

Application of Ensemble Sensitivity to AR Recon Operations

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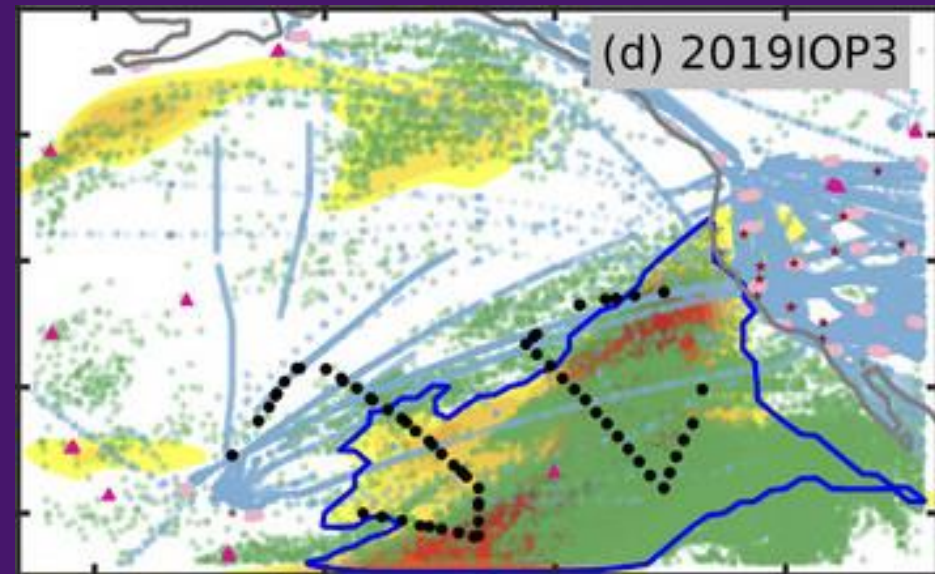
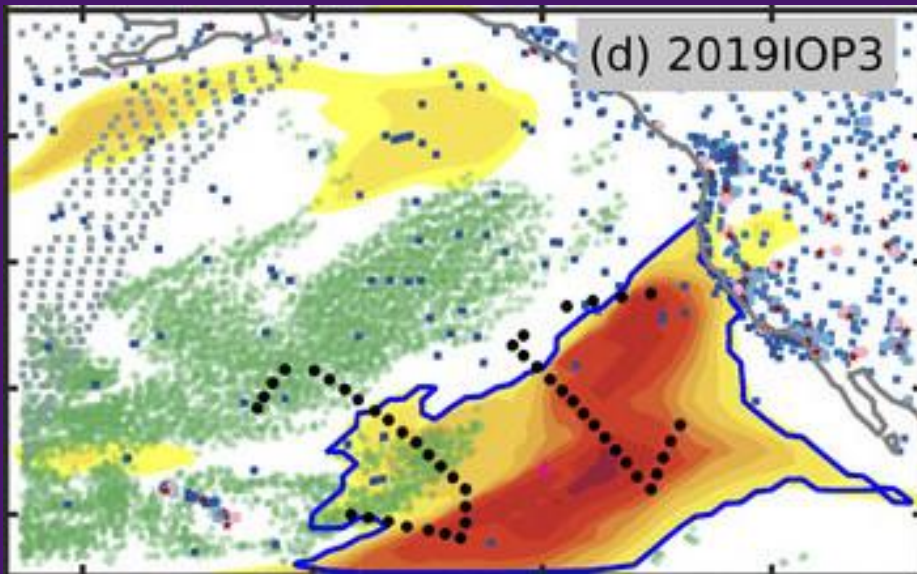


WPC HMT Seminar Series
6 February 2025

Support from FIRO, USACE

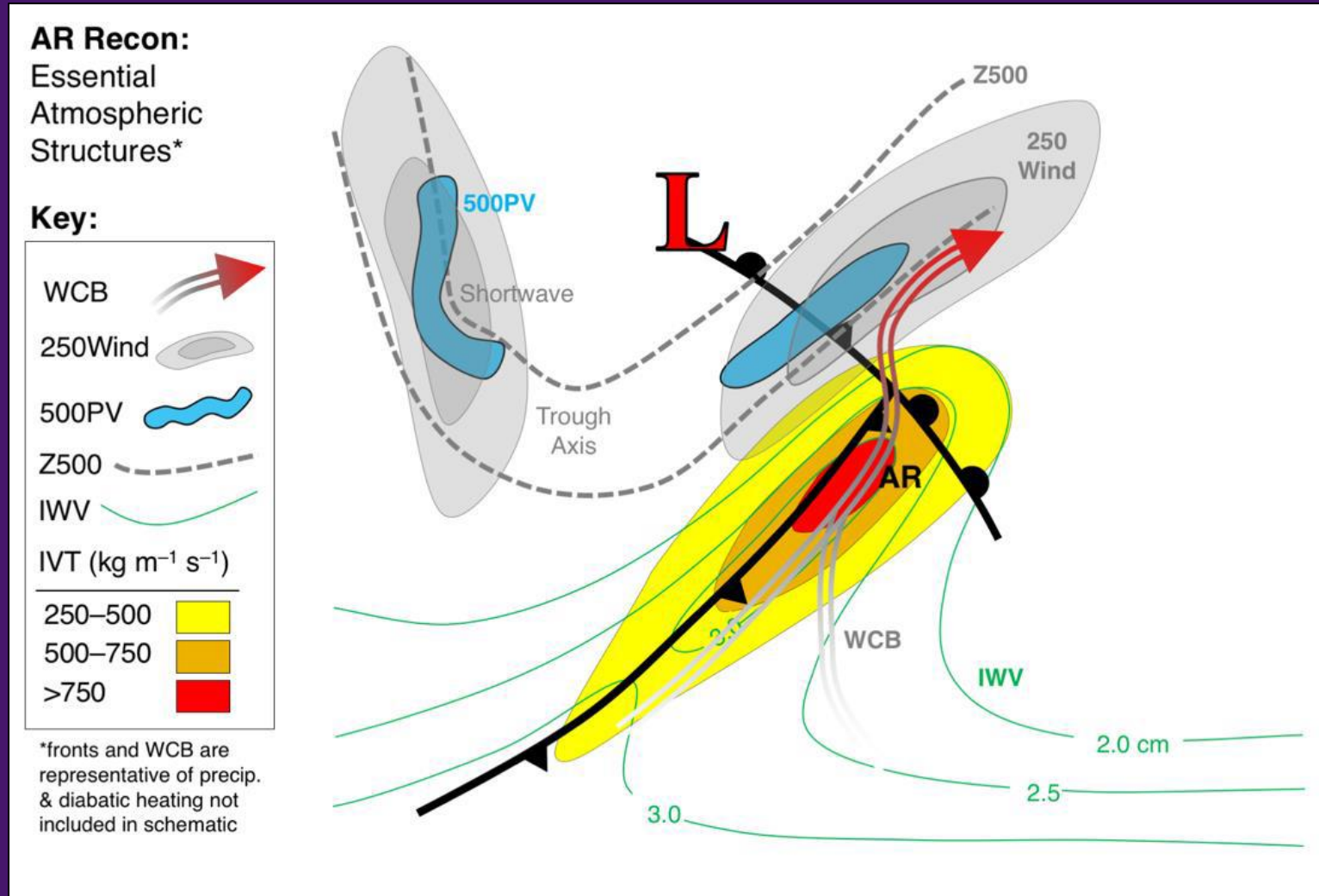
Overview

- 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



Overview

- Aircraft have limited range, so often cannot sample all potential features of interest
- Atmospheric River contain multiple essential atmospheric structures that may need to be observed
- Interested in objectively identifying how uncertainty in essential atmospheric structures will yield the largest change in forecast



Wilson et al. (2022), BAMS

Overview

- Can better understand this using the ensemble-based sensitivity method, direct observational assets toward sensitive regions
 - Utilizes 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

Outline

- Overview of ensemble-based sensitivity, including metrics developed for AR applications
- Demonstration of products for 0000 UTC 2 Feb. 2025 (IOP 11)
 - Example of combination AR system in Eastern Pacific
- Demonstration of products for 0000 UTC 21 Jan. 2025 (ECIOP 2)
- Preliminary Sensitivity Climatology for the West Coast



Credit: NOAA



Credit: US Air Force

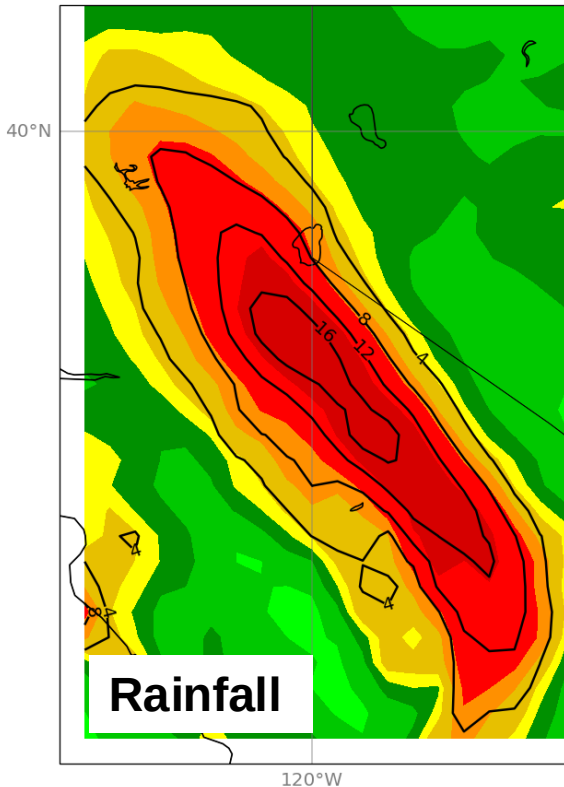
Ensemble Sensitivity

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

Ancell and Hakim 2007, Torn and Hakim 2008

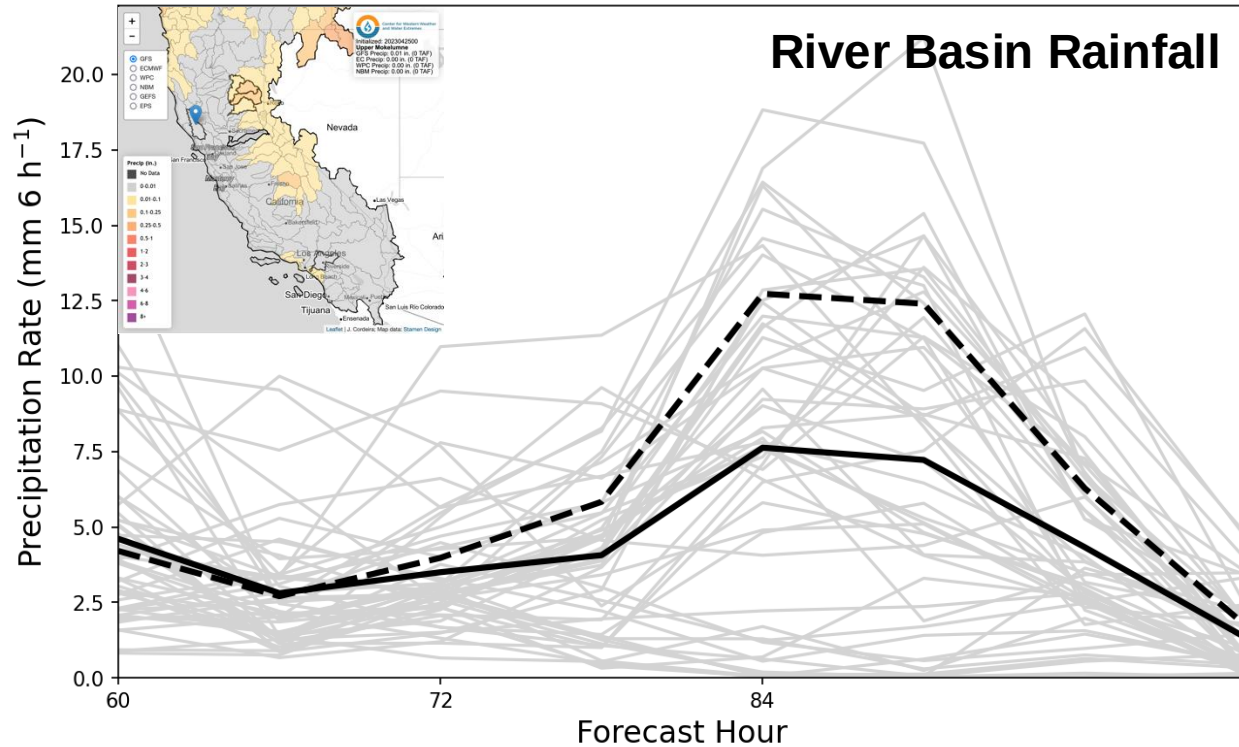
- Ensemble-based method of computing the sensitivity to model state variables at earlier time
- Above equation is linear regression based on ensemble:
 - Dependent variable is ensemble estimate of a forecast metric our outcome that is a function of the model output (multiple options available)
 - Independent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

2023011300 84-108 hour Precipitation, 0.641 of variance

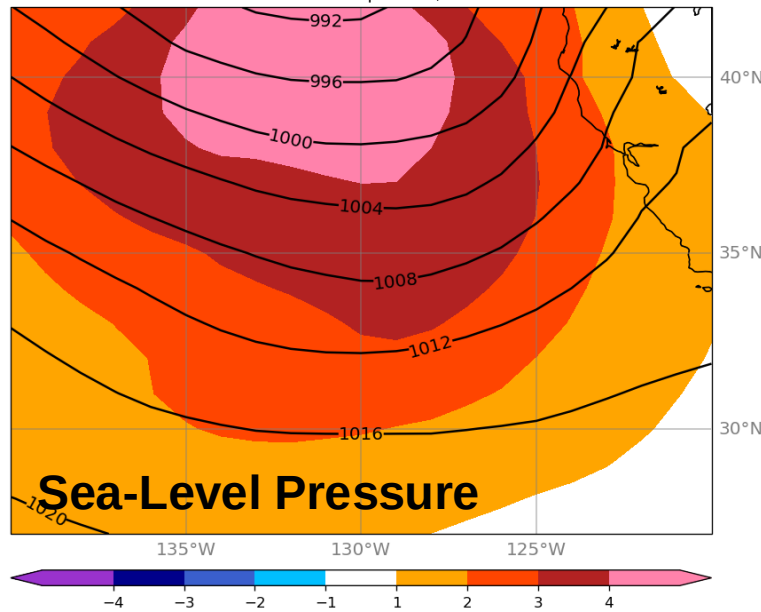


Variety of User-Defined Metric Choices

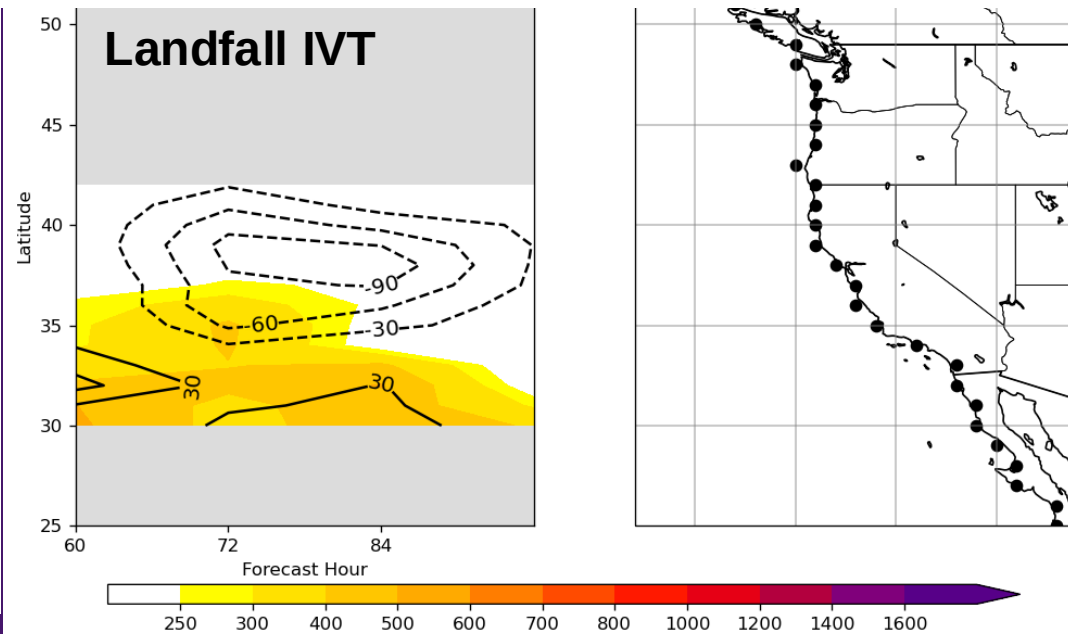
2023011300 60-102 hour Precipitation, 0.653 of variance



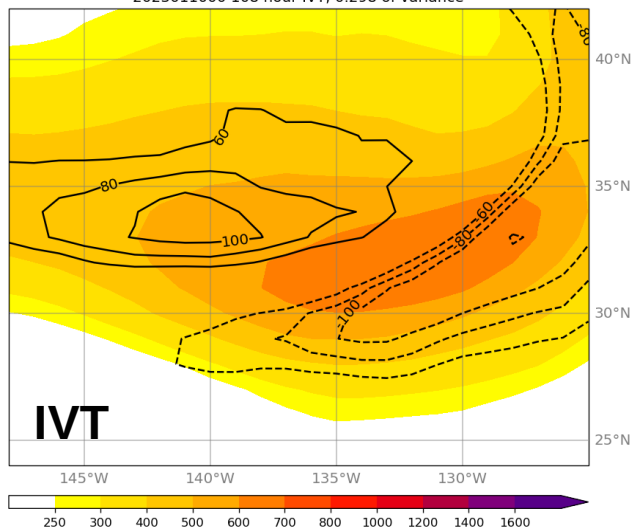
2023011000 108 hour Precipitation, 0.630 of variance



Landfall IVT

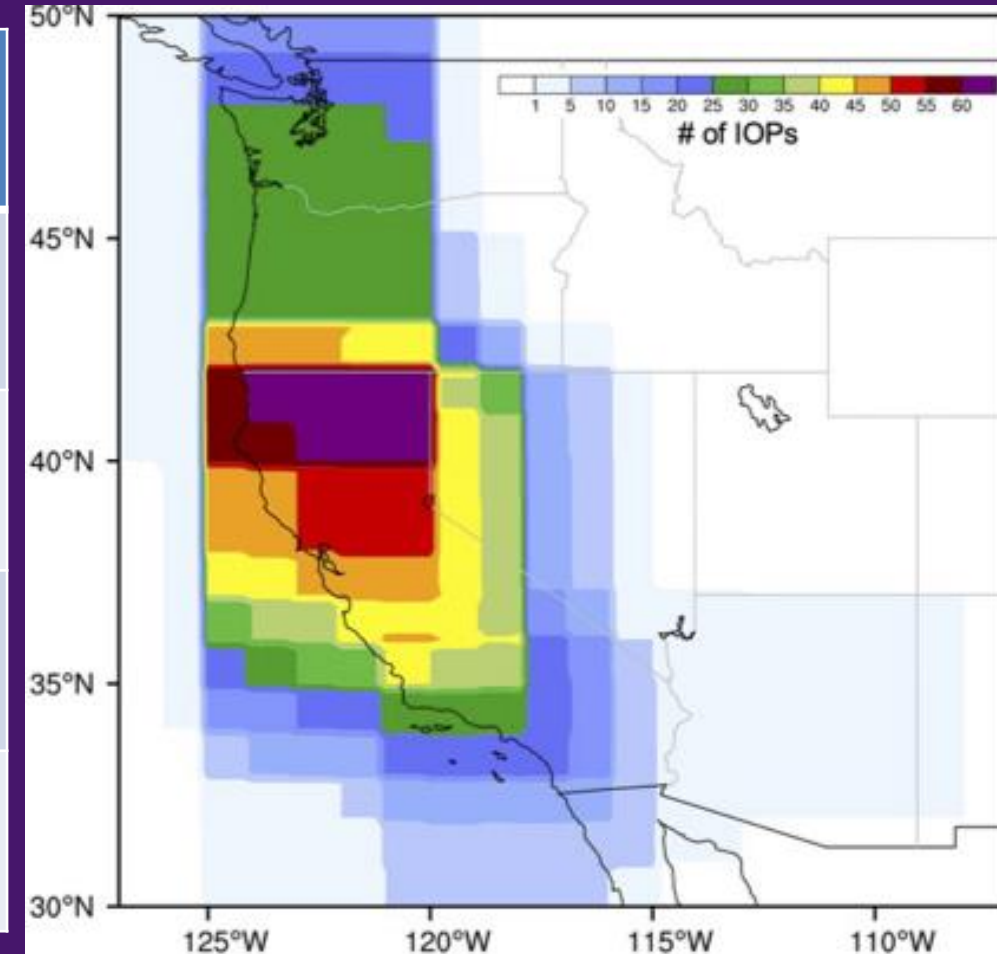


2023011000 108 hour IVT, 0.298 of variance



Metrics

Metric	2022/2023	2023/2024	2024/2025
Precipitation	92 (14)	82 (11)	21 (6)
IVT Landfall	42	59	8
IVT	38	14	0
Sea-level Pressure	16 (5)	4 (1)	2 (2)



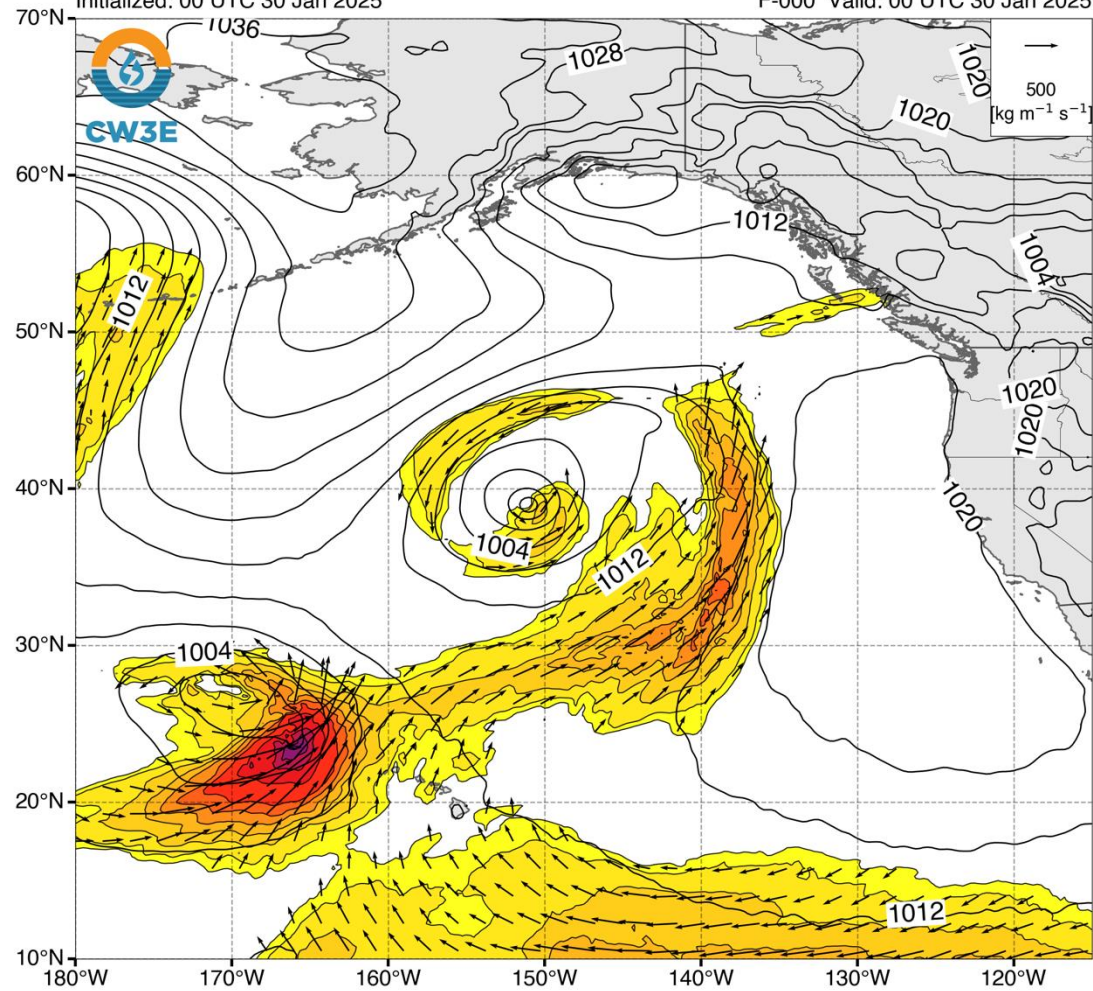
Credit: Minghua Zheng, Jia Wang

Operations

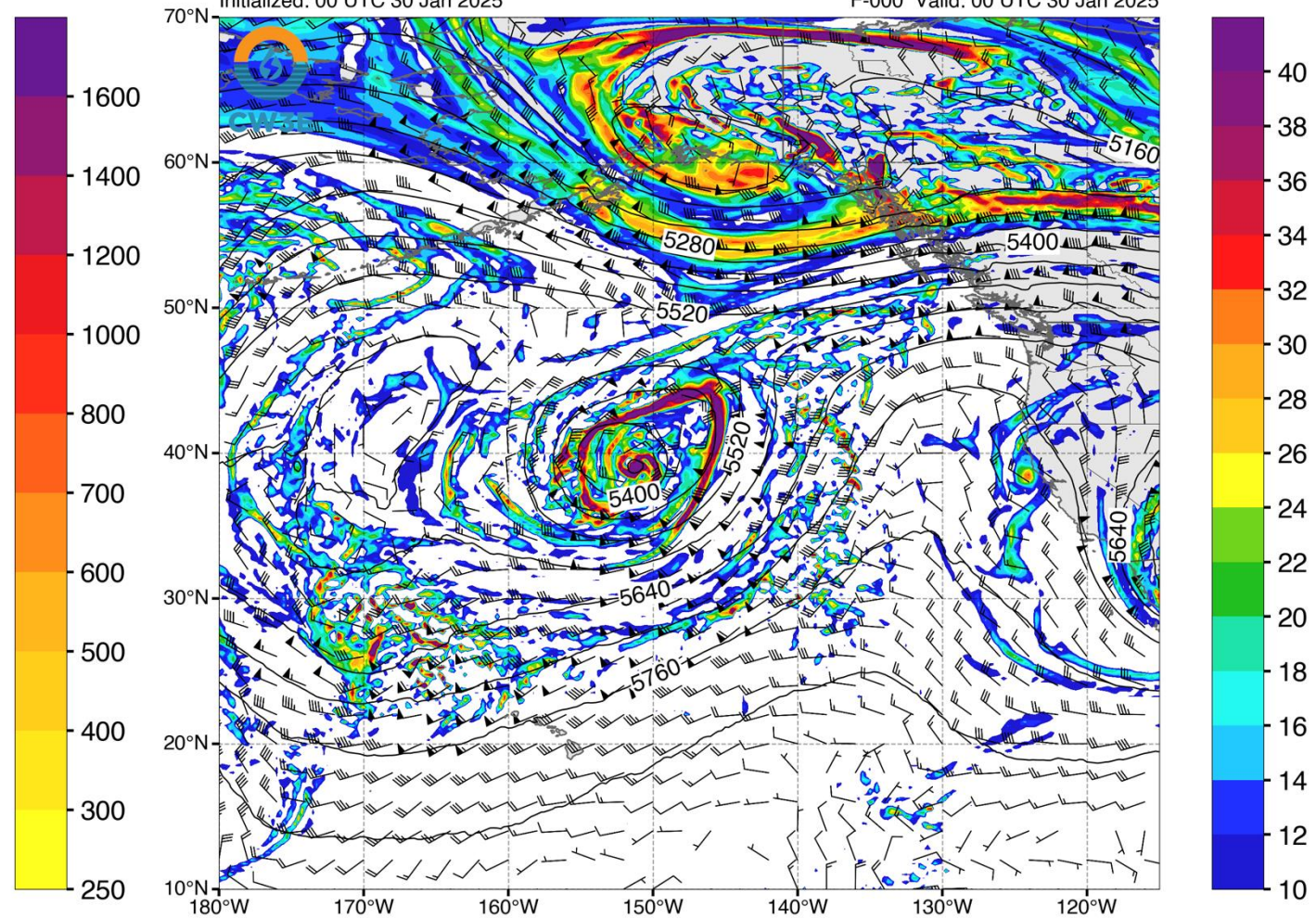
- Sensitivity calculations carried out using portable python code, which can ingest forecasts from ECMWF, GFS, and West-WRF ensemble systems
- Support daily AR Recon briefings from November-March
- Three domains: Eastern Pacific, US East Coast, and Western Pacific (recent expansion to Europe for NAWDIC by Peyton Capute)
- Metrics chosen based on coordination with GEFS/CMC, COAMPS adjoint sensitivities
- Three primary fields: IVT, 850 hPa θ_e , 250 hPa PV

0000 UTC 30 January

NCEP GFS IVT ($\text{kg m}^{-1} \text{s}^{-1}$; shaded), IVT Vector, and SLP (hPa; contours)
Initialized: 00 UTC 30 Jan 2025 F-000 Valid: 00 UTC 30 Jan 2025

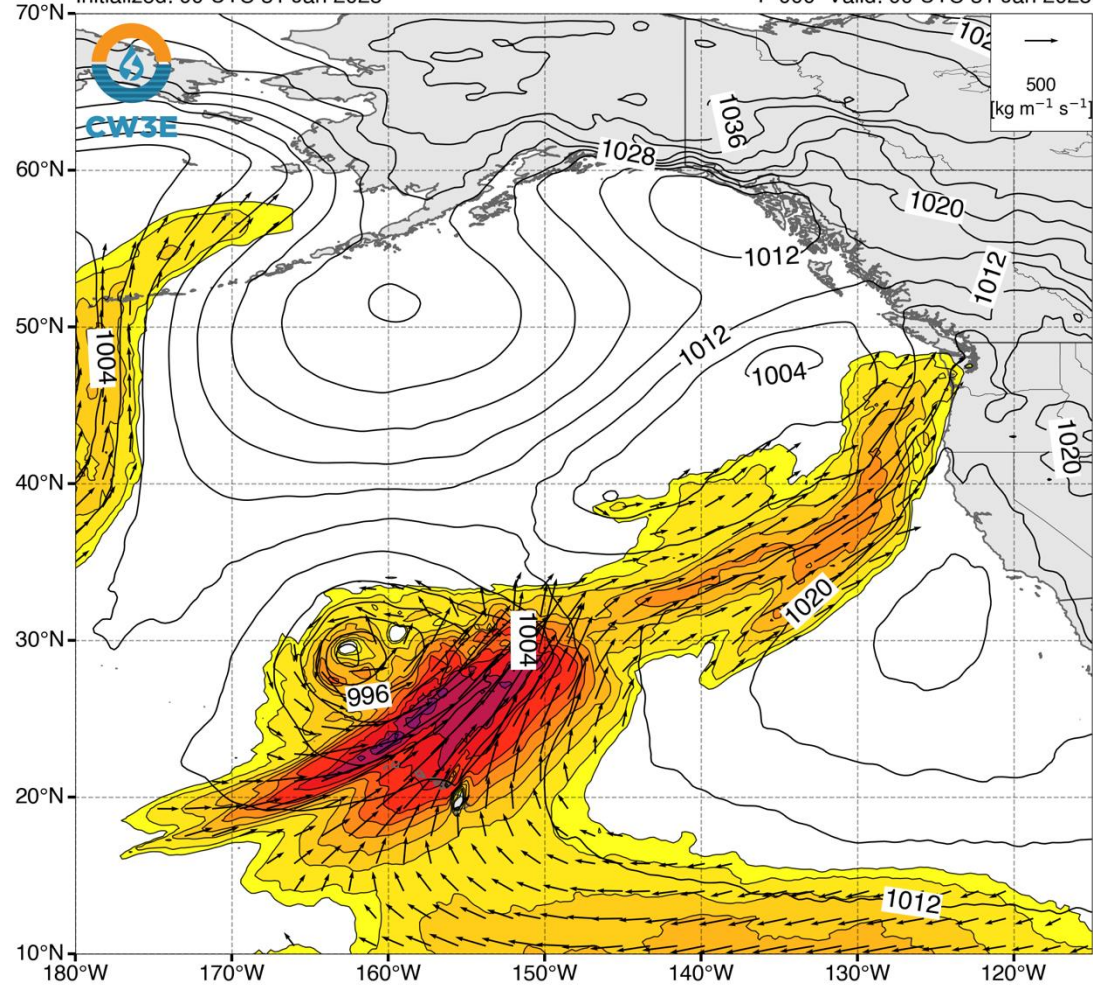


NCEP GFS 500-hPa Absolute Vorticity ($\times 10^{-5} \text{s}^{-1}$; shaded), Height (gpm), and Winds
Initialized: 00 UTC 30 Jan 2025 F-000 Valid: 00 UTC 30 Jan 2025

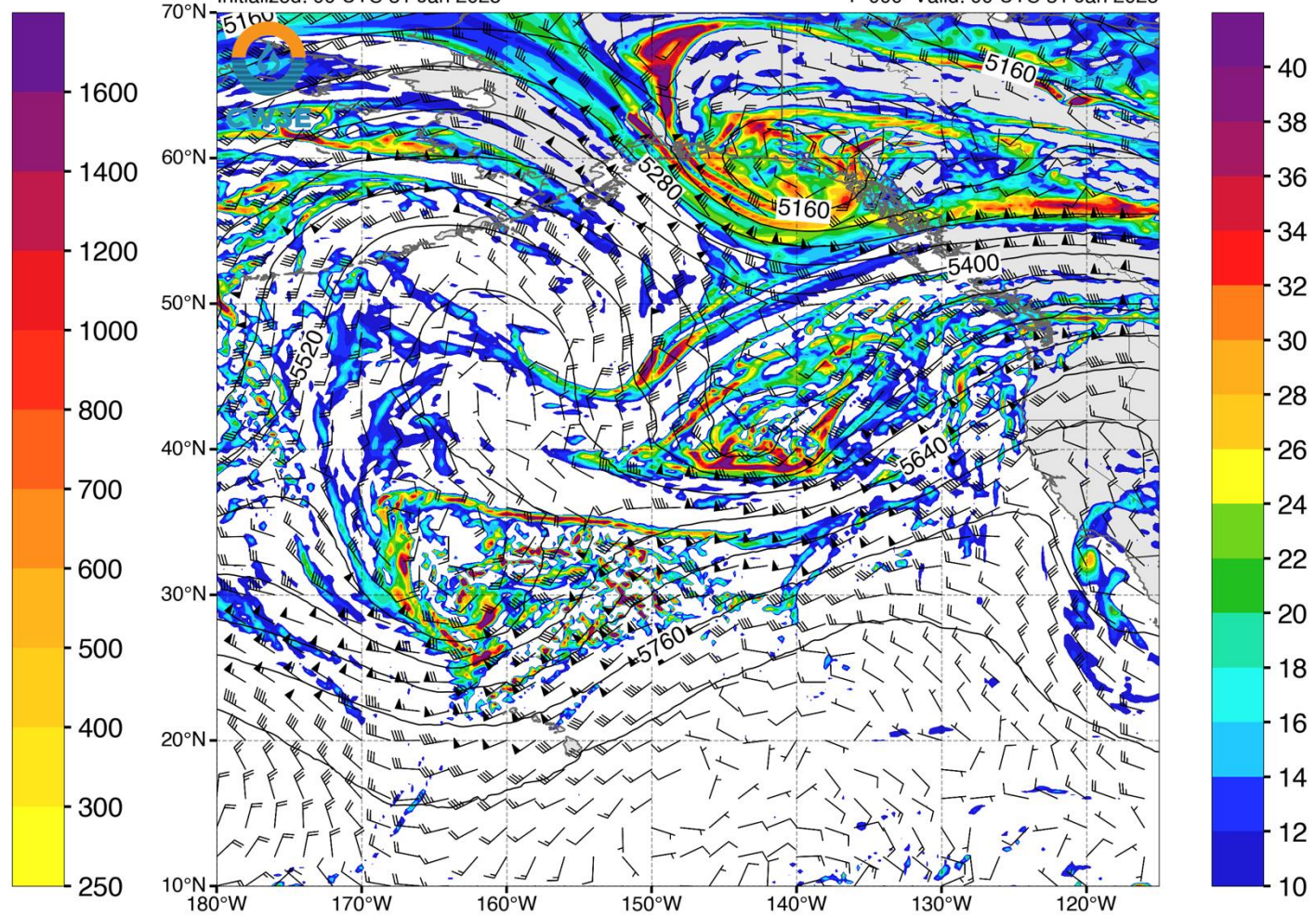


0000 UTC 31 January

NCEP GFS IVT ($\text{kg m}^{-1} \text{s}^{-1}$; shaded), IVT Vector, and SLP (hPa; contours)
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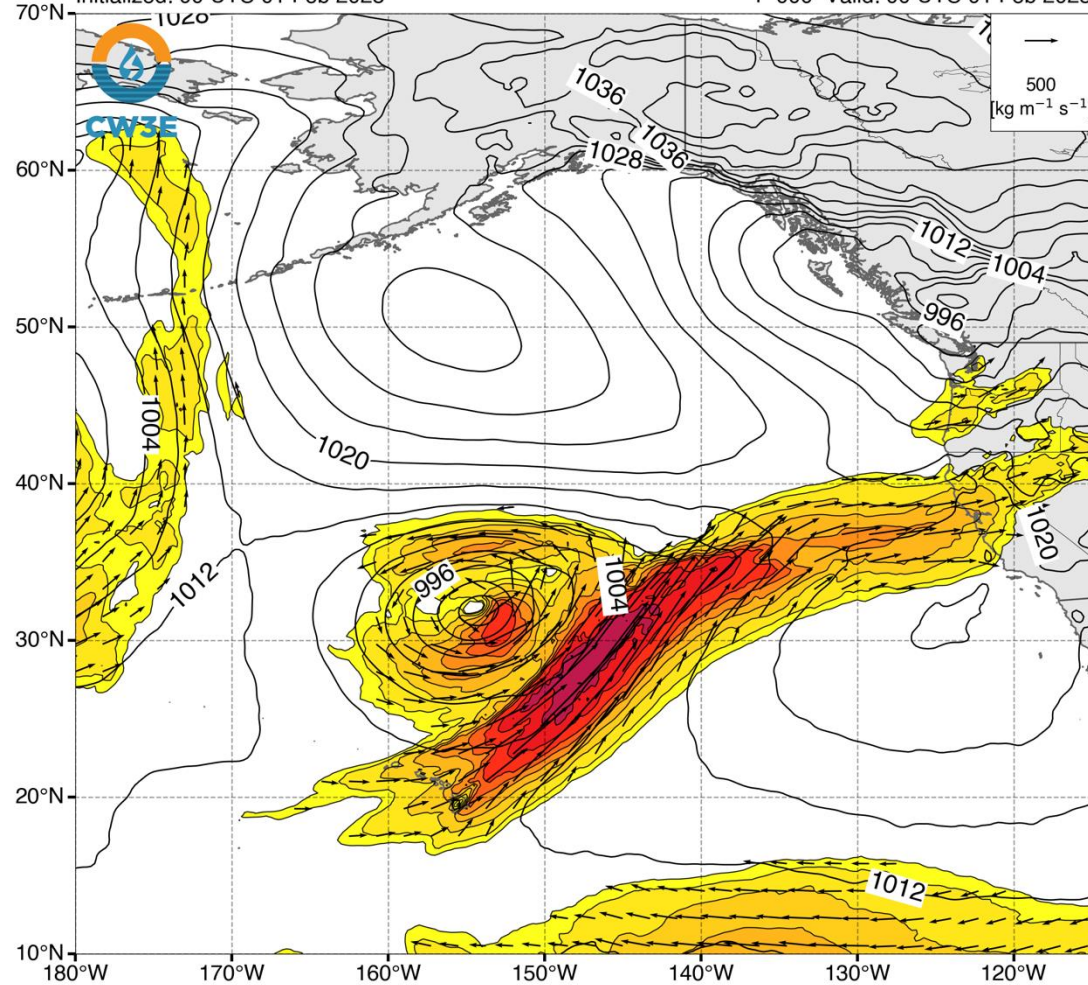


NCEP GFS 500-hPa Absolute Vorticity ($\times 10^{-5} \text{s}^{-1}$; shaded), Height (gpm), and Winds
Initialized: 00 UTC 31 Jan 2025 F-000 Valid: 00 UTC 31 Jan 2025

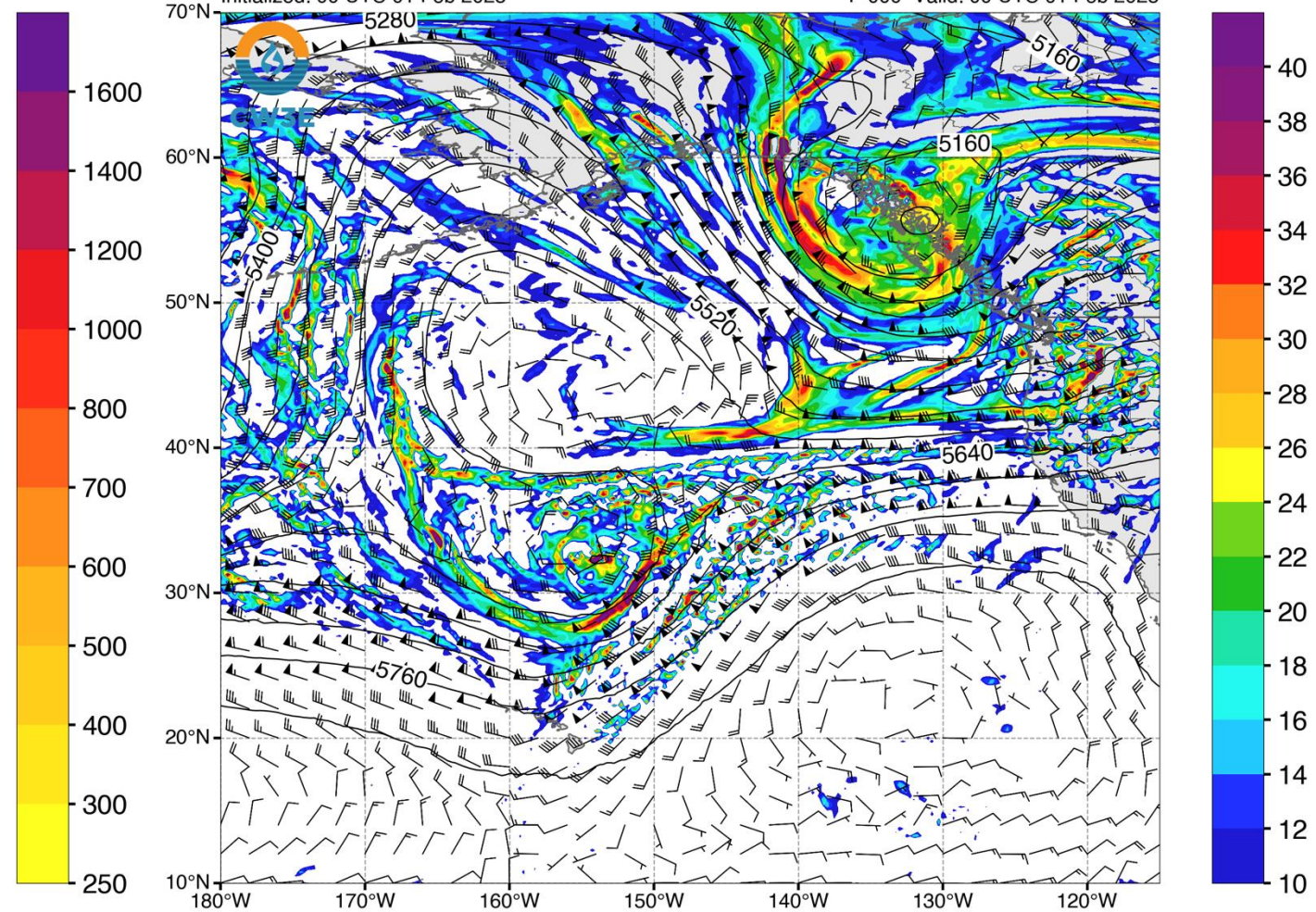


0000 UTC 1 February

NCEP GFS IVT ($\text{kg m}^{-1} \text{s}^{-1}$; shaded), IVT Vector, and SLP (hPa; contours)
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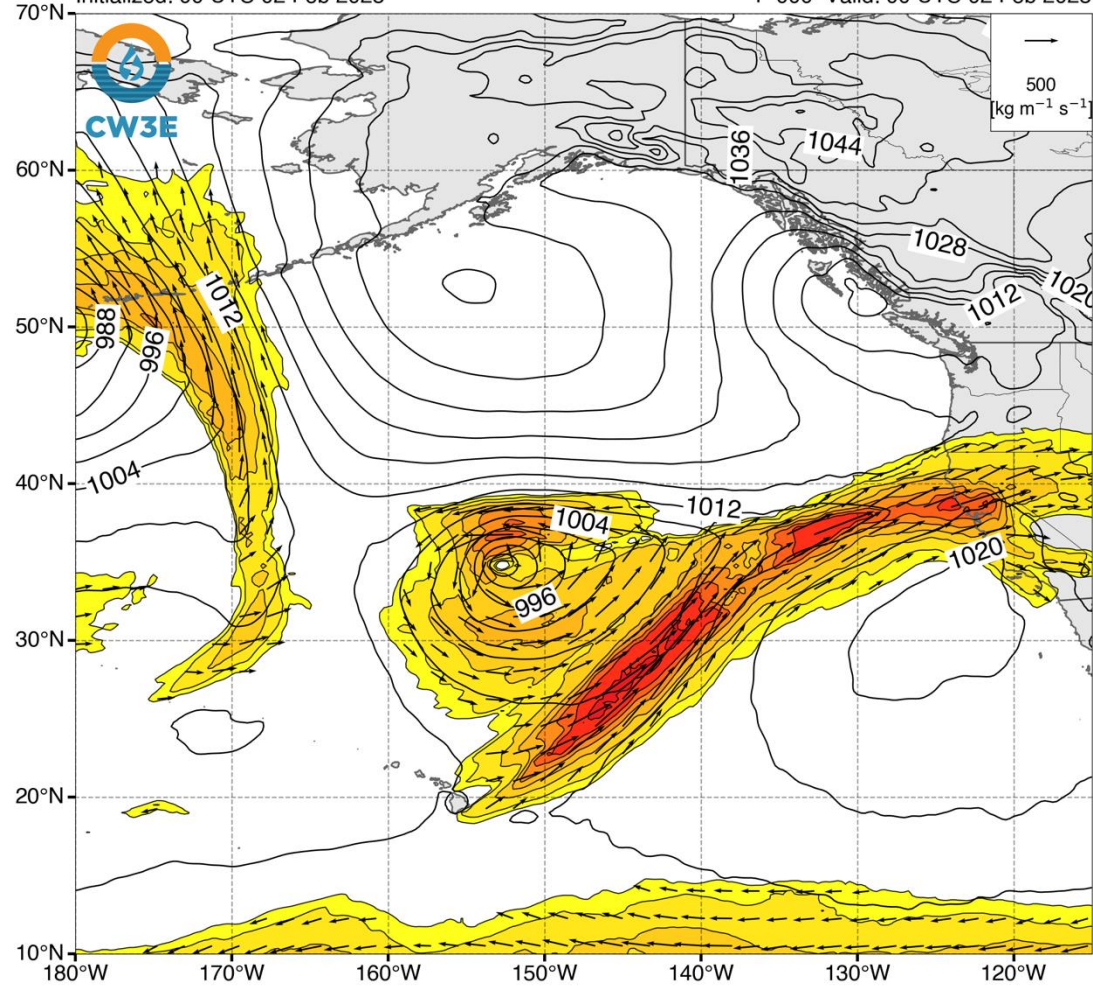


NCEP GFS 500-hPa Absolute Vorticity ($\times 10^{-5} \text{s}^{-1}$; shaded), Height (gpm), and Winds
Initialized: 00 UTC 01 Feb 2025 F-000 Valid: 00 UTC 01 Feb 2025

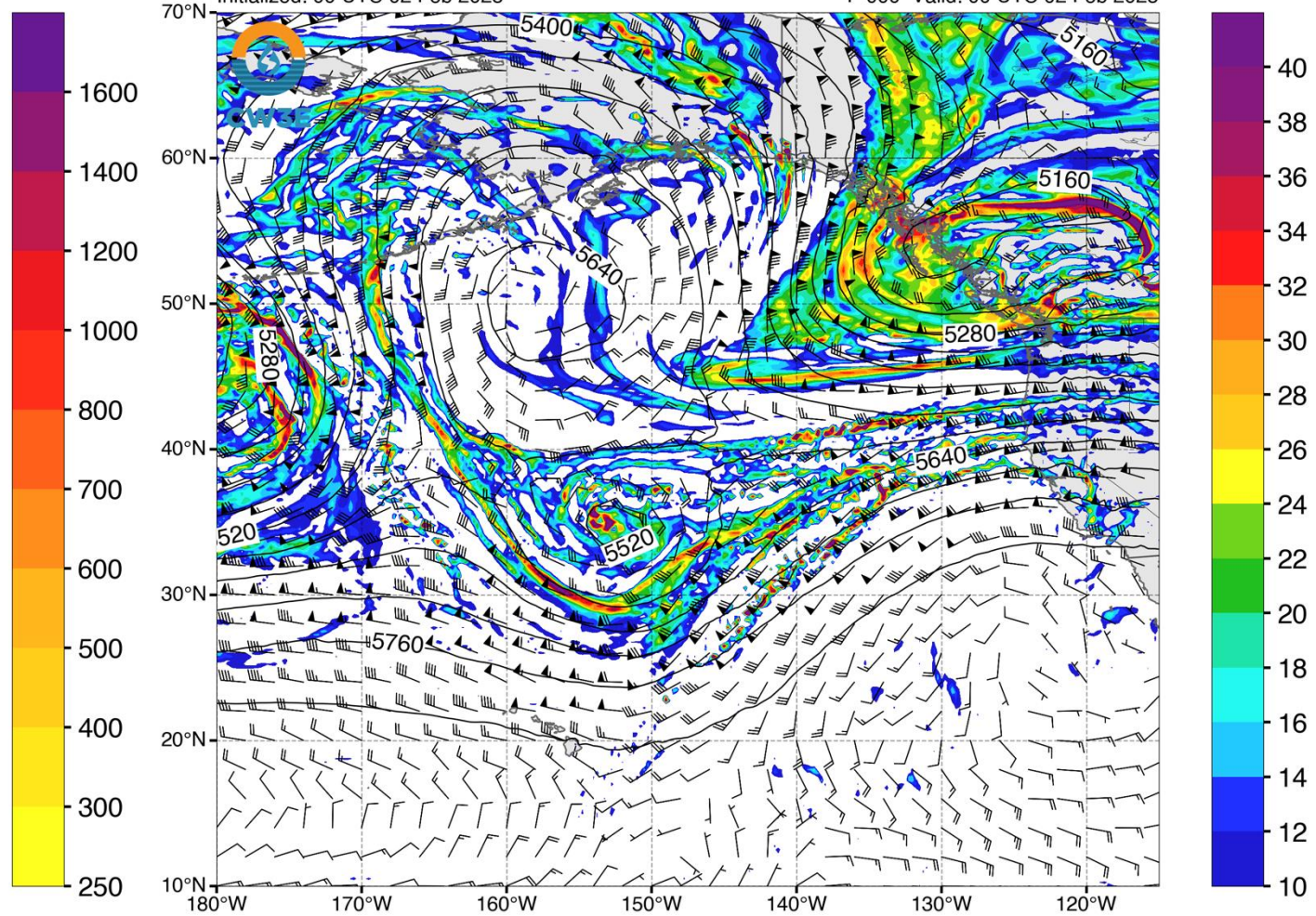


0000 UTC 2 February

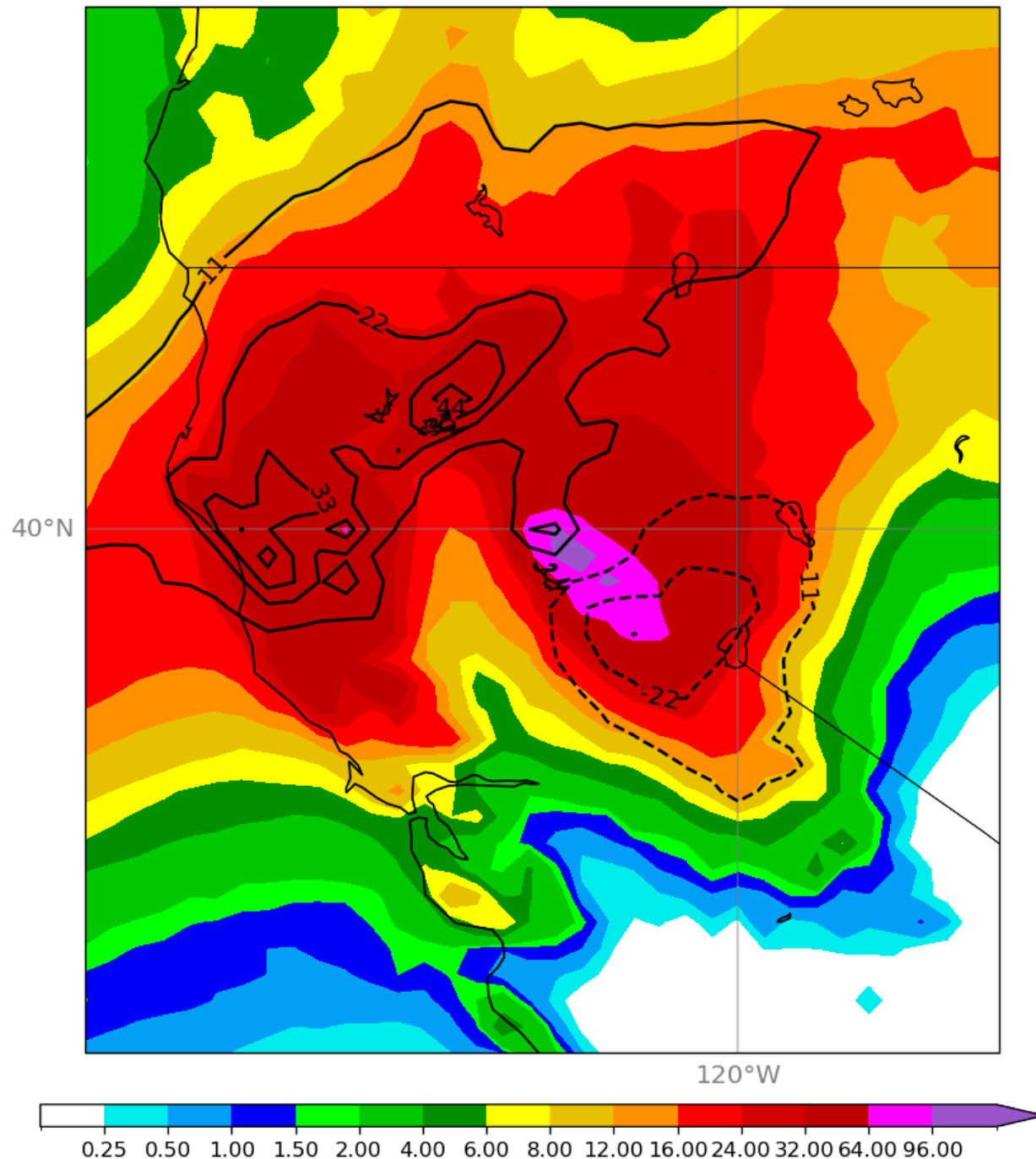
NCEP GFS IVT ($\text{kg m}^{-1} \text{s}^{-1}$; shaded), IVT Vector, and SLP (hPa; contours)
Initialized: 00 UTC 02 Feb 2025 F-000 Valid: 00 UTC 02 Feb 2025



NCEP GFS 500-hPa Absolute Vorticity ($\times 10^{-5} \text{s}^{-1}$; shaded), Height (gpm), and Winds
Initialized: 00 UTC 02 Feb 2025 F-000 Valid: 00 UTC 02 Feb 2025



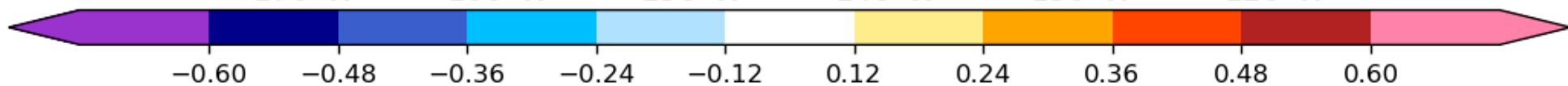
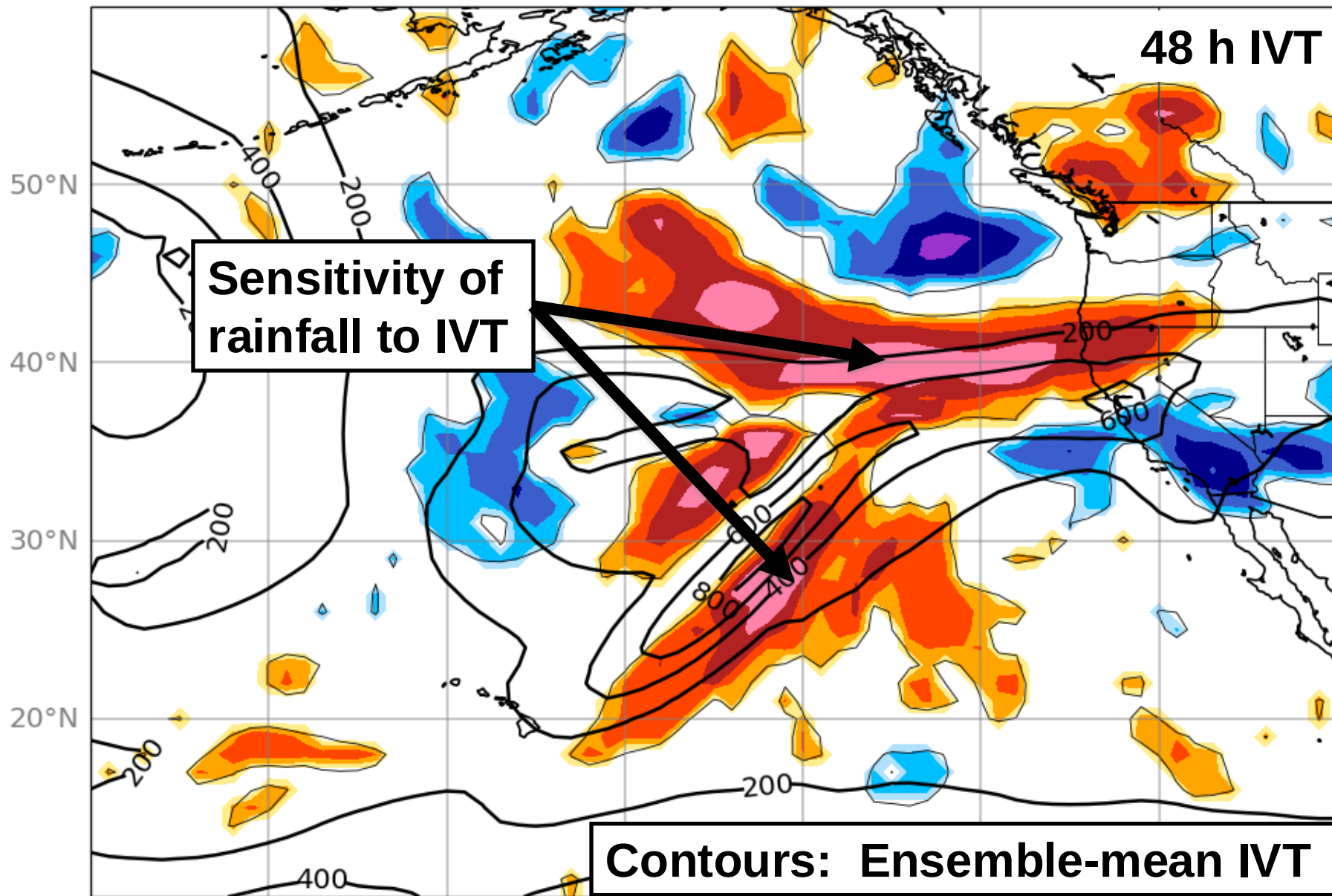
2025013100 60-84 hour Precipitation, 0.511 of variance



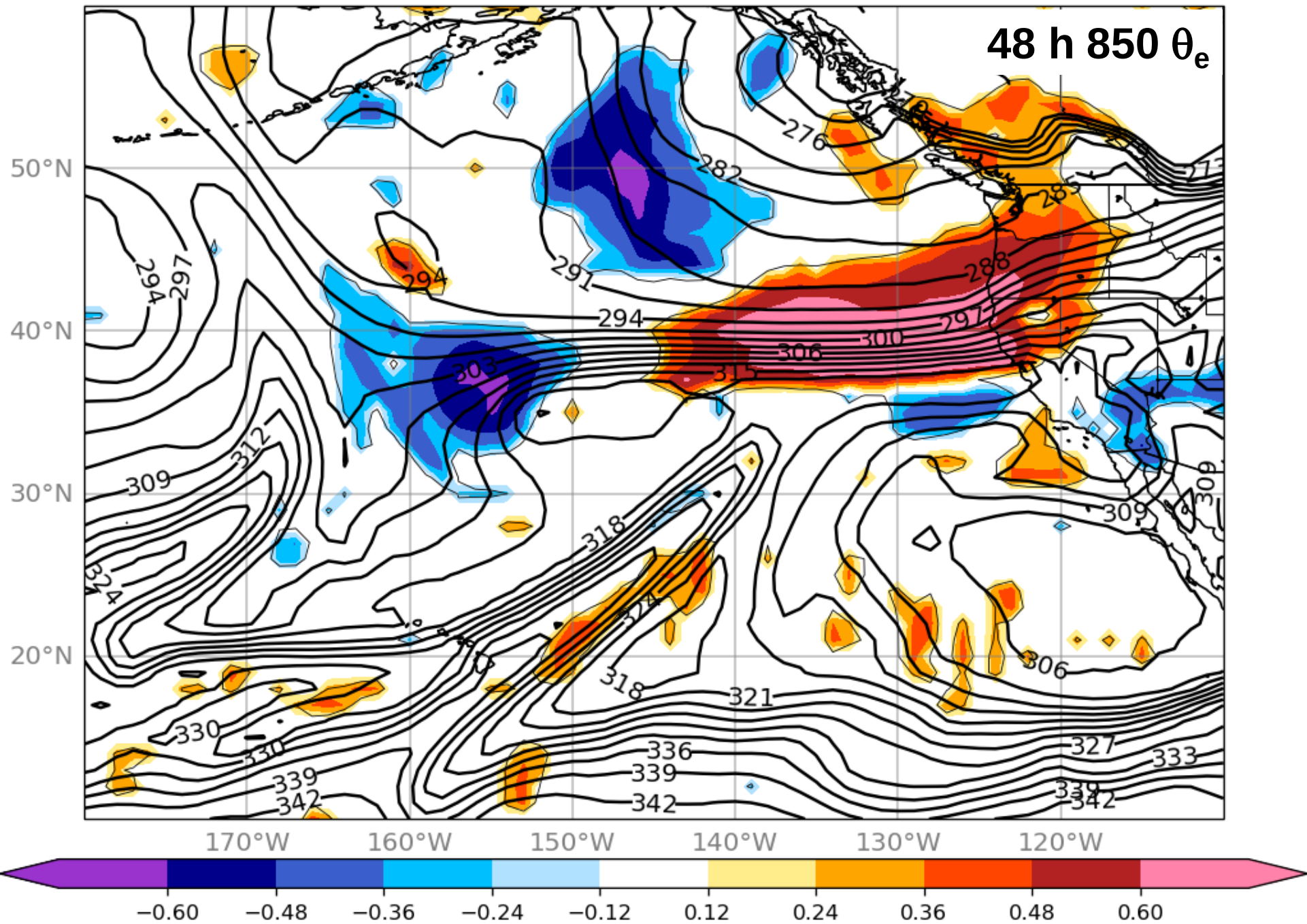
Metric: First EOF of precipitation between 1200 UTC 2 Feb. to 1200 UTC 3 Feb. (best method of looking at precipitation variability within a geographical domain). Shading is the ensemble-mean precipitation, dashed is the precipitation EOF.

In this case, positive values of the metric are associated with more precipitation along the coastal California mountains, less over the northern Sierra.

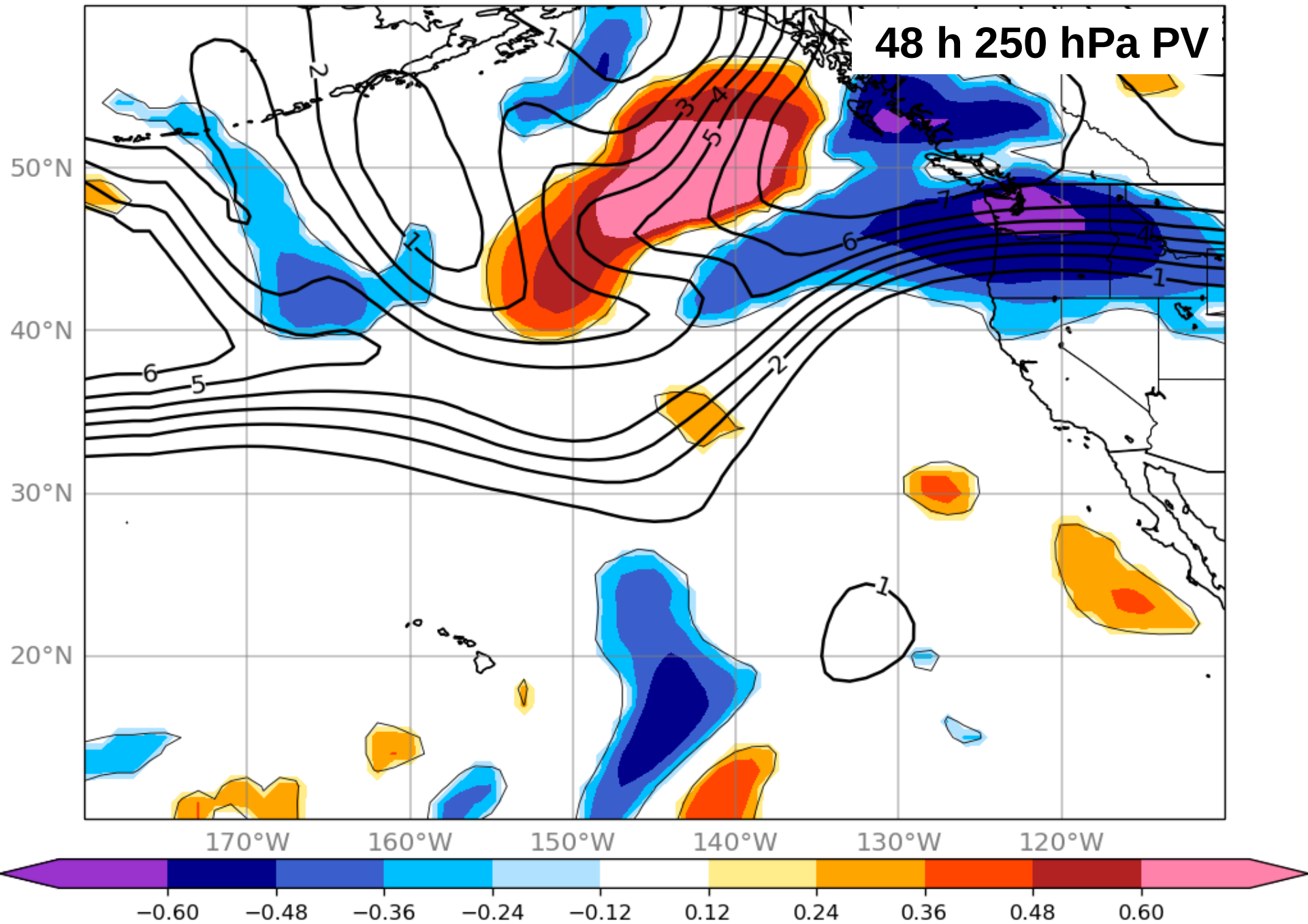
2025013100 F048 IVT, precipitation PC (2025020212 - 2025020312)



2025013100 F048 850 hPa θ_e , precipitation PC (2025020212 - 2025020312)

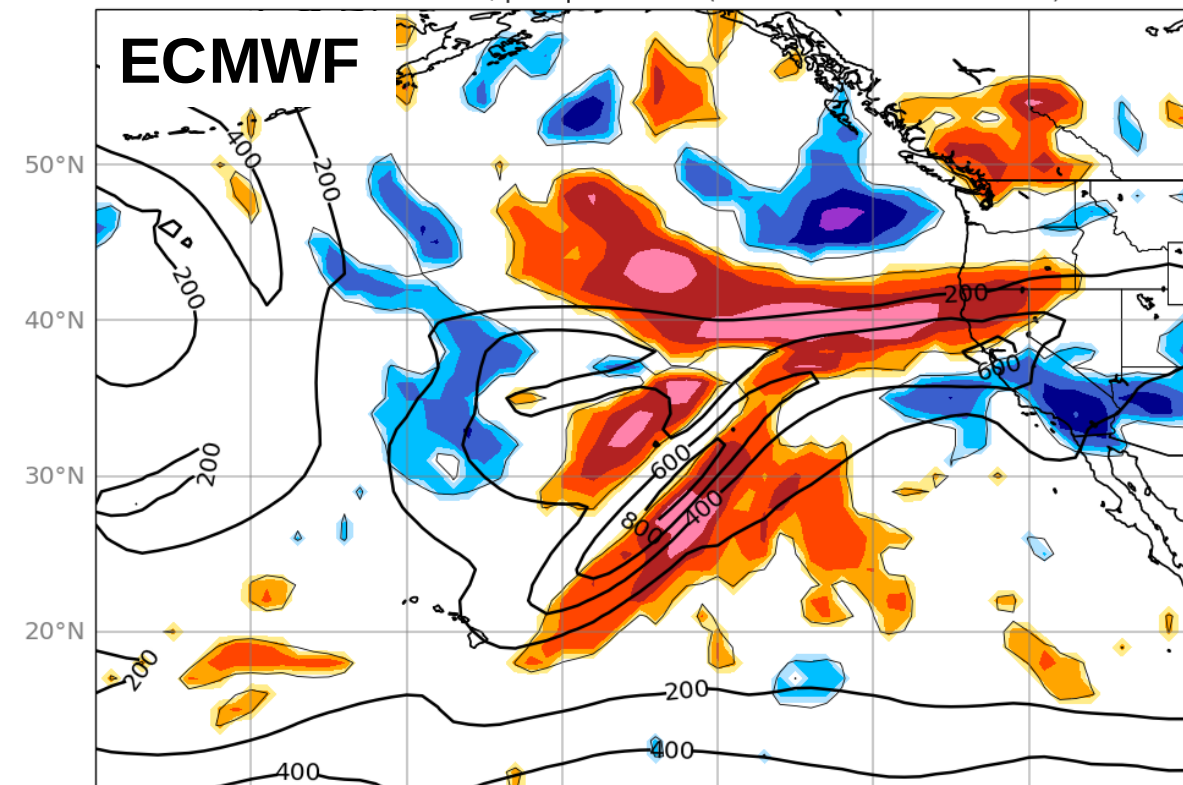


2025013100 F048 250 hPa PV, precipitation PC (2025020212 - 2025020312)



2025013100 F048 IVT, precipitation PC (2025020212 - 2025020312)

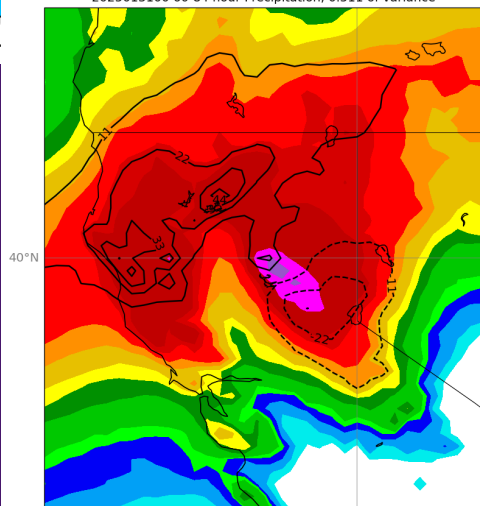
ECMWF



170°W 160°W 150°W 140°W 130°W 120°W

-0.60 -0.48 -0.36

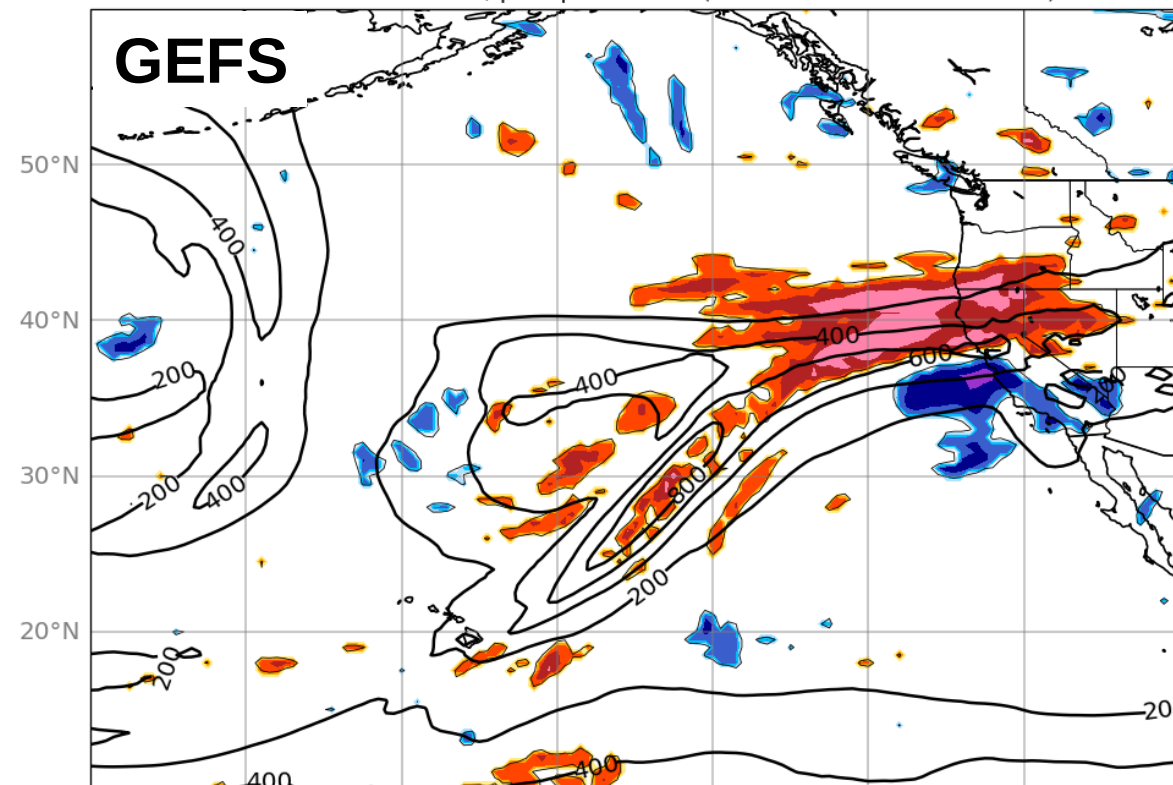
2025013100 60-84 hour Precipitation, 0.511 of variance



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

2025013100 F048 IVT, precipitation PC (2025020212 - 2025020312)

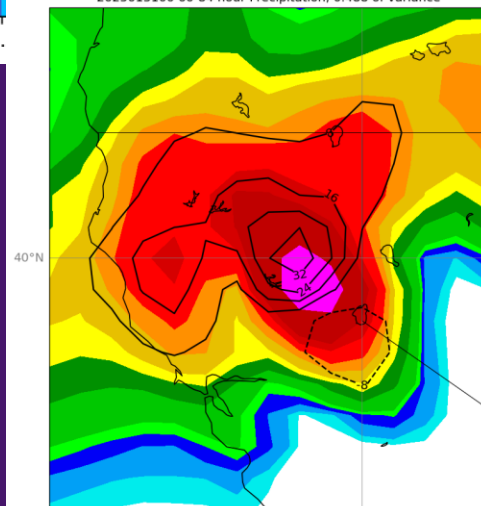
GEFS



170°W 160°W 150°W 140°W 130°W 120°W

-0.60 -0.48 -0.36

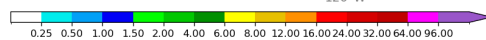
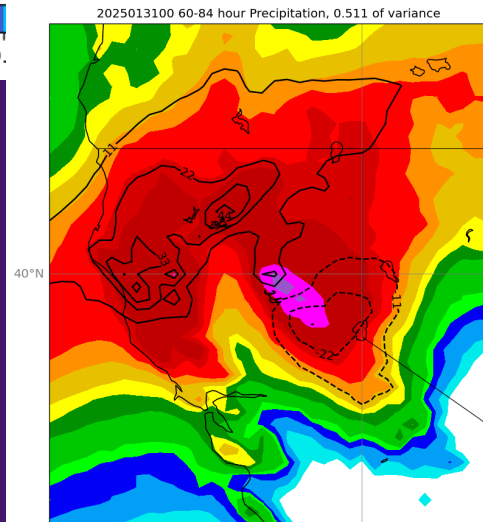
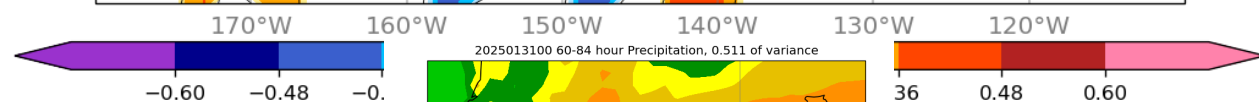
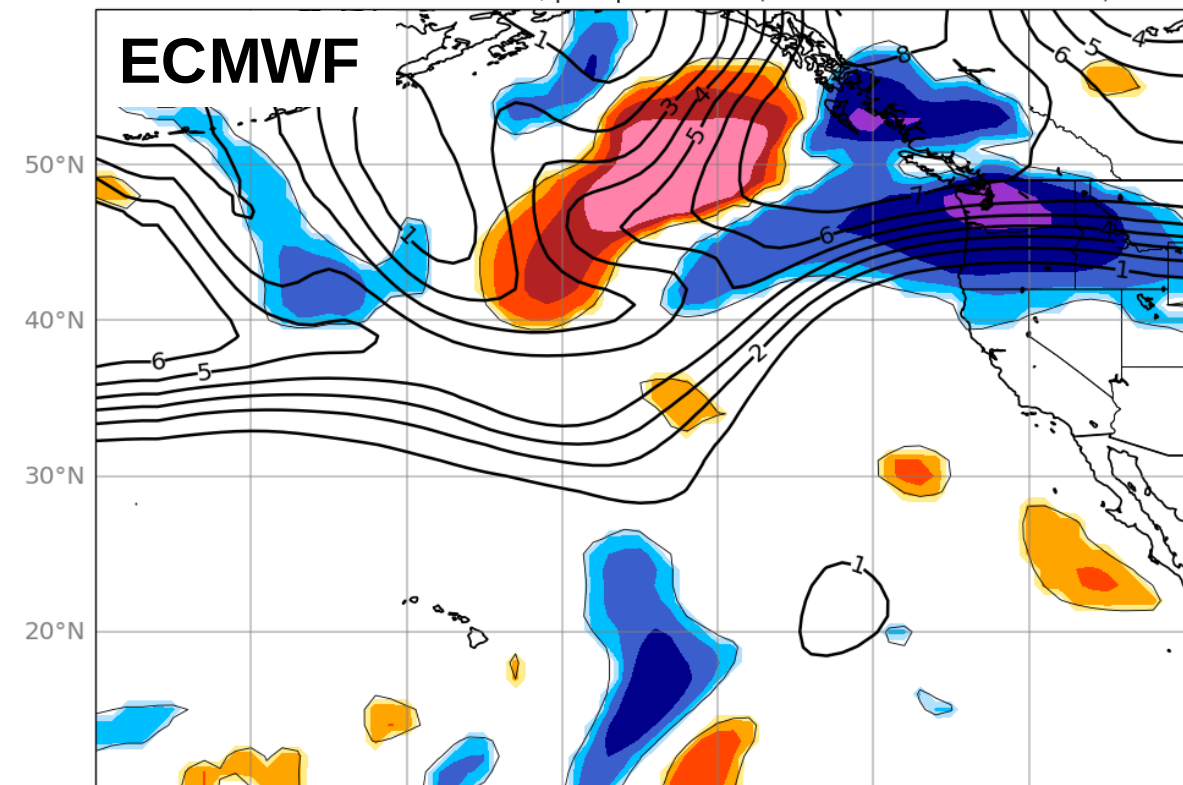
2025013100 60-84 hour Precipitation, 0.488 of variance



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

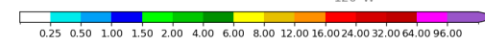
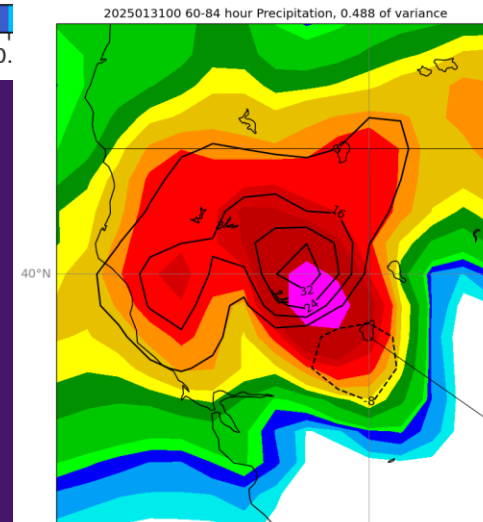
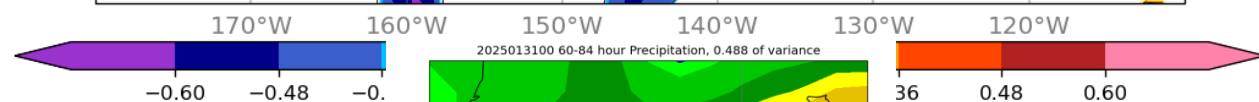
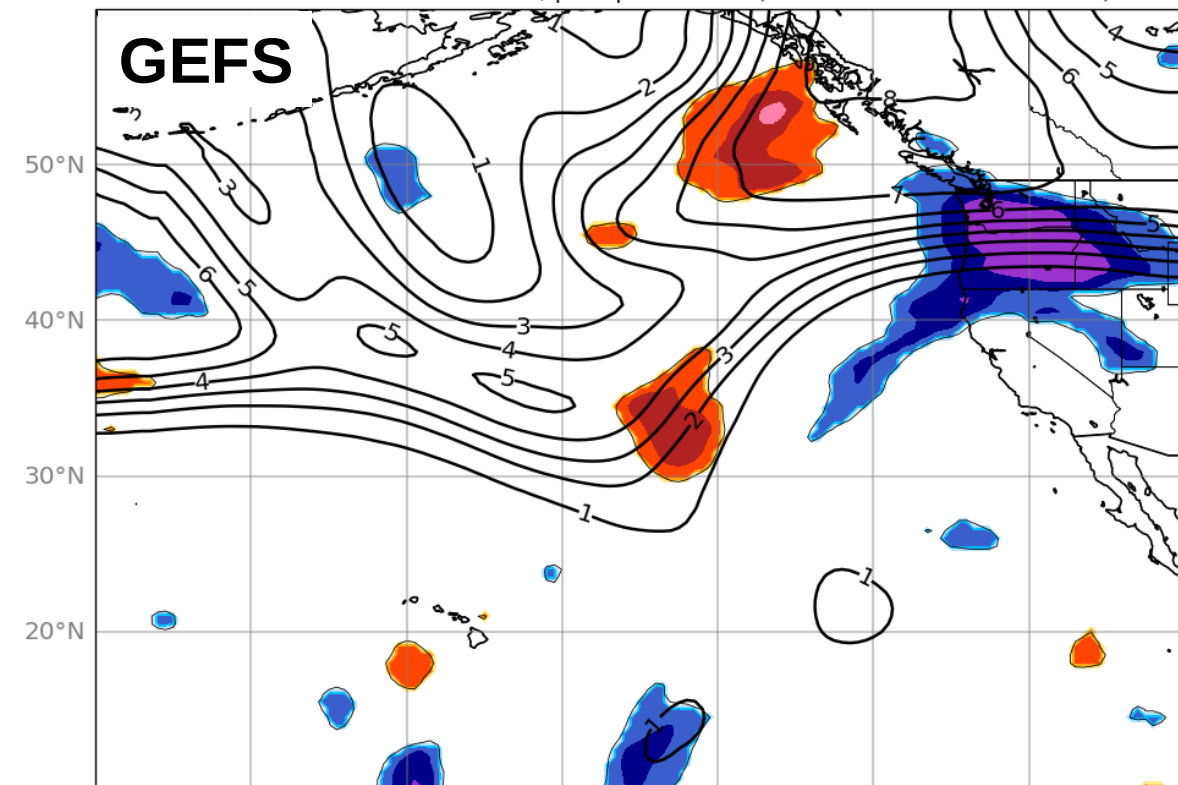
2025013100 F048 250 hPa PV, precipitation PC (2025020212 - 2025020312)

ECMWF

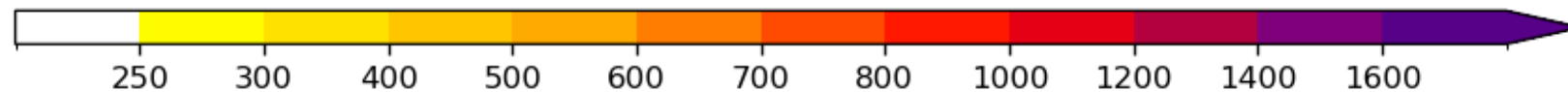
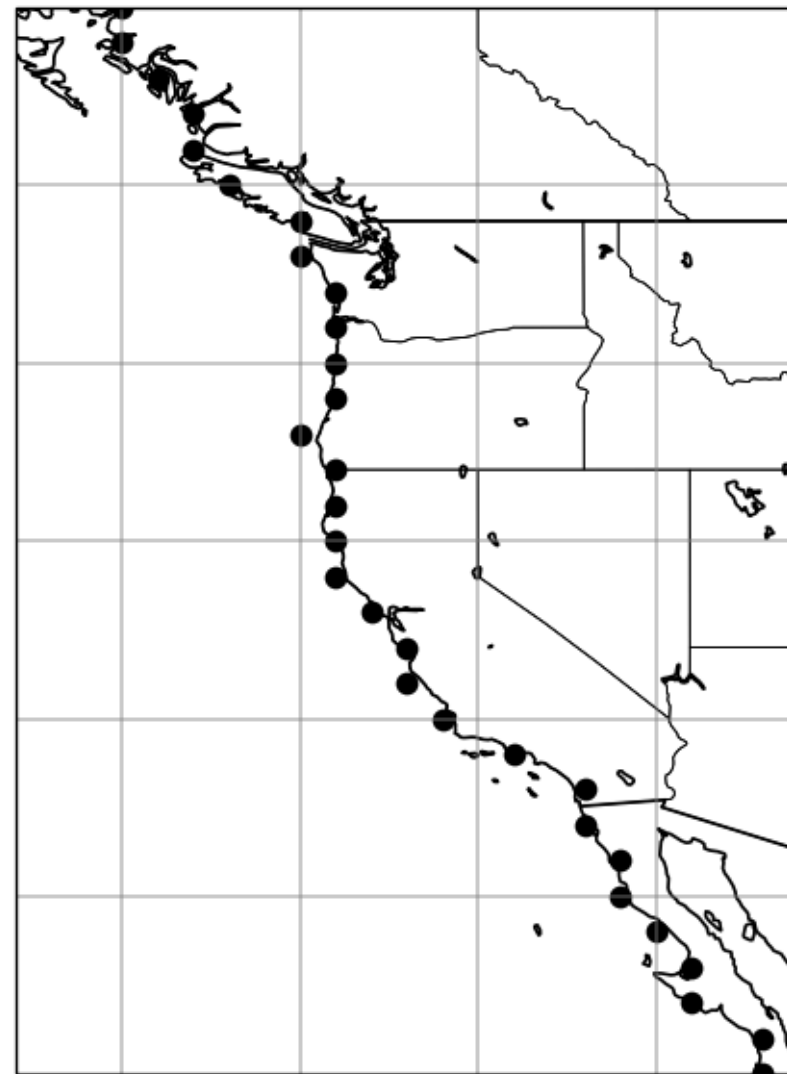
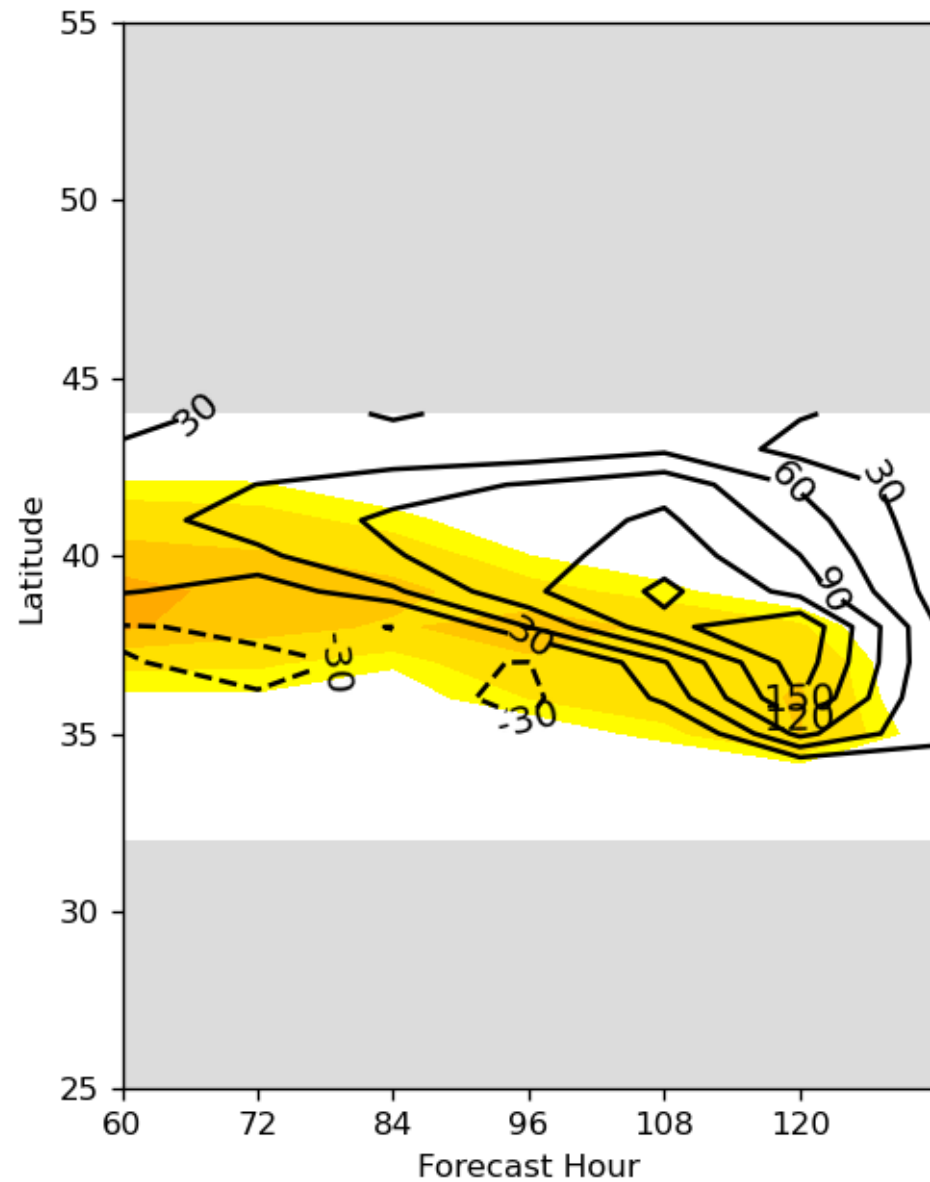


2025013100 F048 250 hPa PV, precipitation PC (2025020212 - 2025020312)

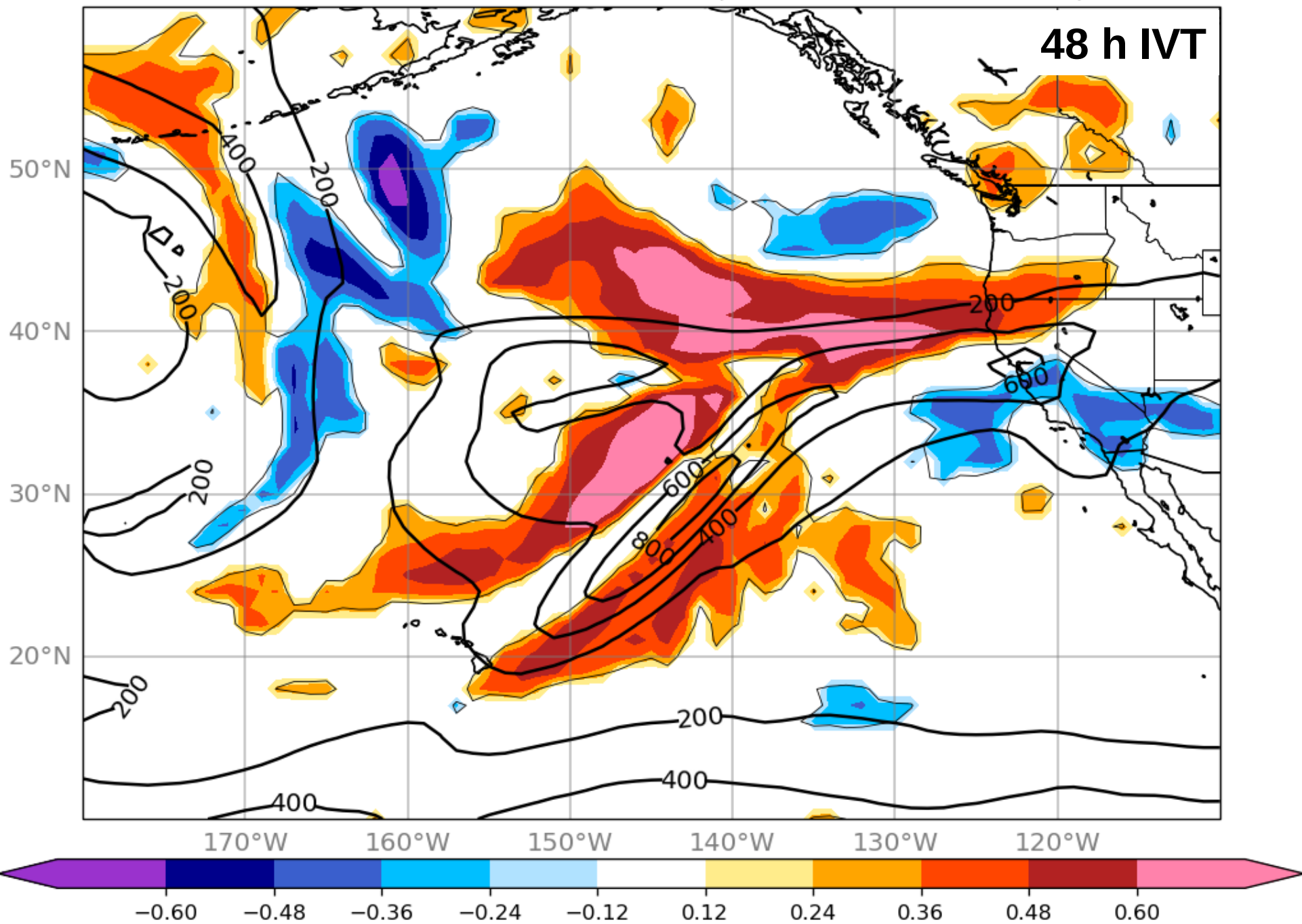
GEFS

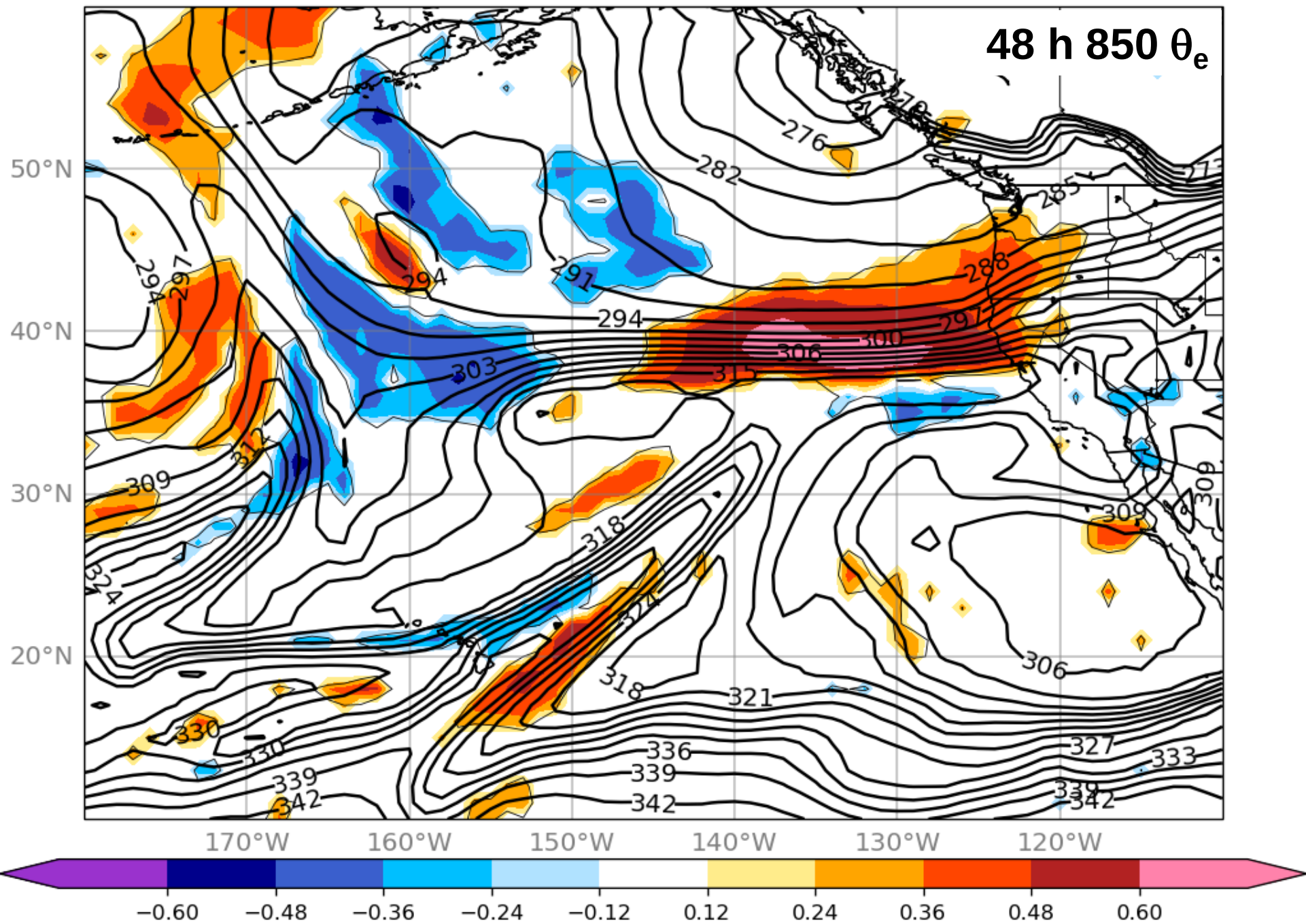


2025013100 60-132 hour IVT, 0.407 of variance



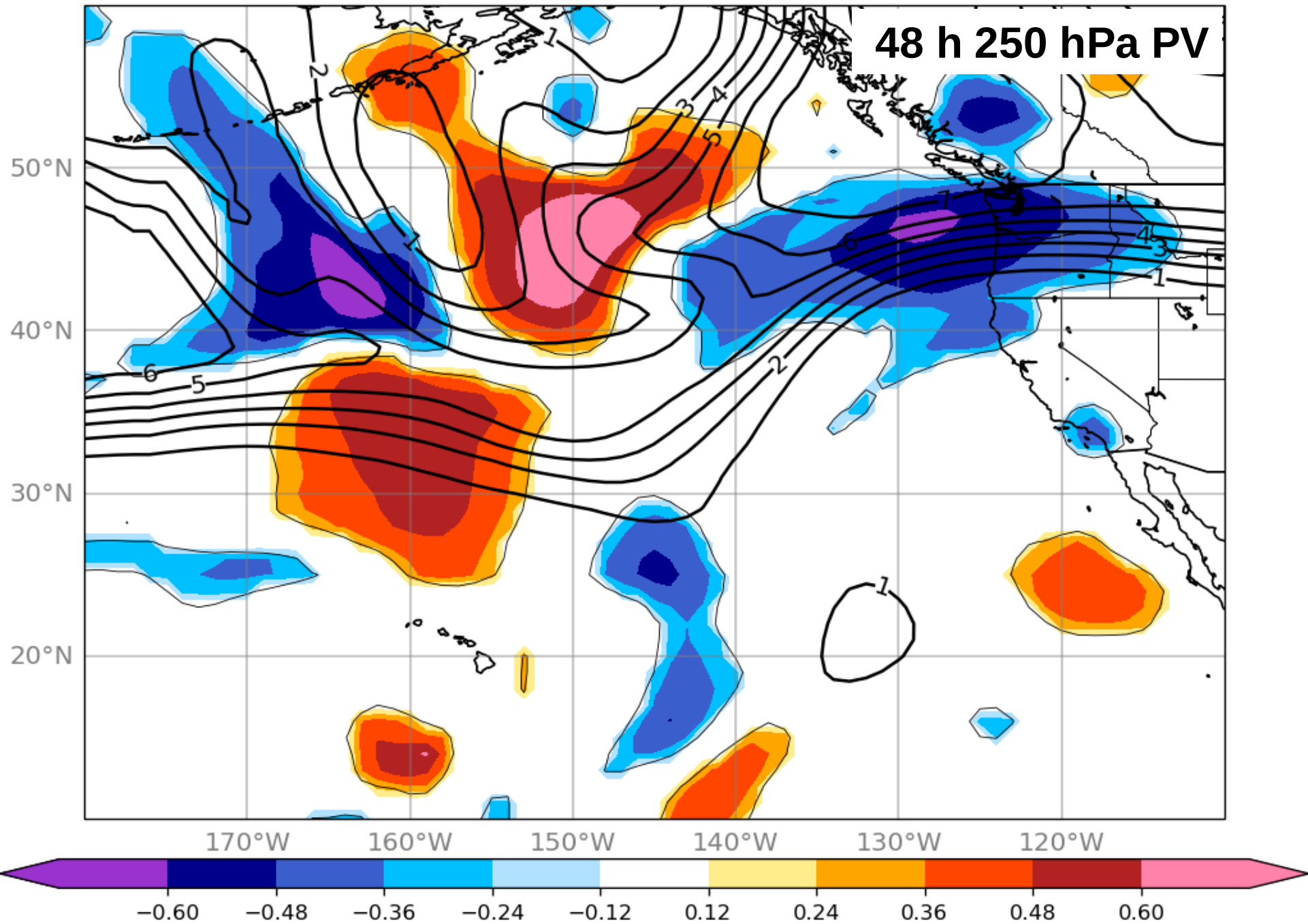
2025013100 F048 IVT, IVT Landfall PC (2025020212 - 2025020512)





2025013100 F048 250 hPa PV, IVT Landfall PC (2025020212 - 2025020512)

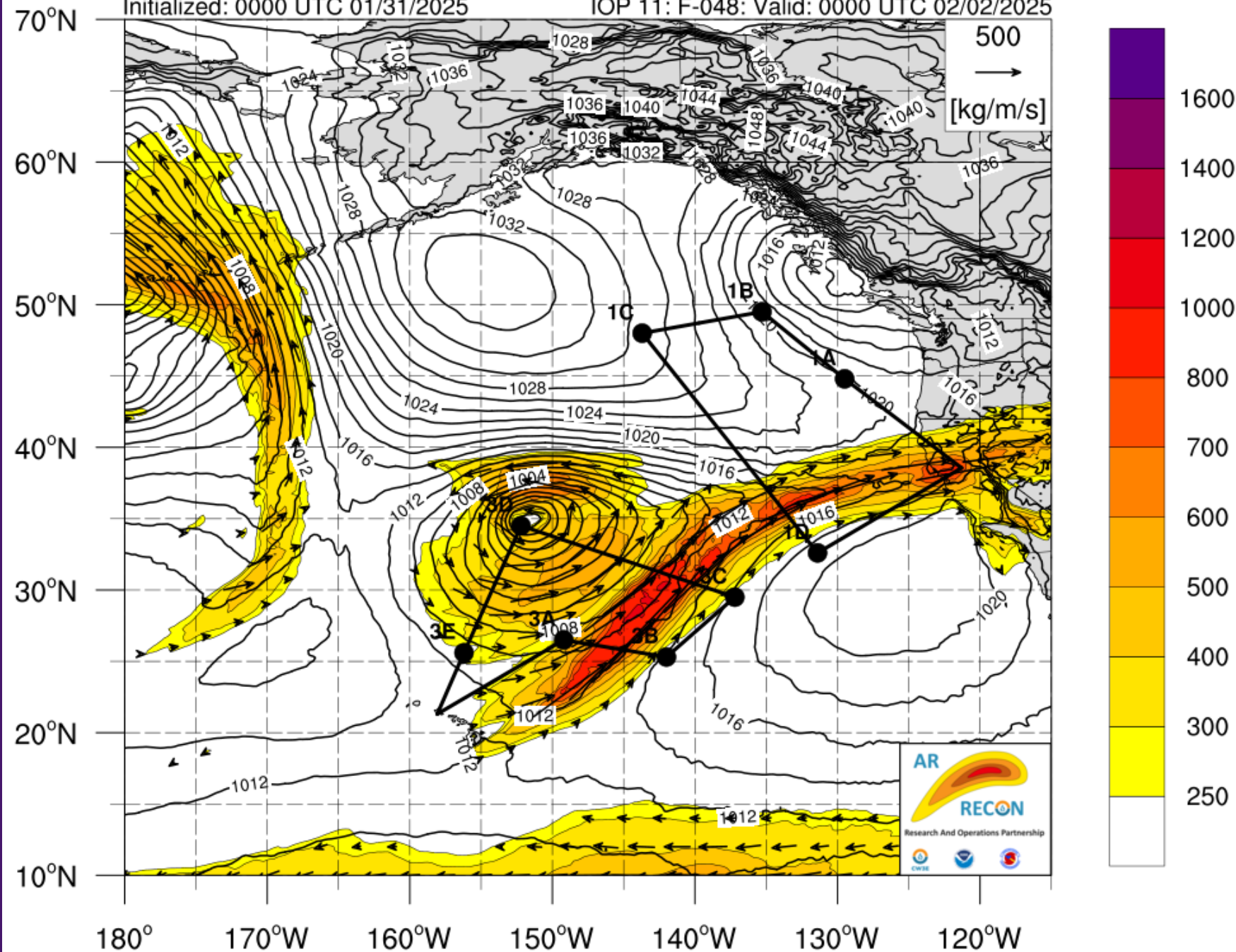
48 h 250 hPa PV



C-130 samples near-shore AR and the trough sliding down the coast – canceled due to potential icing conditions at Mather AFB

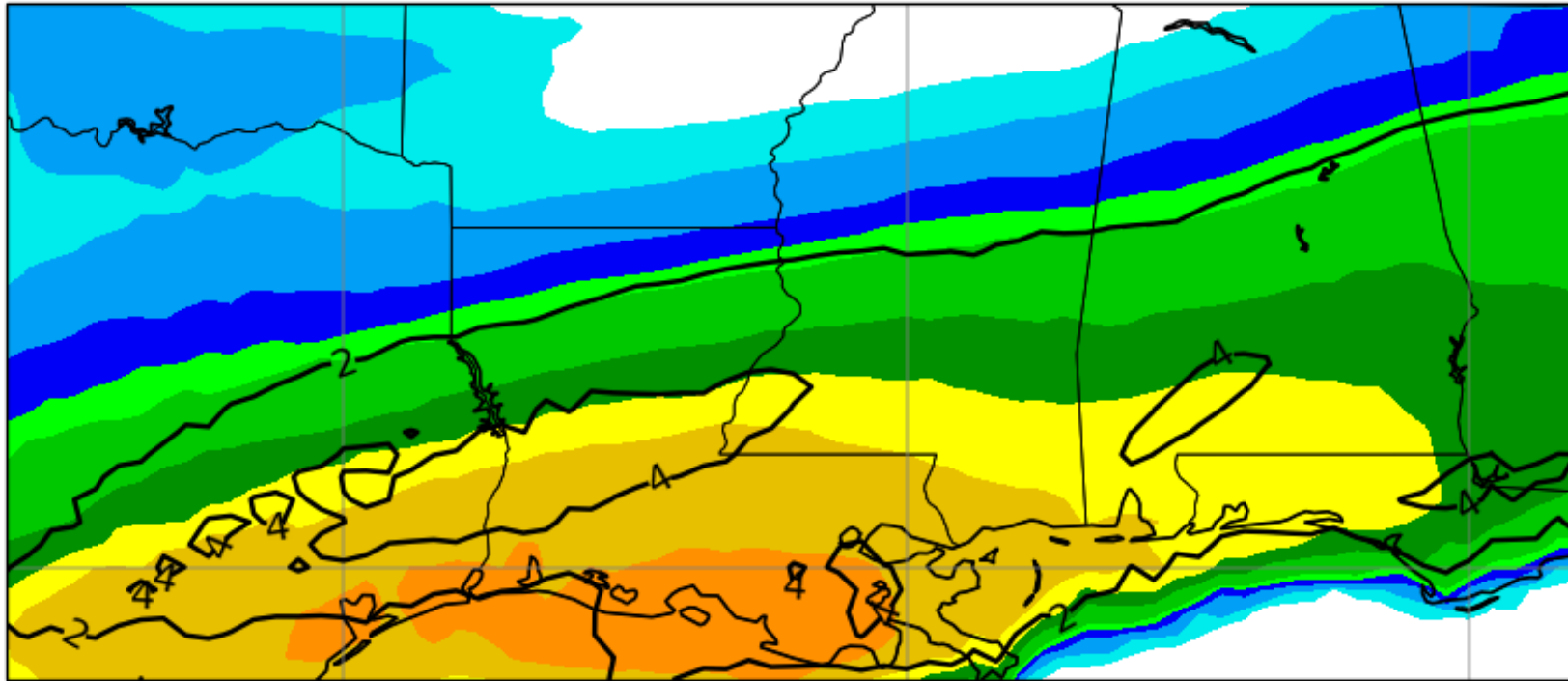
G-IV samples the second system north of Hawaii and the associated AR

NCEP GFS IVT ($\text{kg m}^{-1} \text{s}^{-1}$; shaded), IVT Vector, and SLP (hPa; contours)
Initialized: 0000 UTC 01/31/2025 IOP 11: F-048: Valid: 0000 UTC 02/02/2025



East Coast Example

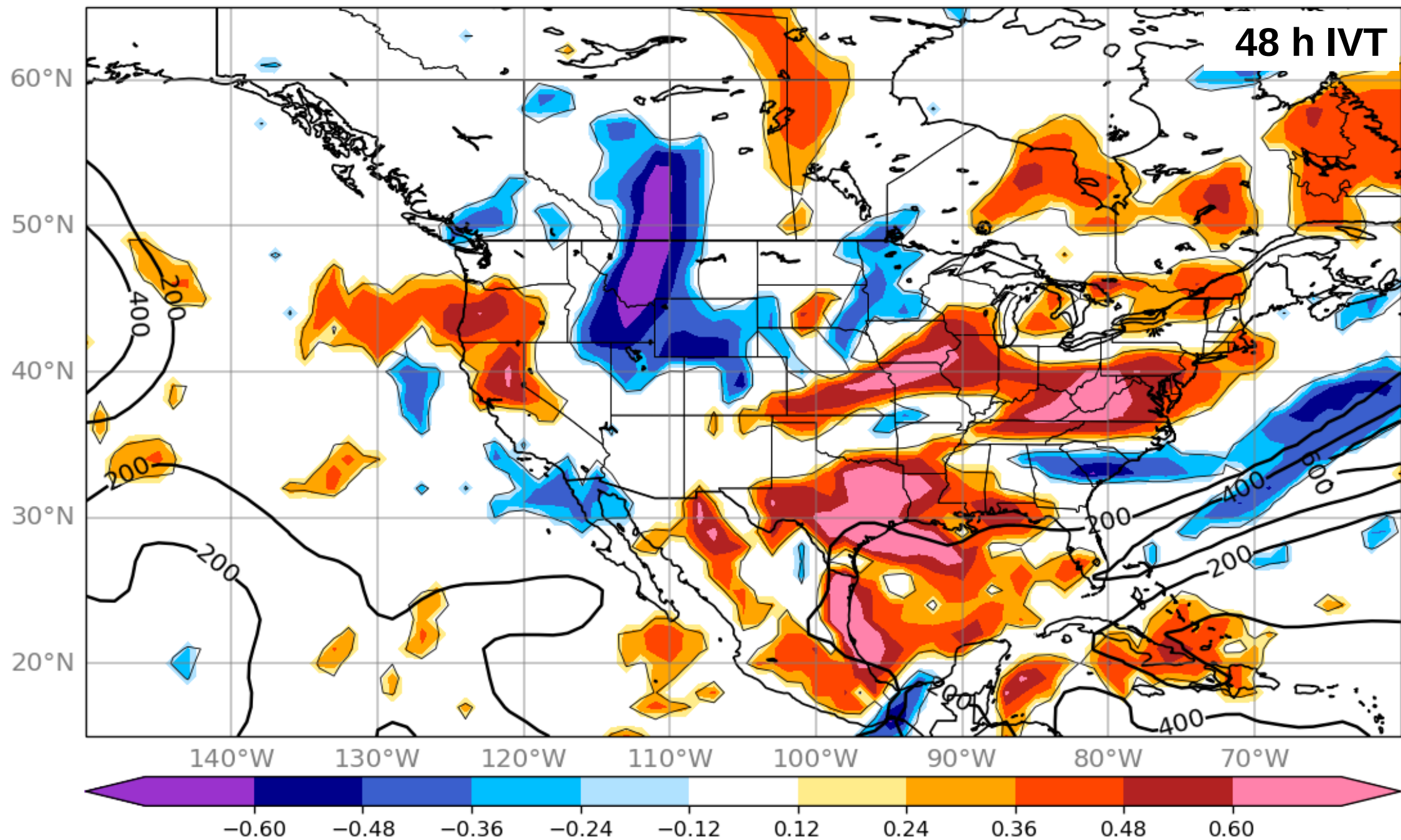
2025011900 48-72 hour Precipitation, 0.666 of variance



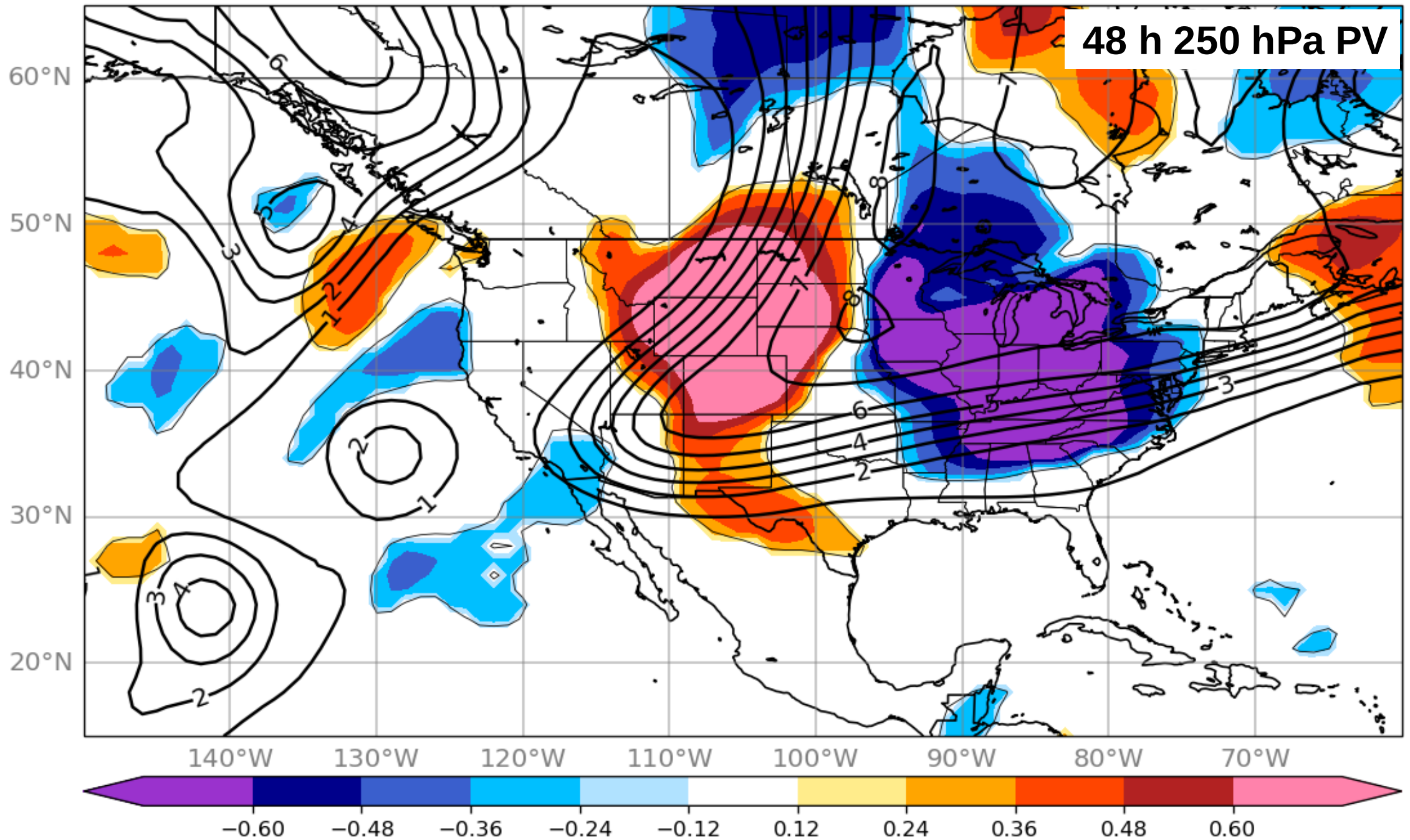
Frozen precipitation between 0000 UTC 21 Jan. and 0000 UTC 22 Jan. based on the ECMWF forecast initialized 0000 UTC 19 January.

Positive values of the metric are associated with more frozen precipitation in Southeast Texas and central Louisiana.

2025011900 F048 IVT, precipitation PC (2025012100 - 2025012200)

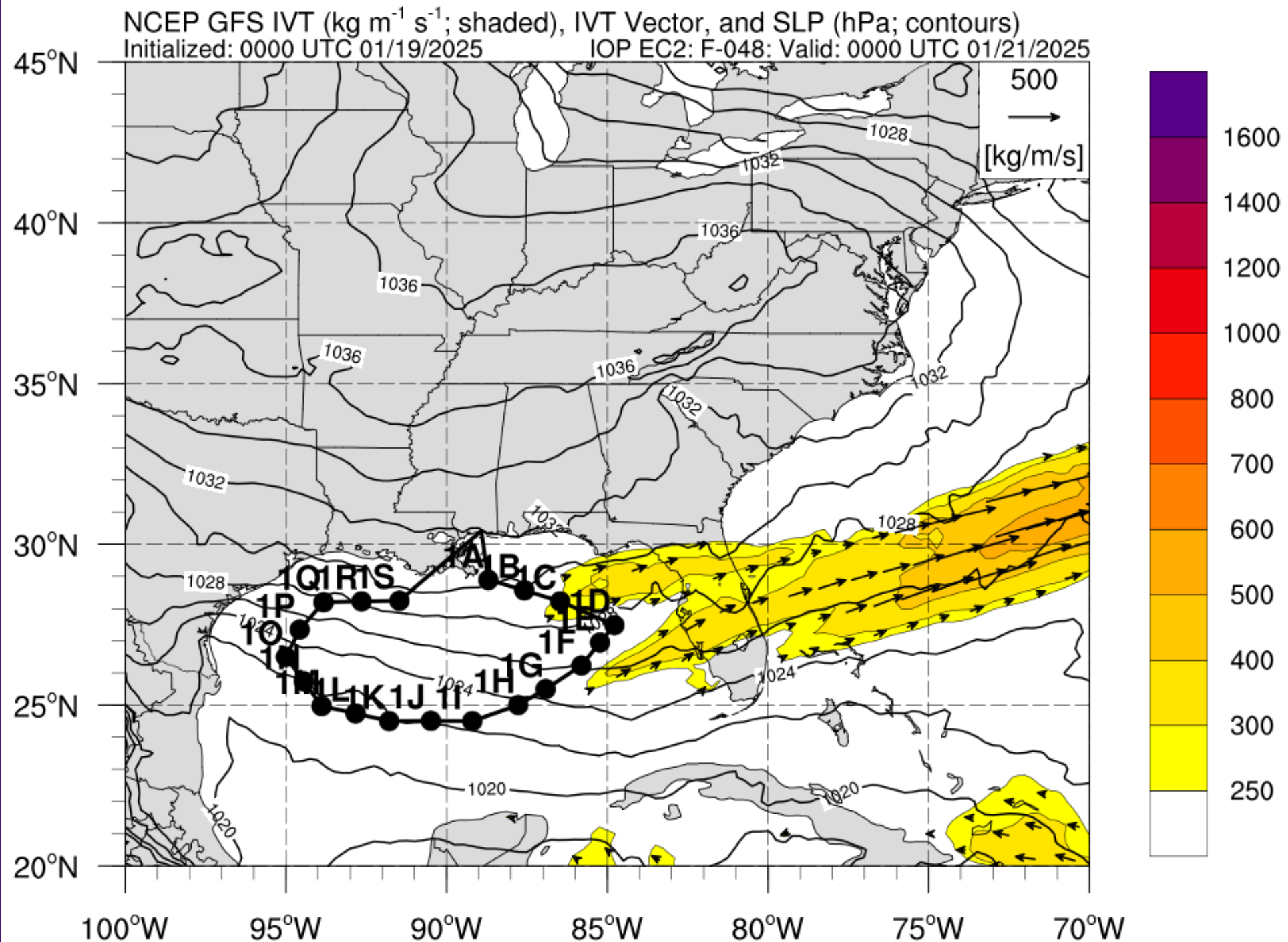


2025011900 F048 250 hPa PV, precipitation PC (2025012100 - 2025012200)



C-130 uses "A66"
track, which
samples western
Gulf of Mexico
sensitive region.

Difficult to draw
custom tracks
due to increased
flight traffic.



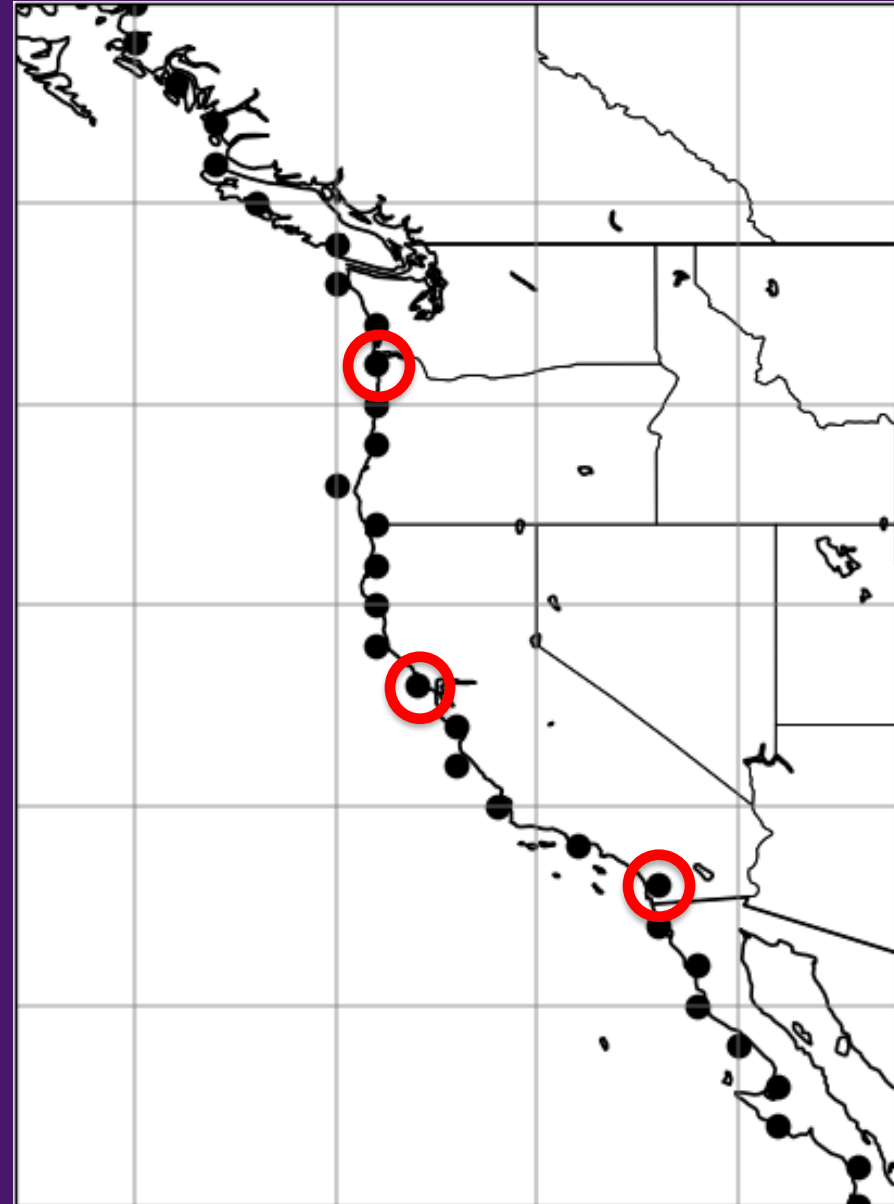
Introduction

- These sensitivity calculations are done on a case-by-case basis, but it has been hard to obtain systematic results because:
 - Metrics change
 - Inconsistent time periods
- Want to assess climatological sensitivity for landfalling AR forecasts in a consistent manner
 - Could be used to guide future observation deployments (i.e., G550s)



Methods

- Identify AR 2+ events for three locations along US West Coast from 2017-2024
 - San Francisco (49 cases)
 - Columbia River (117 cases)
 - Orange County (13 cases)
- ECMWF ensemble forecasts initialized 96 h prior to max. IVT, obtained from TIGGE database
- Metric: EOF decomposition of ensemble IVT landfall

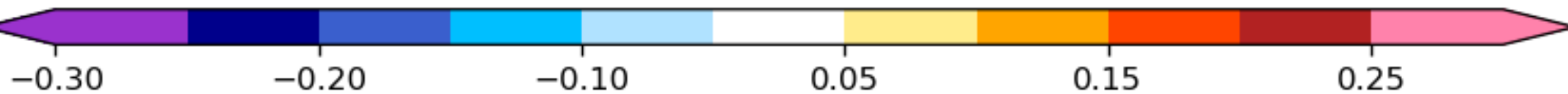


250 hPa PV

96 h

60°N
50°N
40°N
30°N
20°N

130°E 140°E 150°E 160°E 170°E 180°W 170°W 160°W 150°W 140°W 130°W 120°W

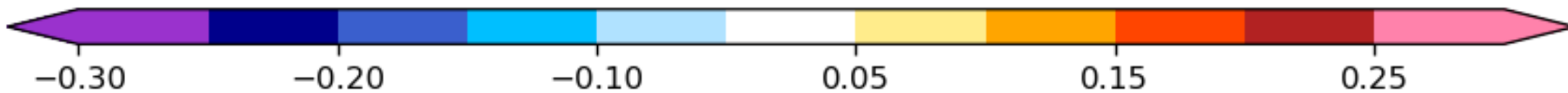


250 hPa PV

72 h

60°N
50°N
40°N
30°N
20°N

130°E 140°E 150°E 160°E 170°E 180°W 170°W 160°W 150°W 140°W 130°W 120°W

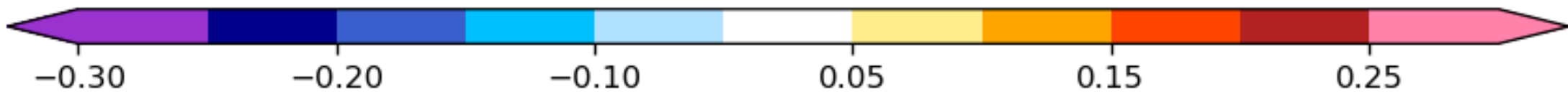


250 hPa PV

48 h

60°N
50°N
40°N
30°N
20°N

130°E 140°E 150°E 160°E 170°E 180°W 170°W 160°W 150°W 140°W 130°W 120°W

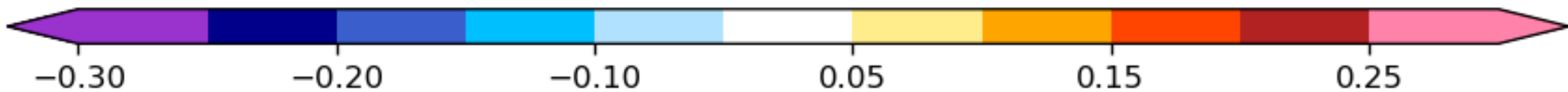


250 hPa PV

24 h

60°N
50°N
40°N
30°N
20°N

130°E 140°E 150°E 160°E 170°E 180°W 170°W 160°W 150°W 140°W 130°W 120°W



San Francisco

48 h

60°N
50°N
40°N
30°N
20°N

130°E 140°E 150°E 160°E 170°E 180°W 170°W 160°W 150°W 140°W 130°W 120°W

-0.30

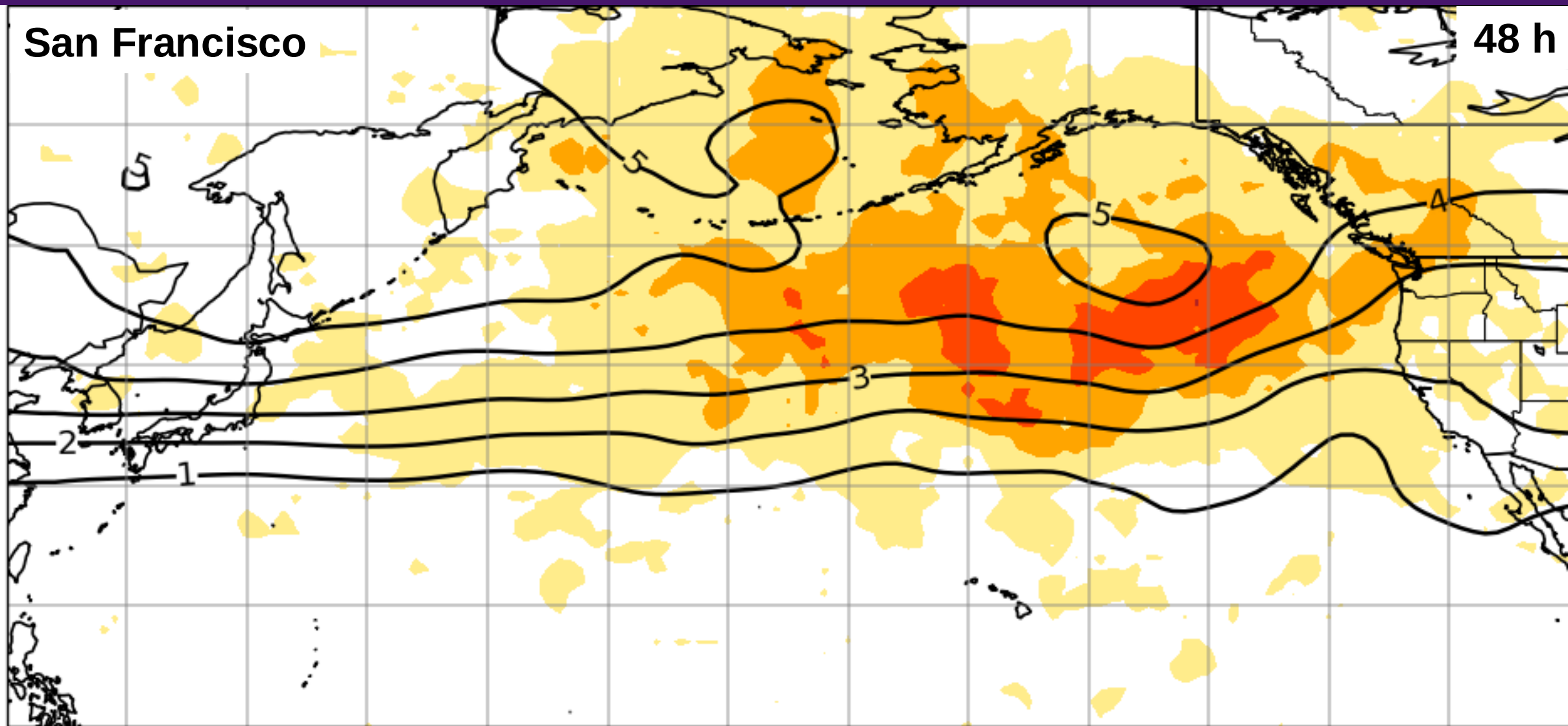
-0.20

-0.10

0.05

0.15

0.25



Orange County

48 h

60°N
50°N
40°N
30°N
20°N

130°E 140°E 150°E 160°E 170°E 180°W 170°W 160°W 150°W 140°W 130°W 120°W

-0.30

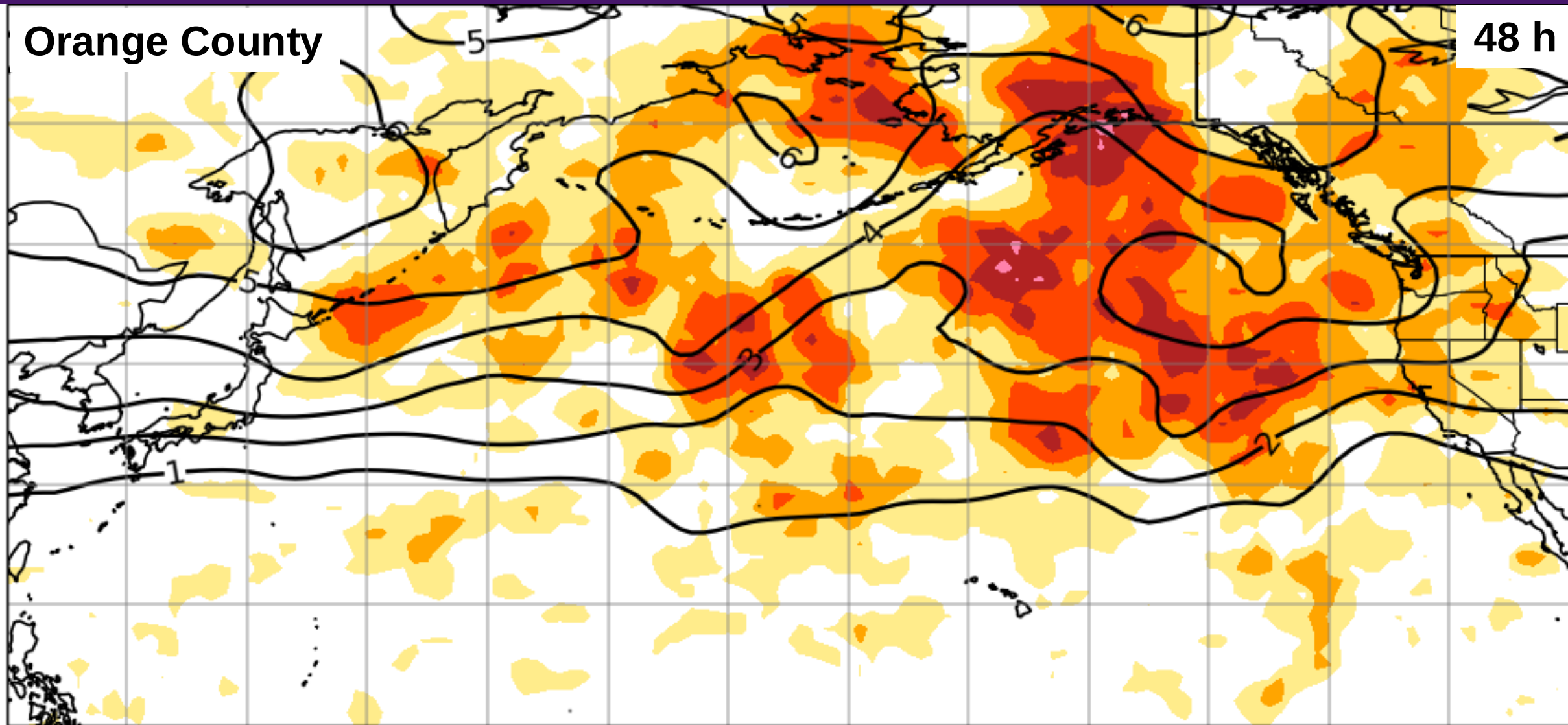
-0.20

-0.10

0.05

0.15

0.25

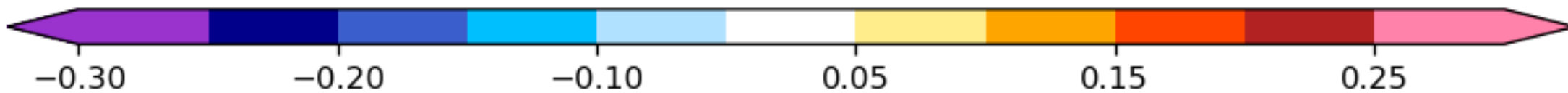


Columbia River

48 h

60°N
50°N
40°N
30°N
20°N

130°E 140°E 150°E 160°E 170°E 180°W 170°W 160°W 150°W 140°W 130°W 120°W



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 various kinds of 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 use sensitivity climatology to guide future observational deployments, such as buoys and second G-550

Websites

- Eastern Pacific:
 - https://www.atmos.albany.edu/facstaff/torn/AR-Sens/ECMWF/ar_sens.php
- East Coast:
 - https://www.atmos.albany.edu/facstaff/torn/AR-East/ECMWF/ar_sens.php