Application of Ensemble Sensitivity during the 2022/2023 AR-Recon Season

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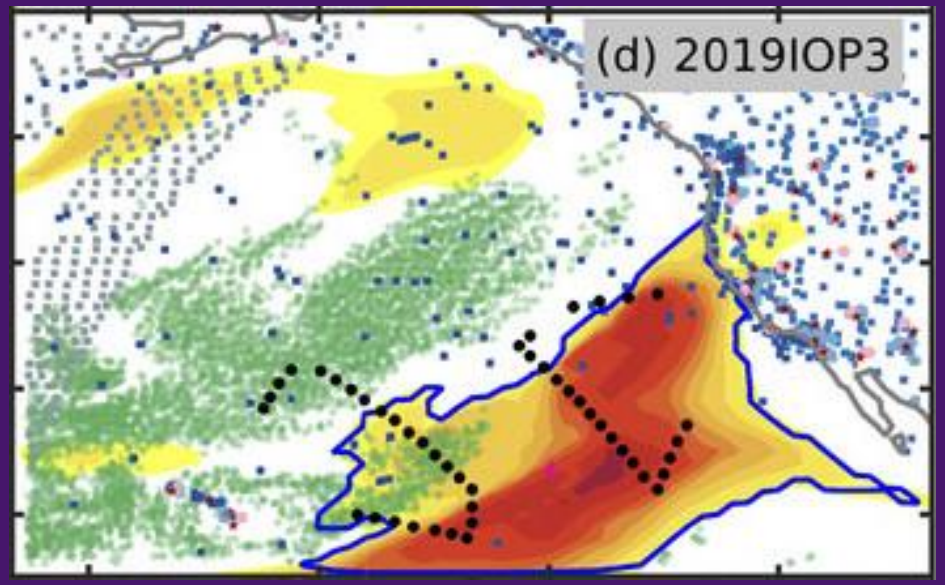
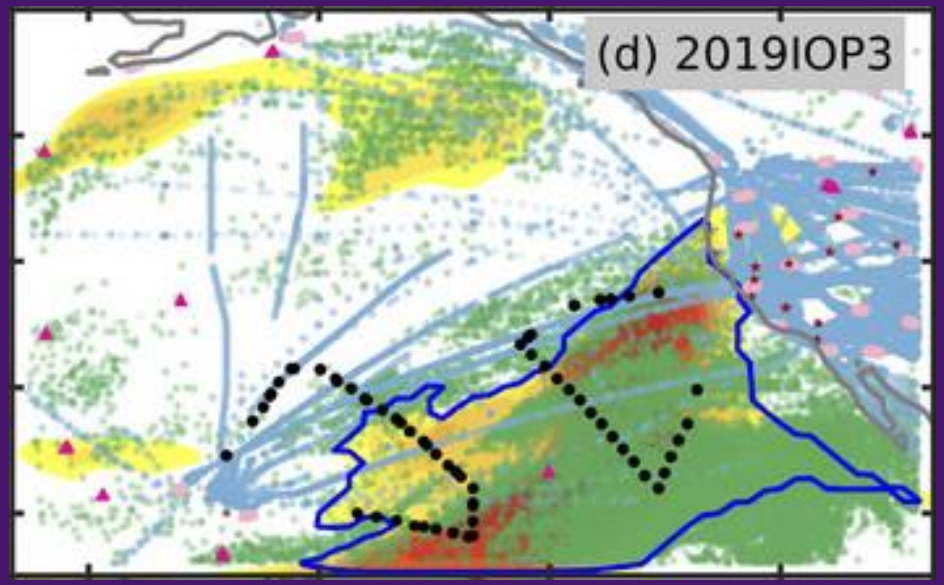
Atmospheric River Reconnaissance Workshop

Support from FIRO, USACE

Overview

- West Coast AR originate over the ocean, meaning there are relatively few in situ observations, and potentially more uncertain precipitation forecasts once they make landfall
- Interested in objectively identifying locations/features where small changes in its representation would result in the largest change in subsequent precipitation forecast





Zheng et al. 2021, BAMS

Overview

- Can better understand this using the ensemble-based sensitivity method, direct observational assets toward sensitive regions
  - Can utilize forecasts already being produced
  - Computationally inexpensive
- Goal of this talk is to briefly discuss the application of this method to winter weather targeting, including AR Recon
  - Method has been employed as part of AR Recon since 2019

Credit: NOAA

Credit: US Air Force

Presentation Overview

- Overview of ensemble-based sensitivity, including metrics developed for AR applications
- Demonstration of products for 0000 UTC 15 Jan. mission (IOP 15)
  - Example of frontal wave sensitivity
- Demonstration of products for 0000 UTC 10 March (IOP 36)
  - Example of upper-tropospheric trough-AR interaction

Credit: NOAA

Credit: US Air Force

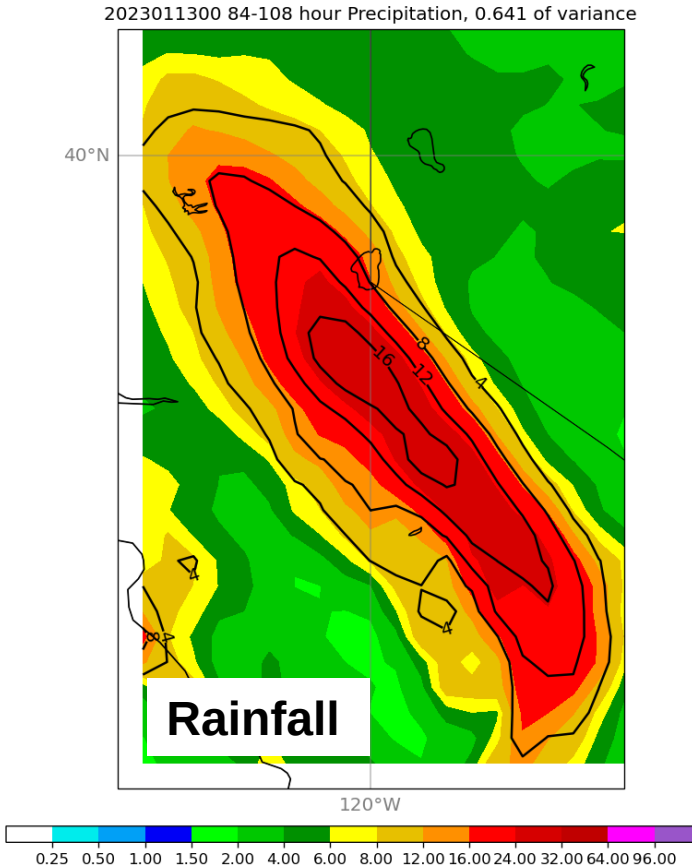
Ensemble Sensitivity

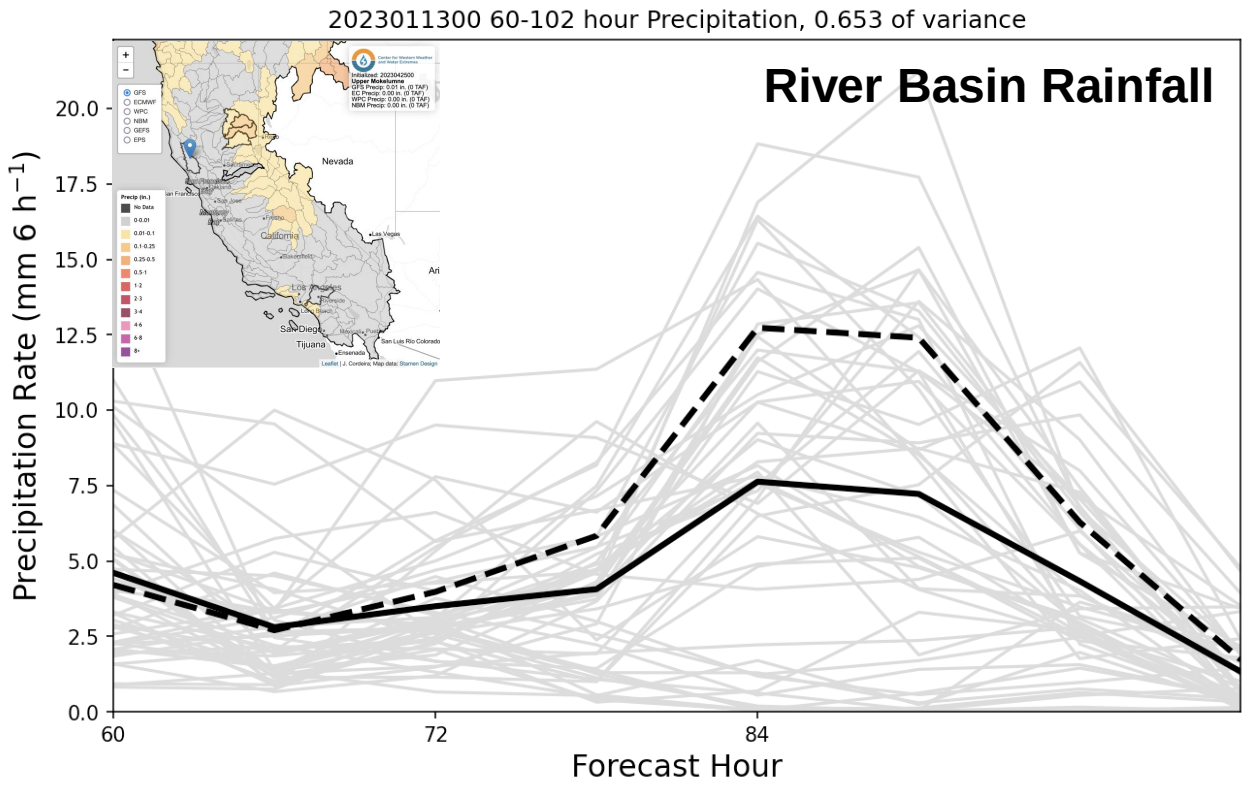
$$\frac{\partial J}{\partial x_{t-\delta t,j}}_{e} \equiv cov(\mathbf{J}, \delta\mathbf{X}_{t-\delta t,j})\mathbf{D}_j^{-1} = \frac{cov(\mathbf{J}, \mathbf{X}_j)}{var(\mathbf{X}_j)}$$

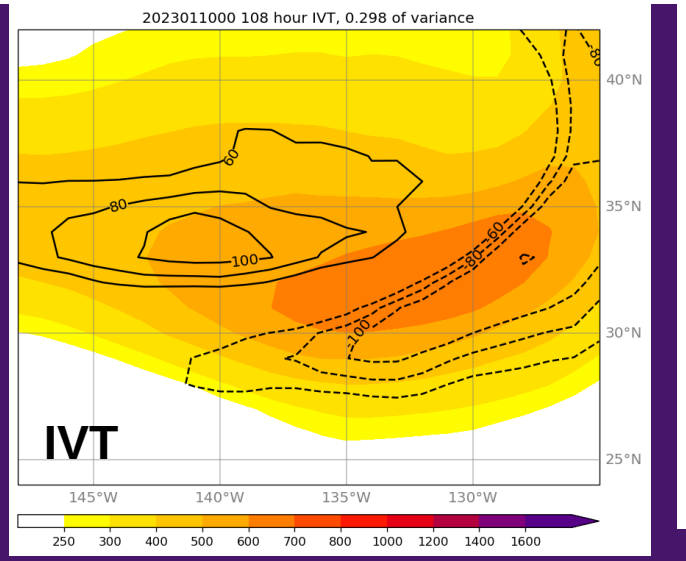
Ancell and Hakim 2007, Torn and Hakim 2008

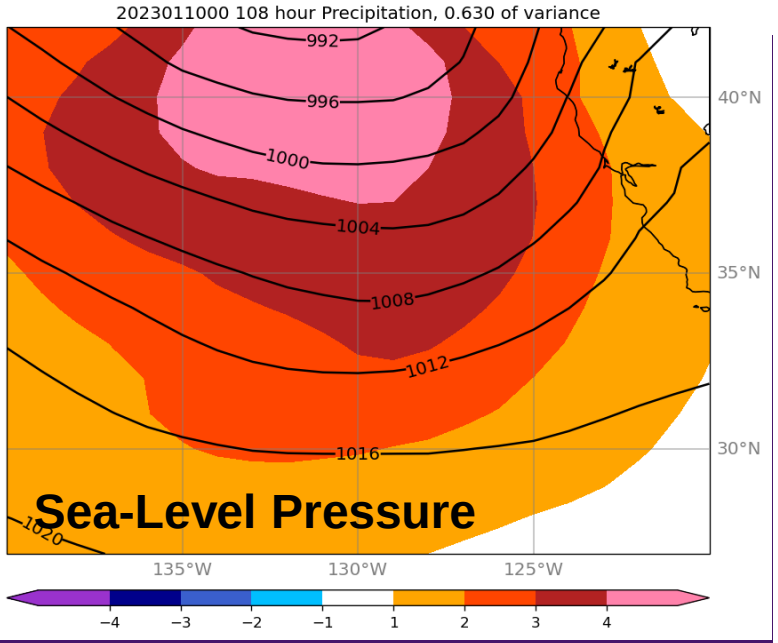
- Ensemble-based method of computing the sensitivity to model state variables at earlier time
- Above equation is linear regression based on ensemble:
  - Dependent variable is ensemble estimate of a forecast metric our outcome that is a function of the model output (multiple options available)
  - Independent variable is ensemble estimate of state variable (i.e., IVT, wind, vorticity, PV, water vapor) at a given location and earlier time

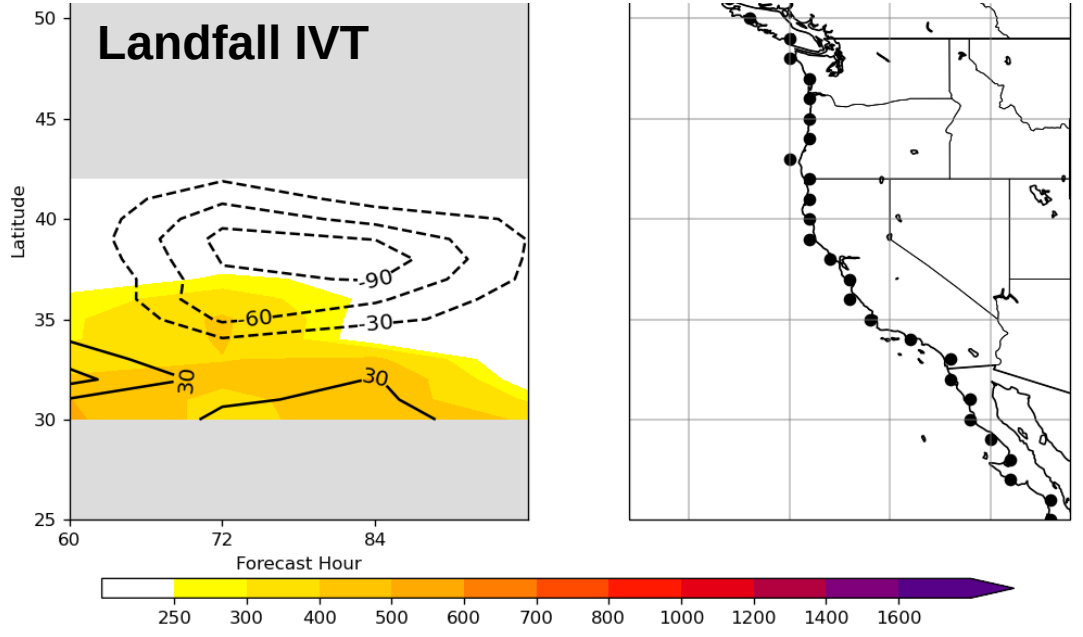
Variety of User-Defined Metric Choices







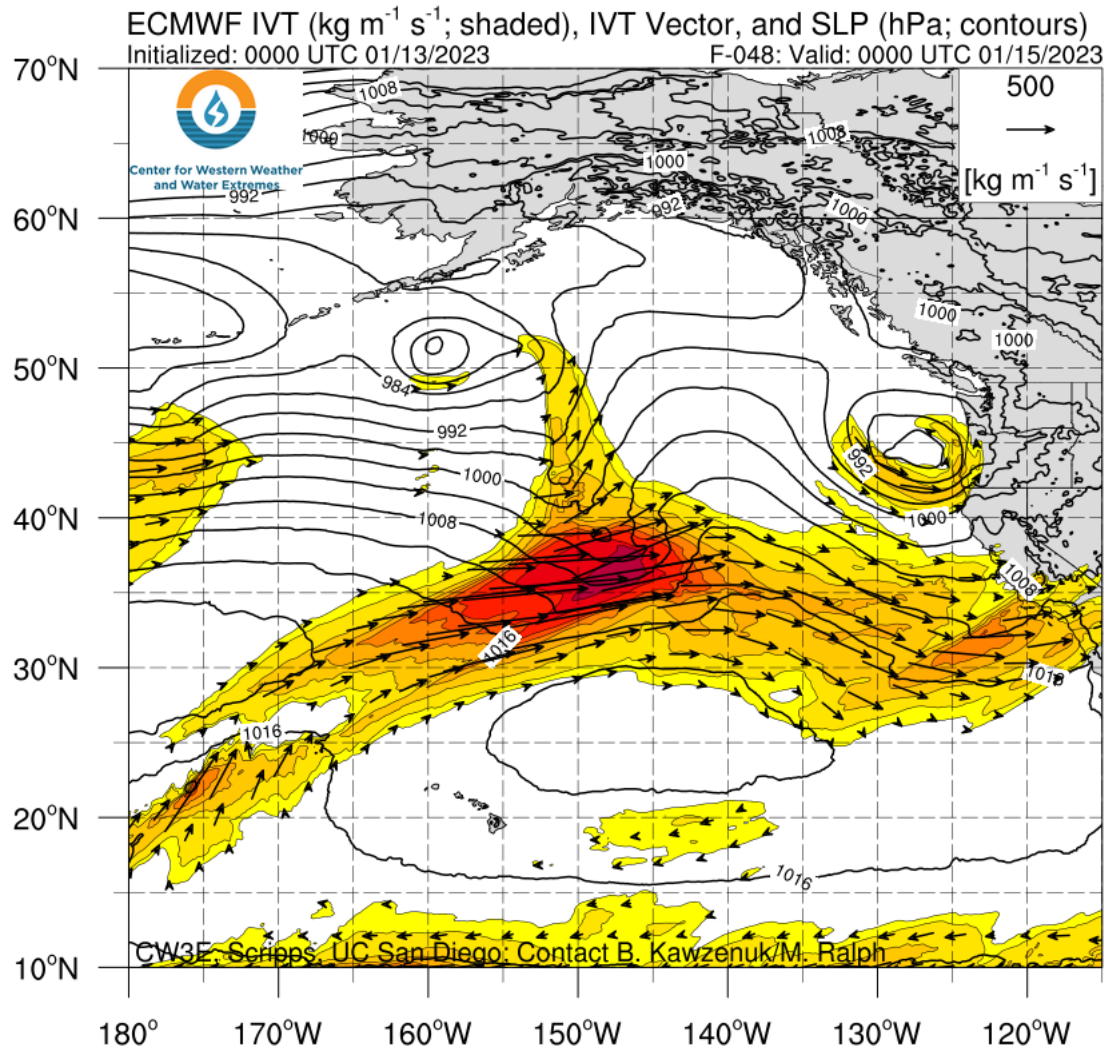


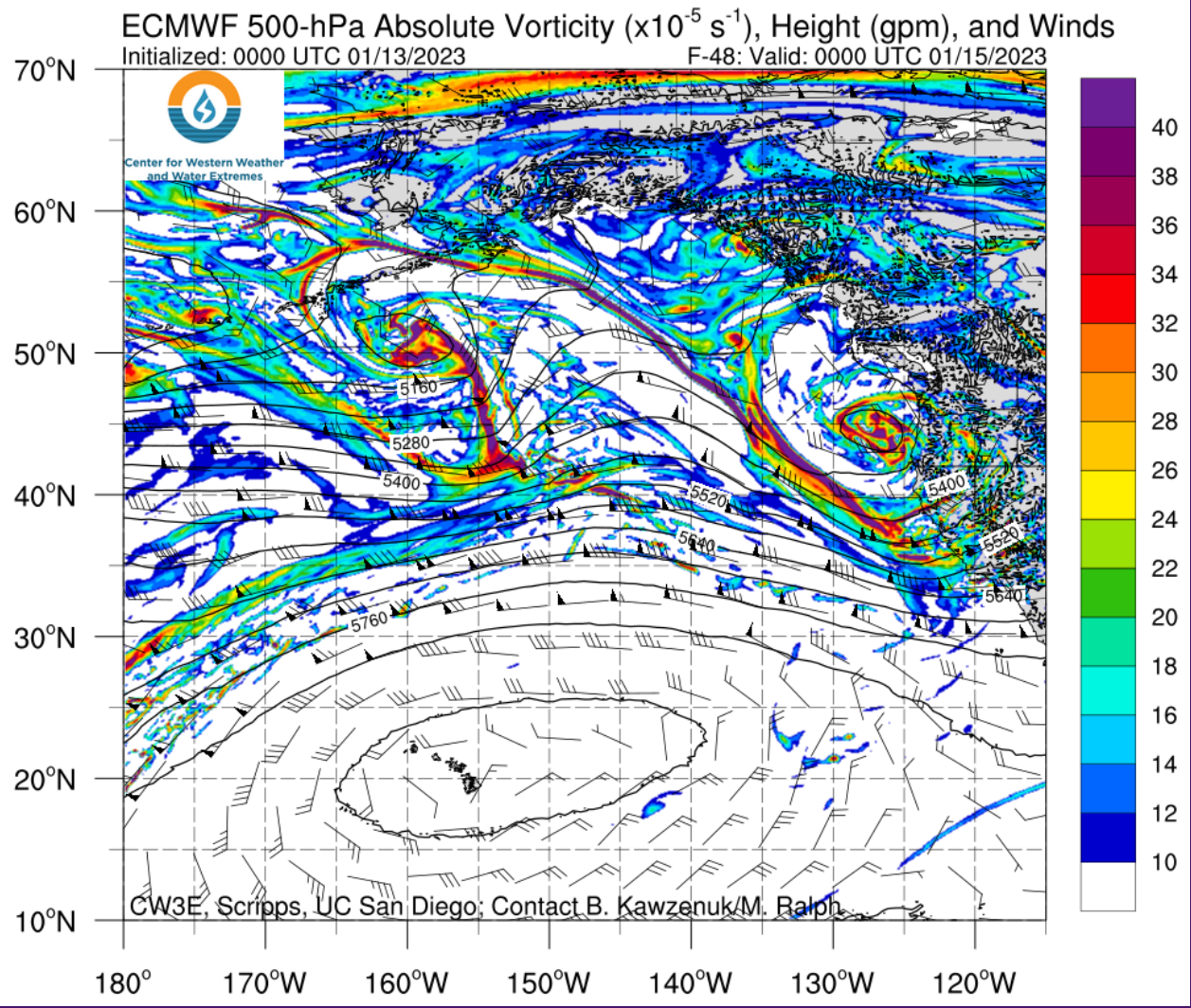


2023 Highlights

- Guidance calculated using spin-off of the JHT-funded python-based software used at NHC
- Capability to calculate sensitivities from ECMWF, GFS, and West-WRF ensemble systems
- Supported daily AR Recon briefings from November-March, including potential East Coast operations
- 227 metrics used during the 2022/2023 season!

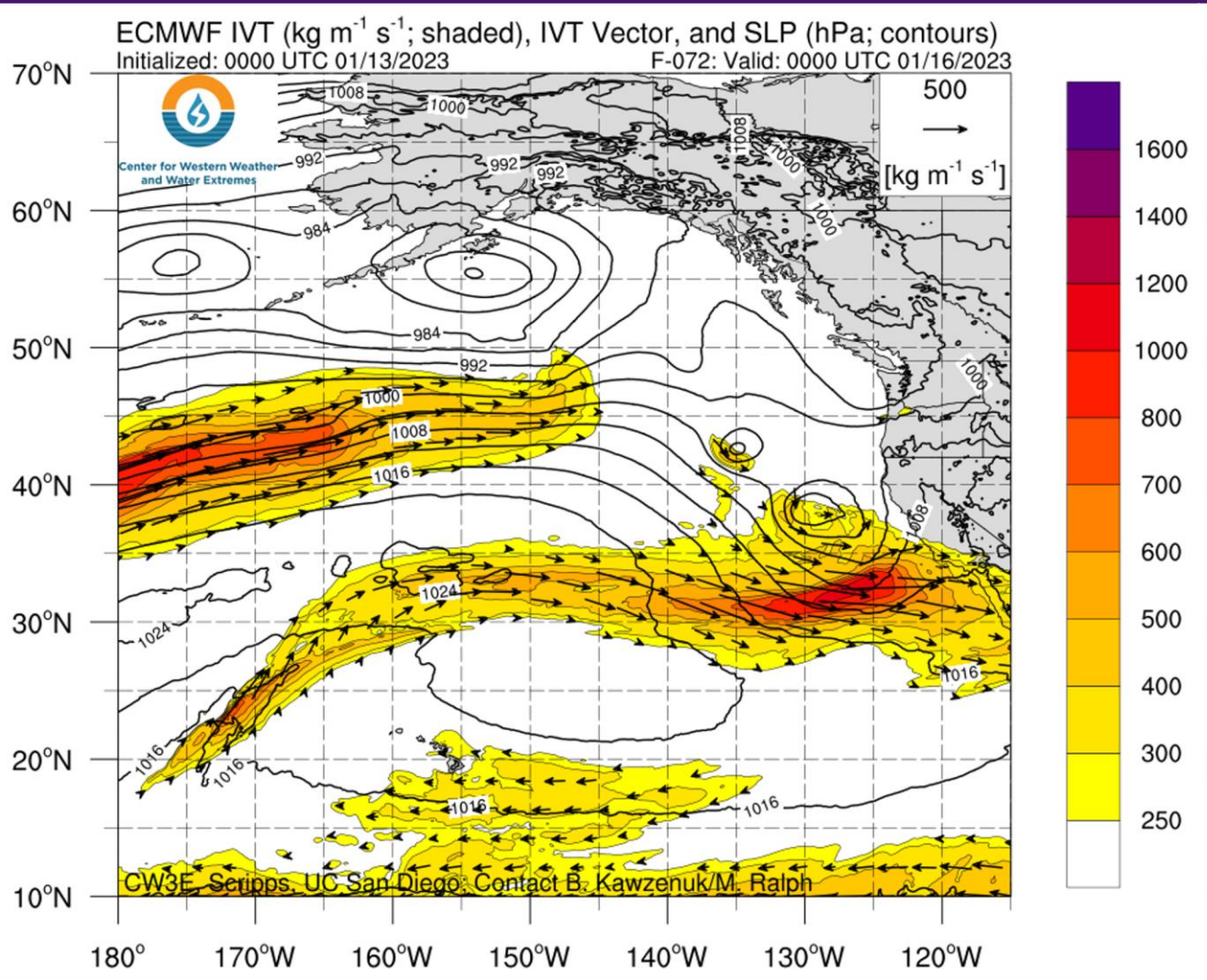
0000 UTC 15 January (IOP 15)

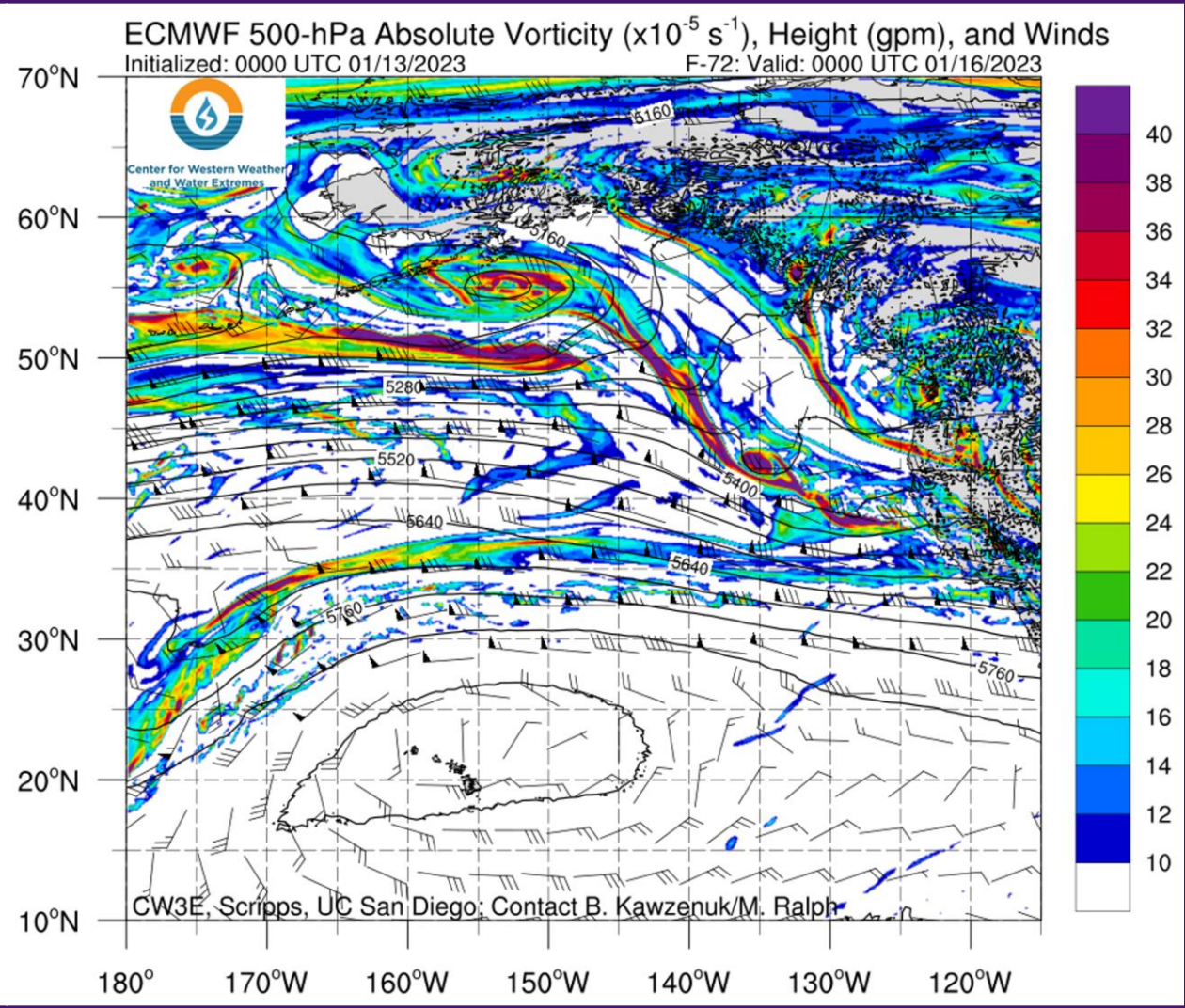




Credit: CW3E Forecast Team

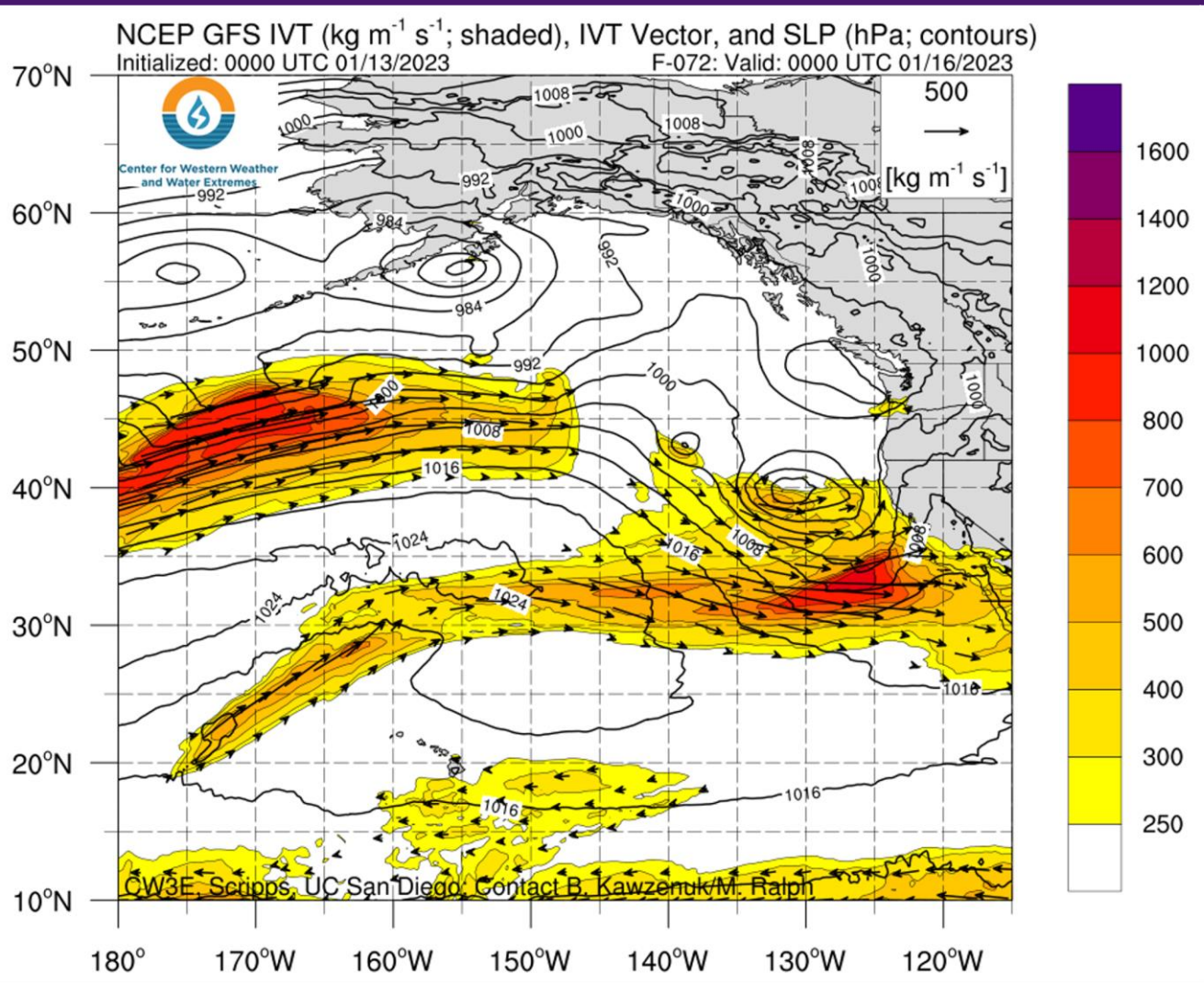
0000 UTC 16 January (ECMWF)

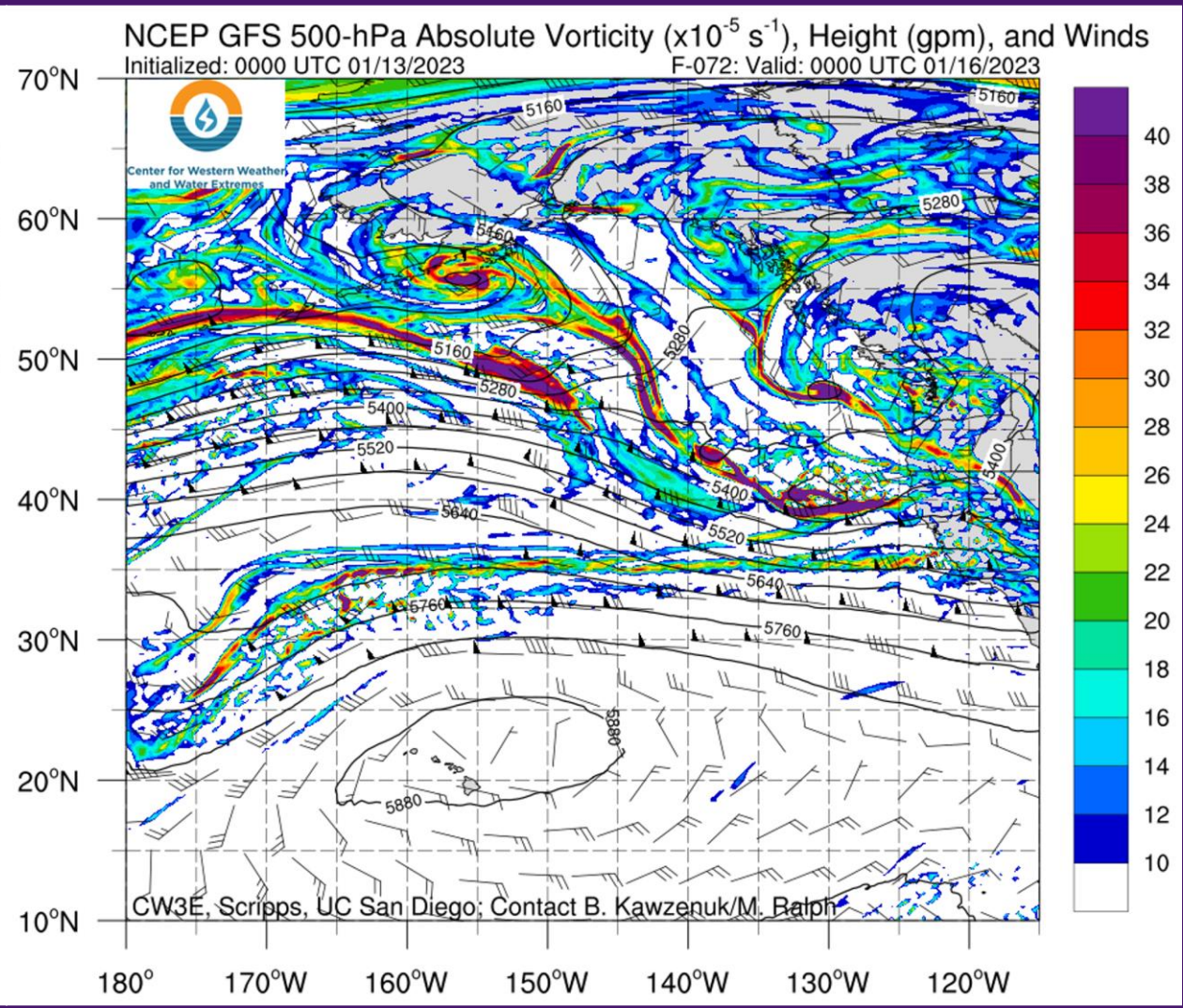




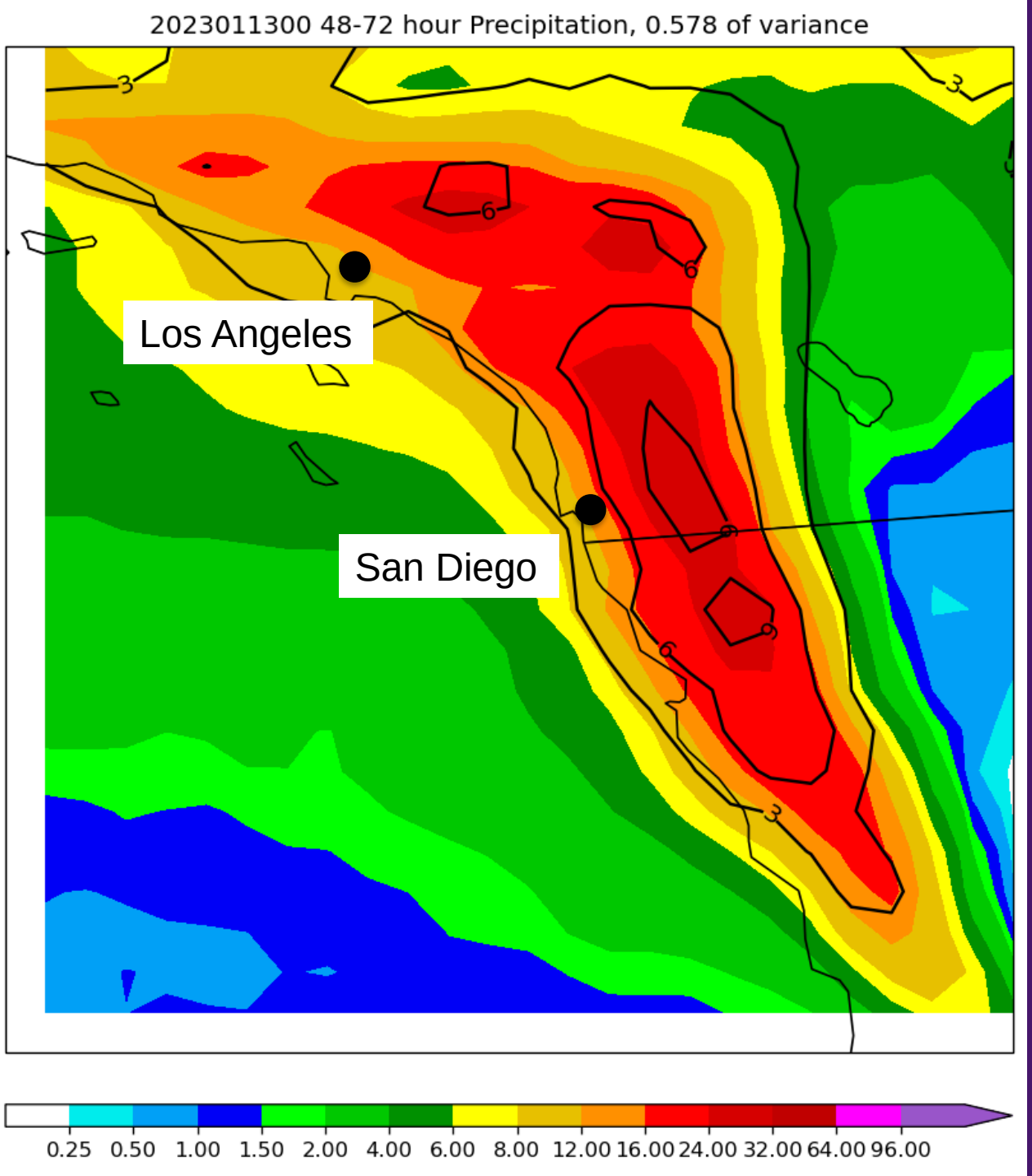
Credit: CW3E Forecast Team

0000 UTC 16 January (GFS)



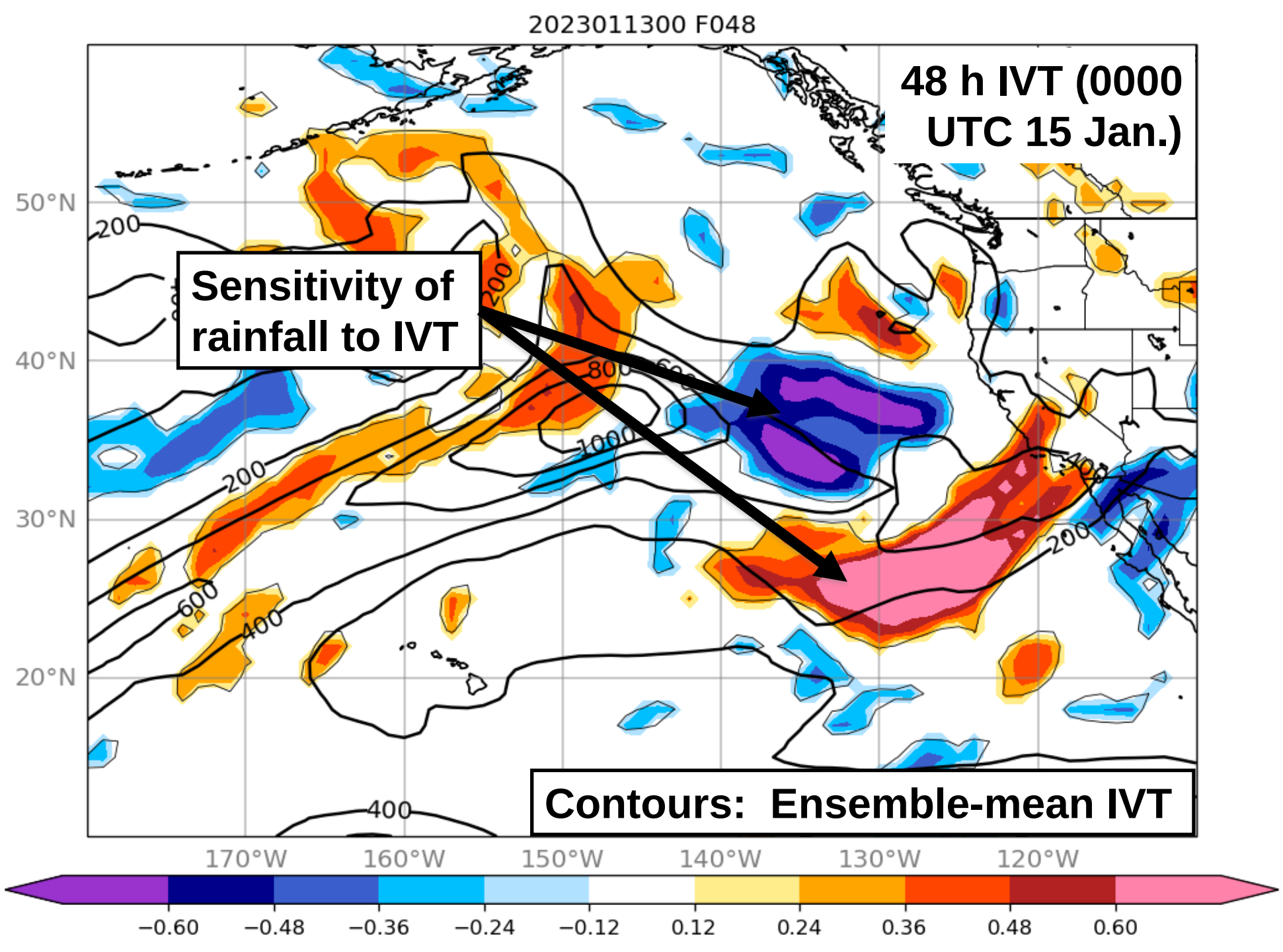


Credit: CW3E Forecast Team

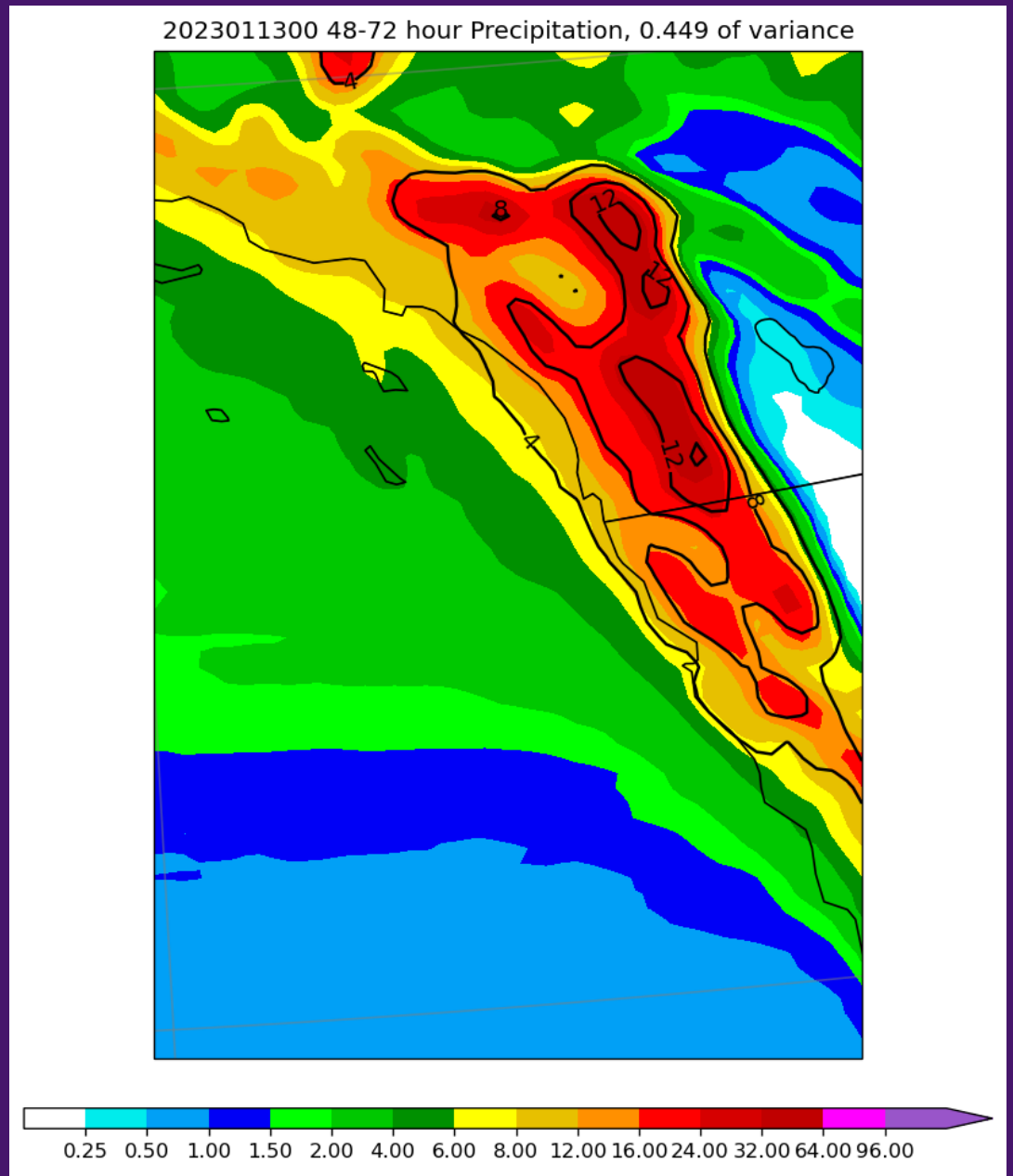


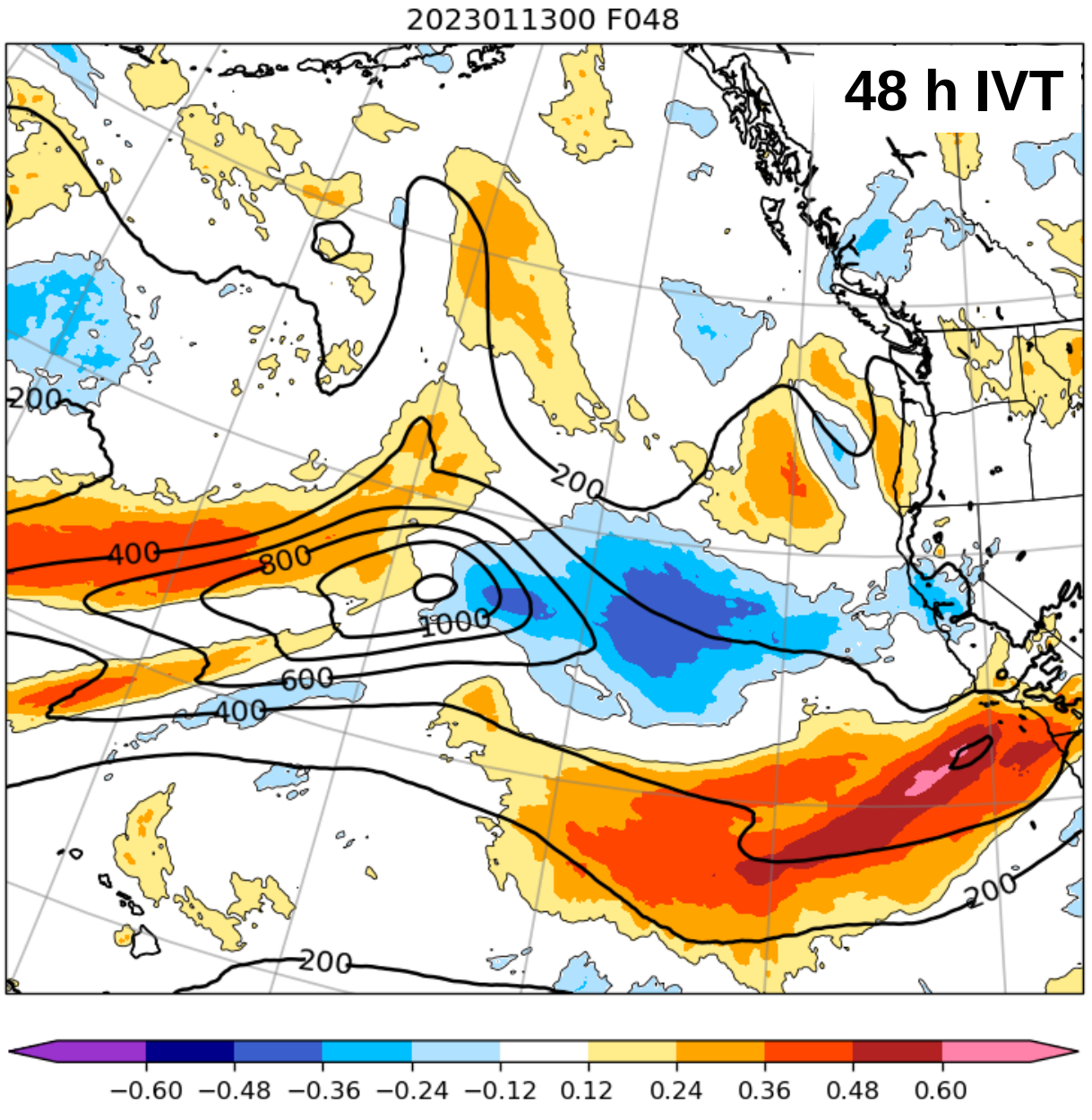
Metric: First EOF of precipitation between 0000 UTC 15 Jan. to 0000 UTC 16 Jan. (best method of looking at precipitation variability within a geographical domain). Shading is the ensemble-mean precipitation, dashed is the precipitation EOF.

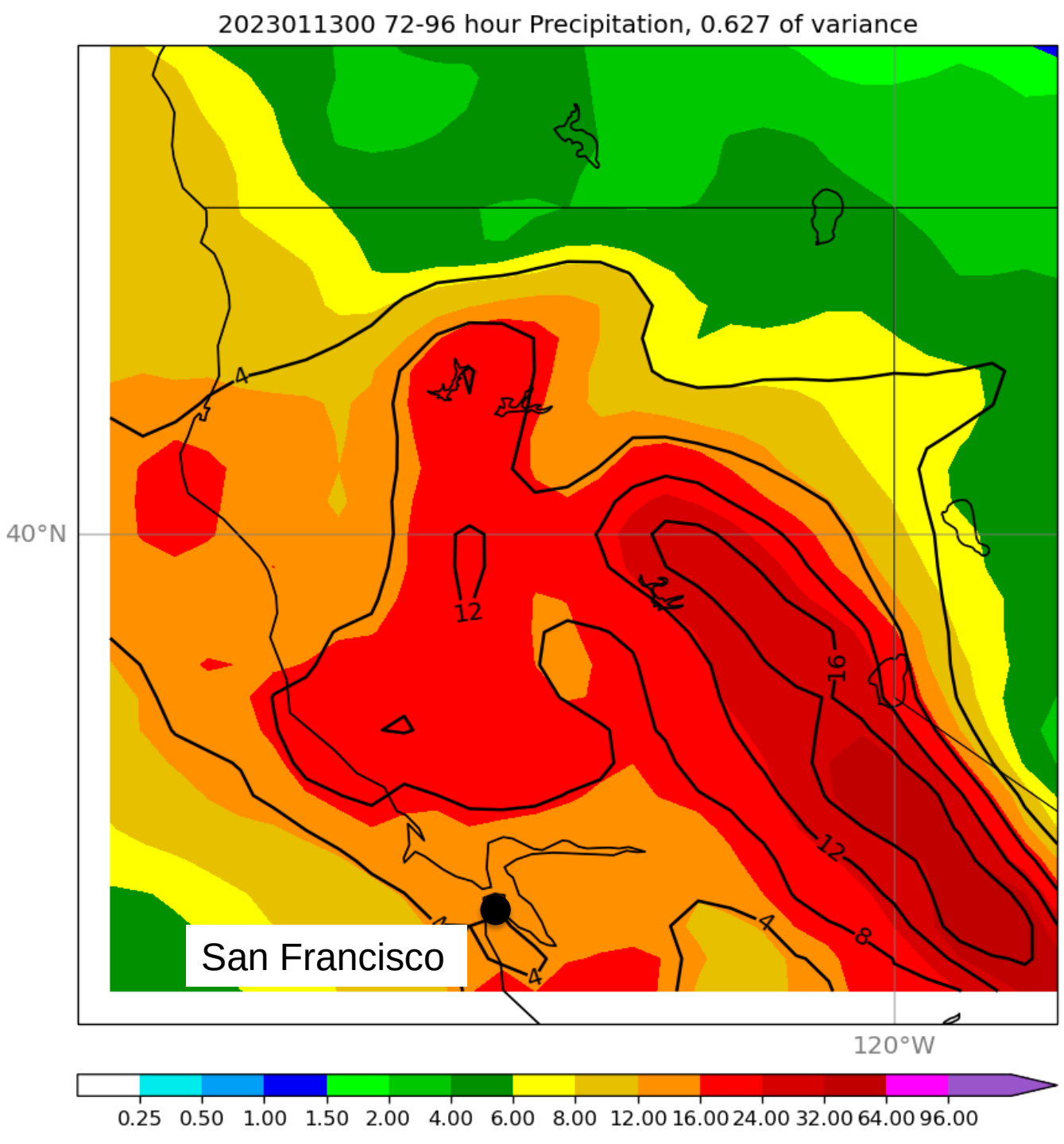
In this case, positive values of the metric are associated with more precipitation along the higher terrain in southern CA


2023011300 F048
48 h IVT (0000 UTC 15 Jan.)
Sensitivity of rainfall to IVT
Contours: Ensemble-mean IVT
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
200
400
600
800
1000
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60

West-WRF Version

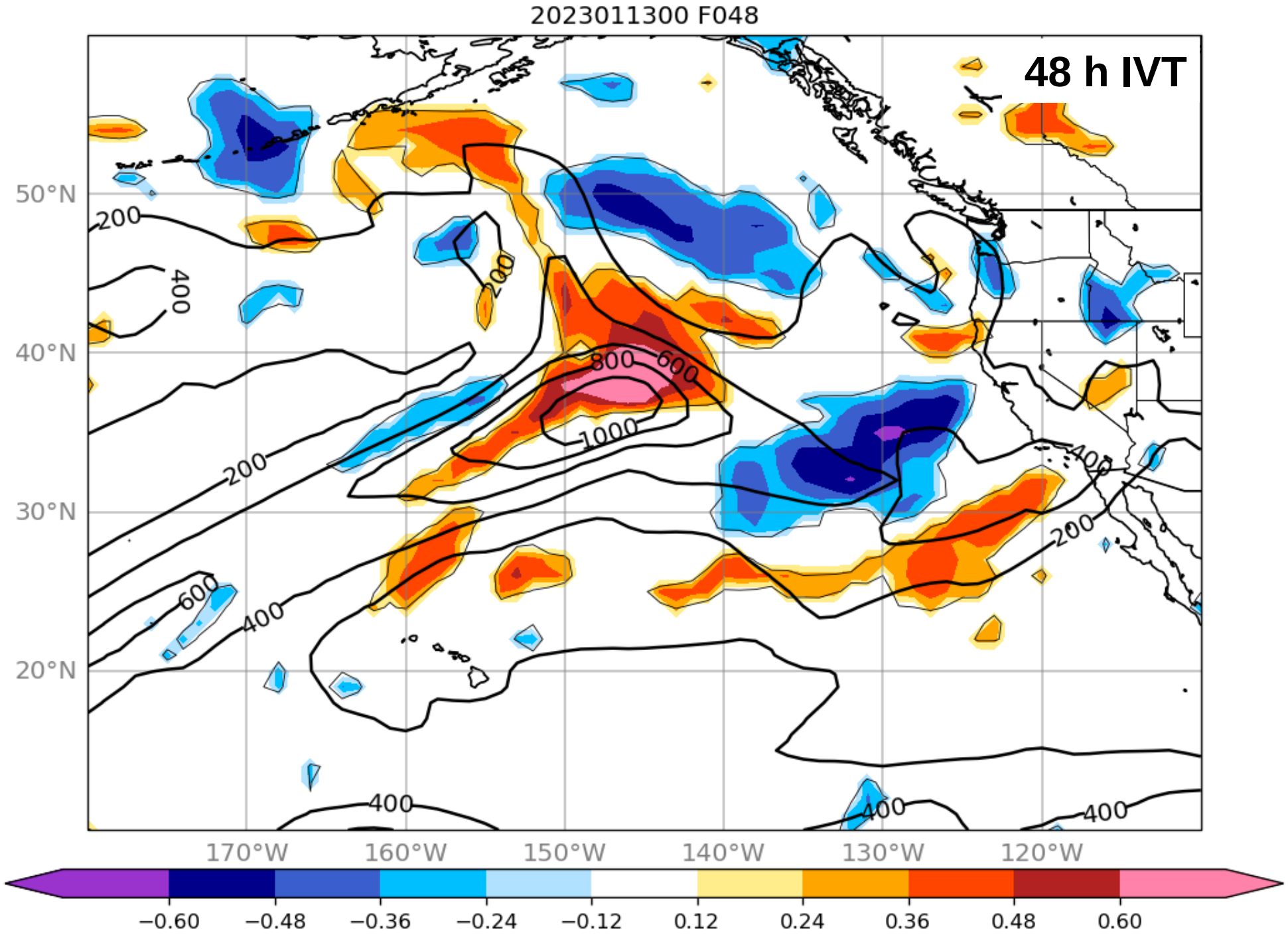


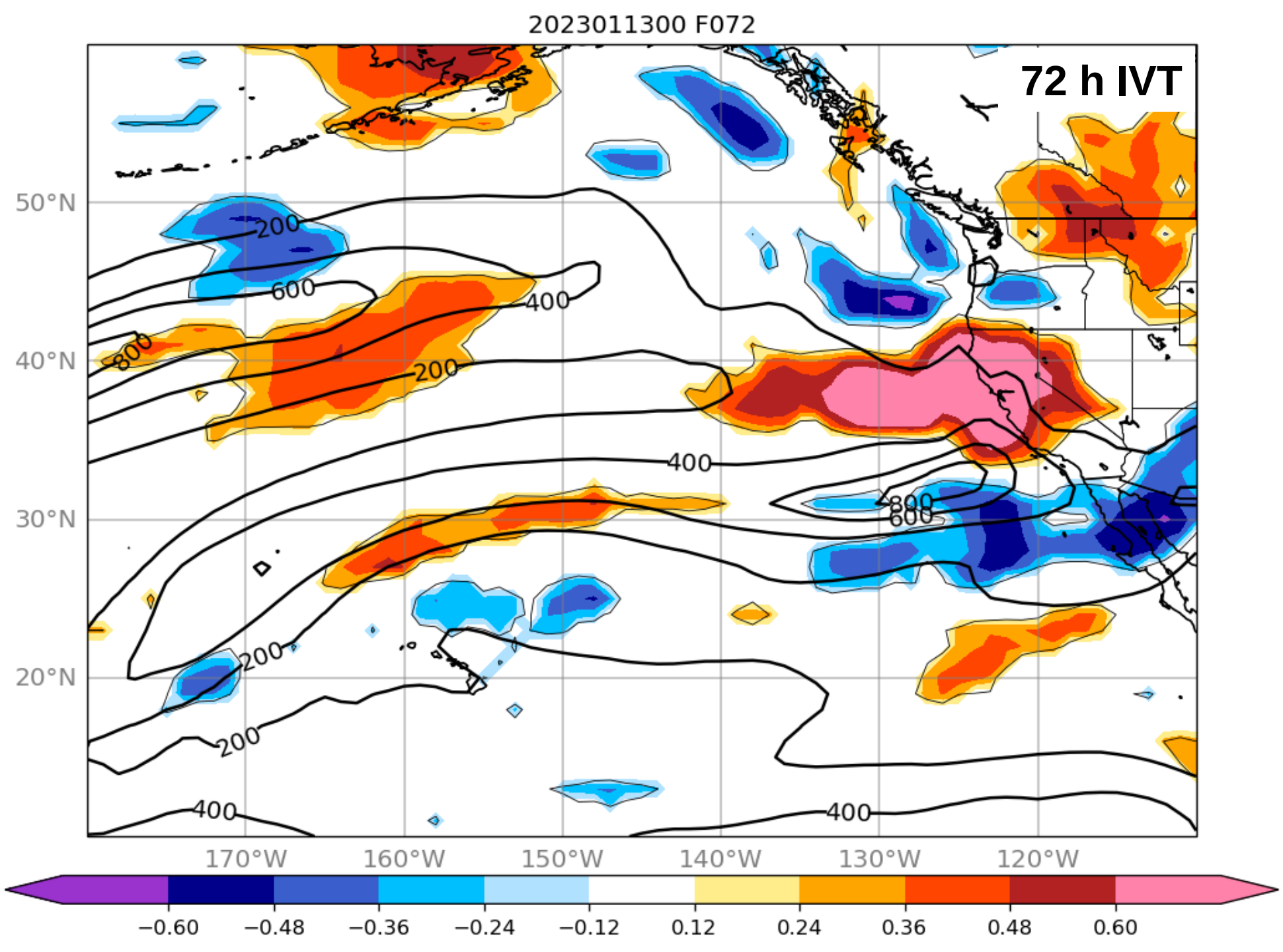


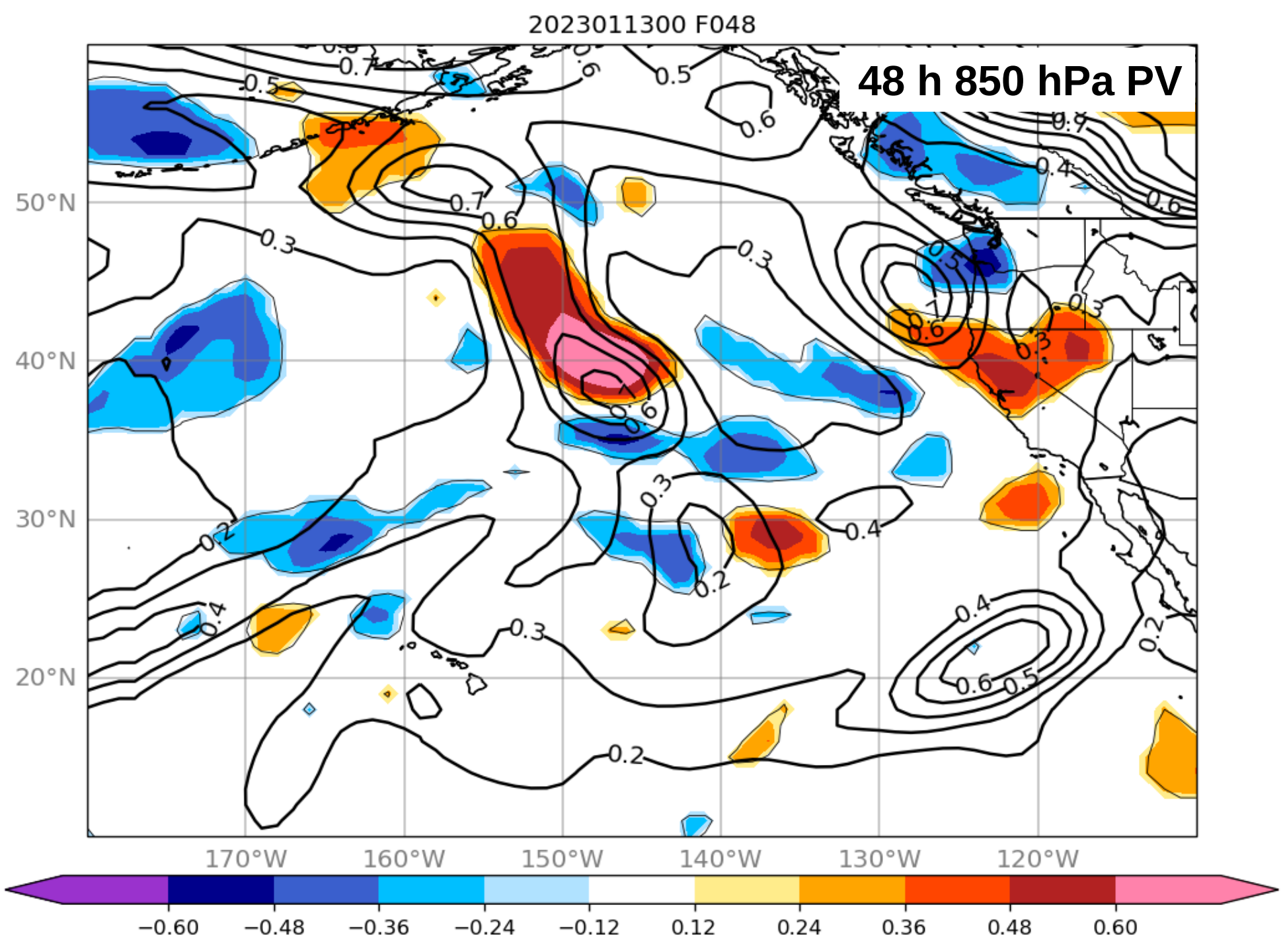


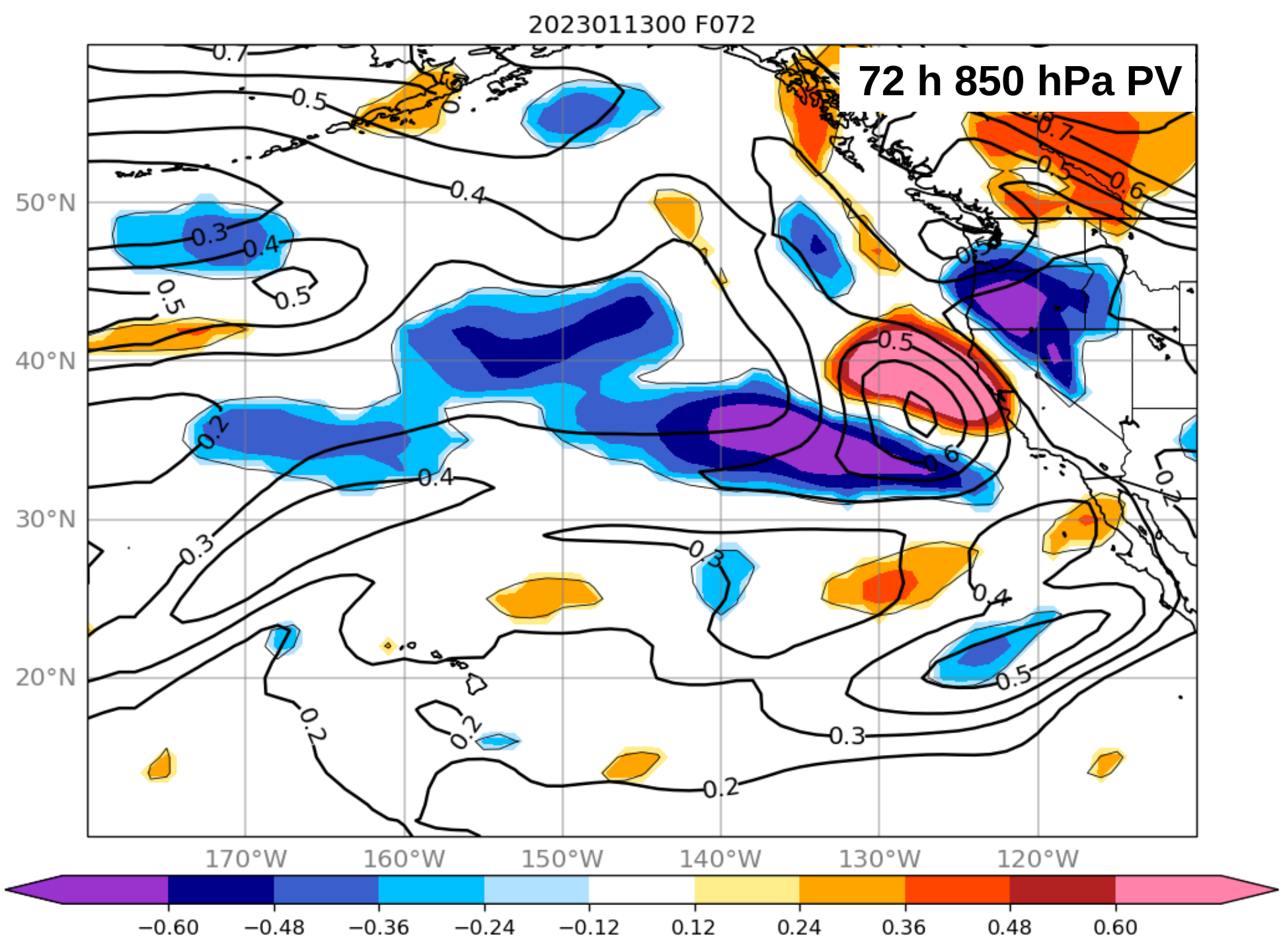
Metric: First EOF of precipitation between 0000 UTC 16 Jan. to 0000 UTC 17 Jan. Shading is the ensemble-mean precipitation, dashed is the precipitation EOF.

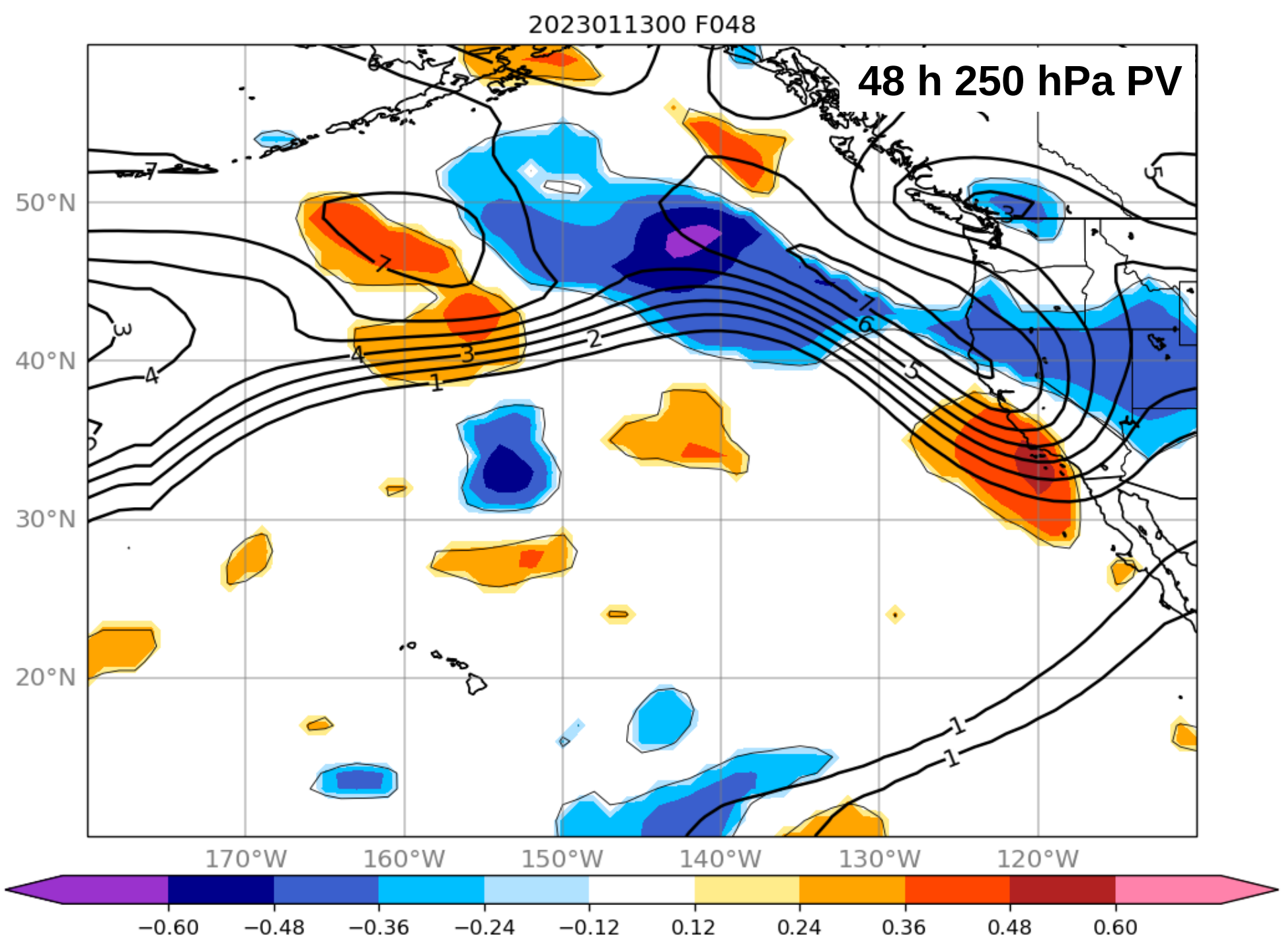
In this case, positive values of the metric are associated with more precipitation in the coastal mountains and northern Sierra Range


2023011300 F048
48 h IVT
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
200
400
600
800
1000
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60

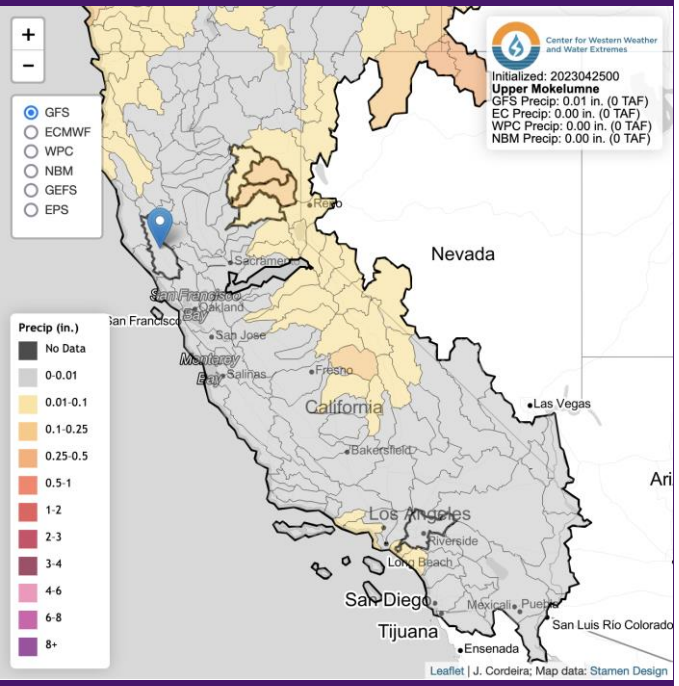

2023011300 F072
72 h IVT
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
200
600
400
800
200
400
800
600
200
200
400
400
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60

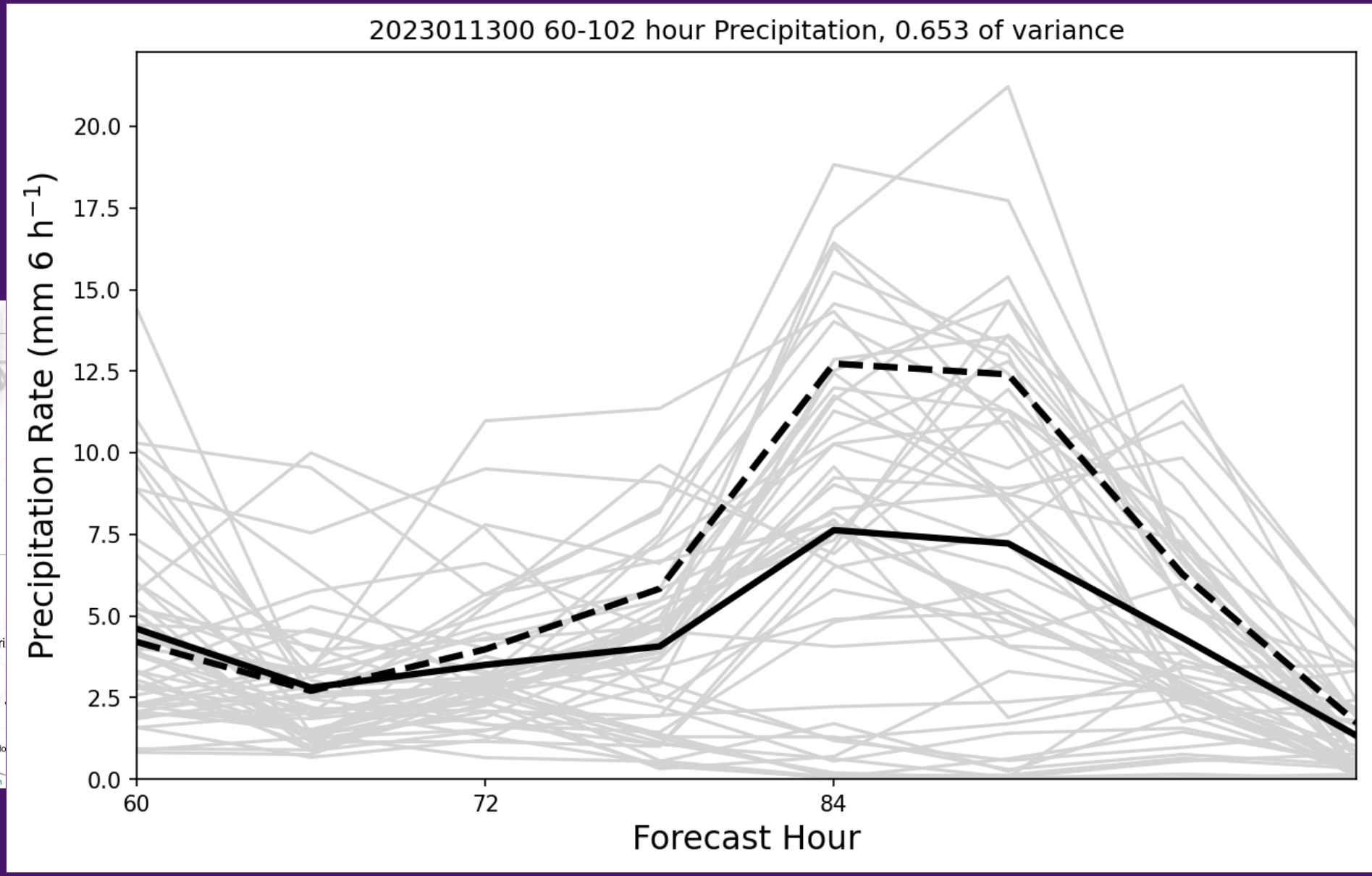

2023011300 F048
48 h 850 hPa PV
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60

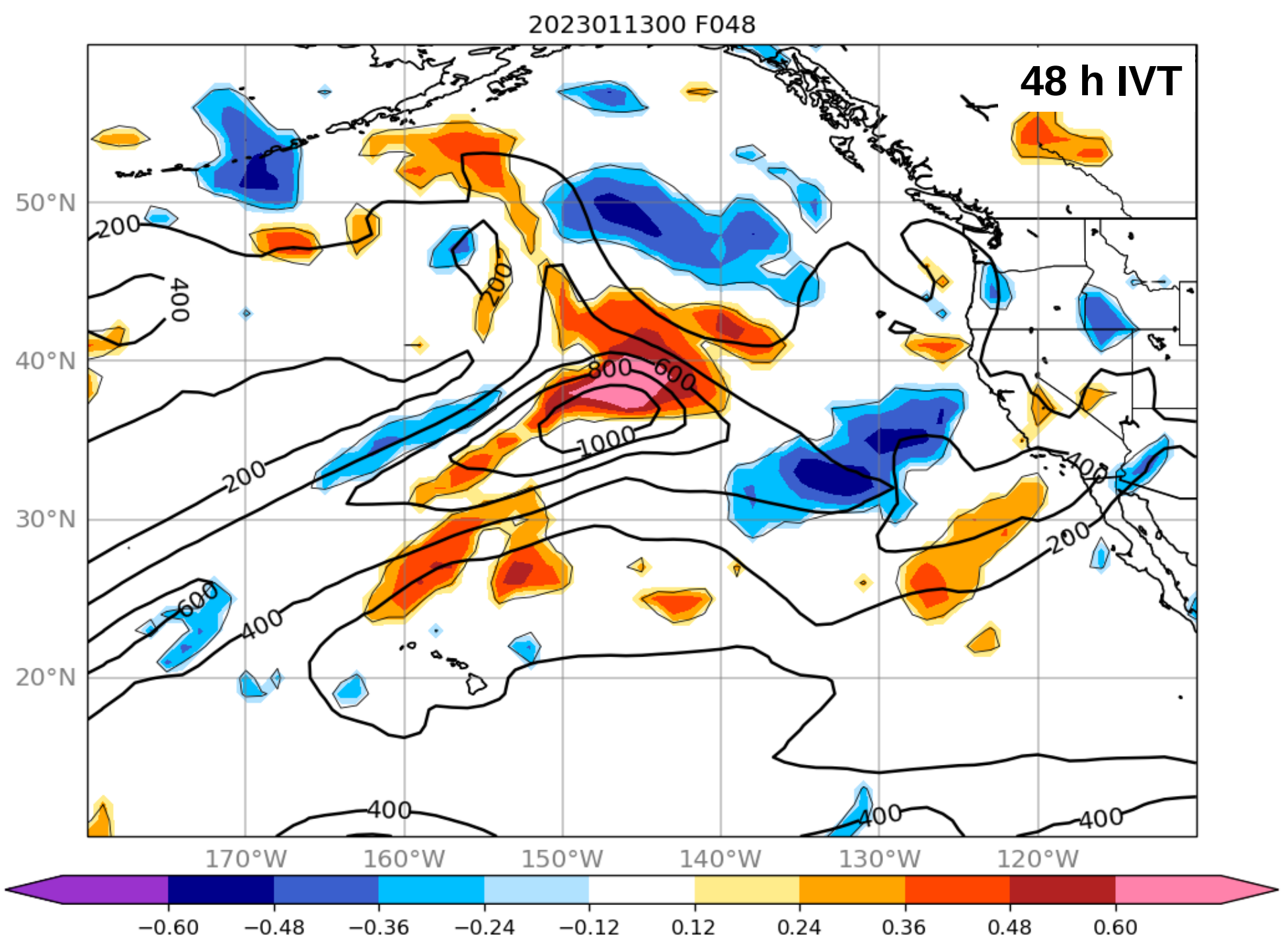

2023011300 F072
72 h 850 hPa PV
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60

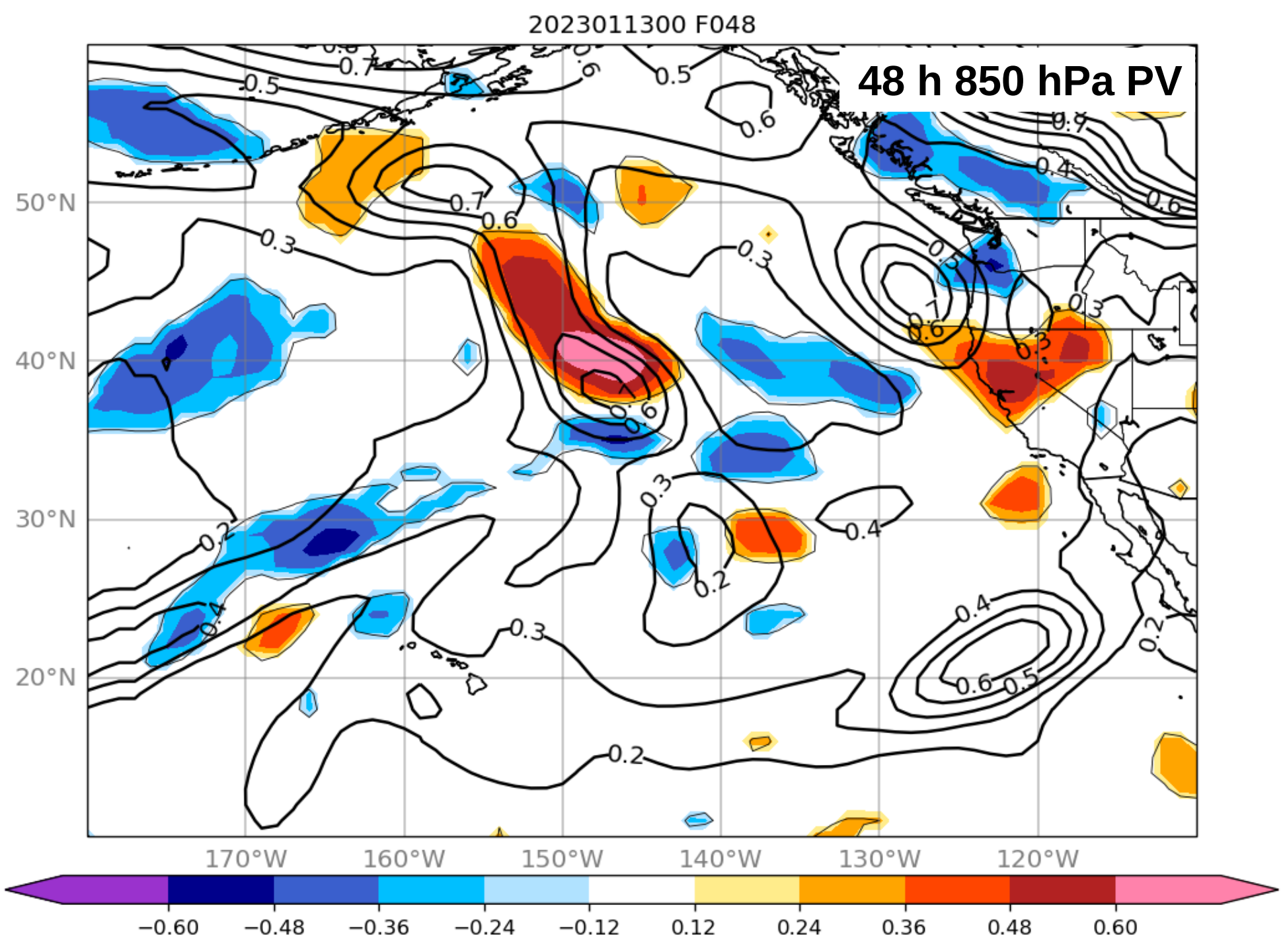

2023011300 F048
48 h 250 hPa PV
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60

Feather-Yuba Watershed



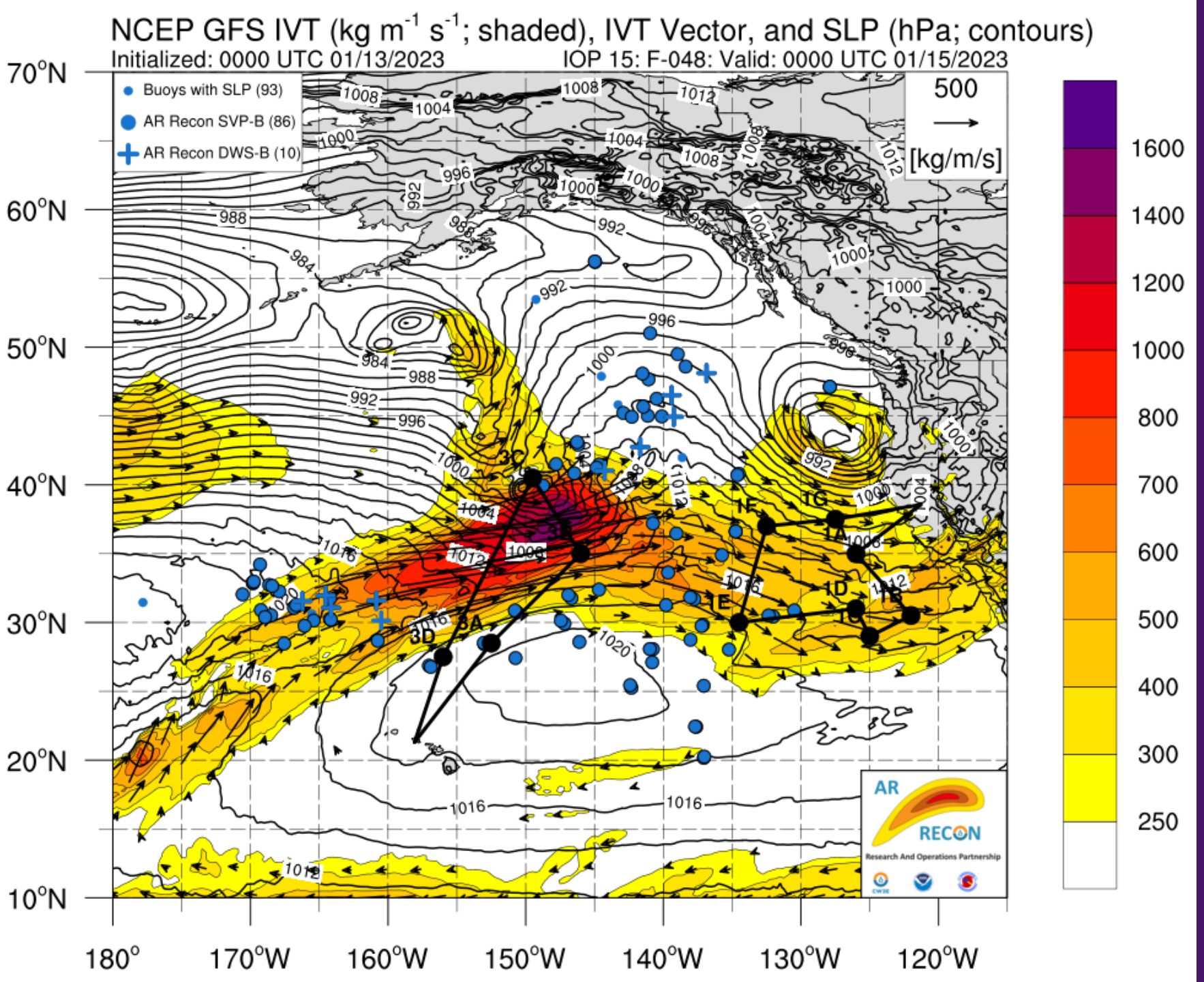



2023011300 F048
48 h IVT
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
200
400
600
800
1000
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60


2023011300 F048
48 h 850 hPa PV
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60

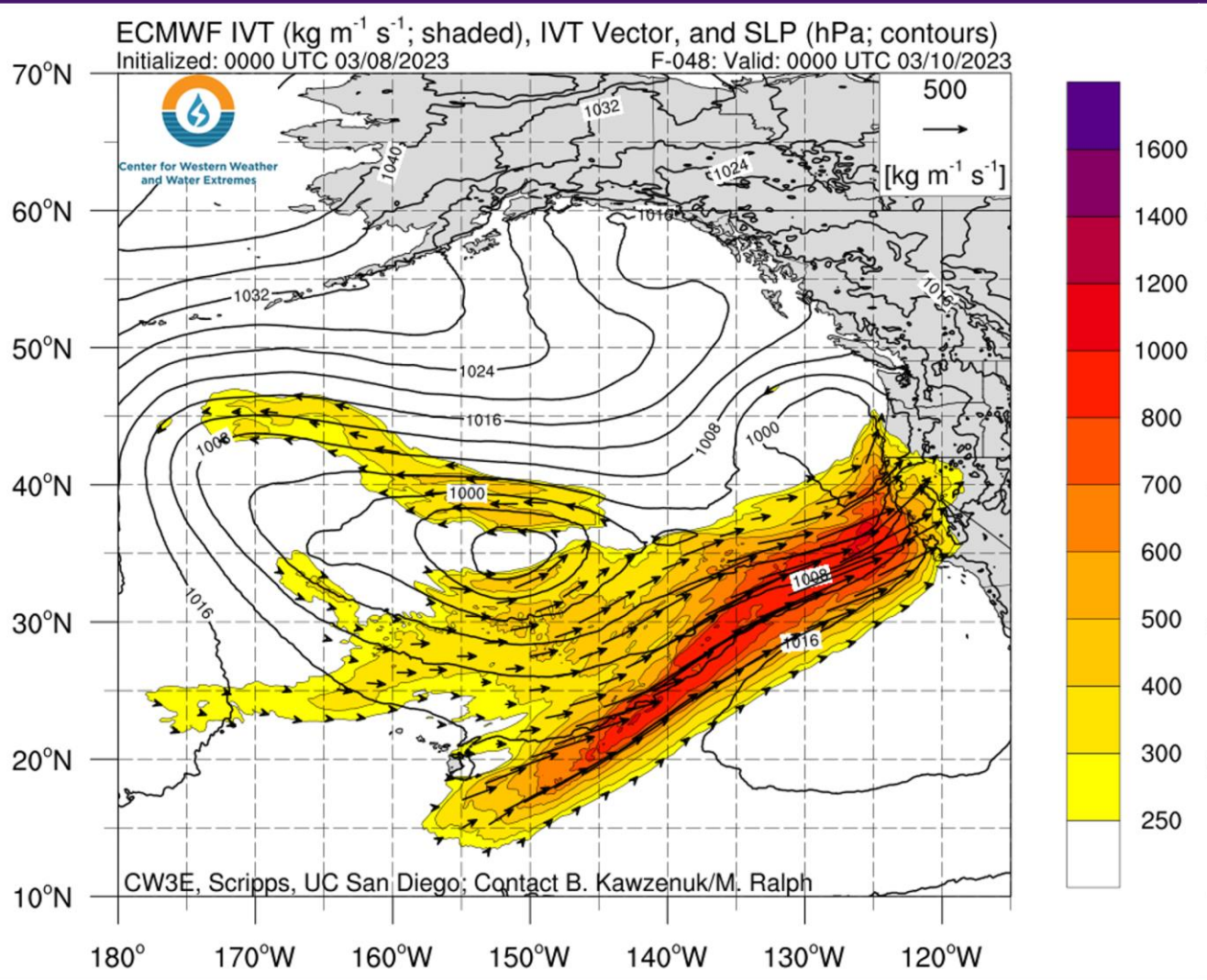
C-130 samples sensitive region associated with the ongoing landfalling AR in southern CA

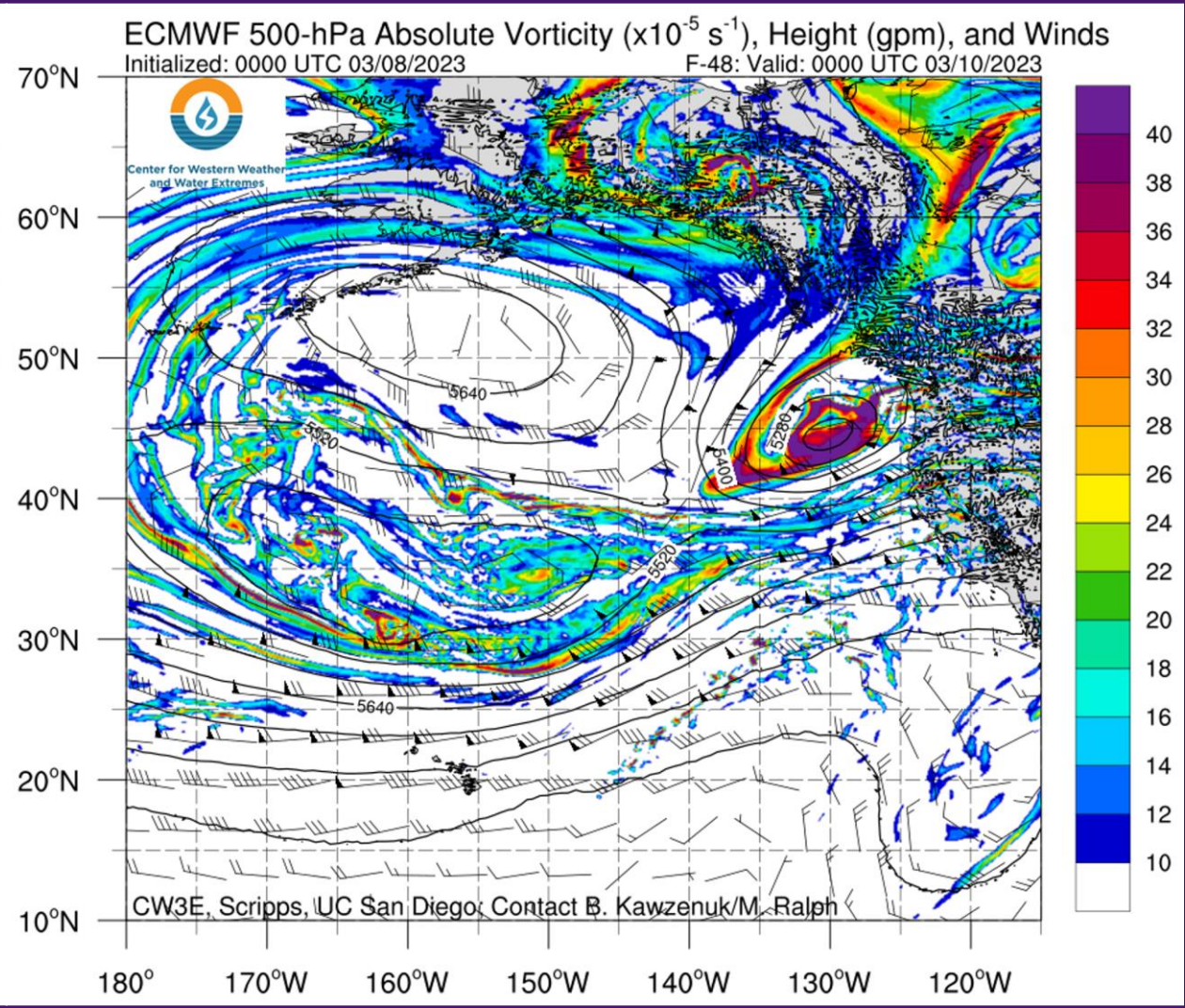
G-IV samples next frontal wave and strong AR shown to be sensitive for northern CA next day



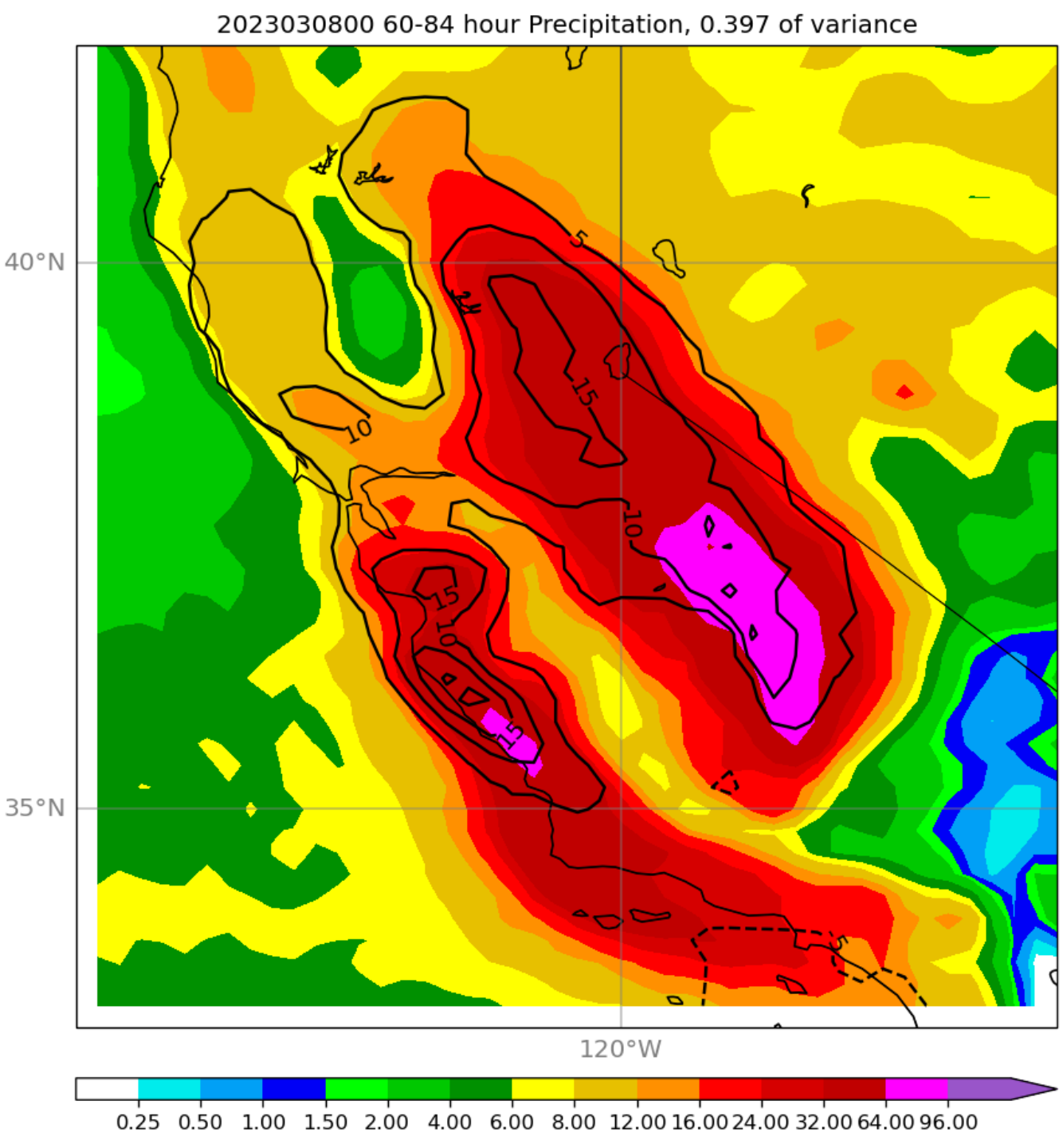
Credit: CW3E Forecast Team

0000 UTC 10 March (IOP 36)



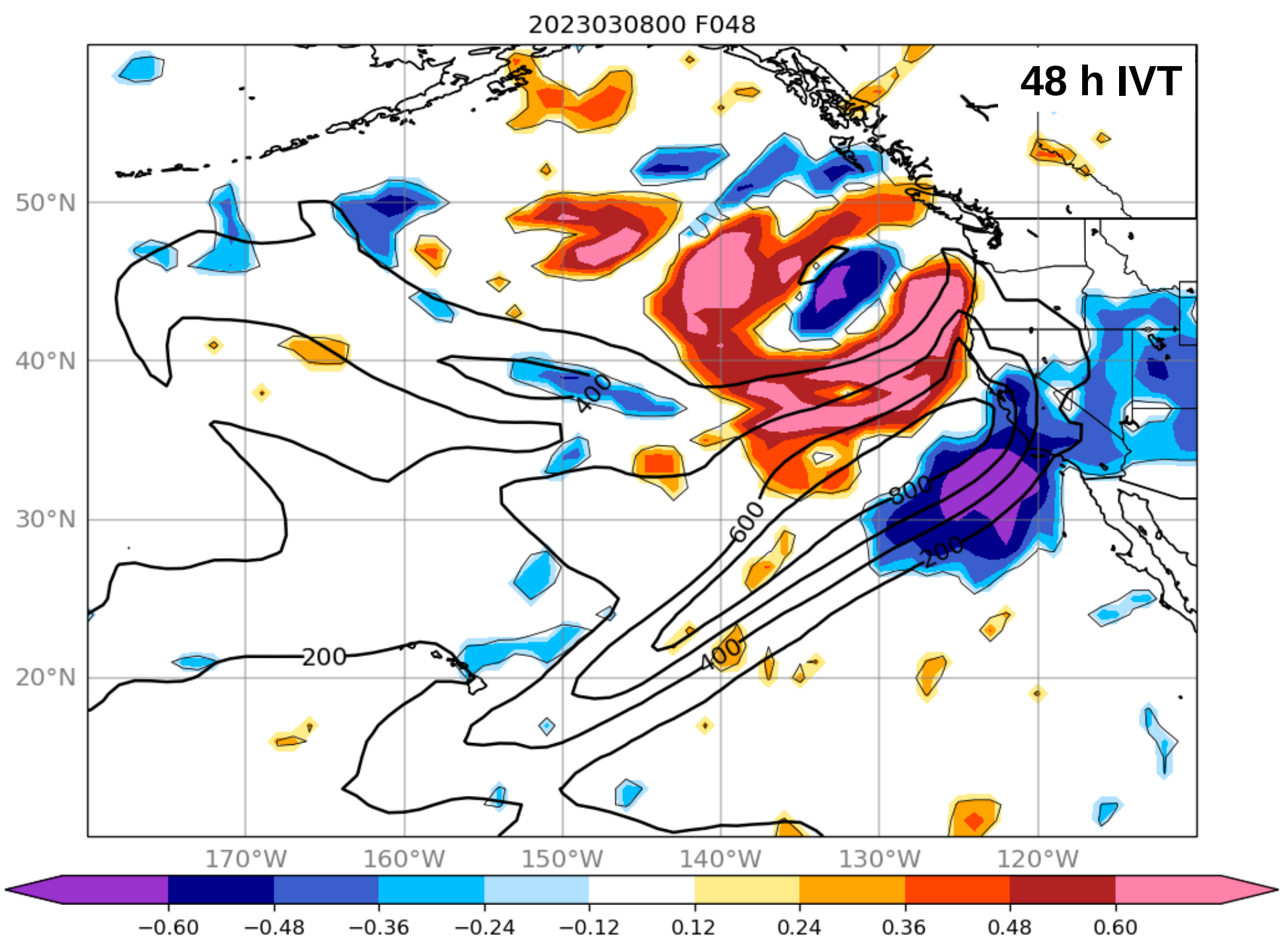


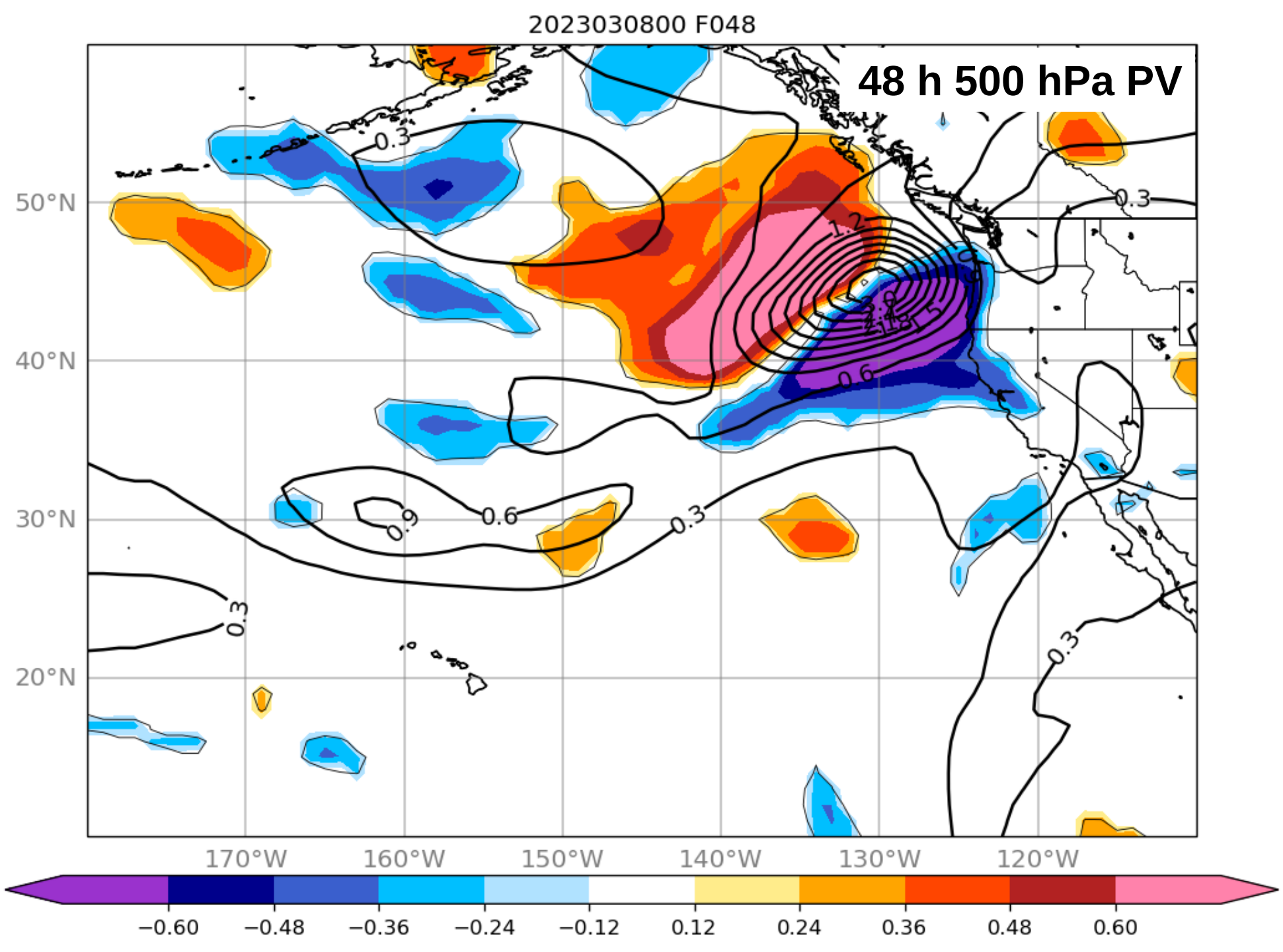
Credit: CW3E Forecast Team



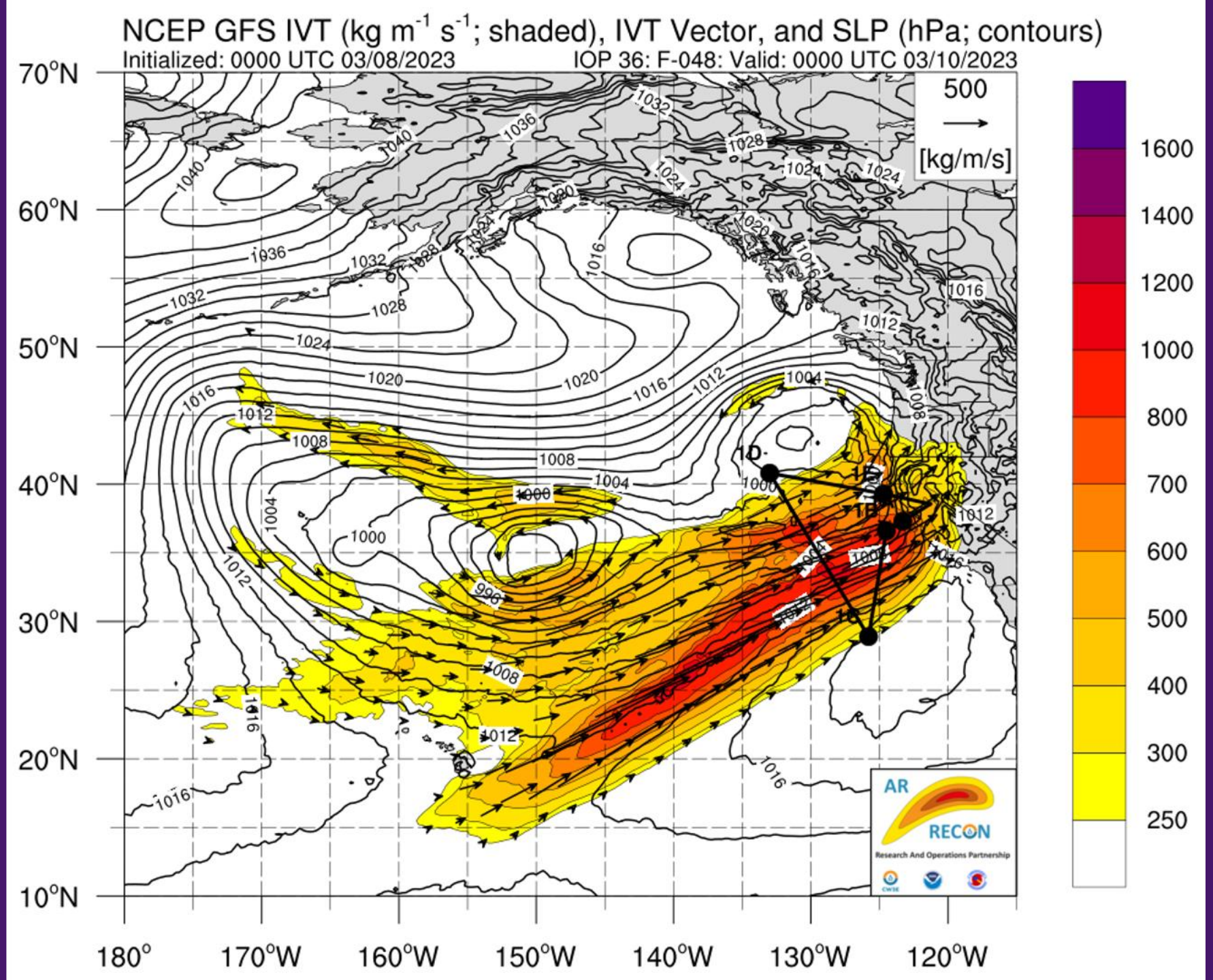
Metric: First EOF of precipitation between 1200 UTC 10 Mar. to 1200 UTC 11 Mar. (best method of looking at precipitation variability within a geographical domain). Shading is the ensemble-mean precipitation, dashed is the precipitation EOF.

In this case, positive values of the metric are associated with more precipitation along central CA coast and in northern Sierra


2023030800 F048
48 h IVT
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
400
600
800
200
200
400
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60


2023030800 F048
48 h 500 hPa PV
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
0.3
1.2
0.6
0.9
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60

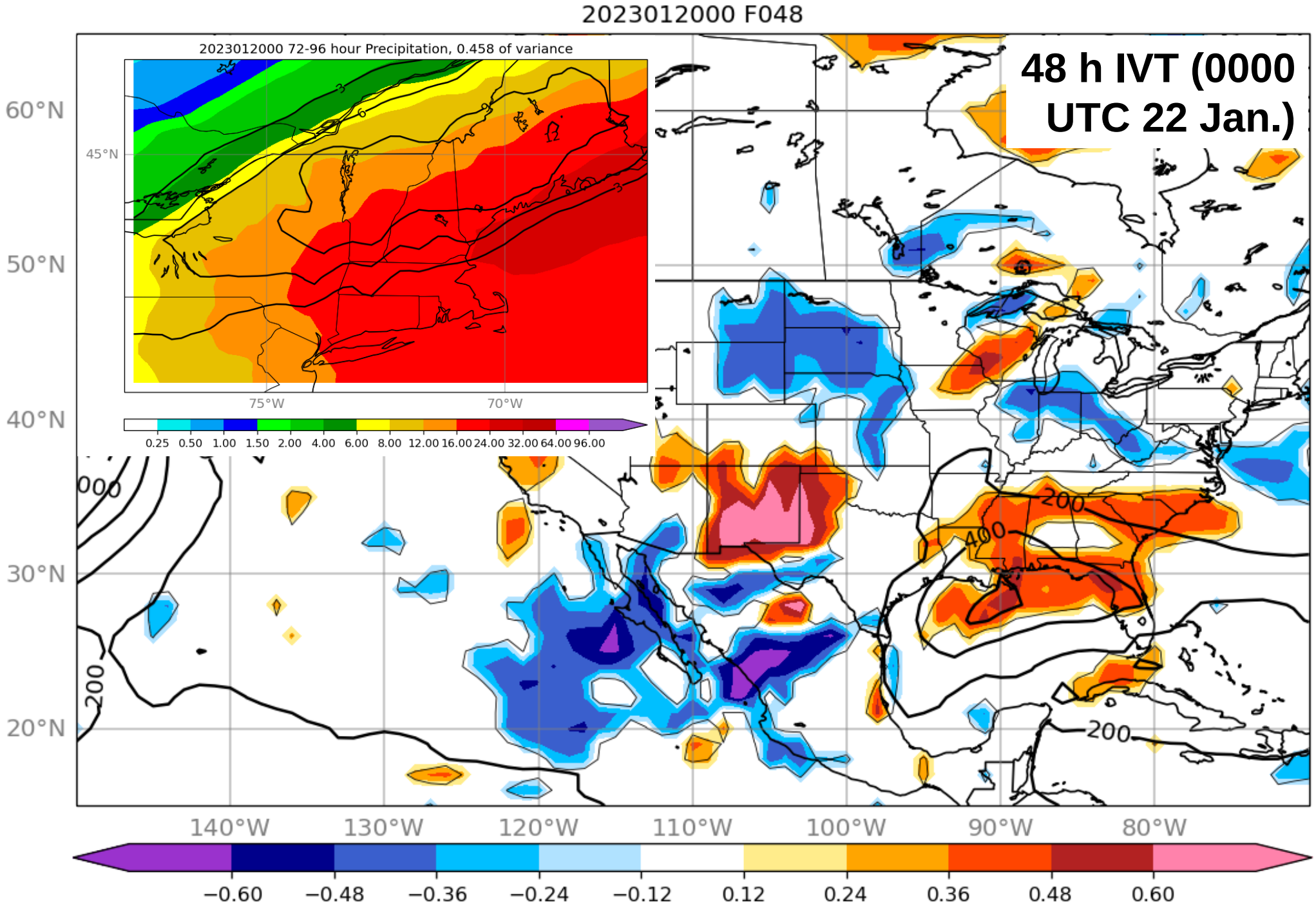
C-130 samples sensitive region both the AR and southern end of upper tropospheric trough



Credit: CW3E Forecast Team

Summary

- Ensemble sensitivity provides a computationally inexpensive, flexible method for estimating the sensitivity of various forecast outcomes to model state
- Numerous forecast metric options have been developed to identify targets for winter weather
- Over many cases, sensitivity maximized in position of synoptic features, including surface fronts, mesoscale waves, and troughs on cold side of fronts
- Future work will develop more tailored metrics, including watershed precipitation and frozen precipitation


2023012000 F048
2023012000 72-96 hour Precipitation, 0.458 of variance
48 h IVT (0000 UTC 22 Jan.)
60°N
50°N
40°N
30°N
20°N
45°N
75°W
70°W
0.25 0.50 1.00 1.50 2.00 4.00 6.00 8.00 12.00 16.00 24.00 32.00 64.00 96.00
200
400
200
200
140°W
130°W
120°W
110°W
100°W
90°W
80°W
−0.60 −0.48 −0.36 −0.24 −0.12 0.12 0.24 0.36 0.48 0.60