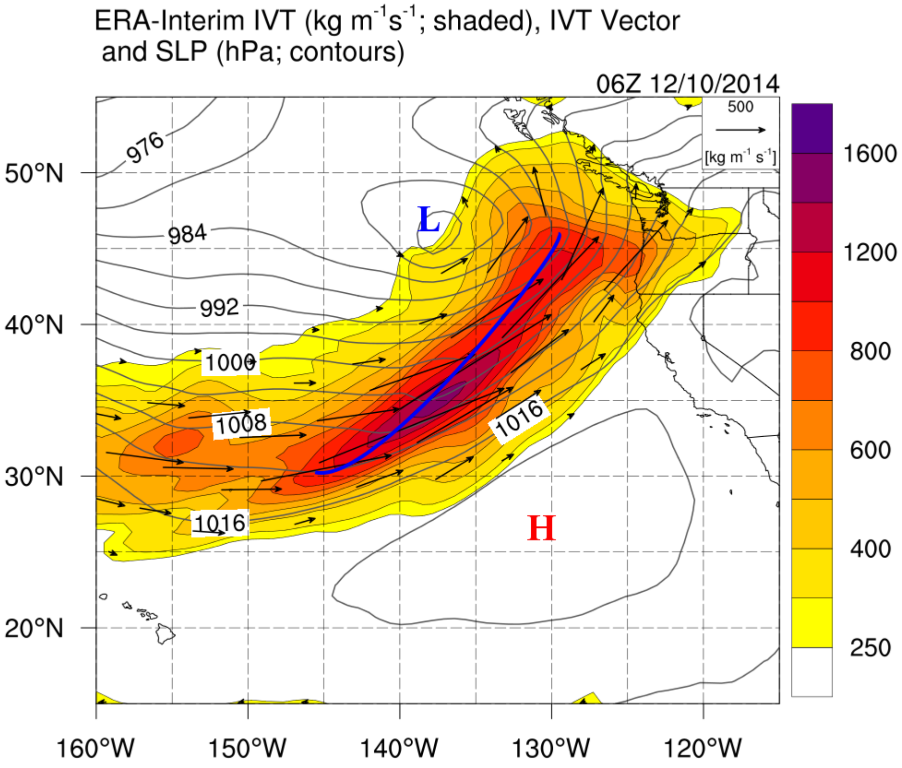
What is a Mesoscale Frontal Wave (MFW)?

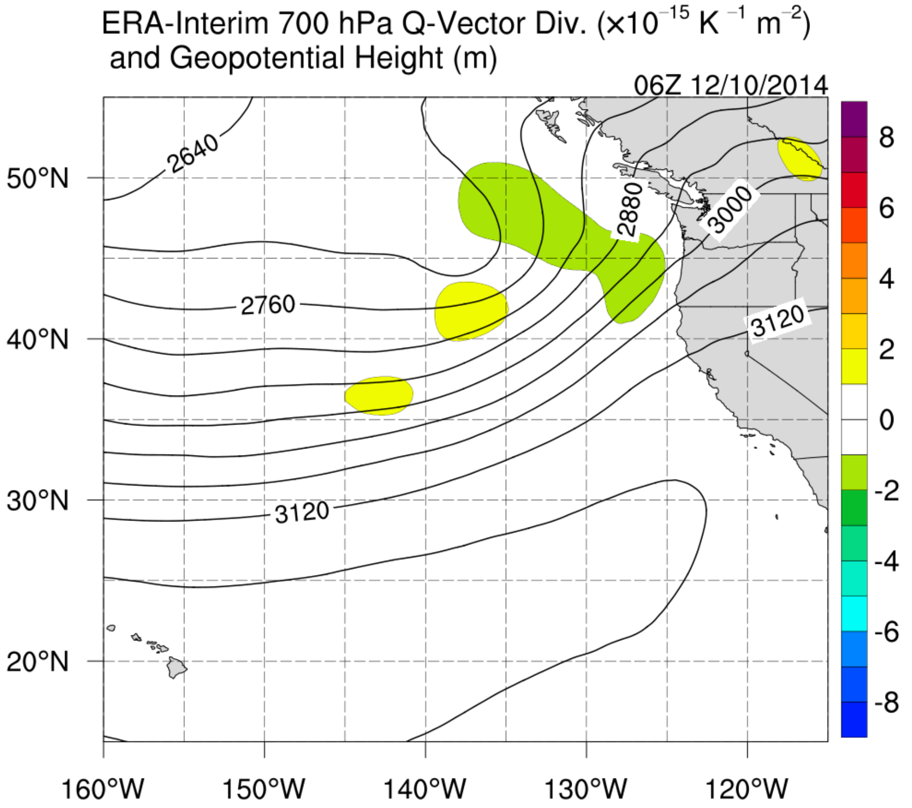
A moderate to strong AR initially made landfall near the central OR coast on 12/10/2014 @ 06 UTC

AR strength (IVT), synoptic Wx pattern (SLP, H, L) and cold front (blue line) indicated.

CA.

low. Many places in N. CA will continue to experience AR conditions for longer than if original cyclone remained as parent.





Mid-Troposphere geopotential and QG forcing of ascent are indicated.

forcing of ascent appears downstream of the new wave.

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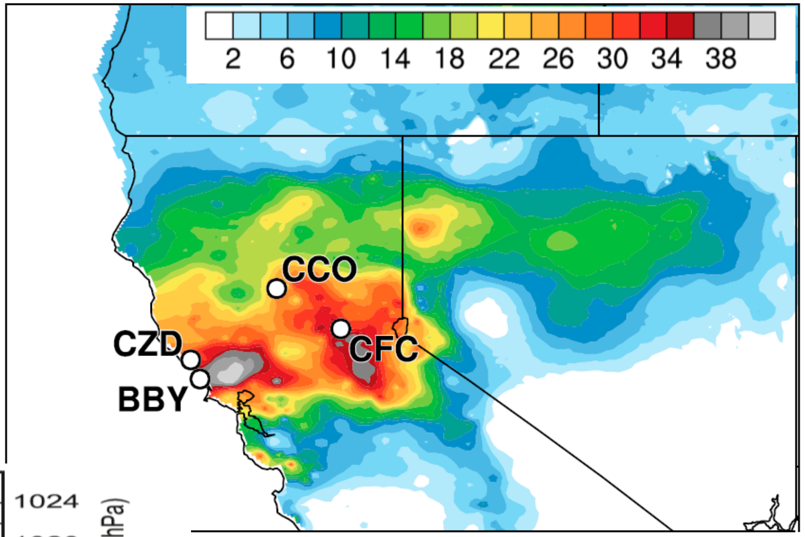
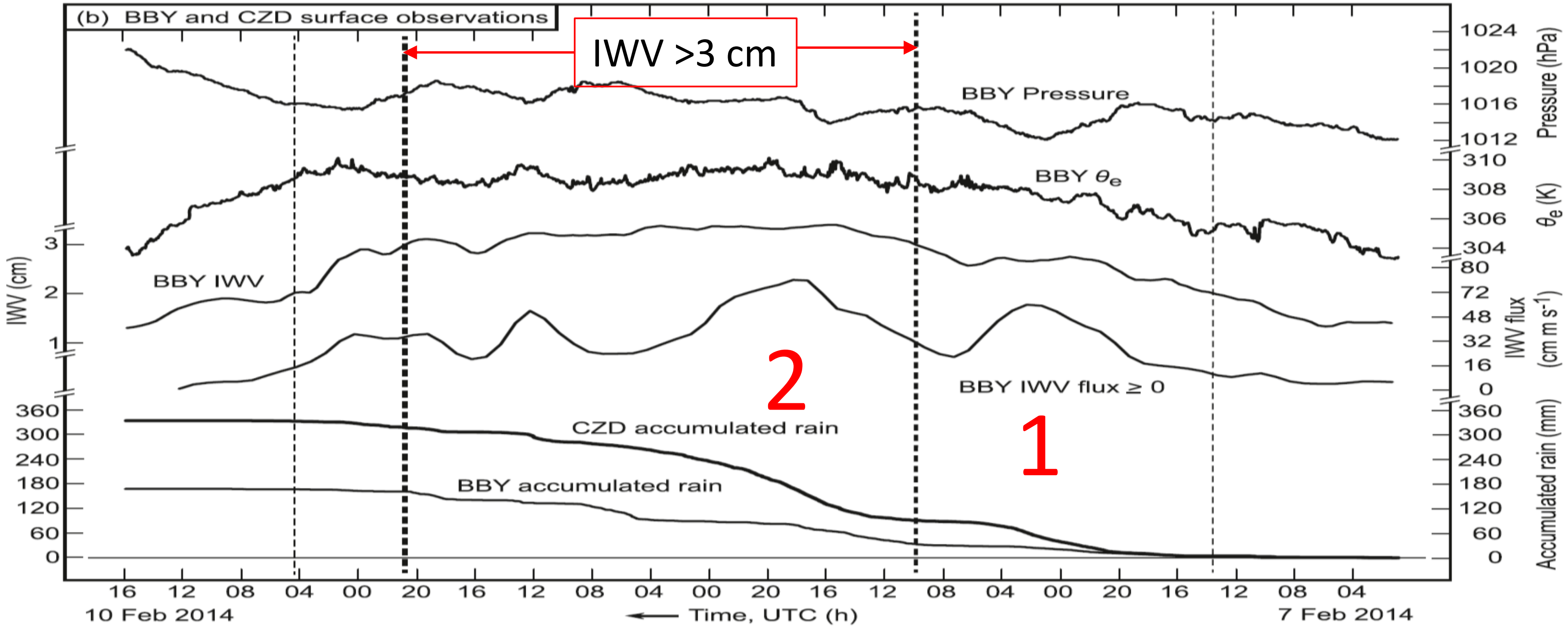
CW3E

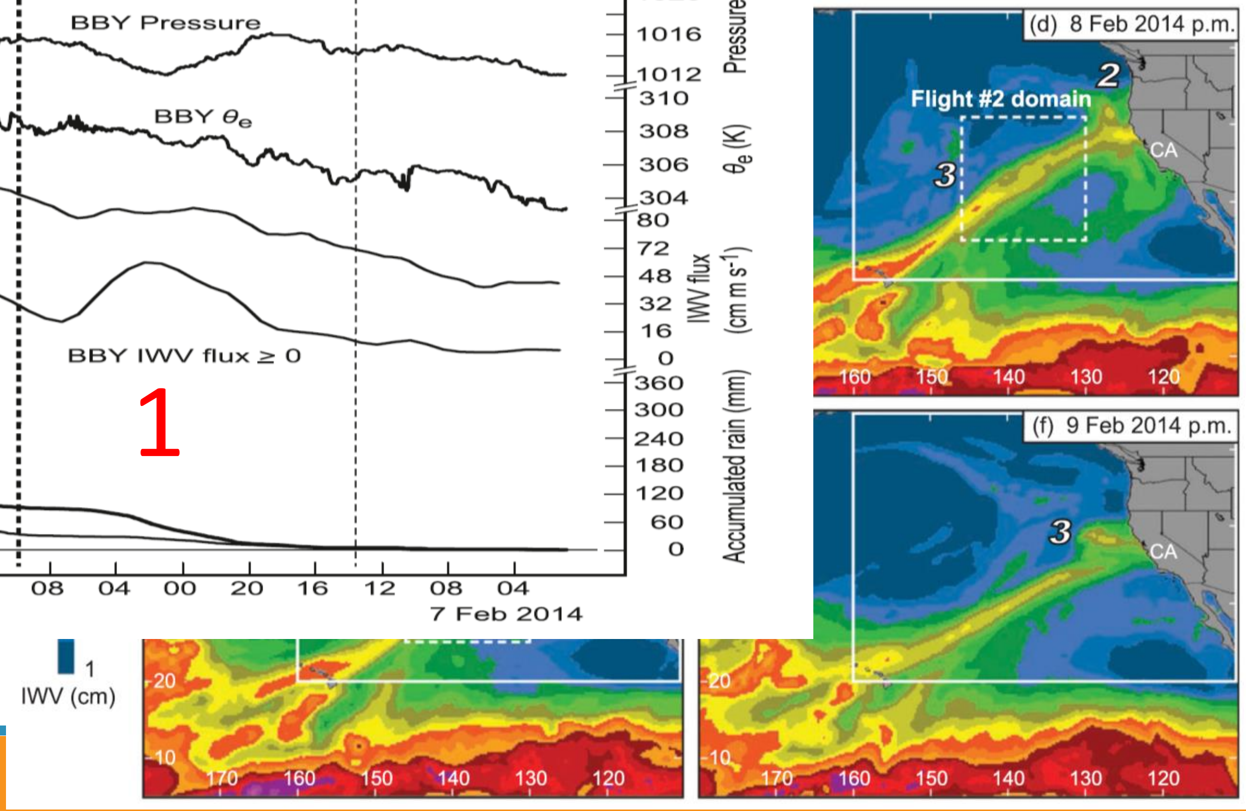
An Airborne and Ground-Based Study of a Long-Lived and Intense Atmospheric River with Mesoscale Frontal Waves Impacting California during CalWater-2014

Neiman, P. J., B.J. Moore, A.B. White, G.A. Wick, J. Aikins, D.L. Jackson, J.R. Spackman, F.M. Ralph, *Mon. Wea. Rev. (2016)*

96-h precip. %-age ending 0000 UTC 11 Feb 2014

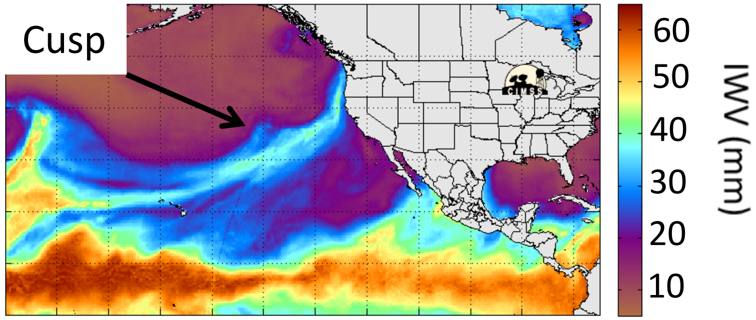






Developing an AR+MFW Case List

Criteria



1. AR Criteria
   - AR conditions must be met at BBY ARO and correct AR geometry verified.
2. Moderate AR or Greater
   - AR must meet or exceed moderate AR thresholds using ARO vapor flux or sounding IVT.
3. Impactful AR Criteria
   - AR must produce > 2 inches precip. at Cazadero or in Russian River Watershed.
4. AR+MFW: 1+2+3 plus…
   - An IWV "cusp" must be observed on primary landfalling AR.
   - A trough in sea-level pressure (identified in reanalysis) must develop offshore "near" existing cold front and persist or deepen for at least 24 hours.
5. AR w/o MFW: 1+2+3 plus…
   - Any cusp or secondary trough indicated in SSM/I must not occur on primary landfalling AR.

Developing an AR+MFW Case List 2

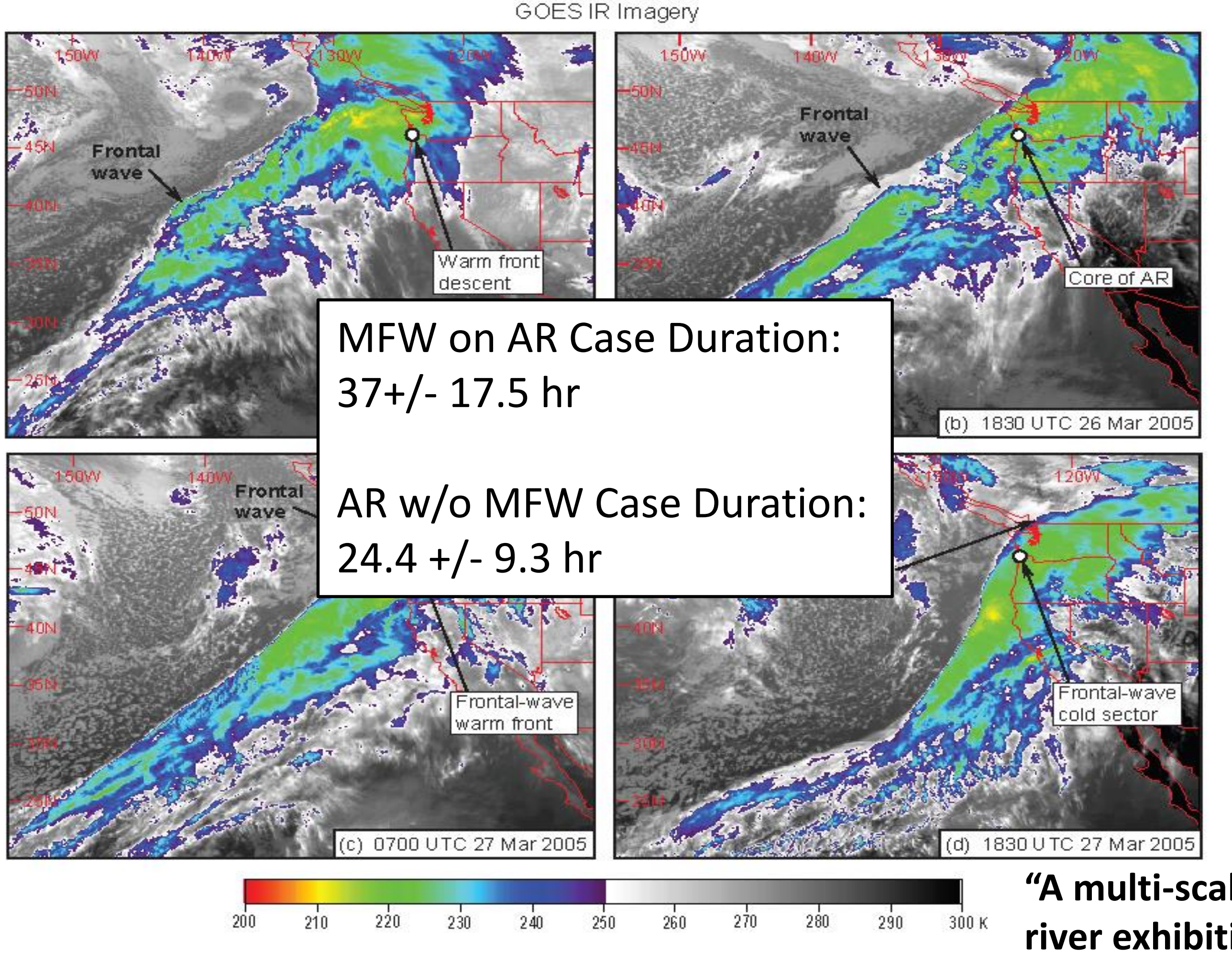
Methods

- First ID includes Observations Only:
  - SSM/I Composite
  - BBY ARO IWV, Vapor Flux, Gauge Precip.
  - CW3E Balloon Soun… available.
- AR strength criteria, MFW… AR w/o MFW criteria we… verified using ERA-Interi… Reanalysis
- 36 Moderate or greater … identified from 2006 – 2…
- 10 are MFW on AR; 16 are AR w/o MFW, 10 had secondary troughs but were rejected.

MFW on AR	AR w/o MFW	
02/26/2006	12/26/2006	03/13/2012
11/13/2006	12/2/2007	03/27/2012
		…4
		…6
03/05/2016	03/15/2011	
03/09/2016	01/20/2012	

Avg. +/- Std. dev.	MFW on AR	AR w/o MFW
ST Precip. @ CZC (mm)	122.1 +/- 92.4	90.2 +/- 59.0
ST BUF @ ARO (cm m s^{-1} hr)	1223.6 +/- 547.8	866.5 +/- 343.7
Max IVT (kg m^{-1} s^{-1})	674.8 +/- 179.7	602.2 +/- 138.2
Duration @ ARO (hr)	37 +/- 17.5	24.4 +/- 9.3
Min SLP of MFW (hPa)	995.2 +/- 14.1	--

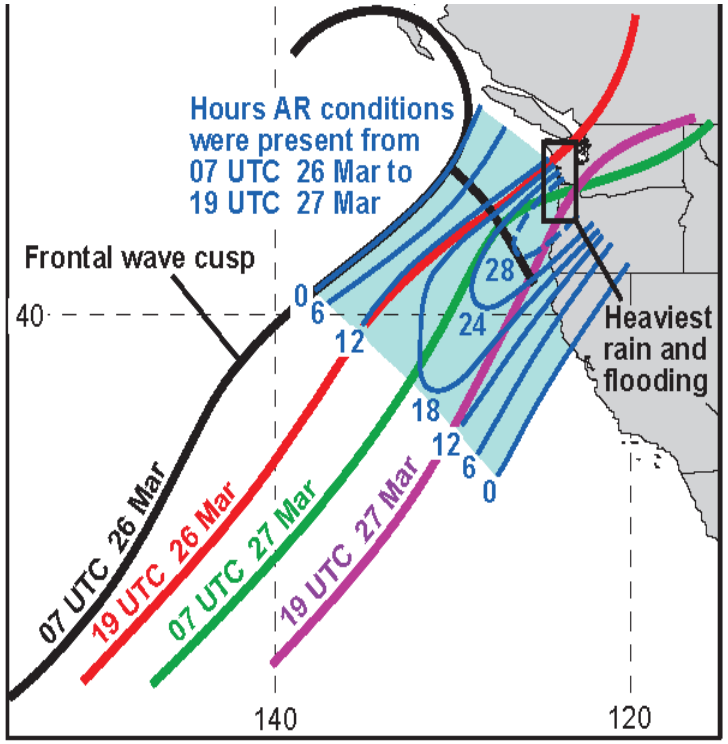
How Can MFW Modulate AR Impact?



MFW on AR Case Duration: 37+/- 17.5 hr

AR w/o MFW Case Duration: 24.4 +/- 9.3 hr

The frontal wave increased the duration of AR conditions and determined where the heaviest precipitation occurred



"A multi-scale observational case study of a Pacific atmospheric river exhibiting tropical-extratropical connections and a mesoscale frontal wave"

*Ralph et al., *Mon. Wea. Rev.* (2011)

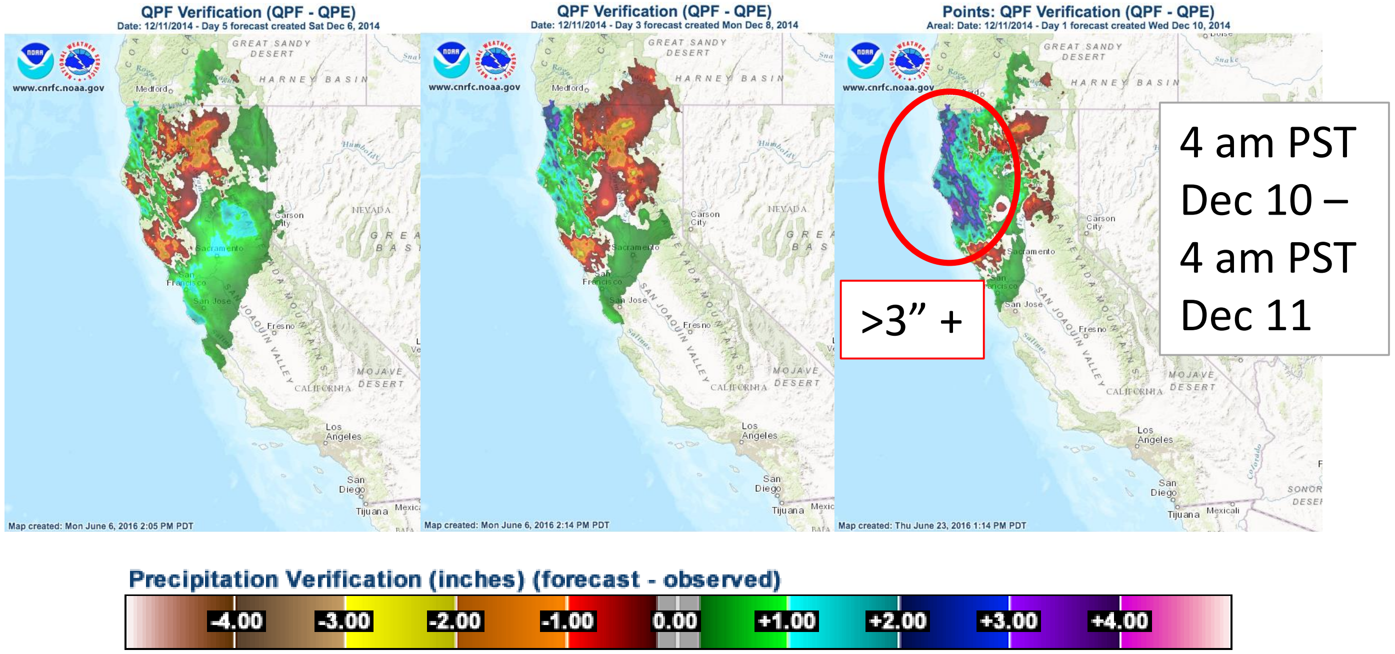
CW3E

How Can MFW Modulate AR Impact?

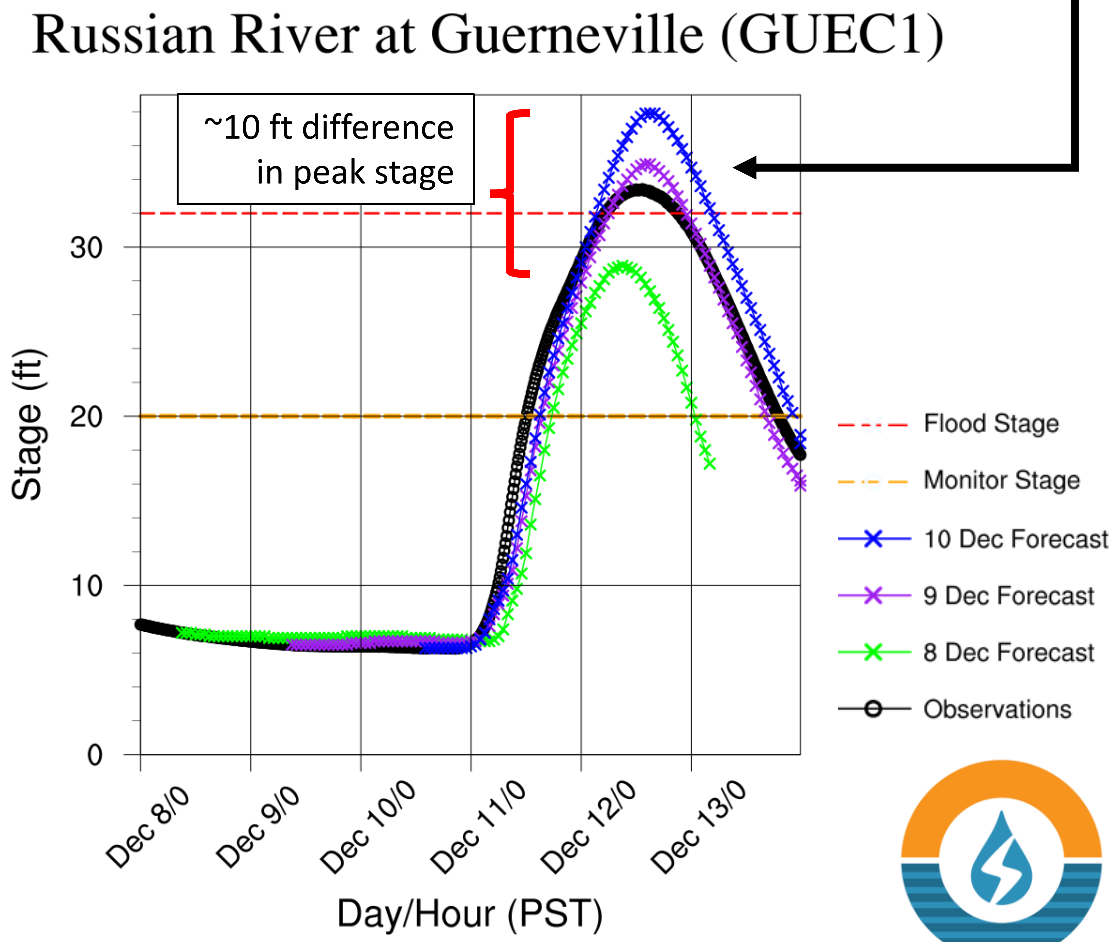
Poorest precipitation and streamflow forecasts were issued less than 24 hr prior to event!

What changed? MFW developed along landfalling AR.

5 – Day 3 – Day 1 - Day



First forecast after the MFW developed.



Synoptic Pattern May Aid Prediction of MFW on AR

Each Composite mean is calculated at beginning of AR conditions measured at the BBY ARO.

IVT (kg m^{-1} s^{-1}; shaded), IVT Vector, and SLP (hPa)

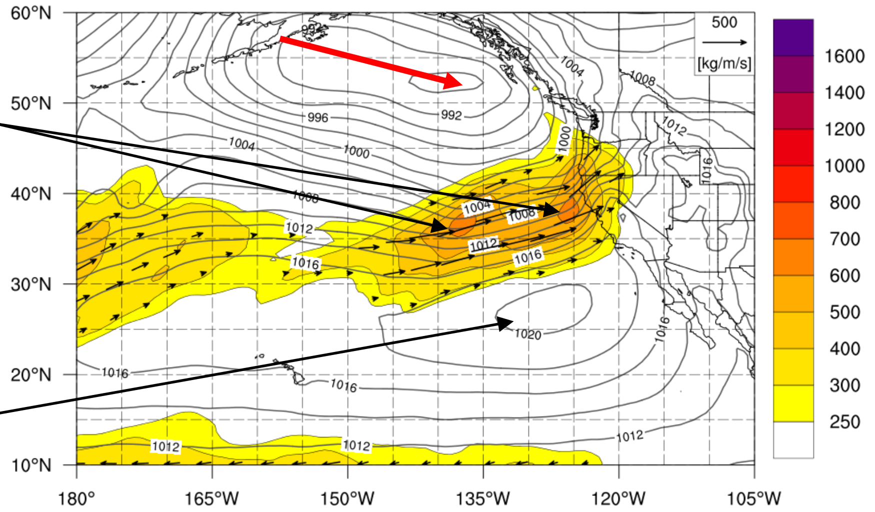
Aleutian/Gulf of Alaska low moves SE prior to landfall (movement indicated by red arrow)

Split IVT Maxima

MFW on AR Composites

WSW oriented AR

Strong subtropical high off Baja Coast

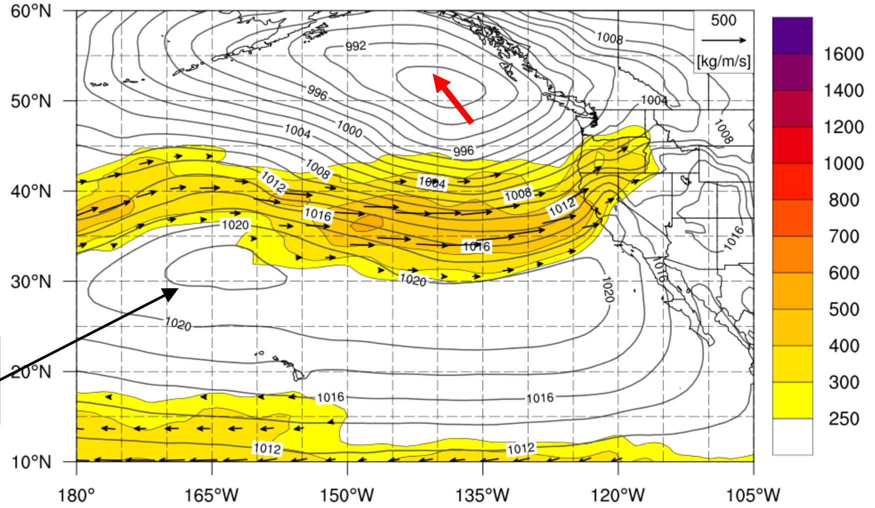


Aleutian/Gulf of Alaska low moves NW prior to landfall (movement indicated by red arrow)

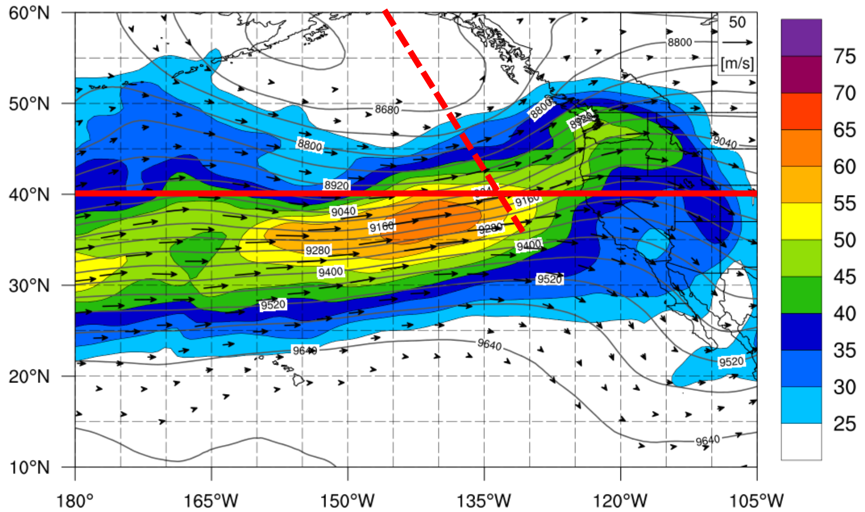
AR w/o MFW Composites

W oriented AR

Strong subtropical high NW of Hawaii



300-hPa Winds (m s^{-1}; shaded) and Geopotential Heights (dam)

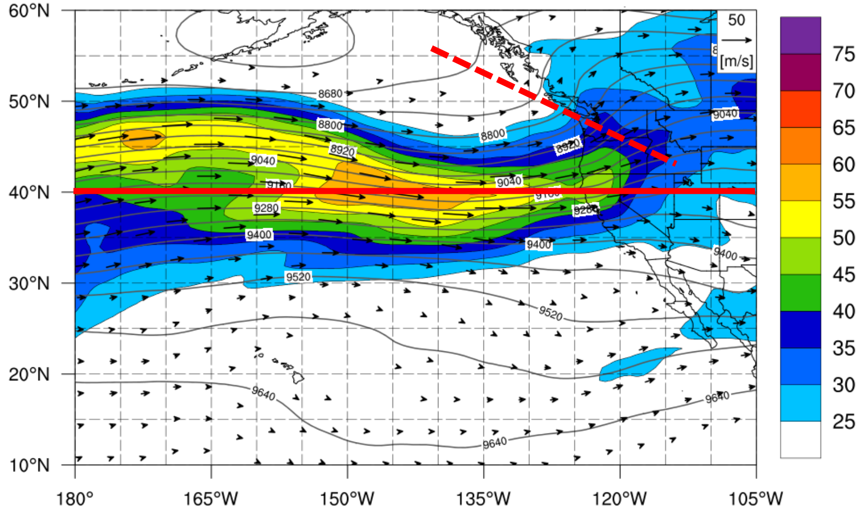


Jet in MFW cases slightly stronger than CTL cases

Mostly SSW orientation

Slightly negatively/ almost neutrally tilted trough

Majority of jet south of 40°N



Mostly W orientation

Very negatively tilted trough

Majority of jet north or along 40°N

*Data from ERA-Interim Reanalysis

Review

- MFW often form on AR of moderate or greater strength in the NE Pacific
- MFW precipitation forecasts appear to be much less skillful when MFW form on landfalling AR then when they do not.
- In part, this may be because MFW formation lengthens local AR conditions
- Certain synoptic scale patterns, including:
  - The location and movement of the Aleutian / Gulf of Alaska Low
  - Extent of the Eastern Pacific Subtropical High
  - Location and orientation of the Pacific Jet Stream

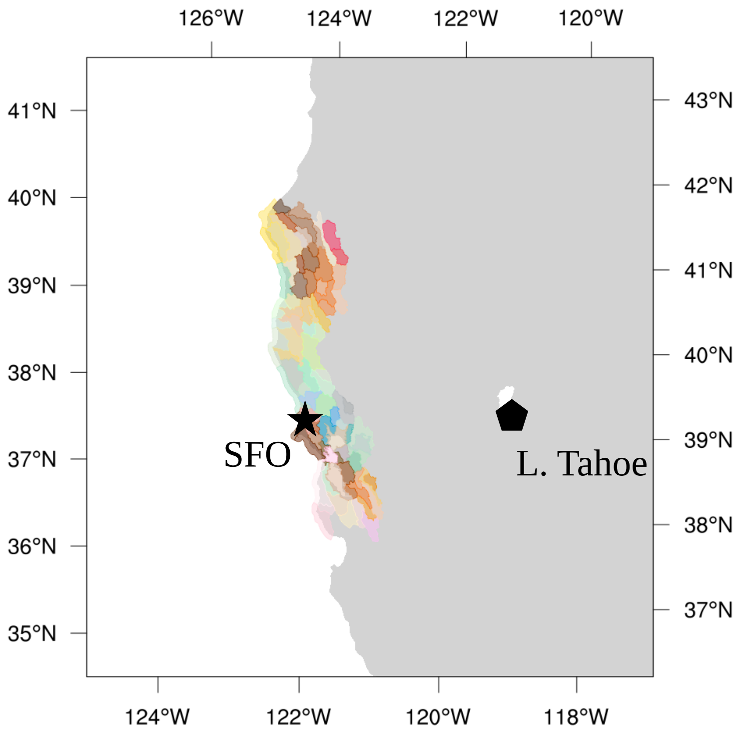
Favor MFW development on N CA Landfalling AR

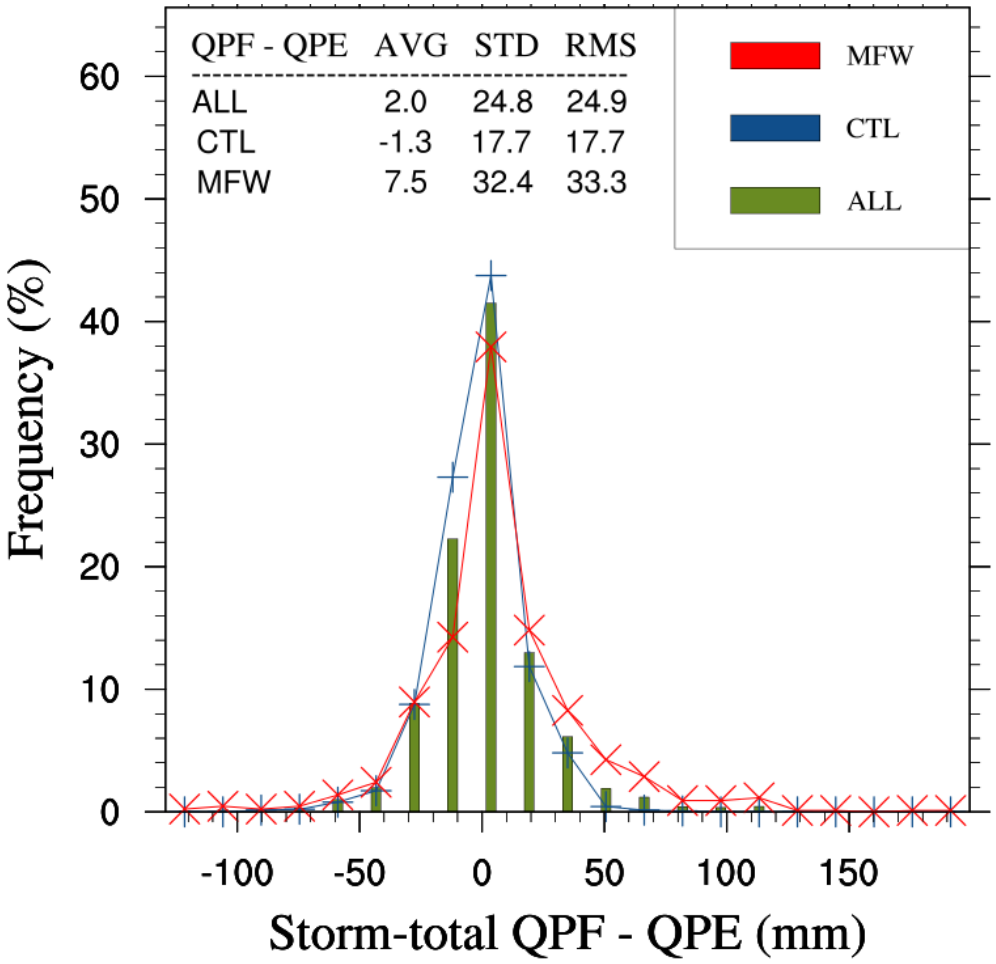
Backup Slides

QPF Skill During MFW on AR

HUC10 watershed boundaries (North Coast and Bay Area) used to compute MAP.

Data:
6 hrly QPF and QPE on 4 km grid from CNRFC.





Histograms of Storm Total QPF Error at 24 hr lead time.

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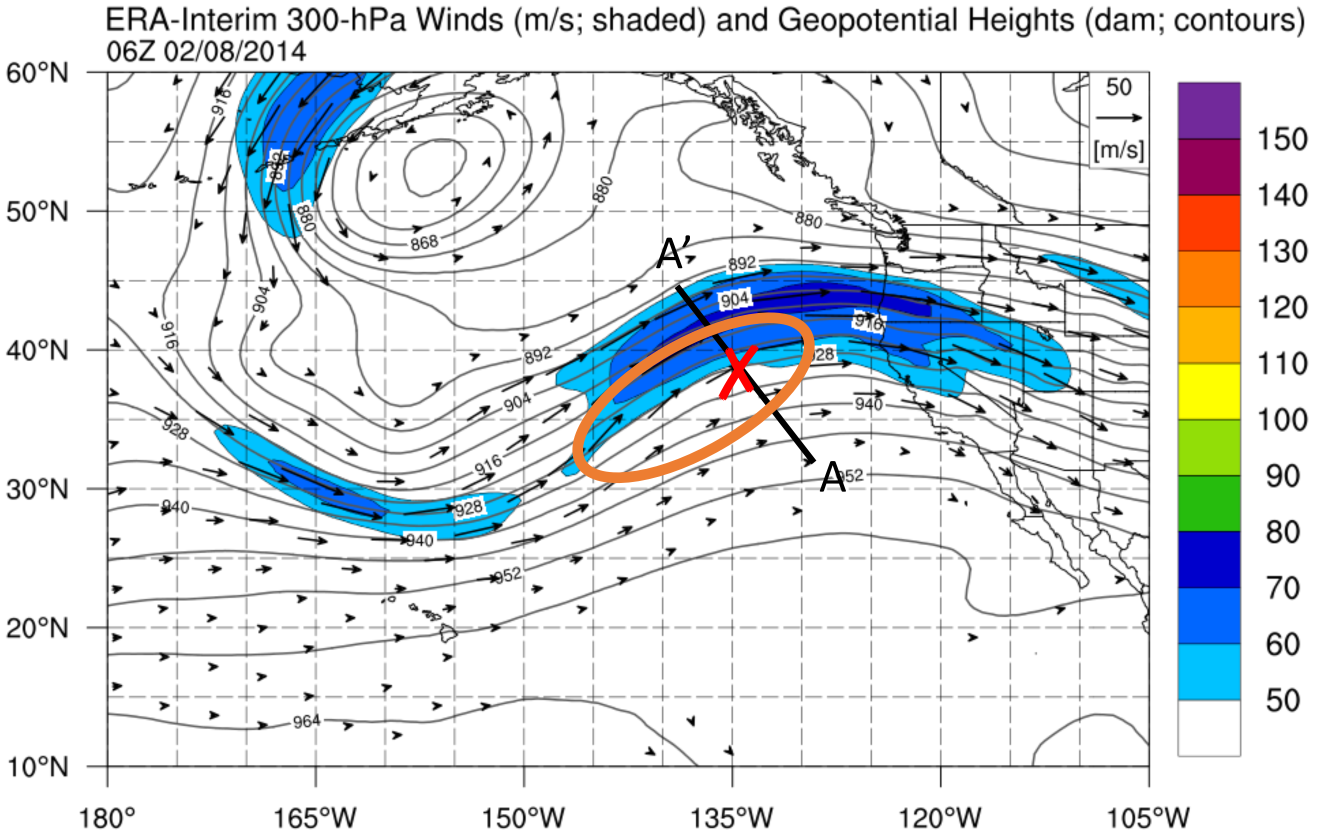
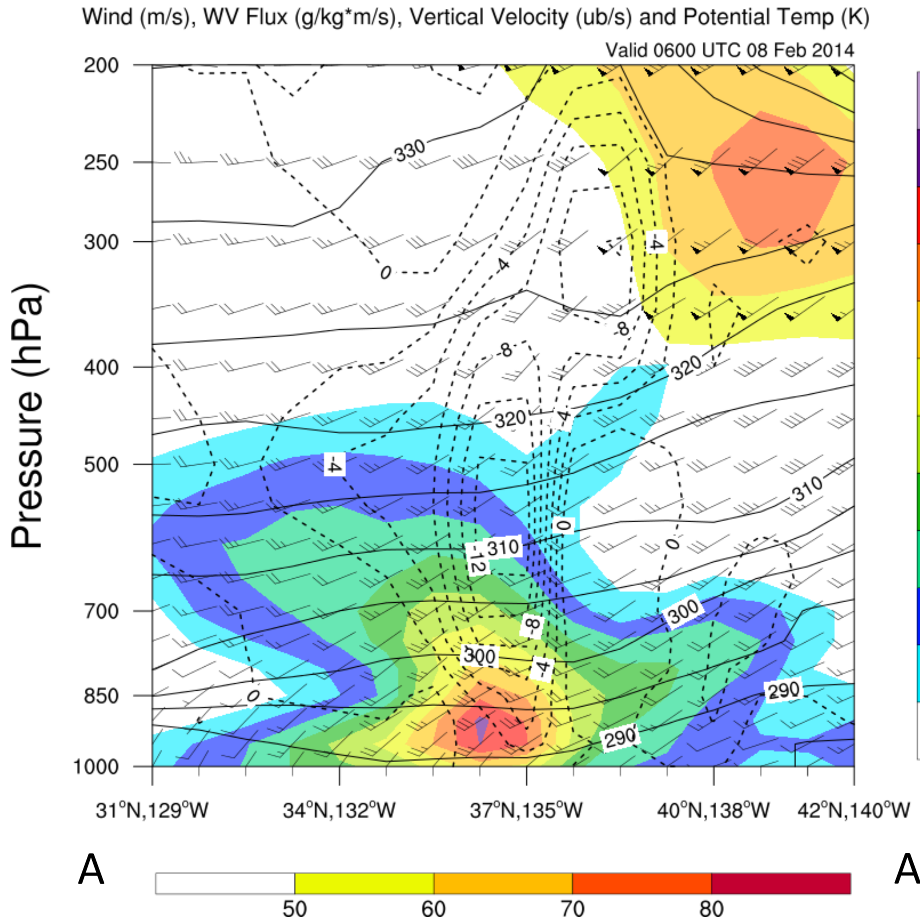
Formation Mechanisms

MFW on AR Case 2014-02-08 (Neiman et al., 2016)





Secondary Cyclogenesis is favored above the existing IVT maxima

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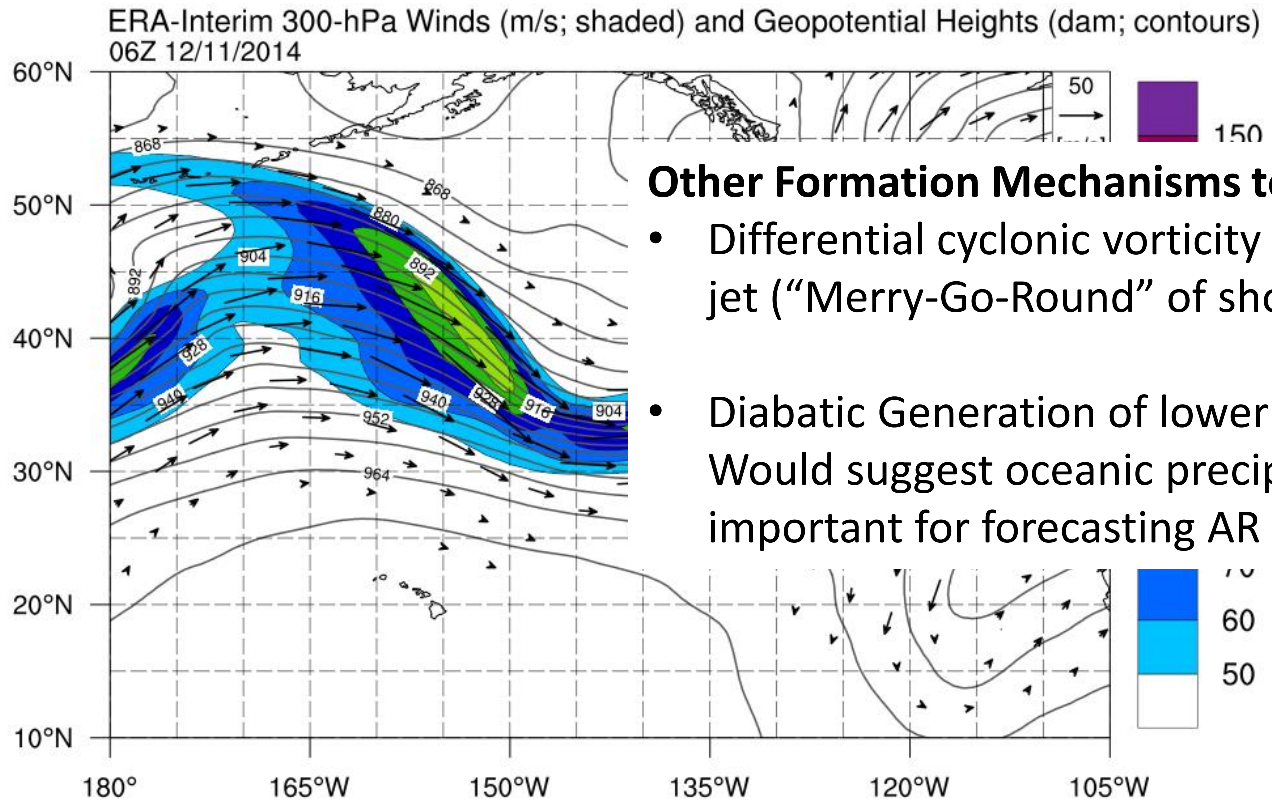
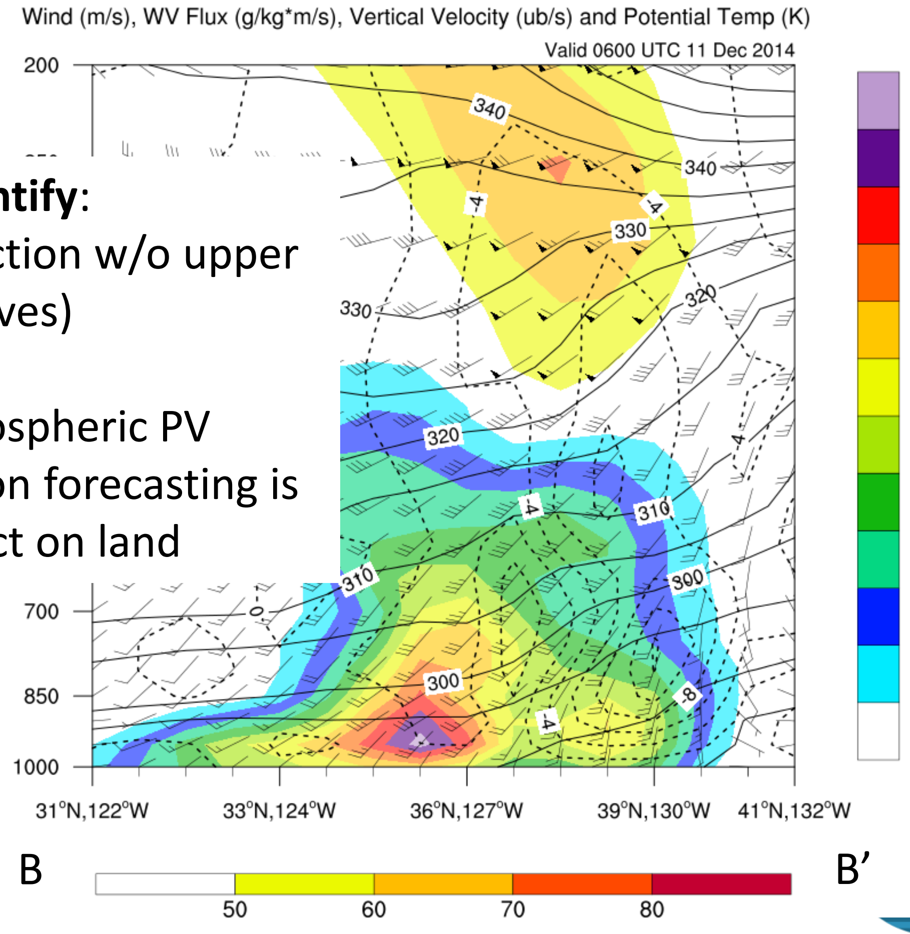
Formation Mechanisms

MFW on AR Case 2014-12-10 (Another AGU storm)



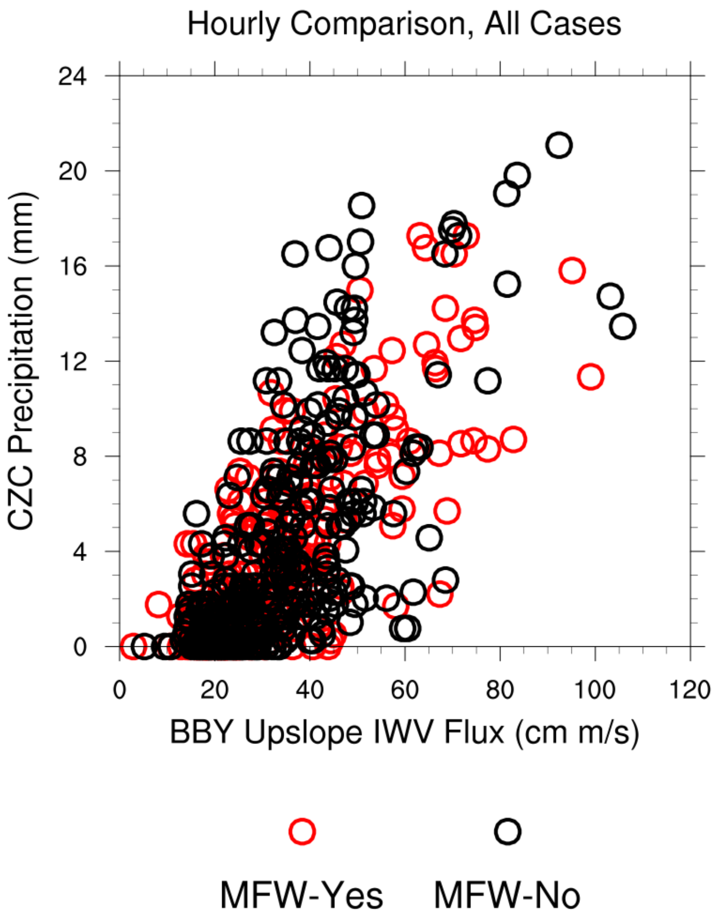
Other Formation Mechanisms to Identify:

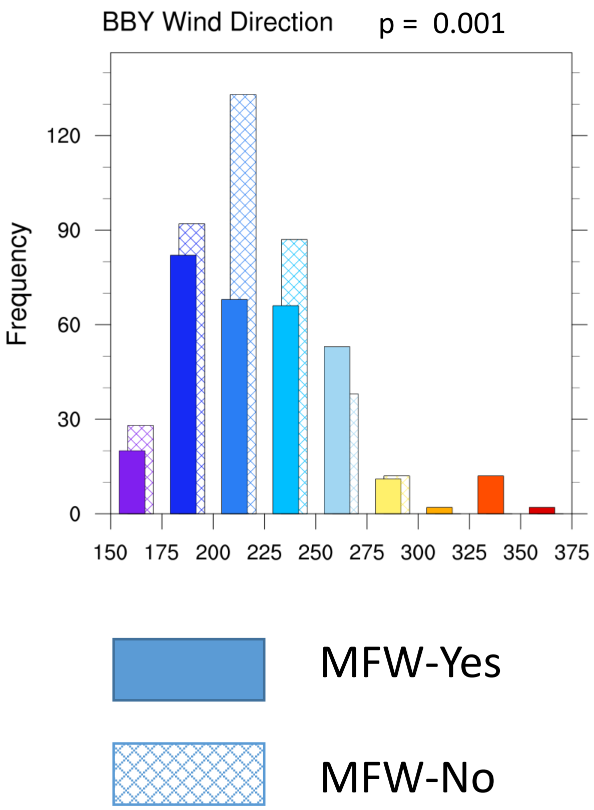
- Differential cyclonic vorticity advection w/o upper jet (“Merry-Go-Round” of shortwaves)
- Diabatic Generation of lower tropospheric PV
  Would suggest oceanic precipitation forecasting is important for forecasting AR impact on land



Secondary cyclogenesis is favored above the existing cold sector

ARO Perspectives

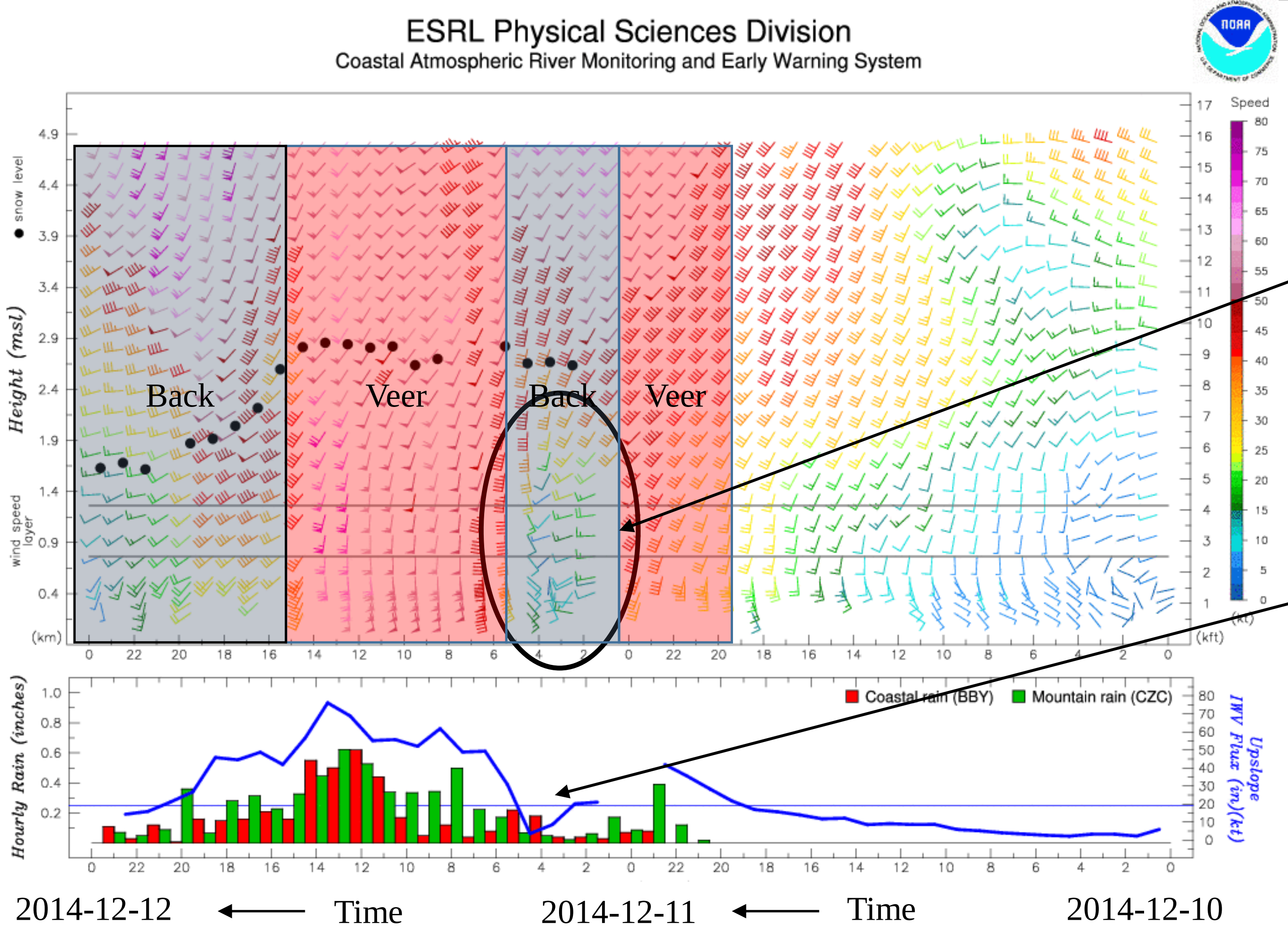




Using Hourly ARO Observations,
Can we detect how precipitation Forcing (water vapor flux in the orographic controlling layer) may differ from AR w/ MFW to AR w/o MFW?

Test for independent distributions (K-S Test) of Bulk Upslope Flux, and its components

ARO Perspectives II



Dip in Controlling Layer upslope wind speed,

not IWV (IWV not shown),

Coincides with a break in precip. rate at mountaintop.

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