Synoptic and Mesoscale Forcing of Southern California Extreme Precipitation

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(under review for JGR-A)

Center for Western Weather and Water Extremes

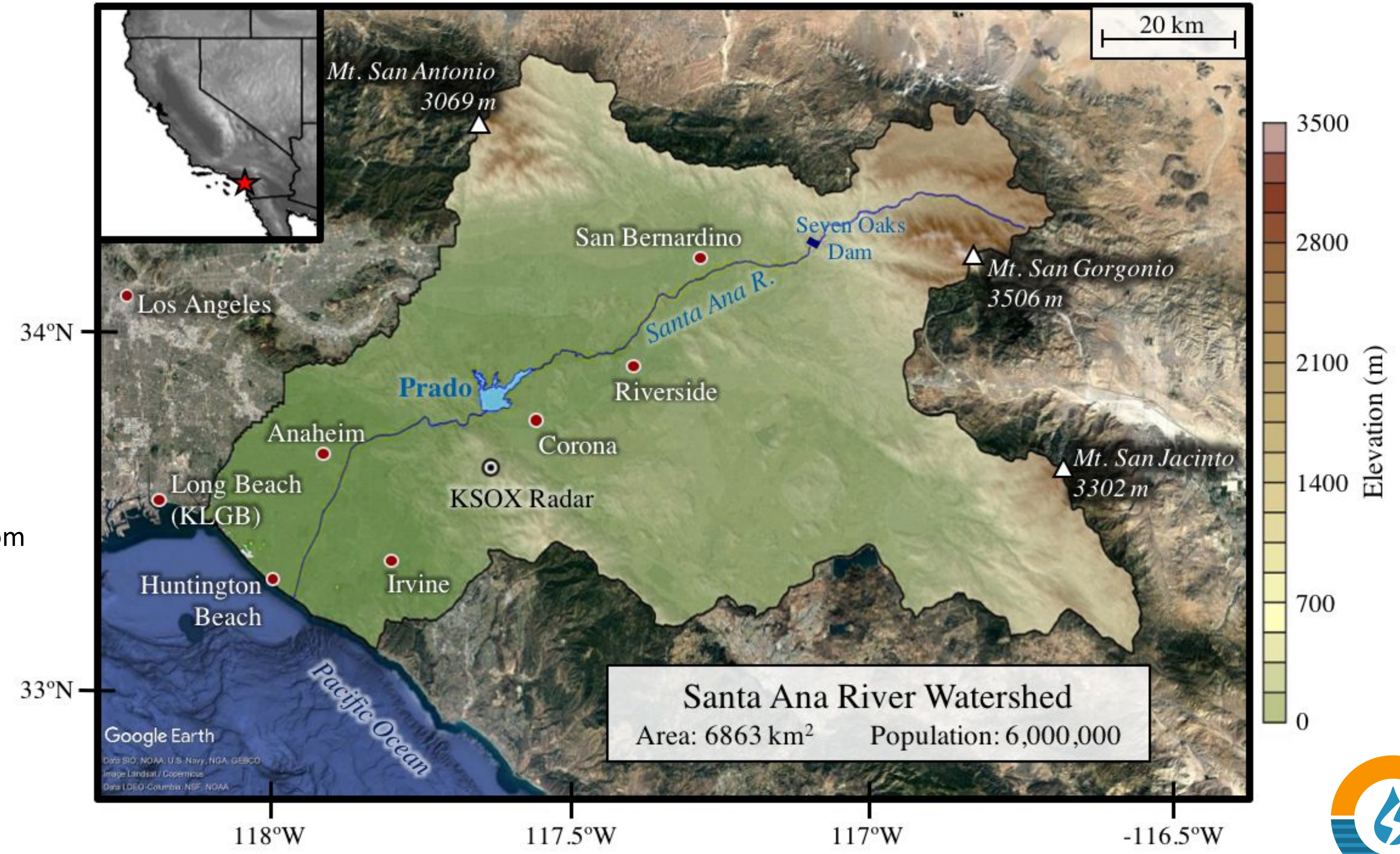
Study Region: Santa Ana Watershed

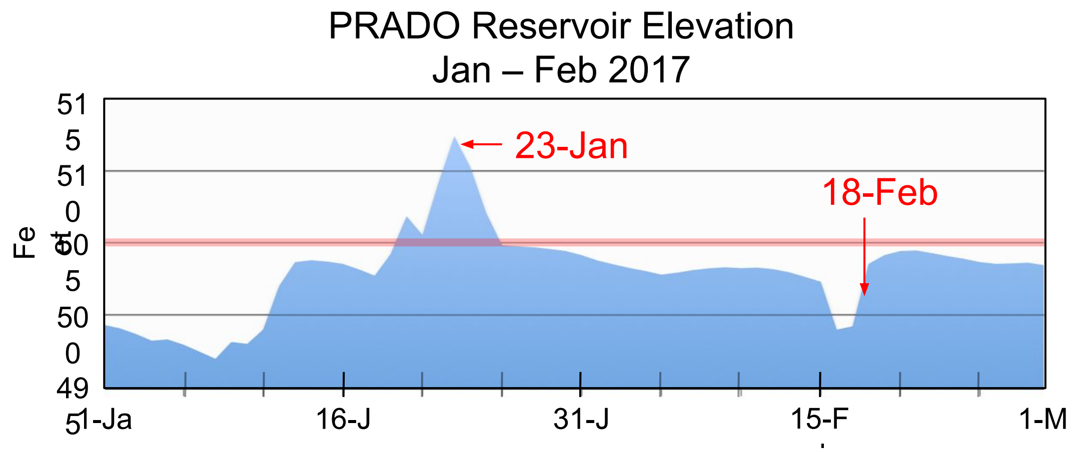
- Meteorological Analysis for Forecast Informed Reservoir Operations (FIRO) at Prado Dam
- Use an “ingredients-based” approach to evaluate precipitation processes in Southern California

- Orographic Forcing
- Synoptic Forcing
- Convection

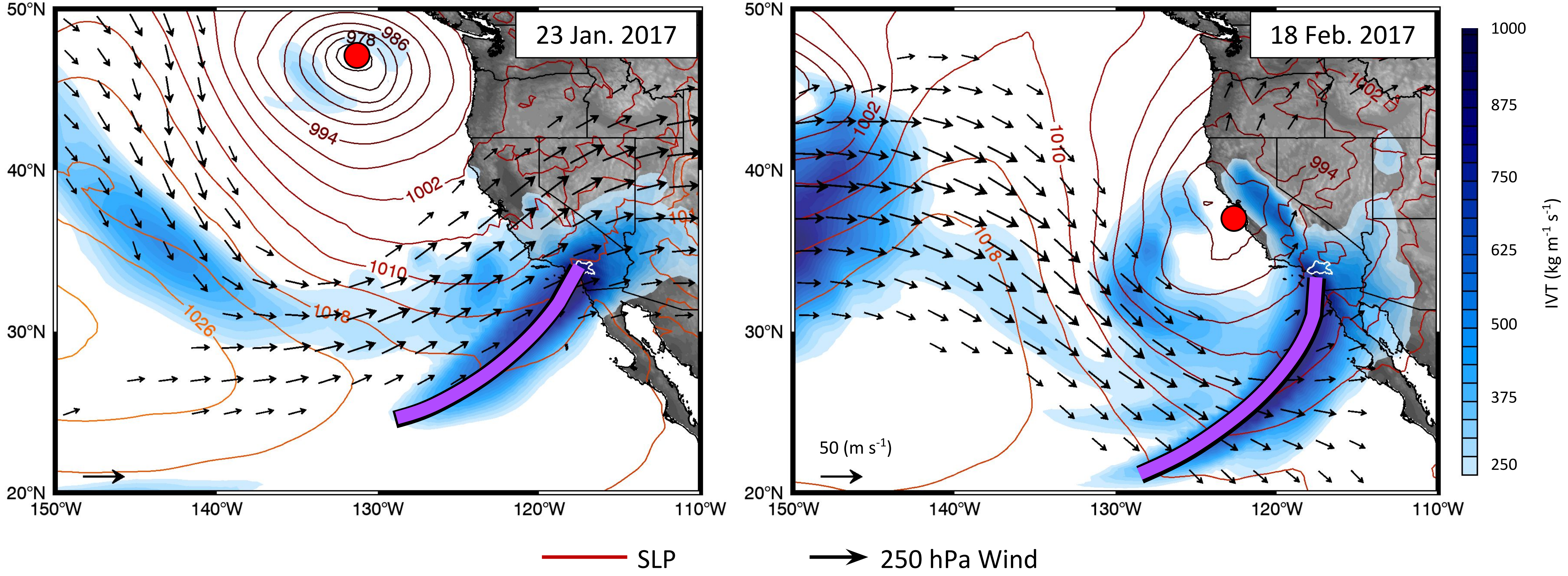
Here, we investigate the primary drivers of precipitation:

1. Using case studies of two events from the remarkable 2016/17 water year
2. Evaluating the mechanisms that generated precipitation in these events relative to the watershed’s climatology.

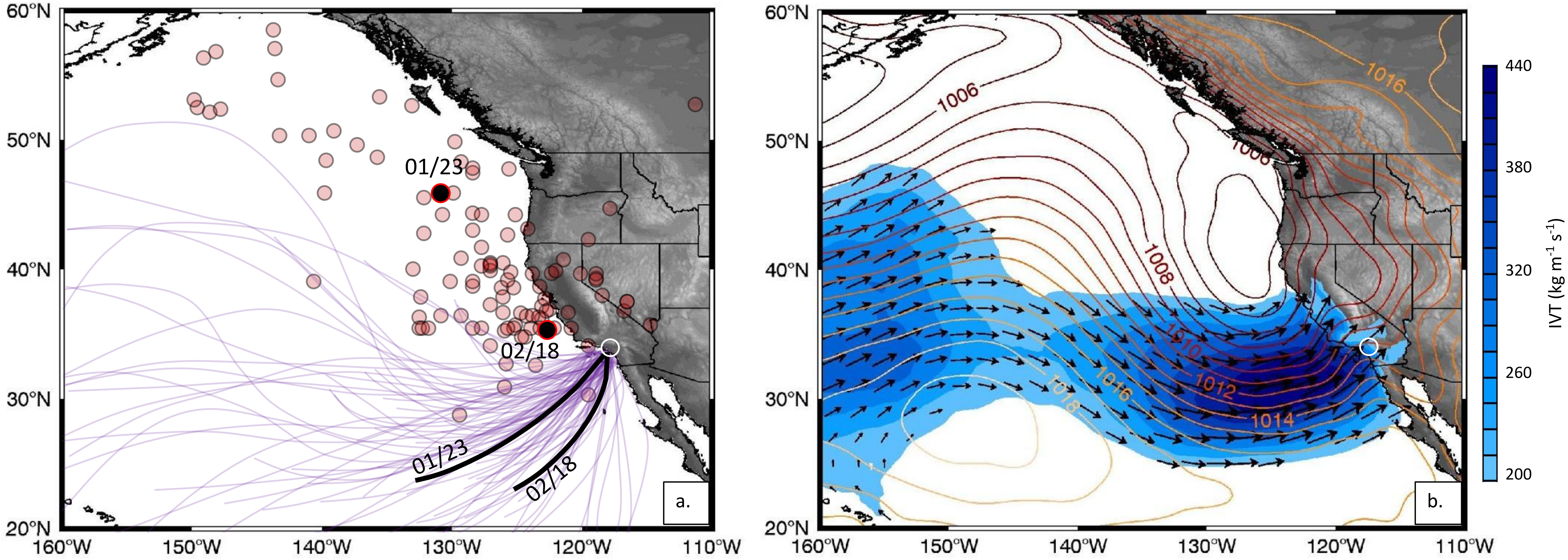




- Investigate two AR events with major impacts on the Santa Ana River Watershed in 2017.
- What are the primary precipitation mechanisms for each event?



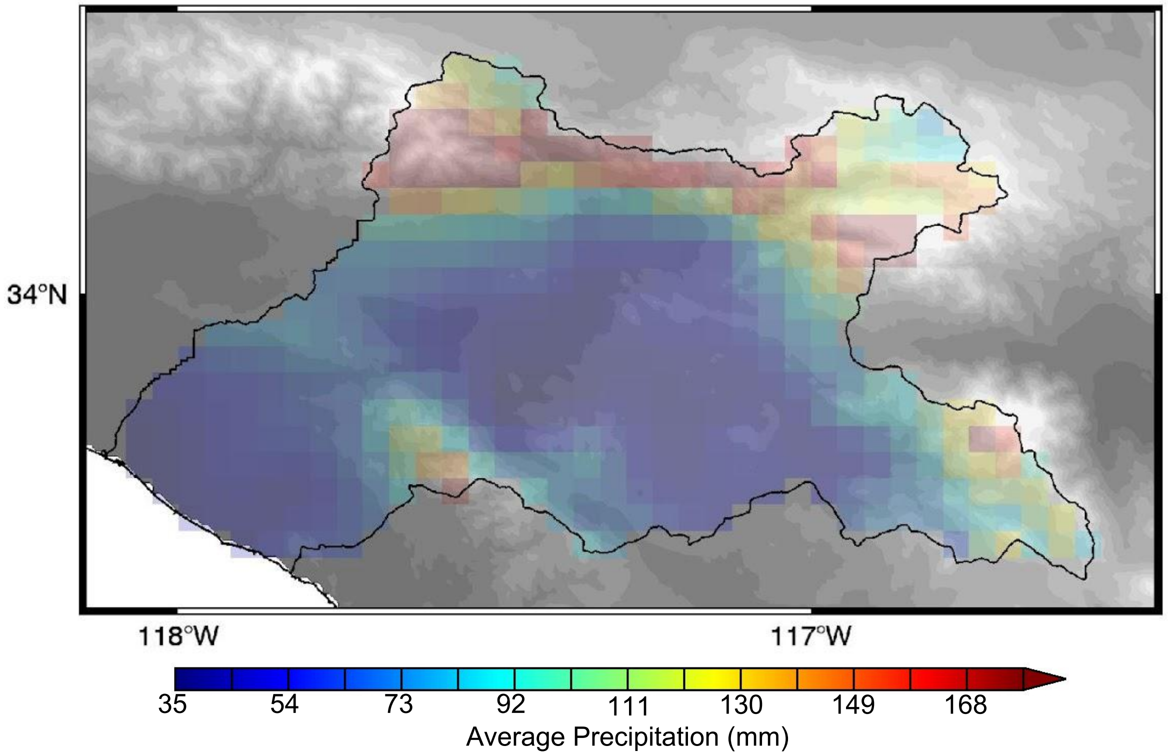
Location of surface low pressure center and orientation of IVT for the 107 precipitation events whose 3-day totals accounted for 50% of PRISM precipitation within the watershed (1981-2017)

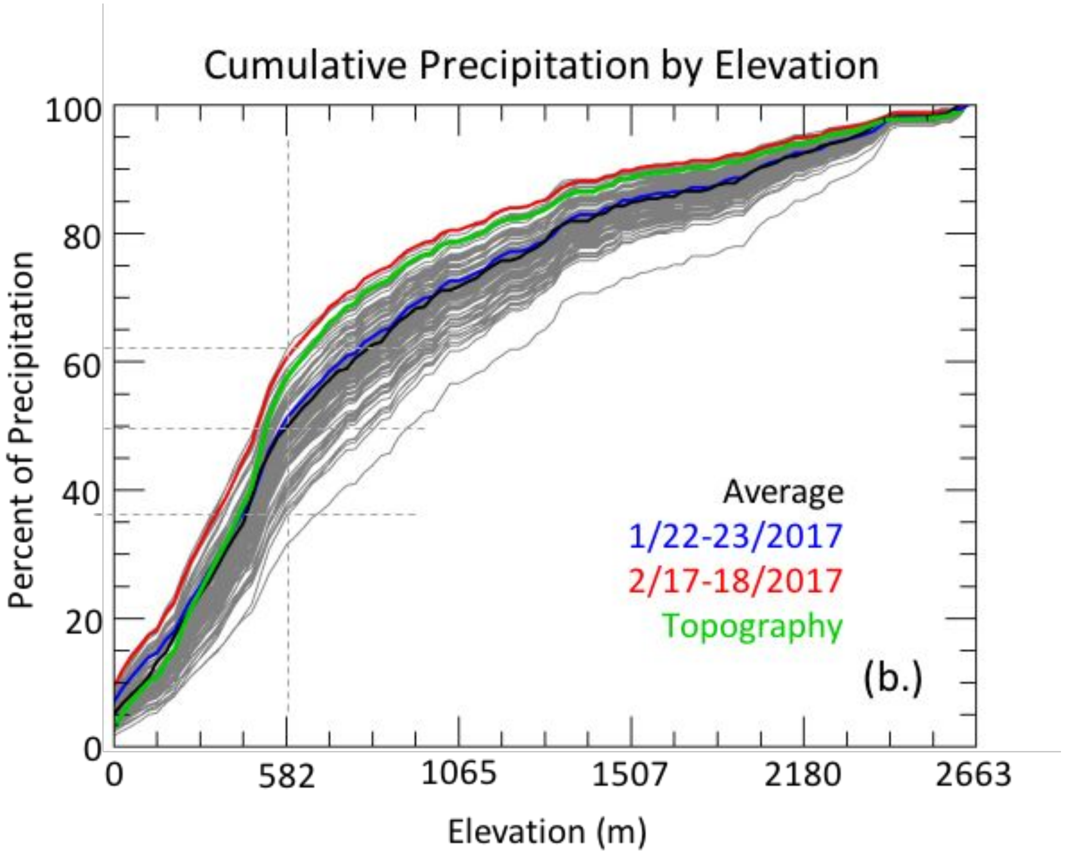


107-Event Composite does a poor job or representing event variability

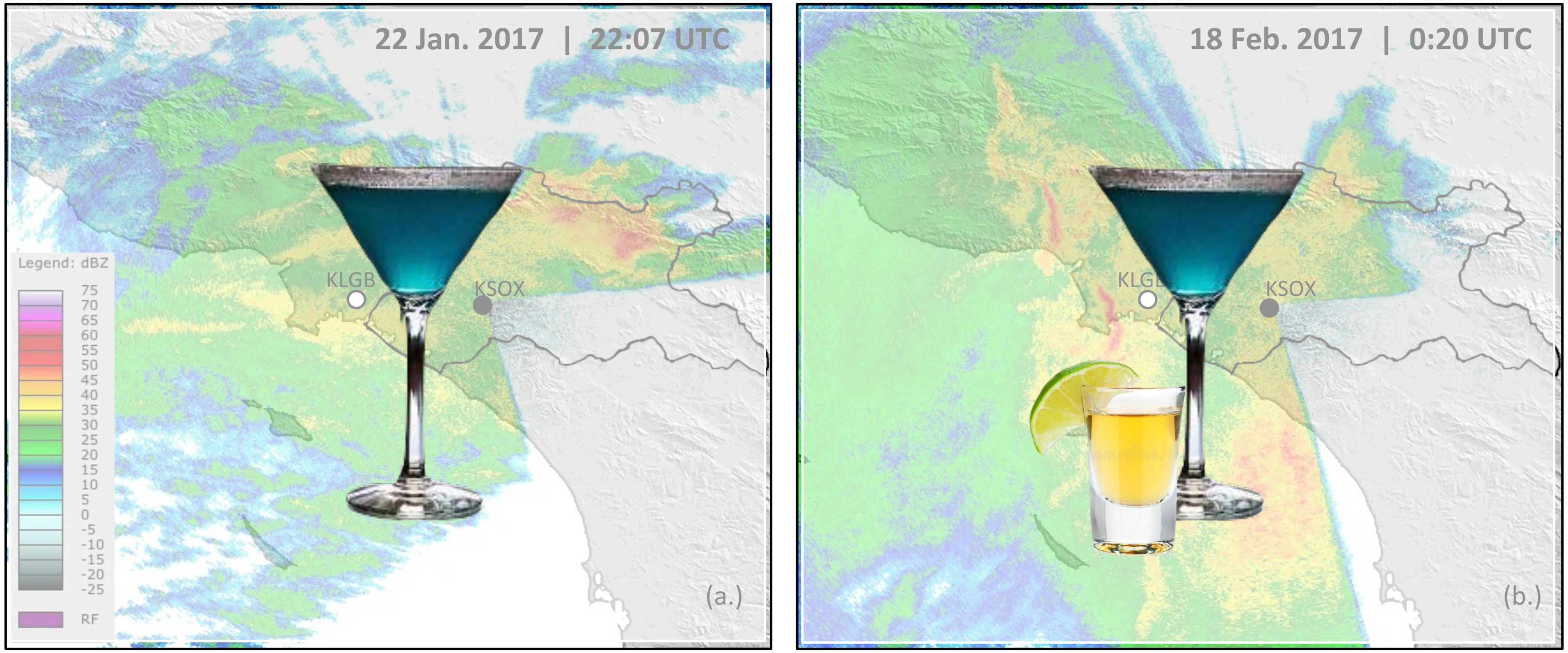
Orographic forcing of moisture is extremely important for precipitation,
but orographic enhancement is not uniform across events

Average Precipitation of 107 Events
(3-day precip = 50% of total winter)



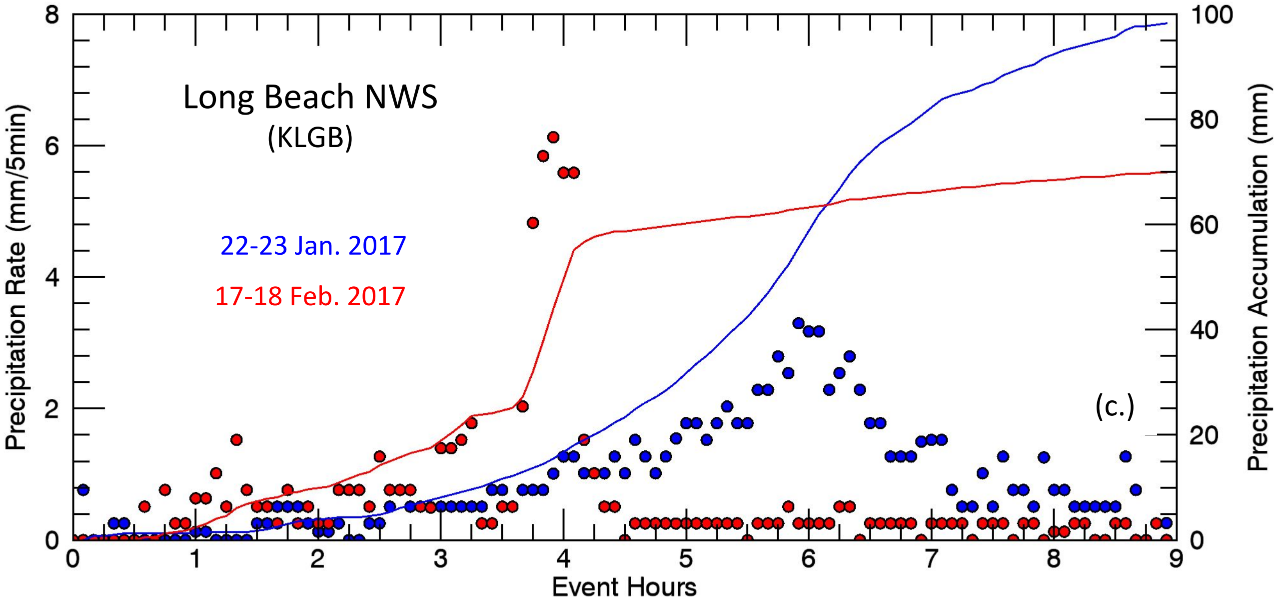


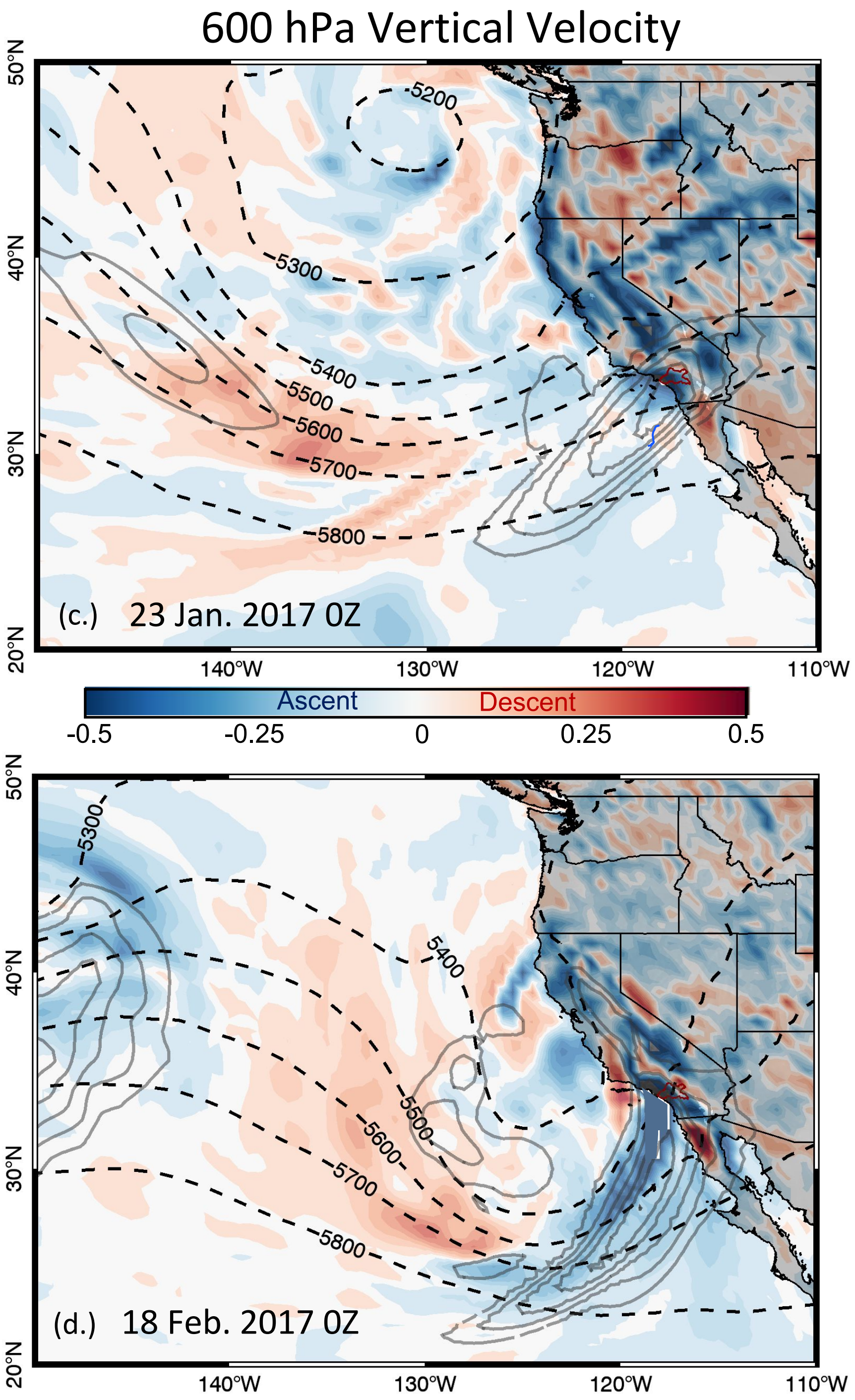
On average, 50% of event precipitation falls below 500m in the basin… but this value ranges more than 25%



The precipitation distributions during the events were also very different.

This leads to questions about what drove each of these events, and what drives extreme precipitation, climatologically.

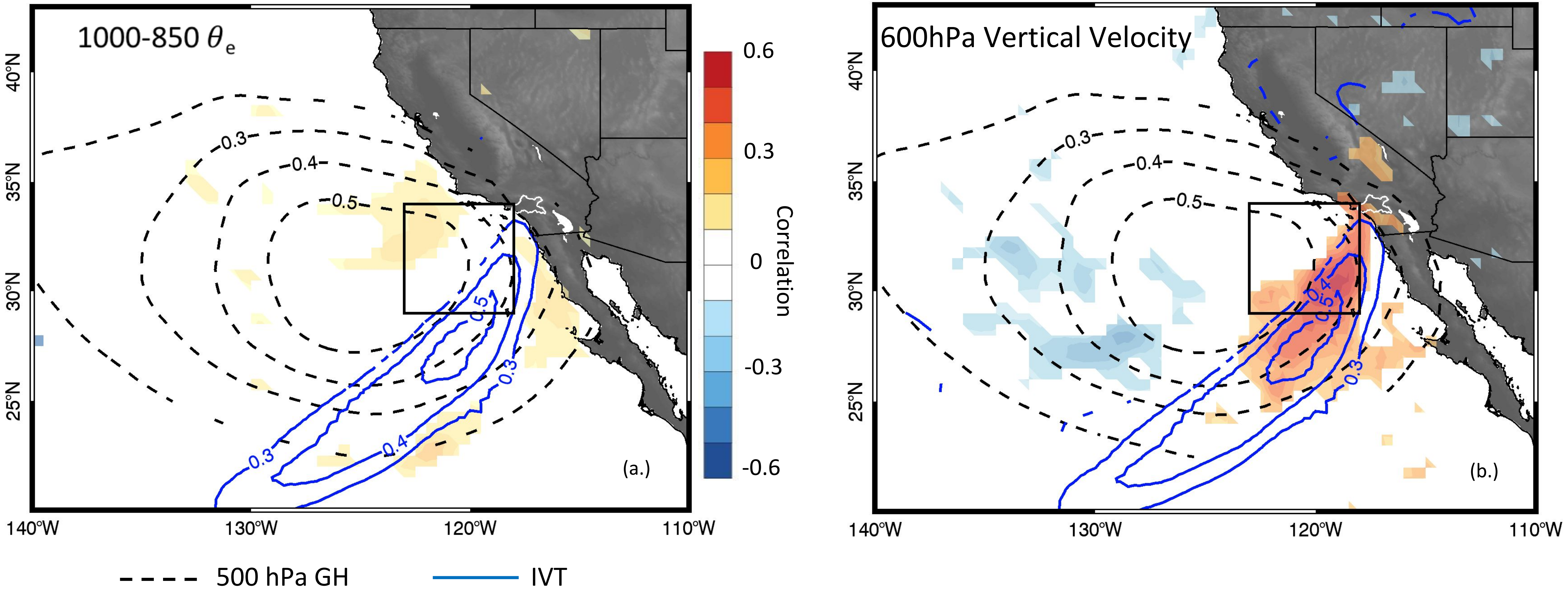




How did convection develop in the Feb case, and why didn't it develop in the Jan case?

1000-850 hPa theta-e gradient (color) in the AR region (gray IVT contour) is more stable in the January case.

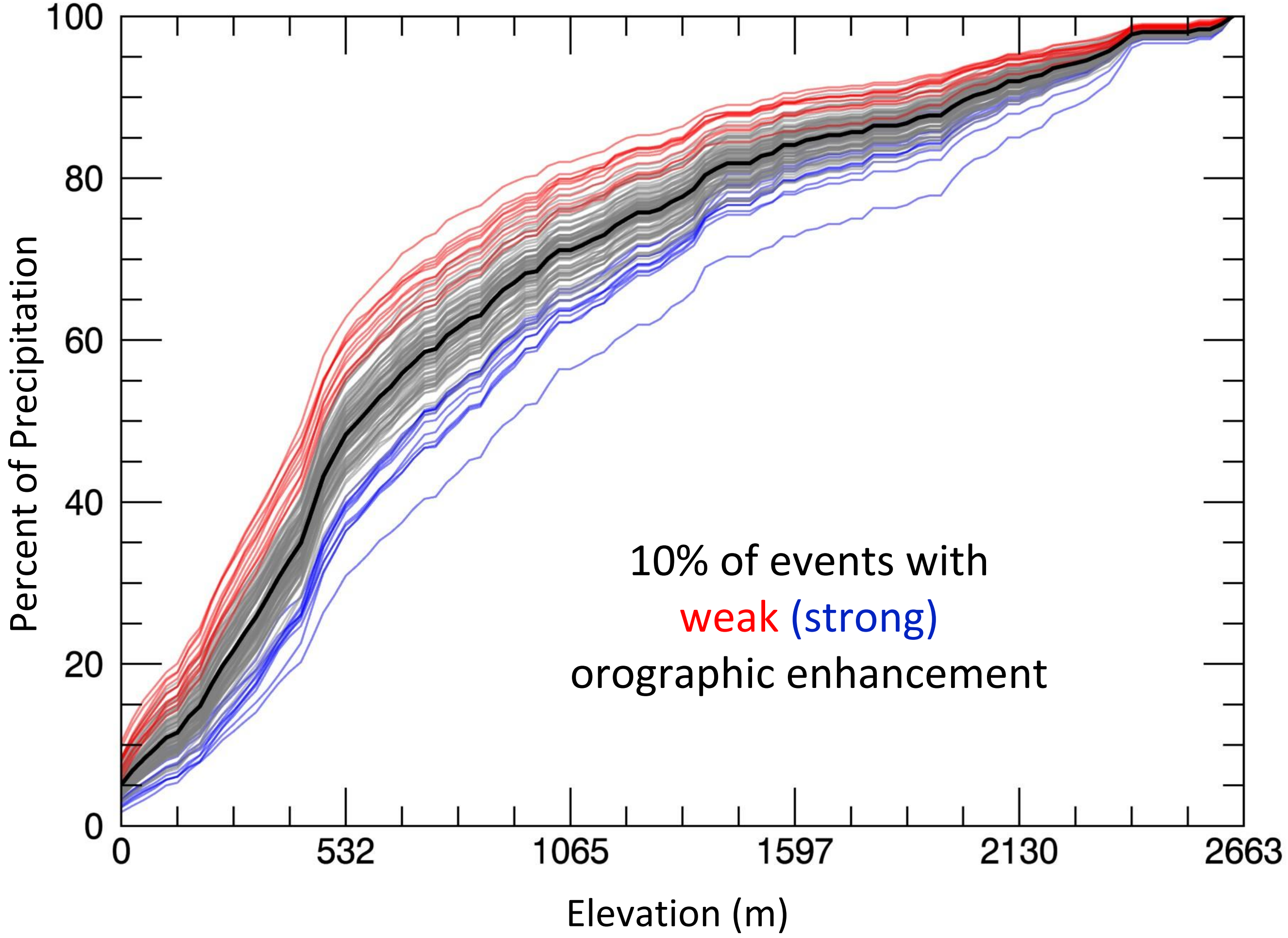
Strong ascent upstream of the watershed does not appear to be co-located with unstable conditions in the Feb case

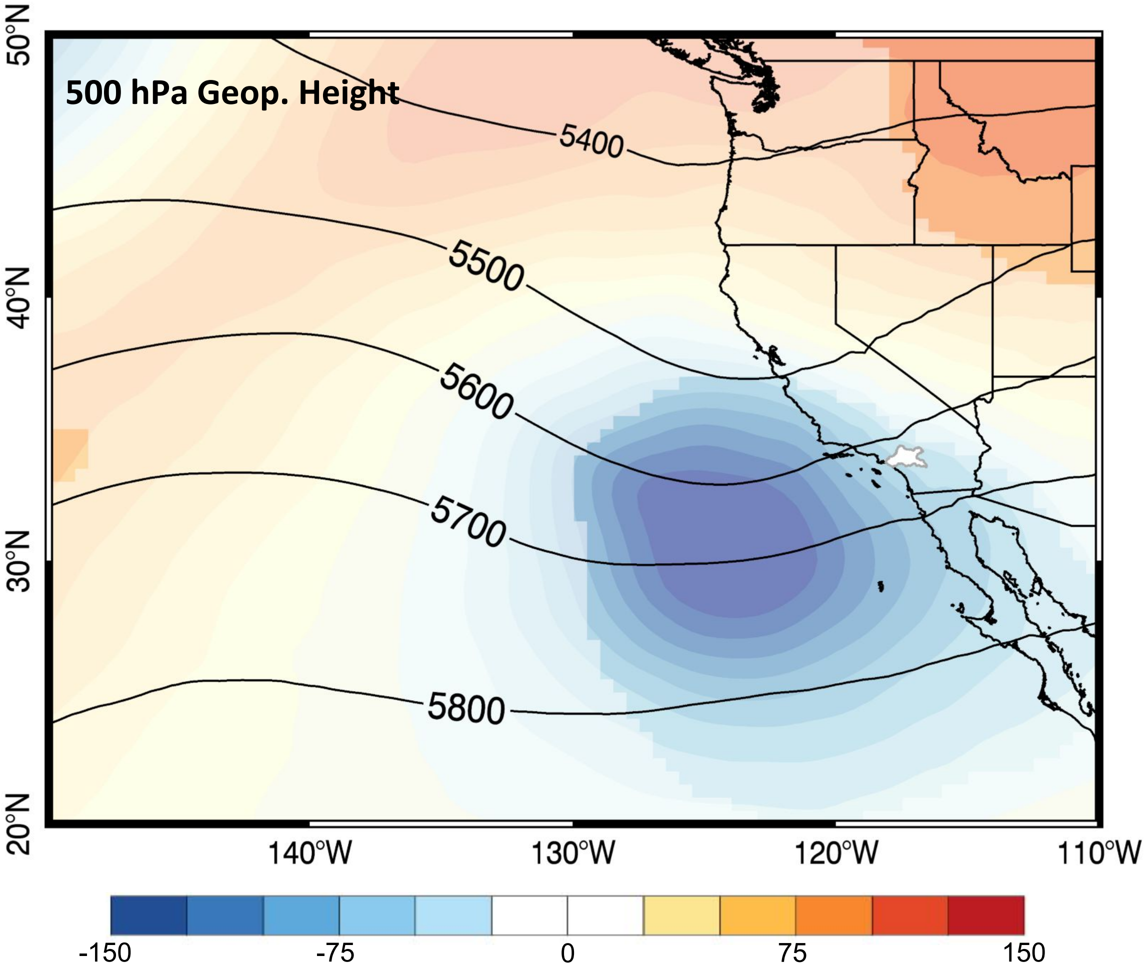


Correlating 107 events’ vertical motion in the IVT > 250 region within the upstream box with stability has no signal

Correlating 107 events’ vertical motion in the IVT > 250 region within the upstream box with vertical motion has a broad, spatially coherent signal, indicating a large-scale mechanism for forced ascent

Is reanalysis-derived upstream vertical motion really what is driving precipitation differences?

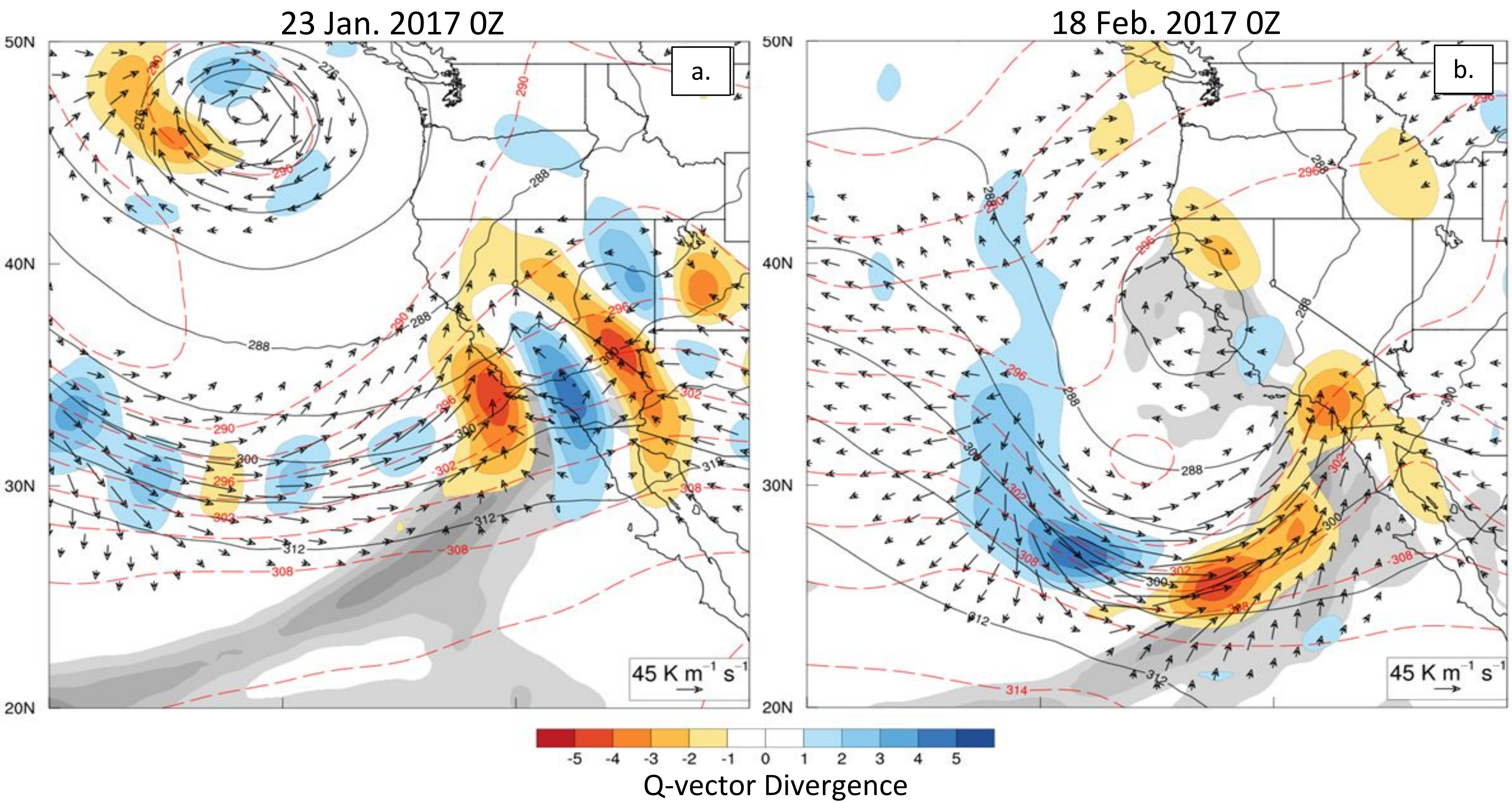




A weakened signal of orographic forcing is associated with a relative deepening of a more proximal trough

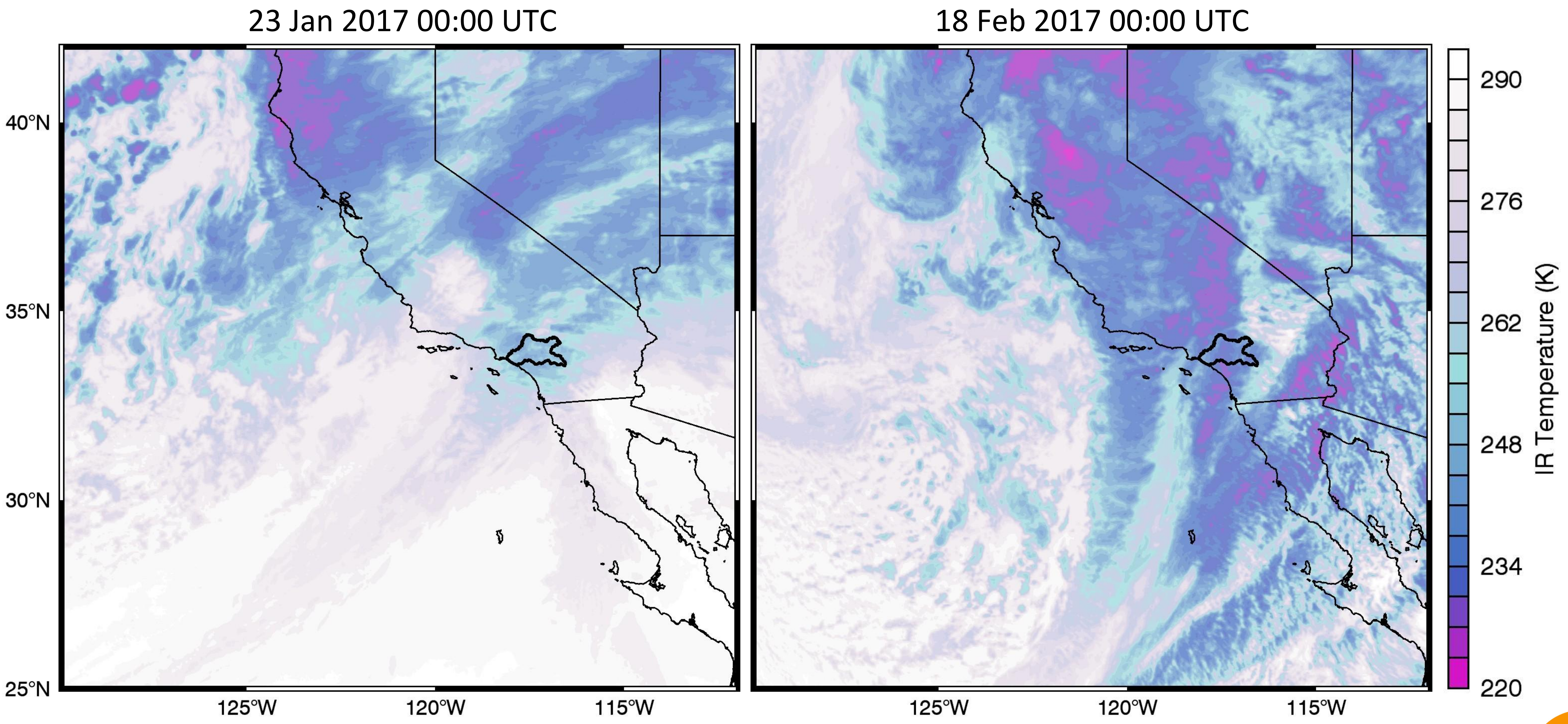
Role of Synoptic Forcing in Generating Precipitation:

Q-Vector convergence (color) at the time of max IVT during AR landfall (contour)



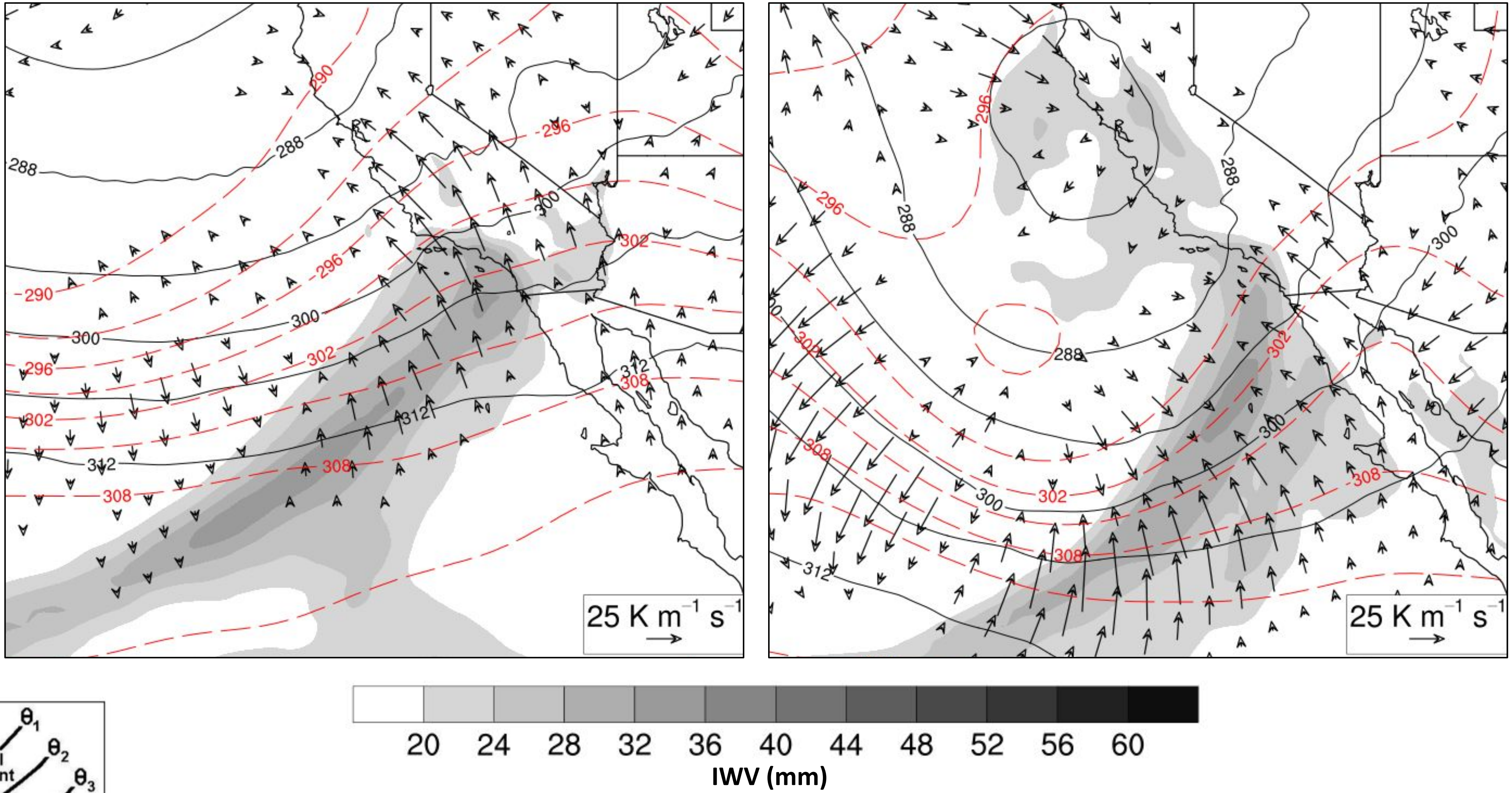
Q-vector convergence over the watershed at the time of maximum IVT infers synoptic forcing for ascent and a possible mechanism for non-orographic precipitation in the Feb event.

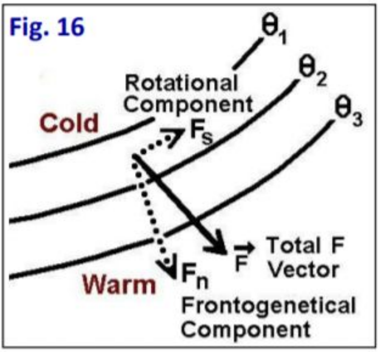
GOES 15 Infrared Brightness Temp



The Feb. event did have deeper cloud structures (9-10km) which also inferred vertical motion in the offshore environment that was associated with synoptic lift. Jan Cloud tops were ~5.5-6km

700-hPa Geo. Hghts., Normal Q-vector comp., Pot. Temp., IWV

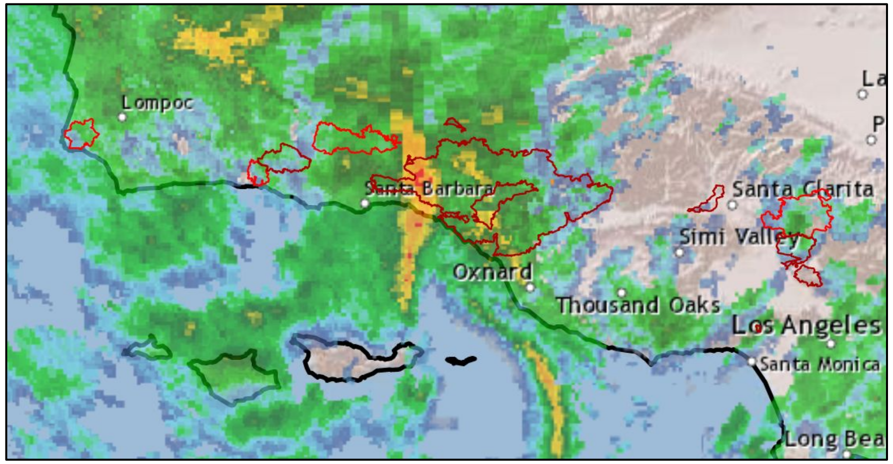




Is frontogenesis responsible for the vertical circulations along the front that drive Narrow cold-frontal rainbands? Qn component is well aligned…

What Produces Extreme Precipitation in S. CA?

- Atmospheric Rivers, but not like in N. CA!
- Generally, shorter duration w/ higher intensity
- Moist upslope flux is only one mechanism
- Synoptic dynamics and forced convection are also important
- A wide variety of conditions can produce “extreme precipitation”
- Going forward, what is the forecast skill for each mechanism?
- Synoptic forcing contribution to precip variance in N. Cal?

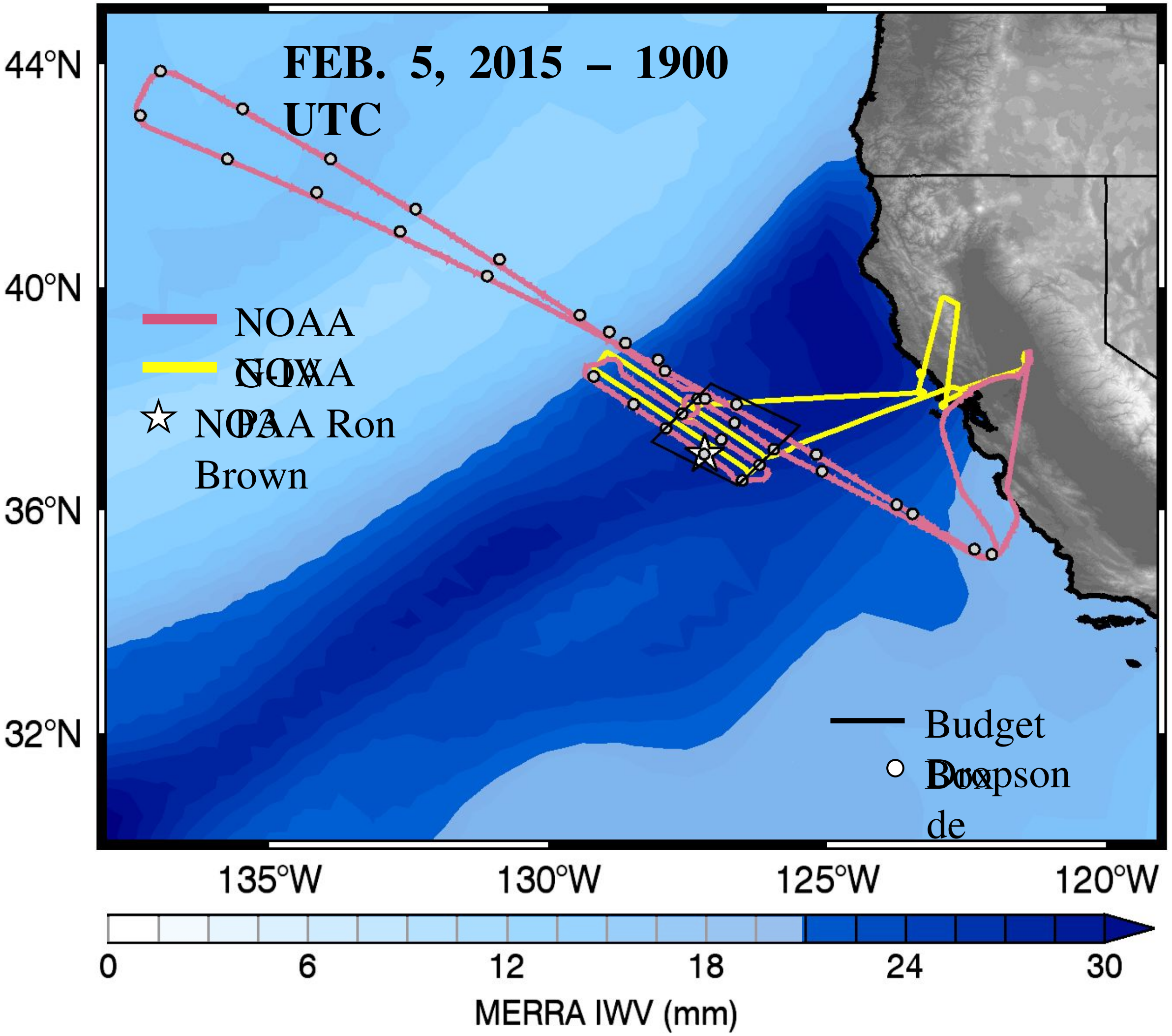


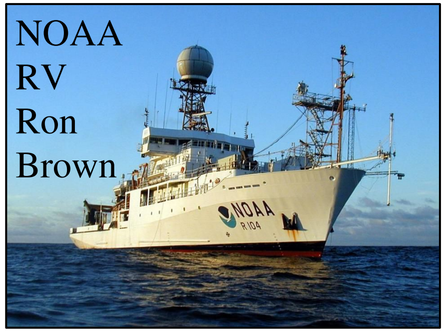
Oakley et al. (2018) in review

https://doi.org/10.5194/nhess-2018-179

Convection Over the Thomas Fire Burn Area Produced Significant Hazards
Rain rates exceeded 0.59”/5min, triggering multiple post-fire debris flows

Foundation: A novel methodology for precipitation estimation from the **NOAA G-IV tail radar** was developed for calculating the observed water vapor budget in an AR.



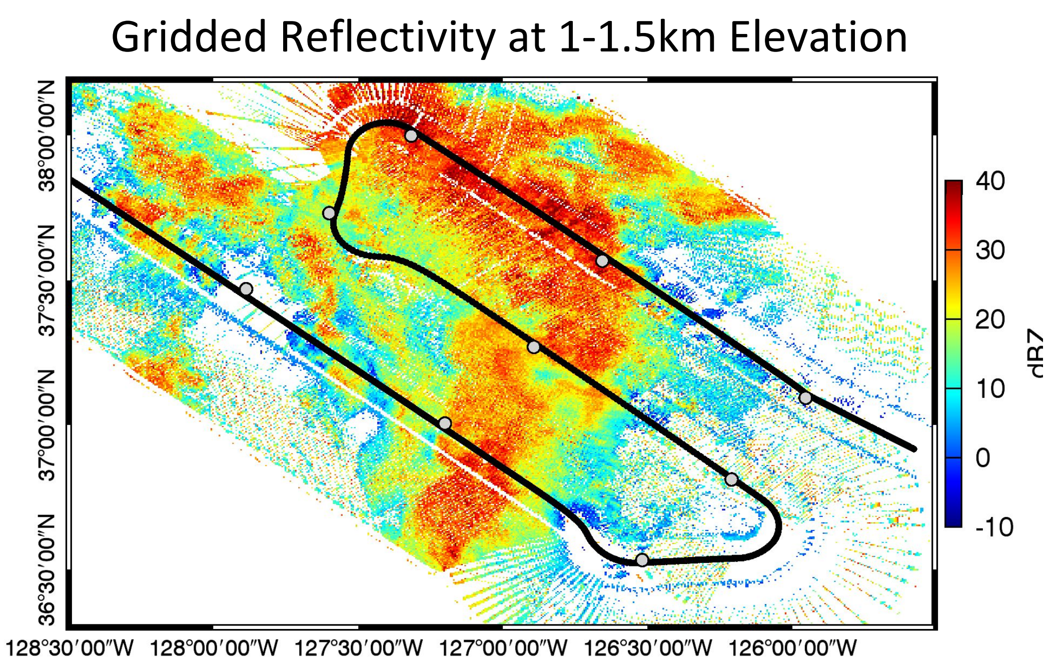


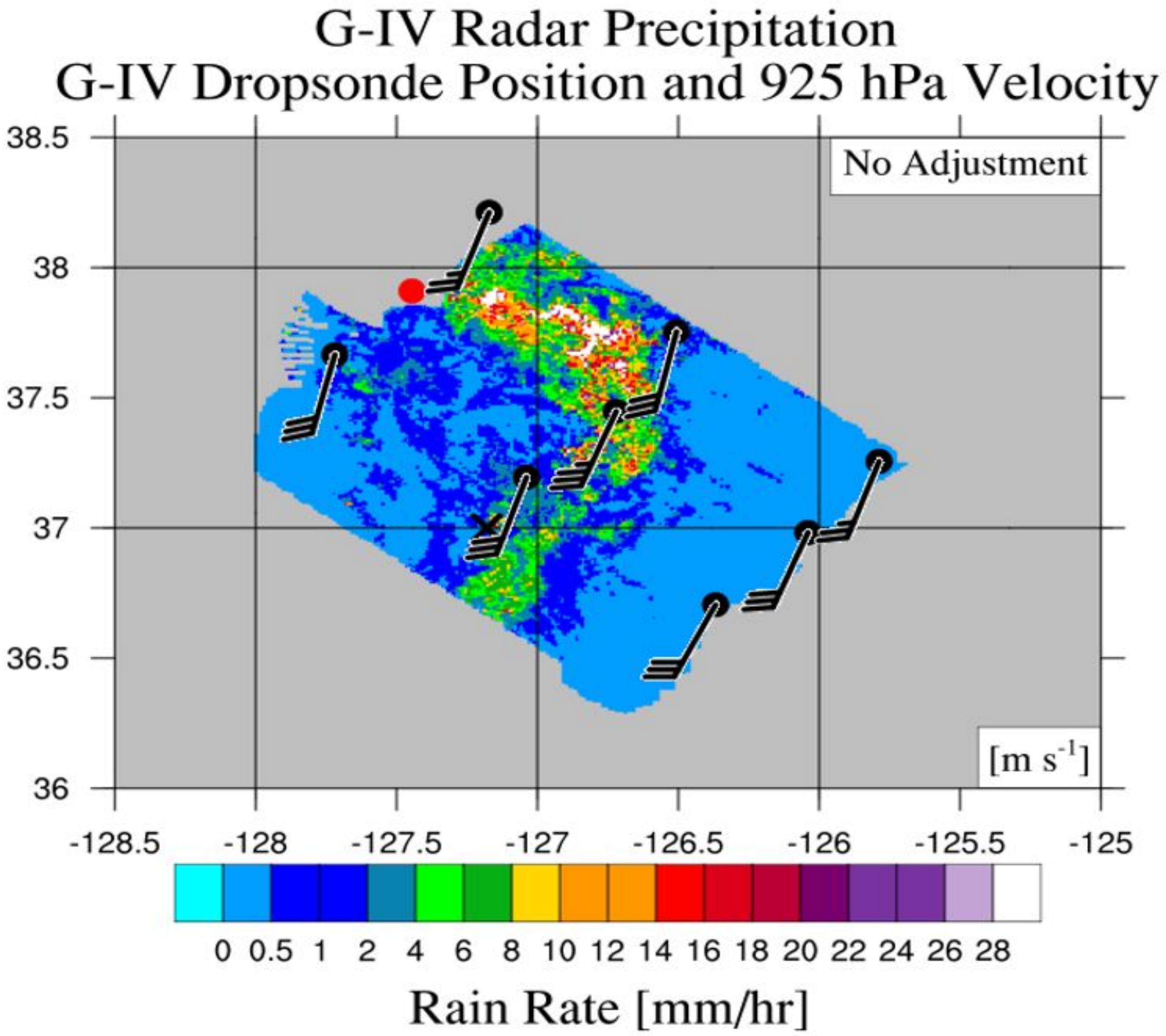
CalWater2 Observing Platforms

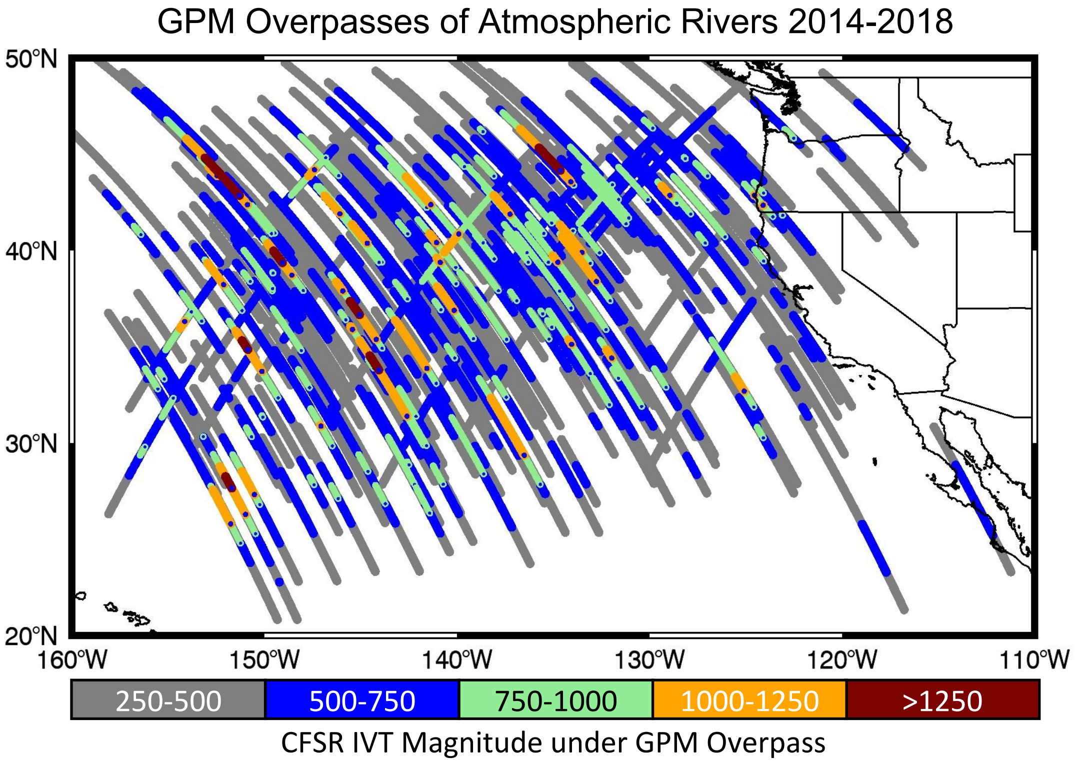
From: Norris et al. (in Prep)

What else can we learn from this instrument?

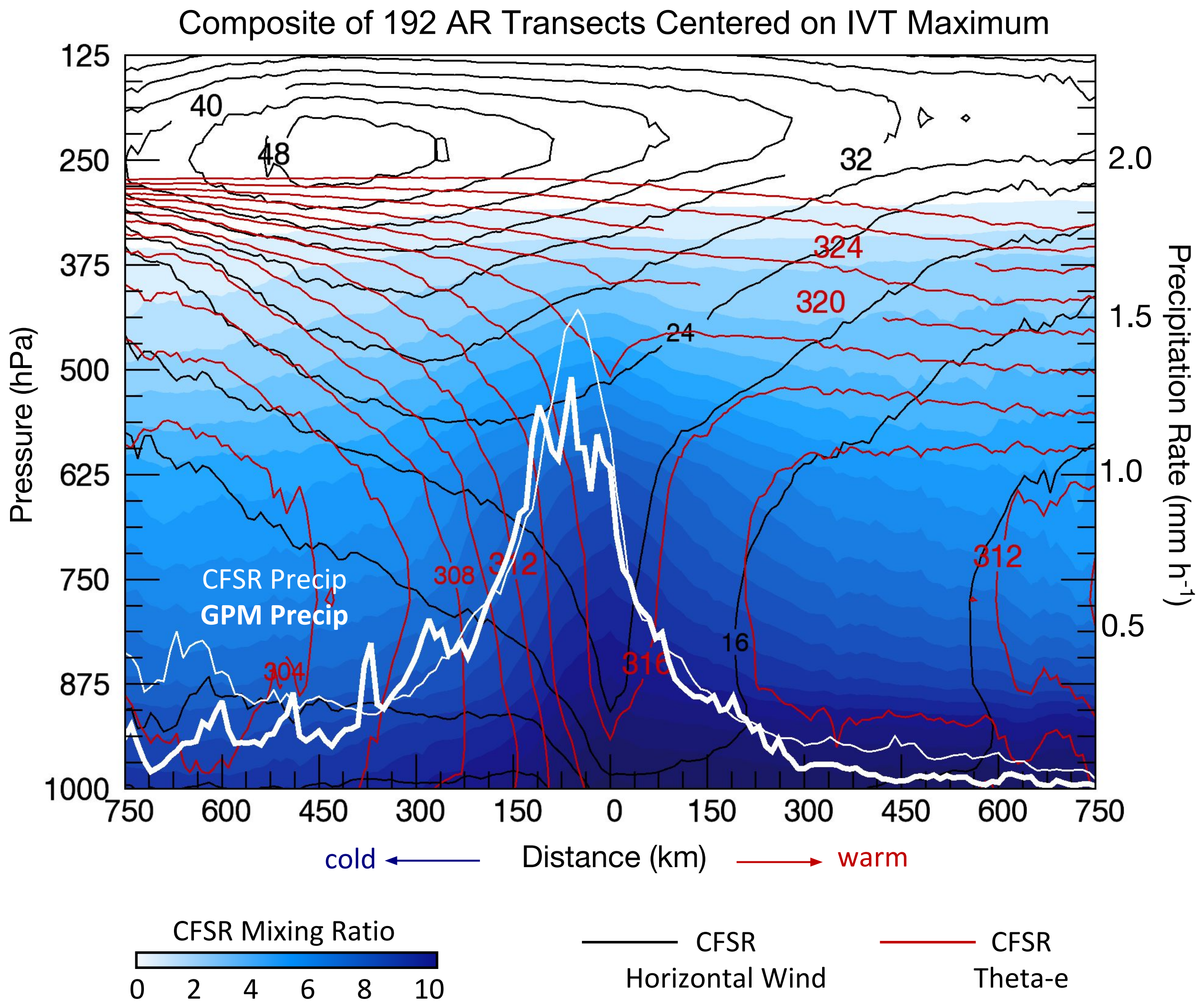
G-IV Tail Radar Reflectivity and Derived Precipitation (budget box study)



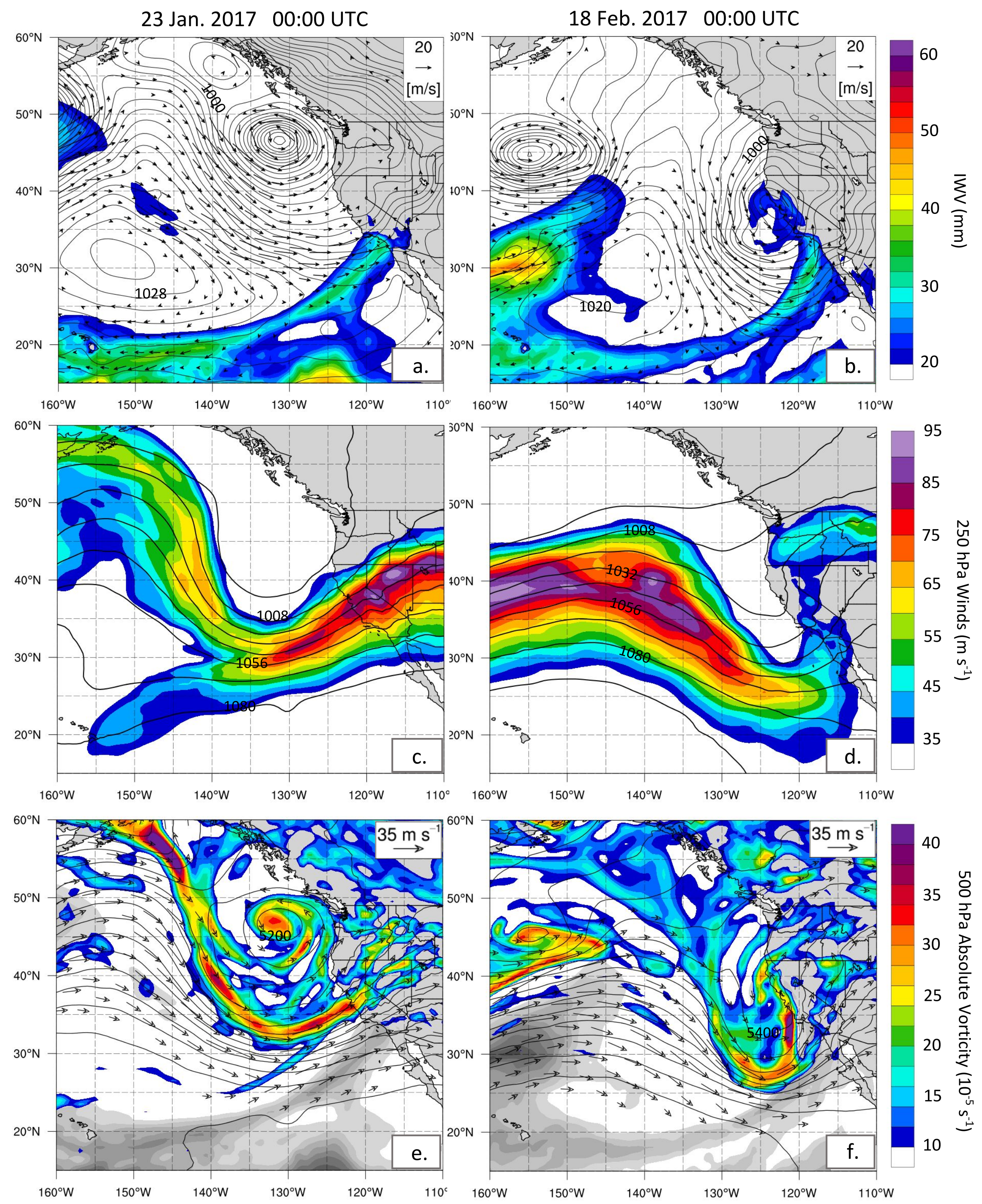




GPM Overpasses of Atmospheric Rivers 2014-2018
50°N
40°N
30°N
20°N
160°W
150°W
140°W
130°W
120°W
110°W
250-500
500-750
750-1000
1000-1250
>1250
CFSR IVT Magnitude under GPM Overpass



Composite of 192 AR Transects Centered on IVT Maximum
Pressure (hPa)
125
250
375
500
625
750
875
1000
Precipitation Rate (mm h-1)
2.0
1.5
1.0
0.5
40
48
32
24
16
324
320
312
308
304
316
CFSR Precip
GPM Precip
750
600
450
300
150
0
cold
Distance (km)
warm
CFSR Mixing Ratio
0
2
4
6
8
10
CFSR
Horizontal Wind
CFSR
Theta-e



23 Jan. 2017 00:00 UTC
18 Feb. 2017 00:00 UTC
IWV (mm)
250 hPa Winds (m s-1)
500 hPa Absolute Vorticity (10-5 s-1)
20 [m/s]
35 m s-1
1000
1028
1020
1008
1032
1056
1080
5200
5400
a.
b.
c.
d.
e.
f.

Hoskins et al. (1978, 1980)

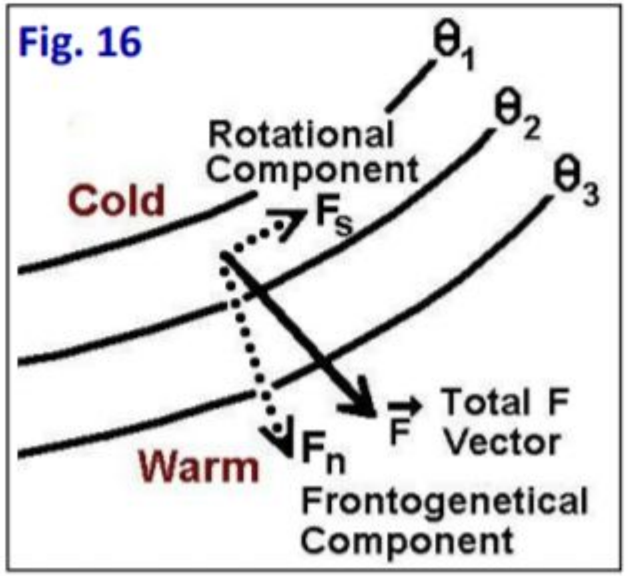
$$\left[\nabla_p{}^2 + \frac{f_o{}^2}{\sigma}\frac{\partial^2}{\partial p^2}\right]\omega = -2\nabla_p \cdot \vec{Q}$$

$$\vec{Q} = -\frac{R}{\sigma p}\begin{bmatrix}\frac{\partial v_g}{\partial x}\cdot\nabla_p T\\ \frac{\partial v_g}{\partial y}\cdot\nabla_p T\end{bmatrix} = \begin{matrix} Q_1 = -\frac{R}{\sigma p}\left[\frac{\partial u_g}{\partial x}\frac{\partial T}{\partial x} + \frac{\partial v_g}{\partial x}\frac{\partial T}{\partial y}\right] = Q_x\ (W - E\ direction) \\ Q_2 = -\frac{R}{\sigma p}\left[\frac{\partial u_g}{\partial y}\frac{\partial T}{\partial x} + \frac{\partial v_g}{\partial y}\frac{\partial T}{\partial y}\right] = Q_y\ (N - S\ direction)\end{matrix}$$

Regions of Q-vector convergence (divergence) suggest QG forcing for ascent (descent)

Q-vectors can be broken into two components, Qn and Qs

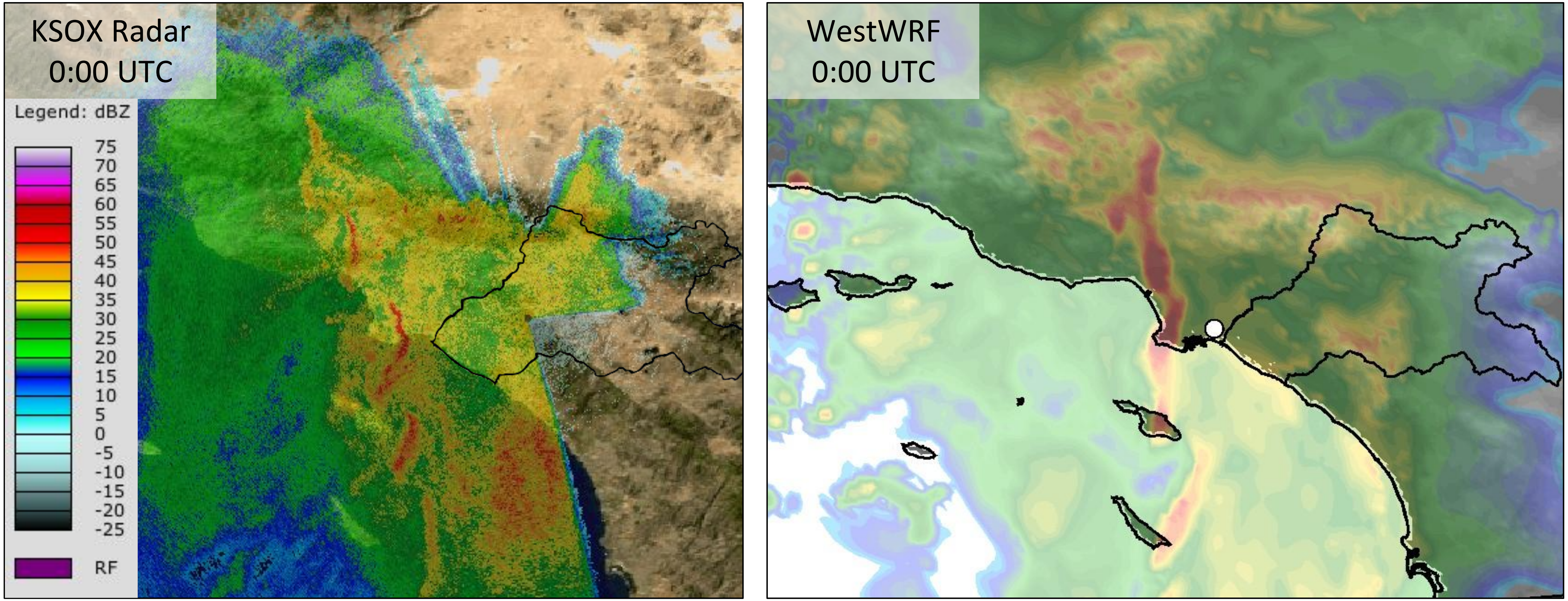
- Qn indicates regions of QG frontogenesis
    - Qn oriented towards warmer (colder) air indicates frontogenesis (frontolysis)
- Qs is the rotational component, describes temperature advection patterns and forces vertical motion on the synoptic scale
    - Qs points with cold air on the left (right) temp. field rotates cyclonically (anticyclonically)

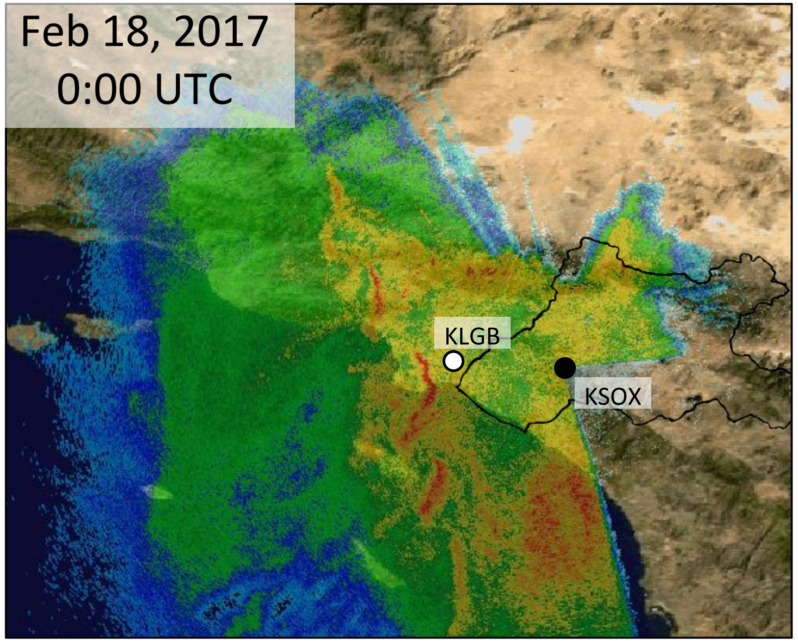


http://www.crh.noaa.gov/Image/lmk/QG_Theory_Review.pdf

How well can we simulate precipitation mechanisms other than moist upslope flux?

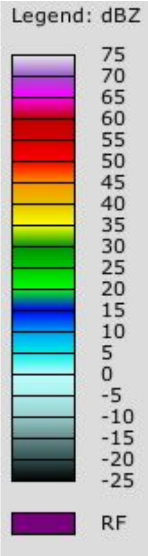
Feb 18, 2017

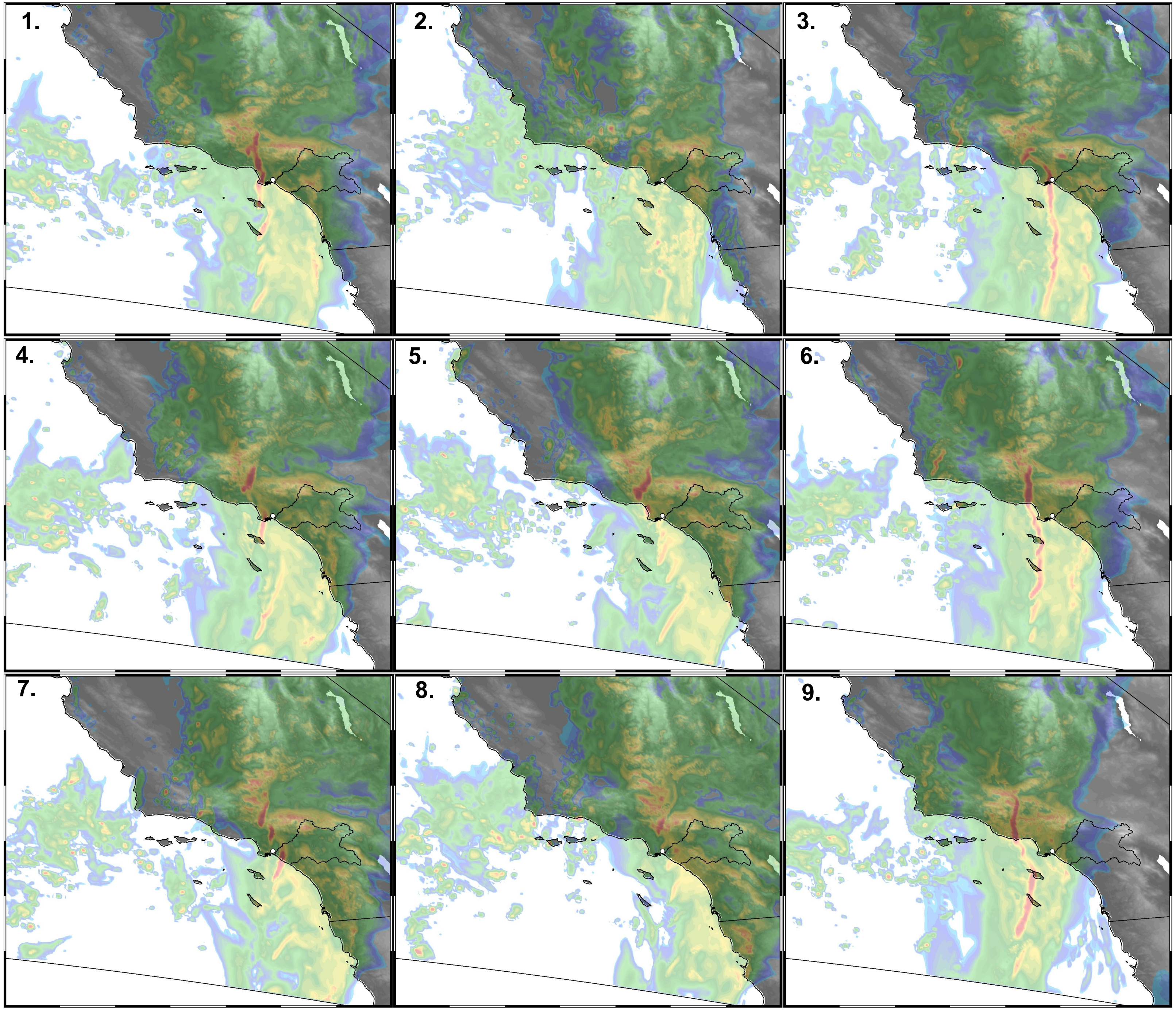




WRF Sensitivity Testing

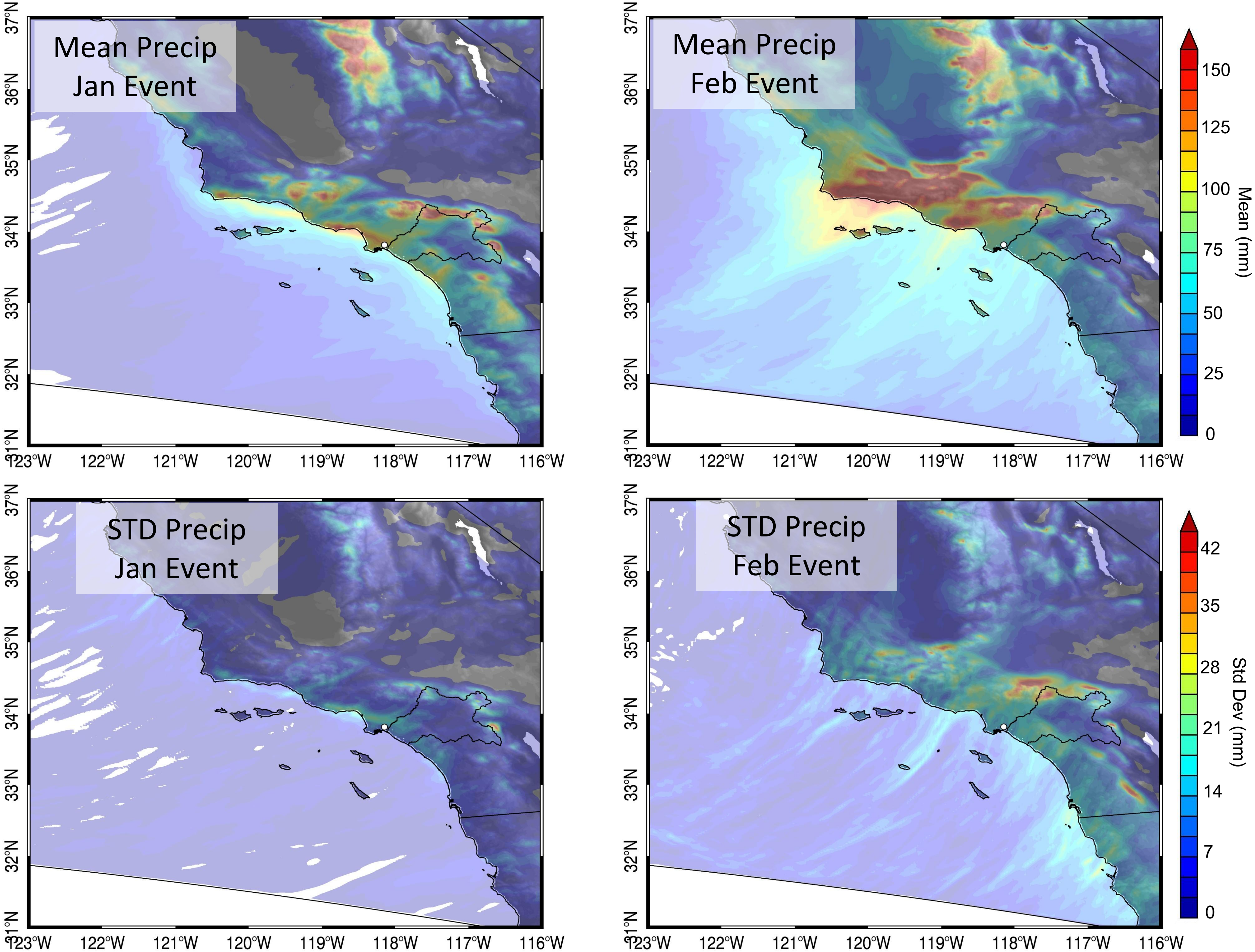
1. Control – WestWRF
2. Control – CONUS
3. Control – WWRF w/ PBL=BLC
4. SKEBS – Control 1 Ens. 1
5. SKEBS – Control 1 Ens. 2
6. SKEBS – Control 1 Ens. 3
7. Perturb – Control 1 Ens. 1
8. Perturb – Control 1 Ens. 2
9. Perturb – Control 1 Ens. 3



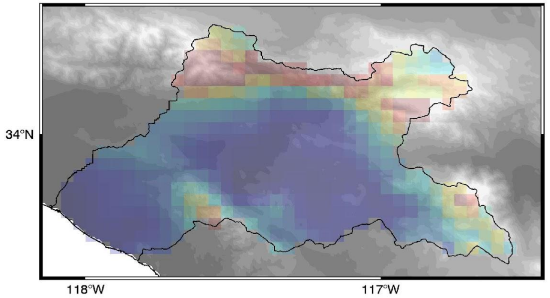


Ensemble mean and standard deviation indicate the comparative disagreement in precipitation over the Santa Ana Watershed in the convective Feb Event

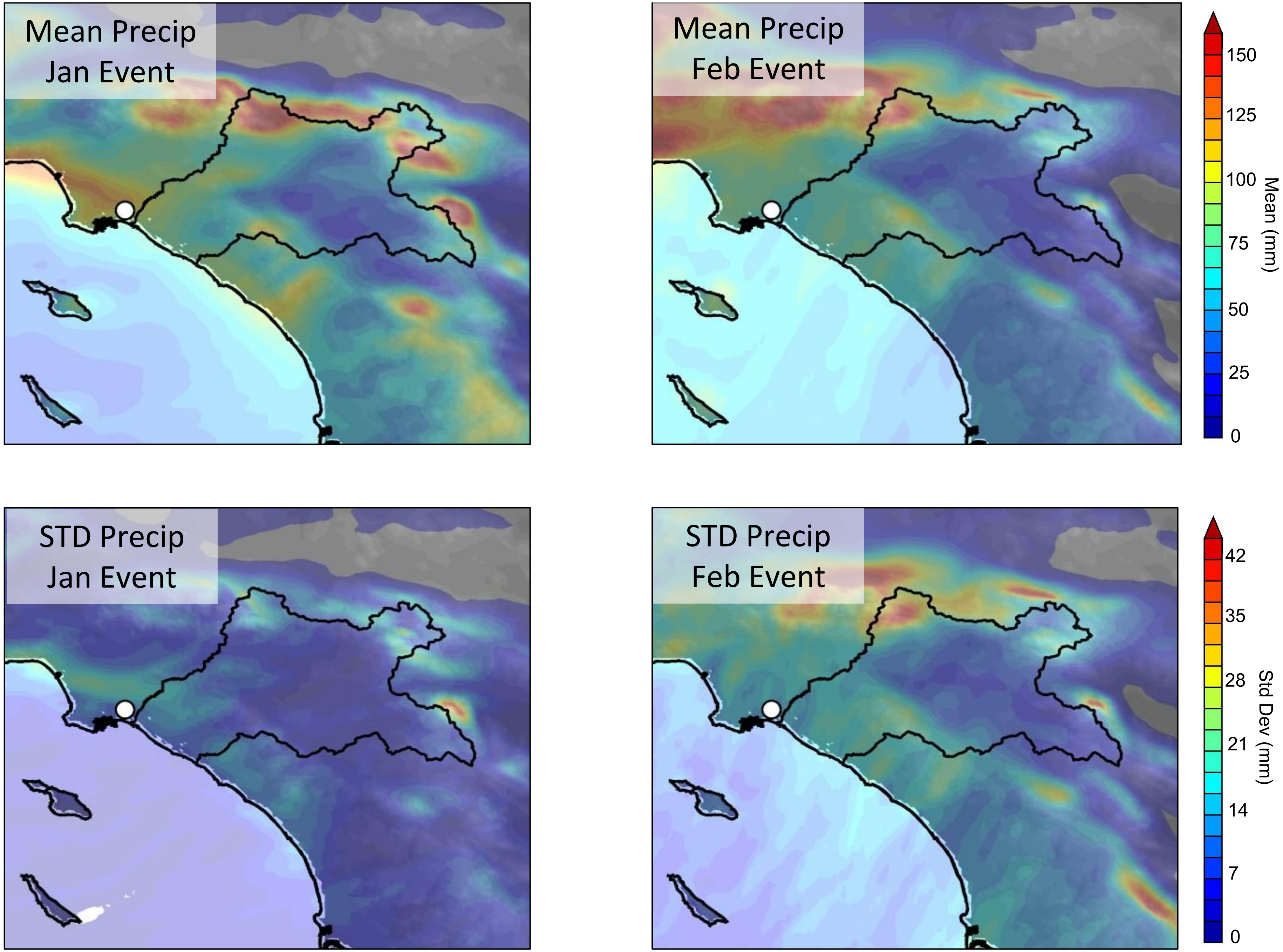
Need to further investigate the role of mesoscale precipitation processes in S CA atmospheric rivers, as well as their impact on predictability.

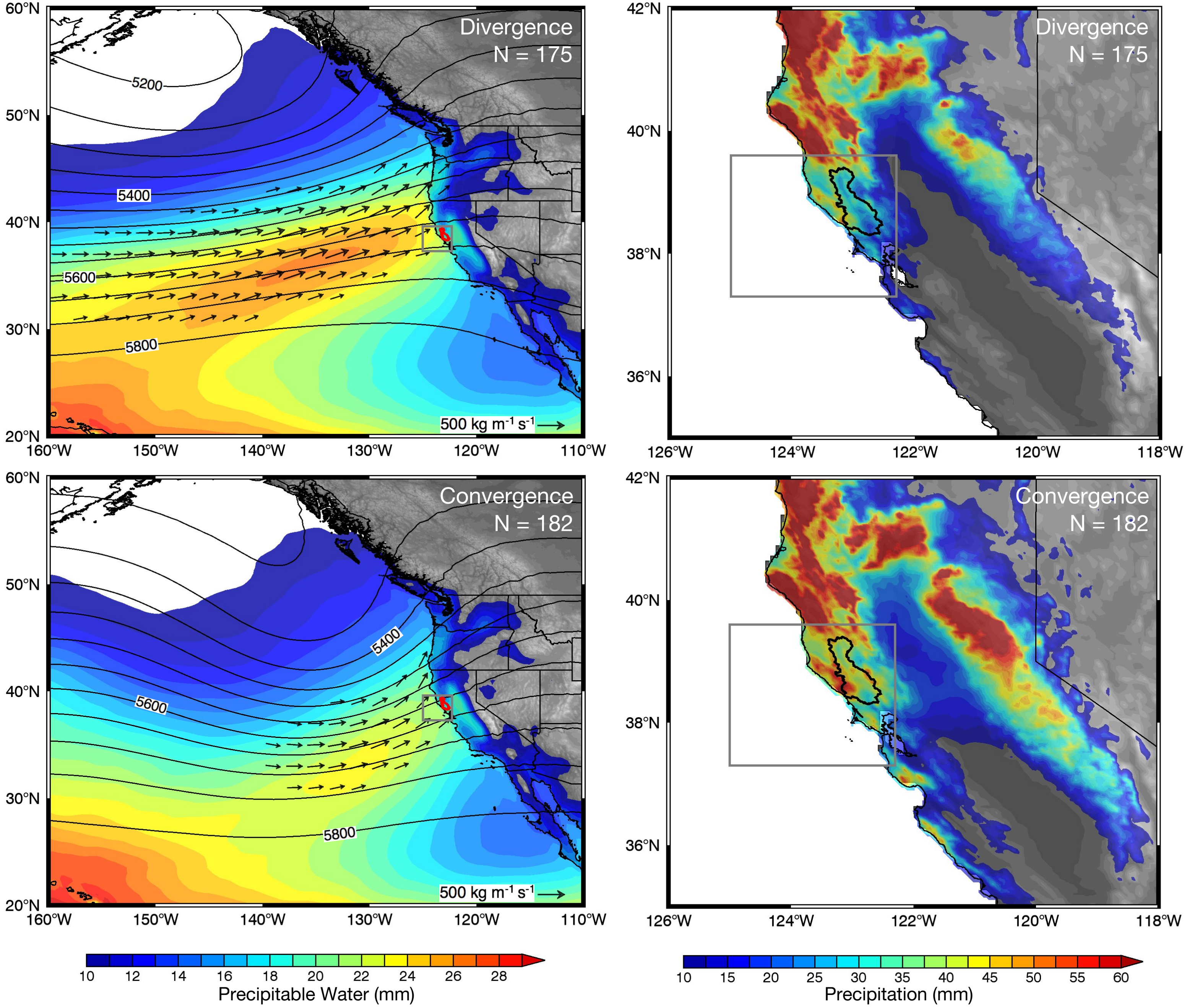


Average Precipitation of 107 Events
(3-day precip = 50% of total winter)

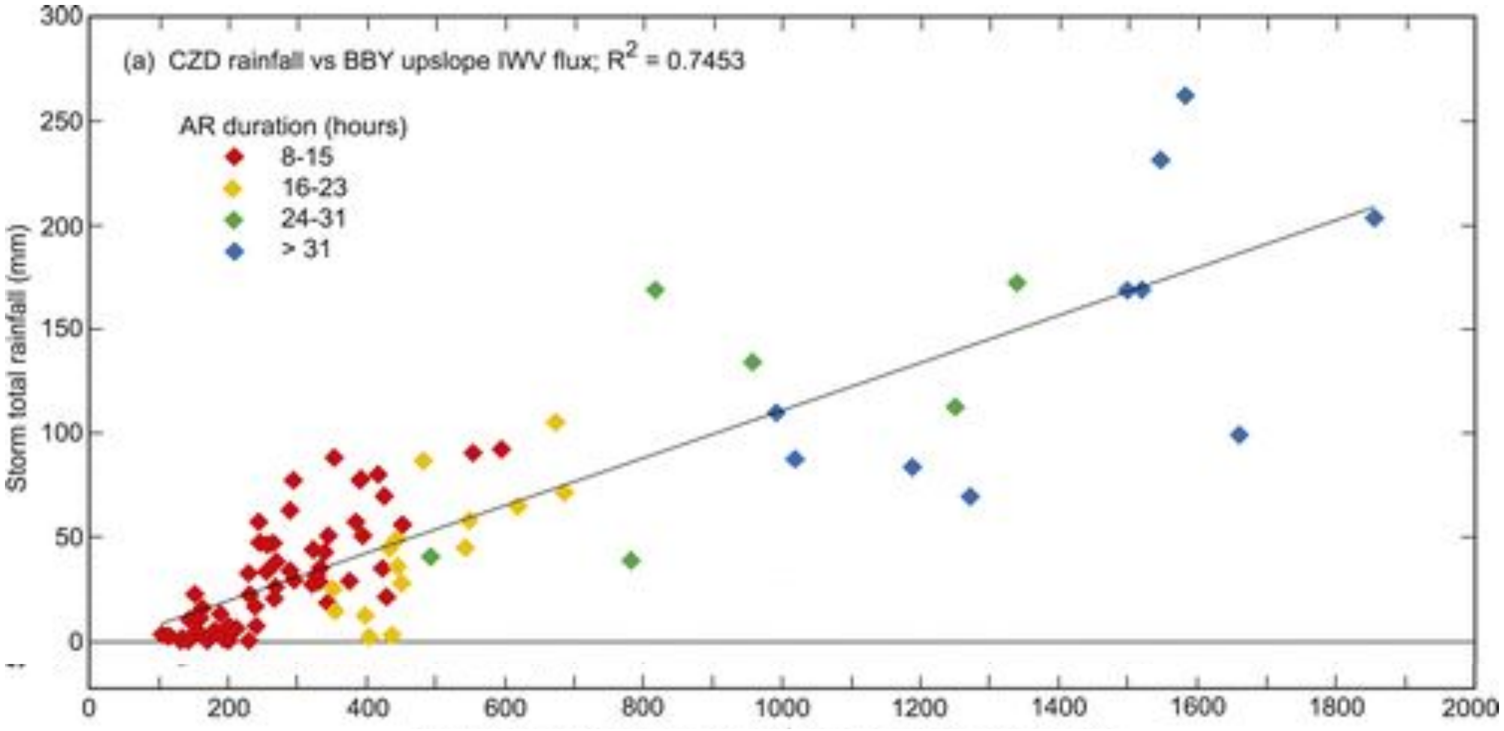


Slightly less precip in the February event, but considerably higher spread in the ensemble.

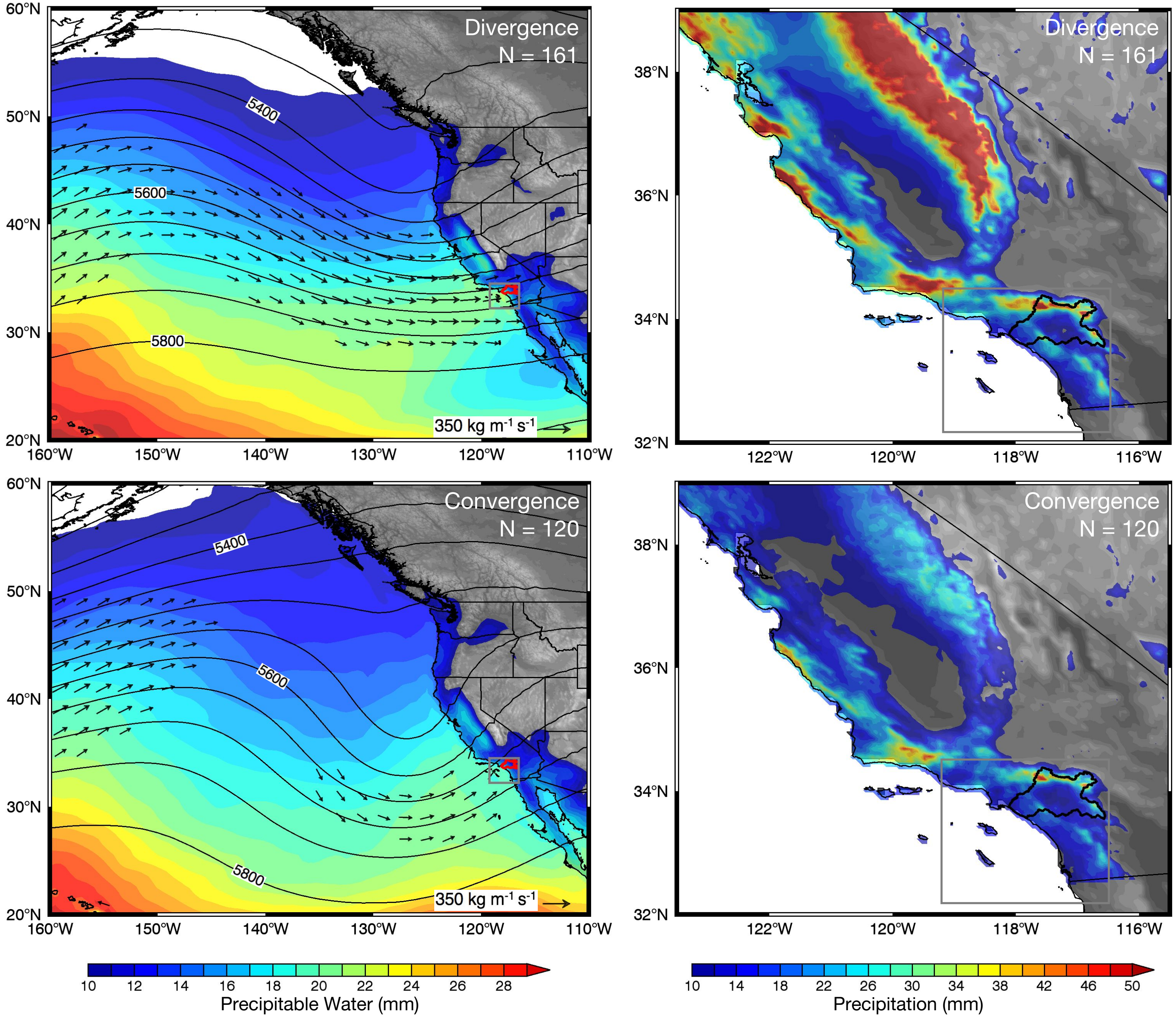



Divergence
N = 175
5200
5400
5600
5800
500 kg m-1 s-1
60°N
50°N
40°N
30°N
20°N
160°W
150°W
140°W
130°W
120°W
110°W
42°N
40°N
38°N
36°N
126°W
124°W
122°W
120°W
118°W
Convergence
N = 182
10 12 14 16 18 20 22 24 26 28
Precipitable Water (mm)
10 15 20 25 30 35 40 45 50 55 60
Precipitation (mm)

147 Events	buf	prc	qg	dur	r	var
all	501	48	-0.54	17.3	0.81	65%
divg	509	46	-0.16	18.6	0.86	75%
conv	496	50	-0.93	16.1	0.73	53%



from *Ralph et al. 2013 (91 cases)*



Divergence
N = 161
Convergence
N = 120
5400
5600
5800
350 kg m-1 s-1
60°N
50°N
40°N
30°N
20°N
160°W
150°W
140°W
130°W
120°W
110°W
38°N
36°N
34°N
32°N
122°W
120°W
118°W
116°W
10 12 14 16 18 20 22 24 26 28
Precipitable Water (mm)
10 14 18 22 26 30 34 38 42 46 50
Precipitation (mm)