NCEP Ensemble Sensitivity Tools with GEFS and CMC products for Atmospheric River Reconnaissance

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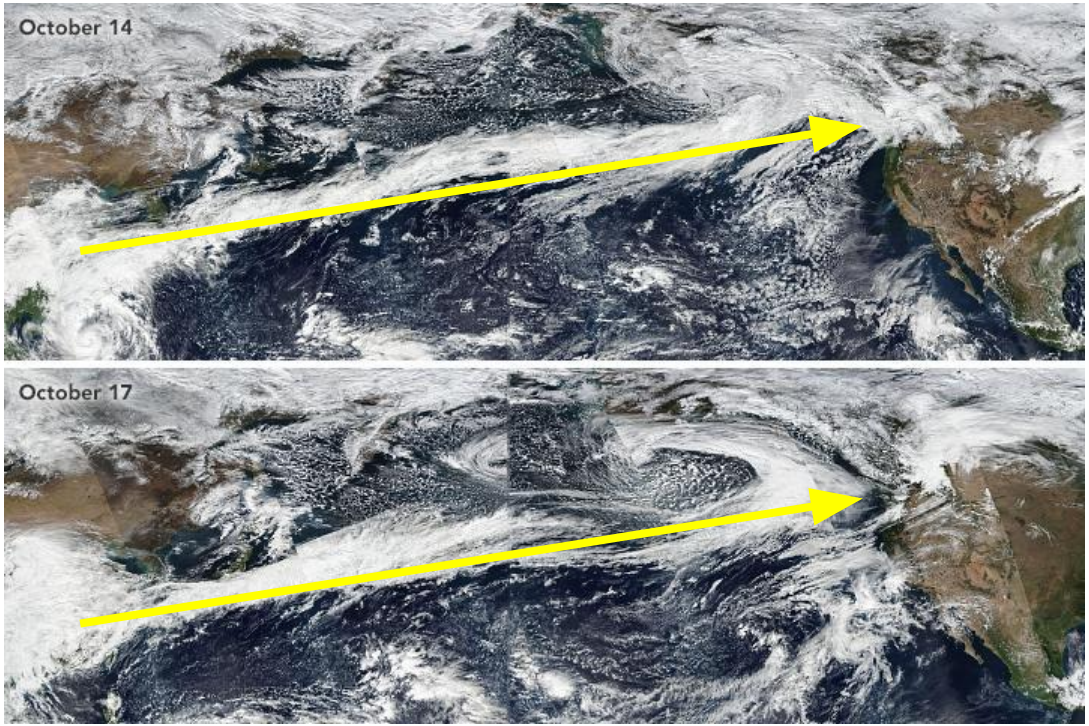
NATIONAL WEATHER SERVICE

Atmospheric River

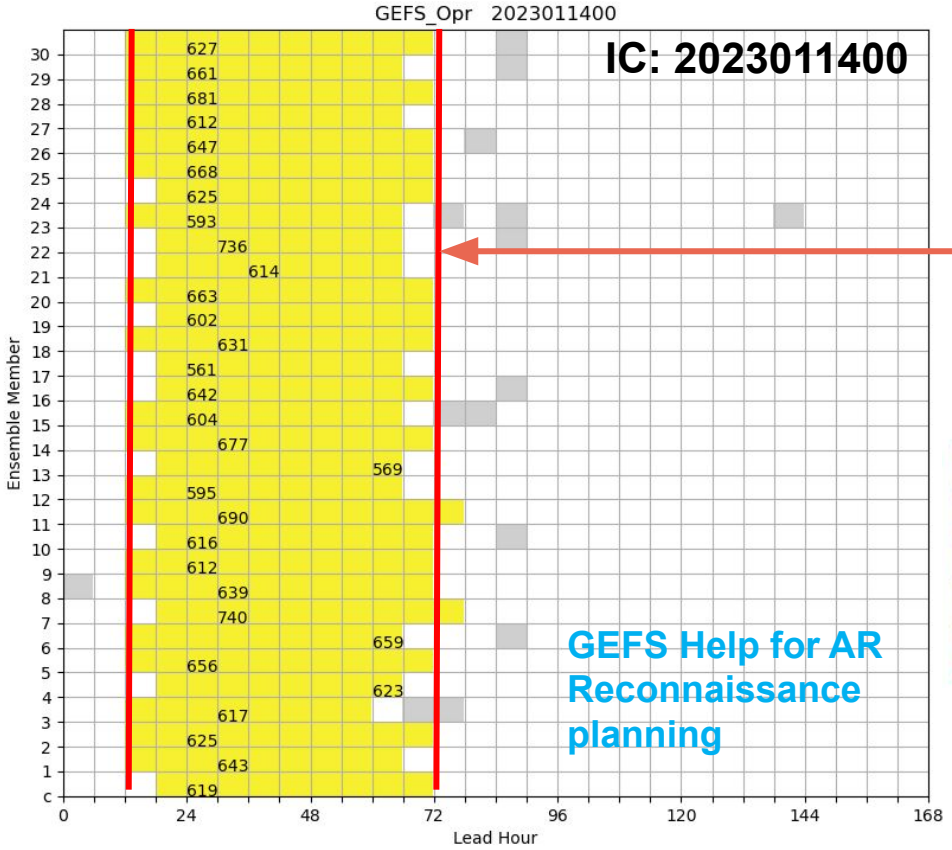
An **atmospheric river** (**AR**) is a narrow corridor or filament of concentrated moisture in the atmosphere

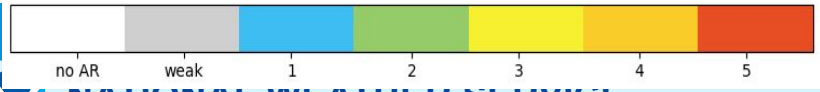


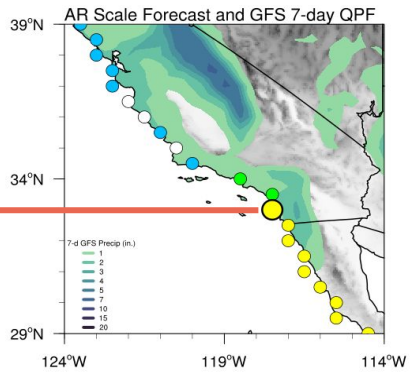
Atmospheric rivers (ARs) are the main water resources in many coastal regions in the western United States.

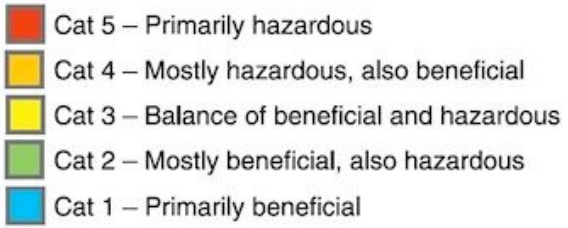
Courtesy Wikipedia: Composite satellite photos of an atmospheric river connecting Asia to North America in October 2017

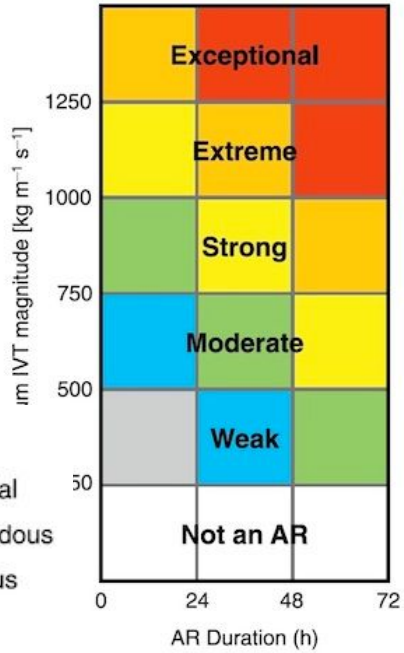
AR scale (33N 117.5W) from GEFS 2023011400 opr forecast







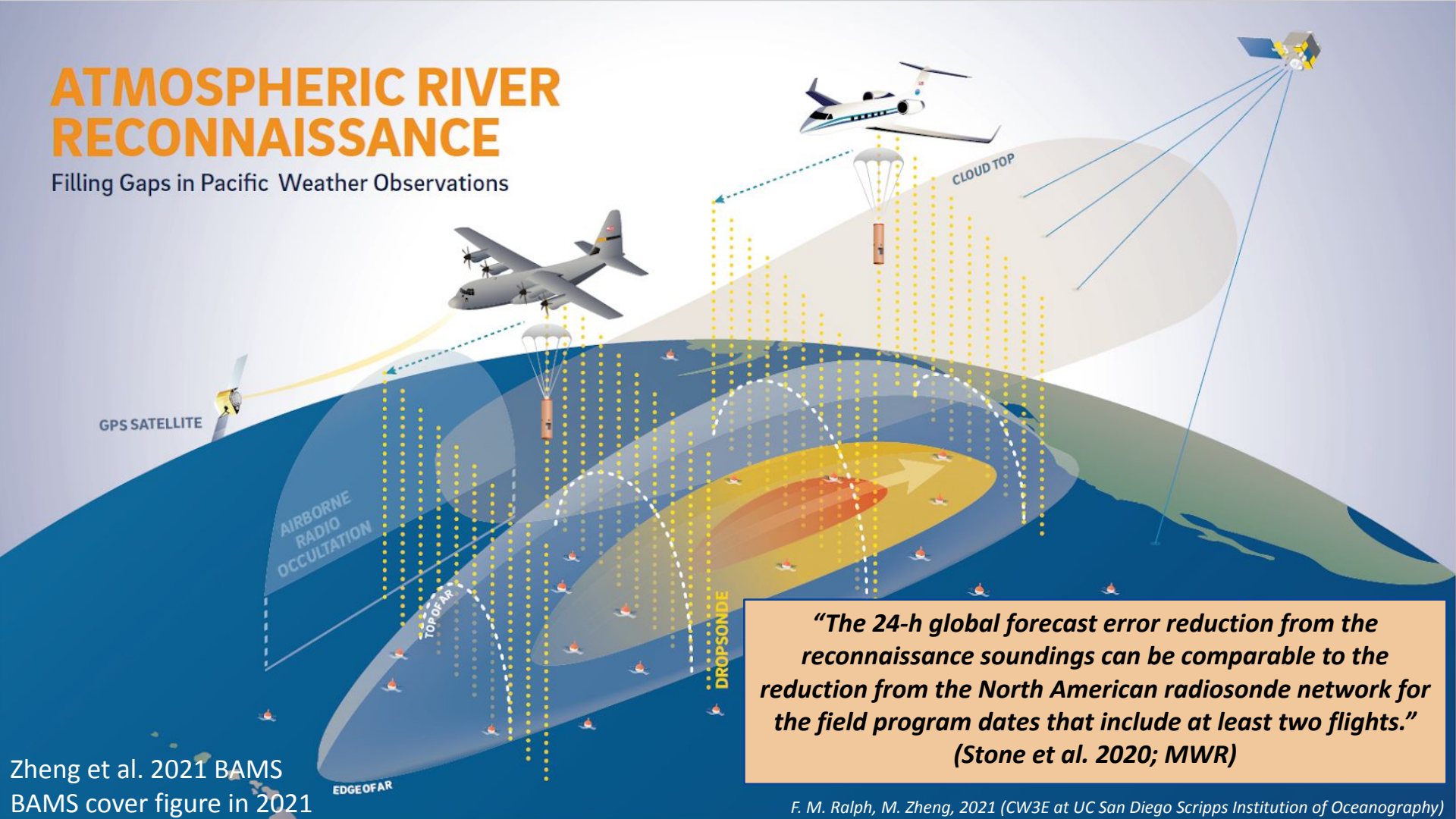




The AR scale categorizes each atmospheric river event at a given location by the peak value of integrated water vapor transport (IVT) and the duration of minimal AR conditions (IVT of at least 250 kg $m^{-1}s^{-1}$). Ralph et al. (BAMS 2019)

Operational goals for Atmospheric River Reconnaissance at NCEP

- Overarching goal: improve operational predictions of land-falling atmospheric rivers and their impacts in the western U.S.
- Enhance the use of aircraft observations in modeling and data assimilation
- Design and develop ensemble based objective sampling strategies
- Run (near) real time data denial experiments
- Improve verification techniques



"The 24-h global forecast error reduction from the reconnaissance soundings can be comparable to the reduction from the North American radiosonde network for the field program dates that include at least two flights." (Stone et al. 2020; MWR)

Zheng et al. 2021 BAMS
BAMS cover figure in 2021

F. M. Ralph, M. Zheng, 2021 (CW3E at UC San Diego Scripps Institution of Oceanography)

Ensemble sensitivity for Atmospheric River Reconnaissance (ARR)

- Apply ensemble based method and products to give better guidance for AR Recon flight track, using multi-model ensembles (**GEFS and CMC**)
- Identify upstream regions/features exhibiting high ensemble forecast variability, with the goal of reducing short-range U.S. West Coast precipitation forecast uncertainty
- Using targeted metric:
  - **Precipitation**
  - **IVT** (vertically **i**ntegrated water **v**apor **t**ransport)
  - **MSLP**
  - **Geopotential Height**
  - **Temperature-850hPa**
- Select targeted region:
  - **Polygon**: using maximum SD
  - **Box**: using Empirical Orthogonal Function (EOF)
- Extend the application to WSR (Gulf and East Coast)

Ensemble Sensitivity

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

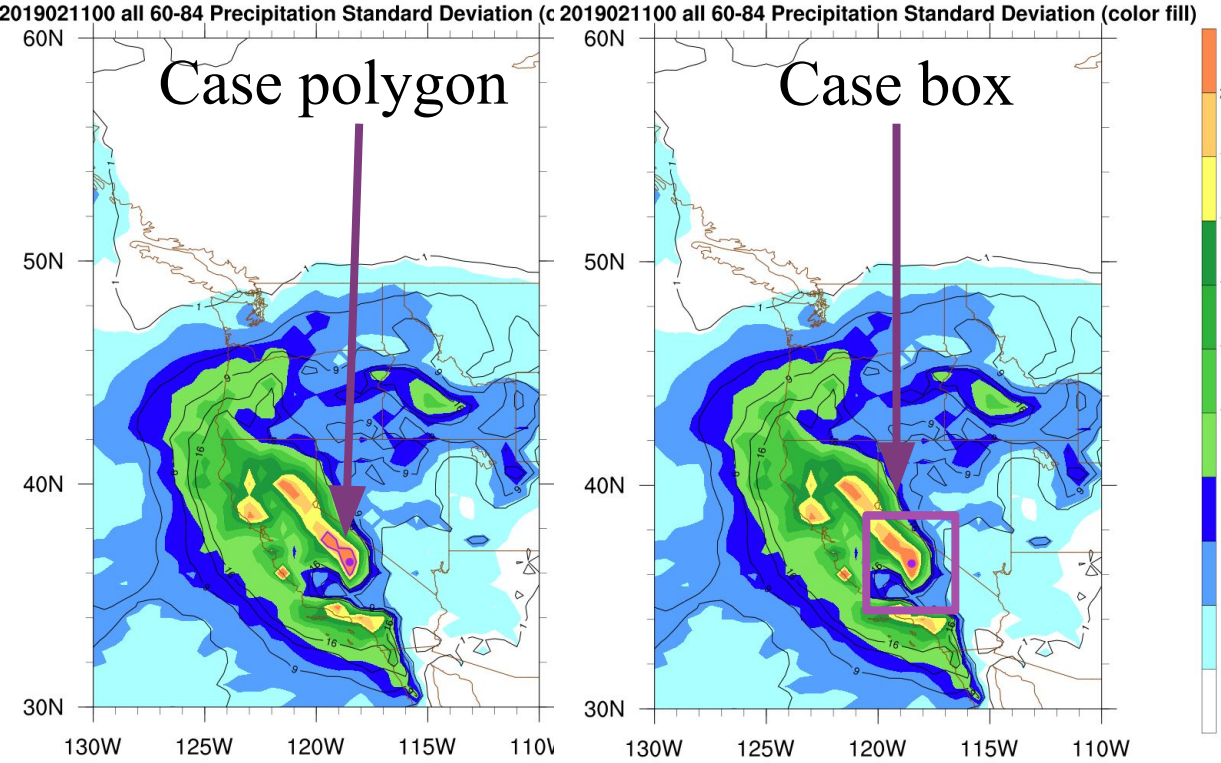
Ancell and Hakim 2007, Torn and Hakim 2008

- 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 forecast metric
  - Independent variable is ensemble estimate of state variable at a location at an earlier time
  - Avoids many of the problems of tangent linear model because uses non-linear forecast trajectories

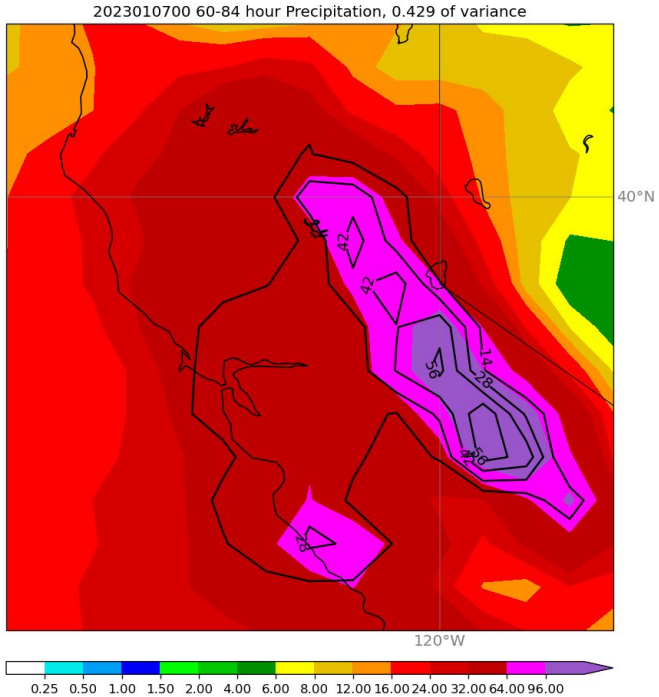
Application for Hurricane, ARR and WSR
(Winter Season Reconnaissance)

From: Ryan Torn
Univ Albany

Metrics: Precipitation (standard Deviation or EOF)

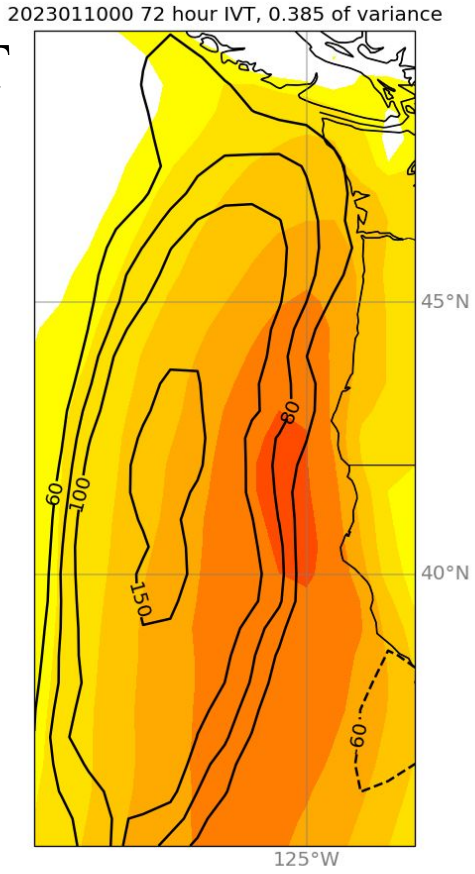


Case EOF

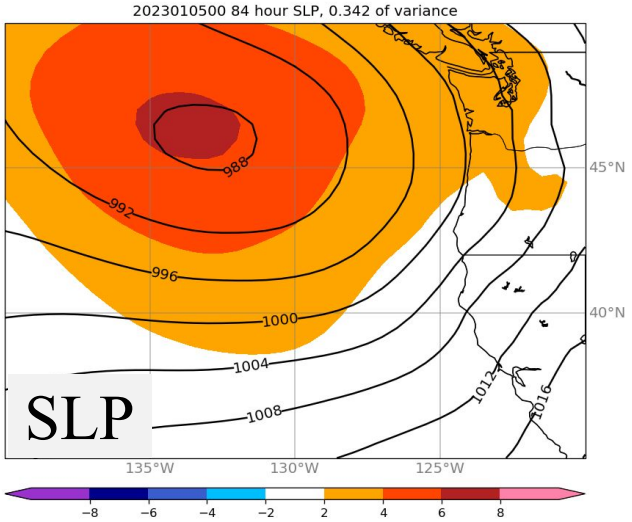


Metrics: IVT/SLP/GHT/850T

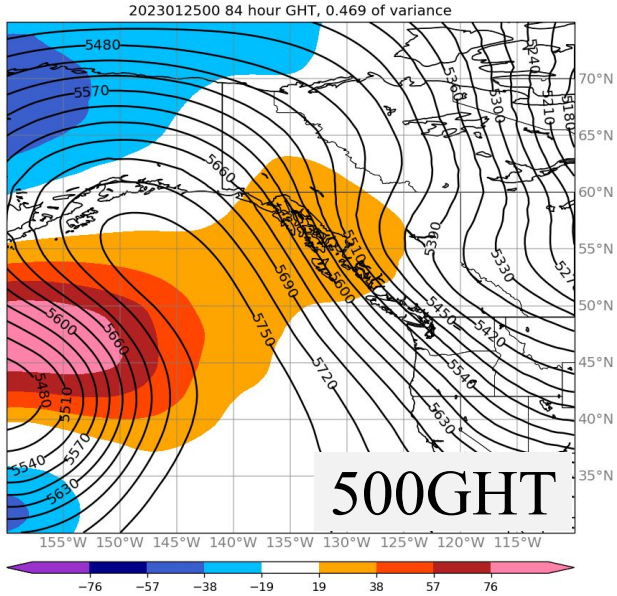
IVT



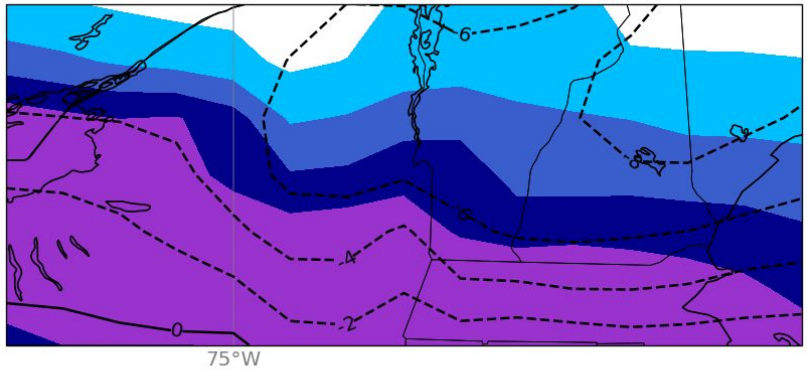
SLP



500GHT



850T



Application of ensemble sensitivity (usually 48 hour ahead for planning)

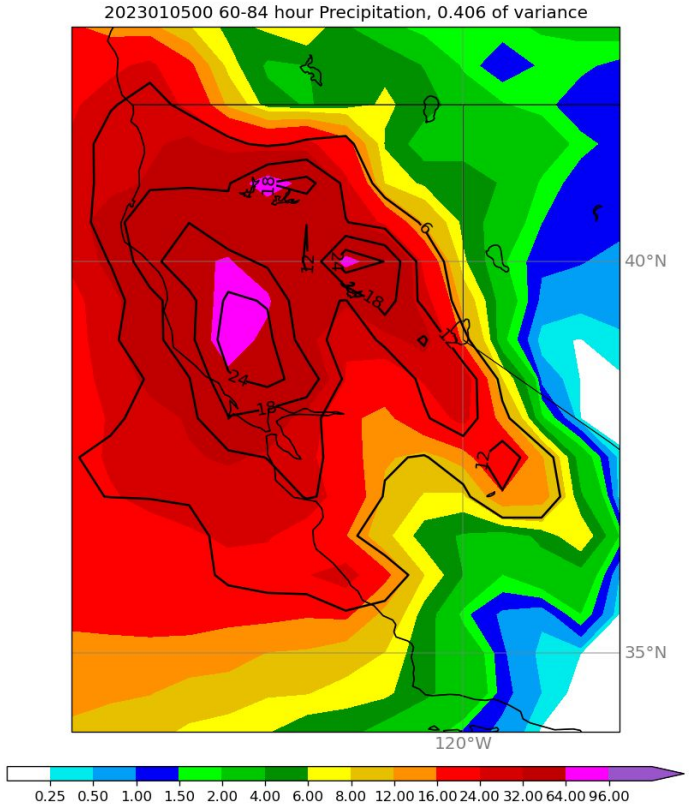
Case: On 5 Jan 2023

ARR 2023 flight 00Z 7 Jan

(IOP 7 – first IOP with both G-IV and AF in 2023)

Using precipitation metrics: 12Z 7 Jan to 12Z 8 Jan

Init: 00Z 05 Jan - GEFS and CMC Precip and EOF: 12Z 07 Jan to 12Z 08 Jan



Color fill: ensemble mean accumulated precipitation.

Contours: leading EOF (40.6%) pattern anomalies.

This pattern suggests leading mode of variability is increasing/decreasing precipitation amounts over CA, with positive values of the metric being associated with more precipitation in CA.

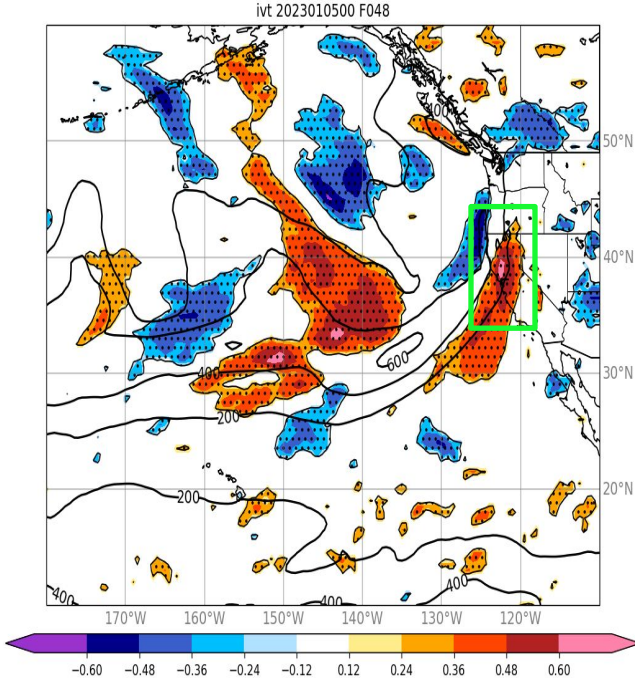
Focus on Sensitivity of Precipitation to fields on 0000 UTC 7 January.

Plan on 5 Jan 2023

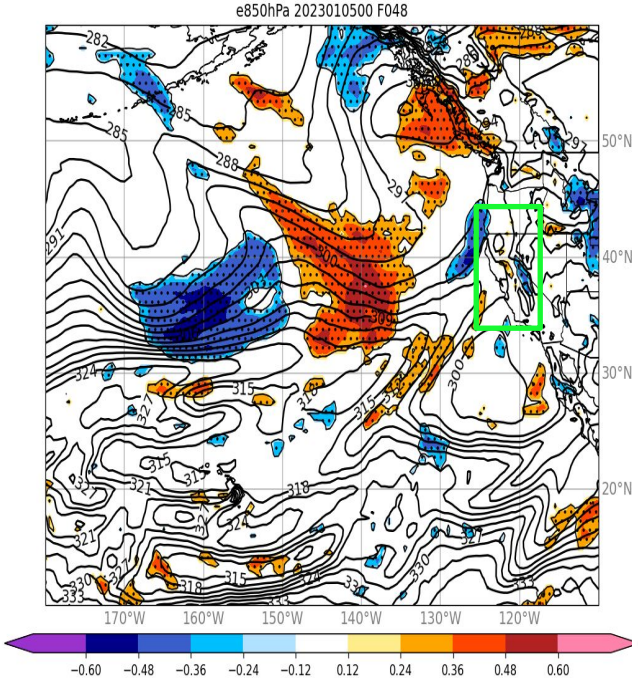
For: 00Z 07 Jan IVT/ 850 hPa Theta-e/250 hPa PV sensitivity (48 hr)

(from precipitation EOF metrics, based on GEFS/CMC real-time products)

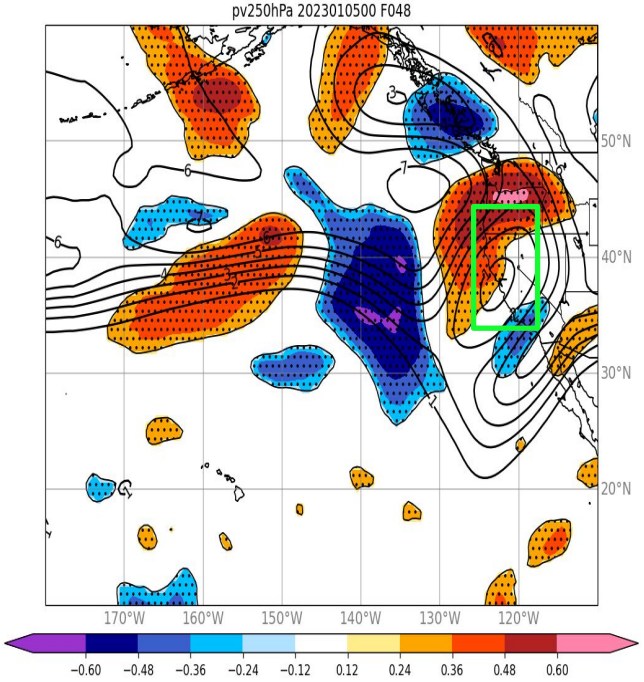
IVT



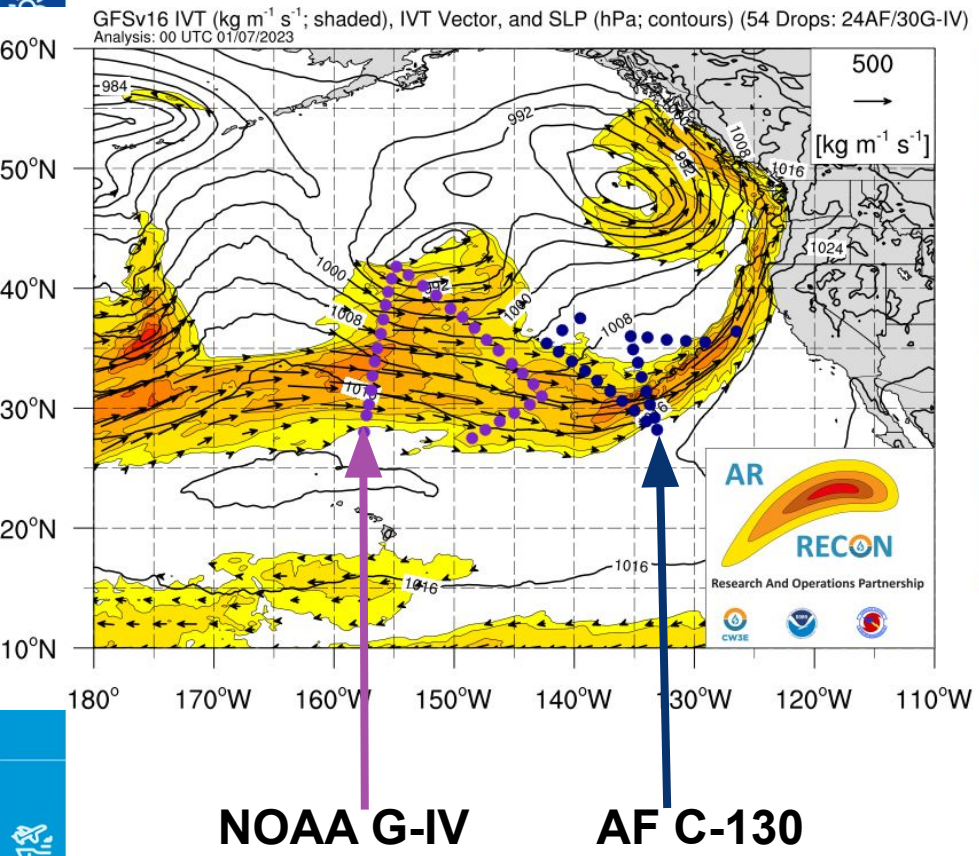
Theta-e 850hPa

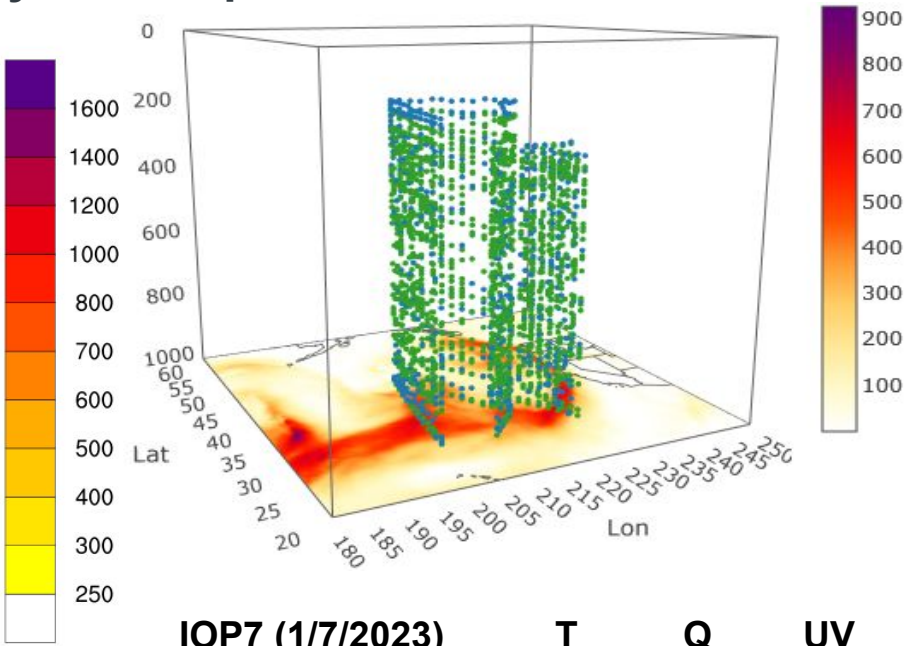


PV 250 hPa



IOP 7 (00Z 7 Jan 2023) flight summary and dropsonde data in GFS DA





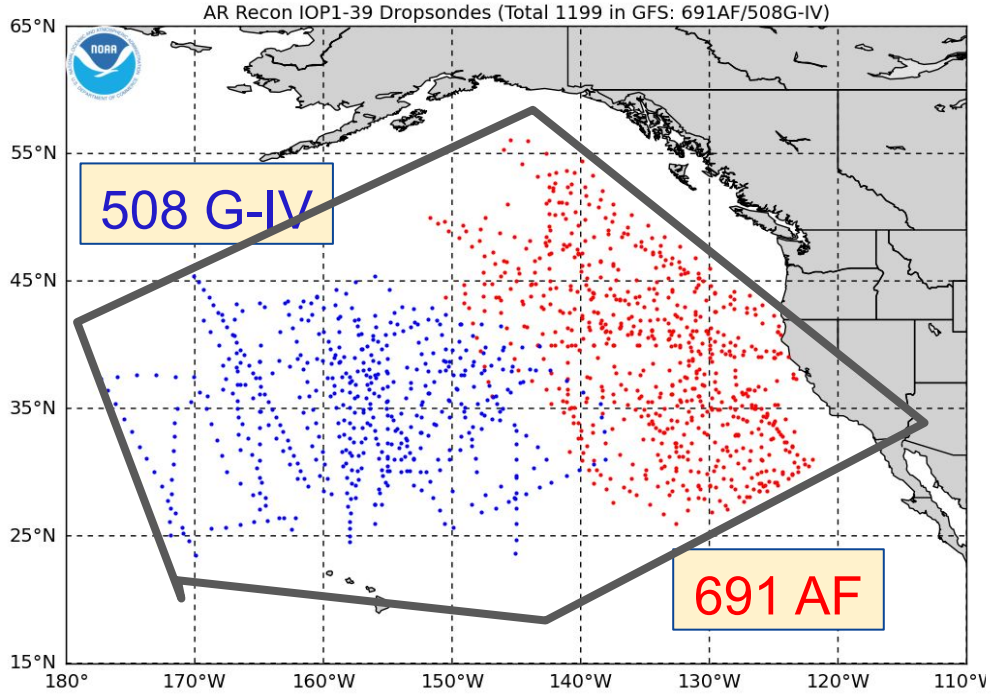
IOP7 (1/7/2023)	T	Q	UV
Data Assimilated	1562	1233	1115
Data Monitored	55	321	0
Data Rejected	0	0	0
Total counts	1617	1554	1115

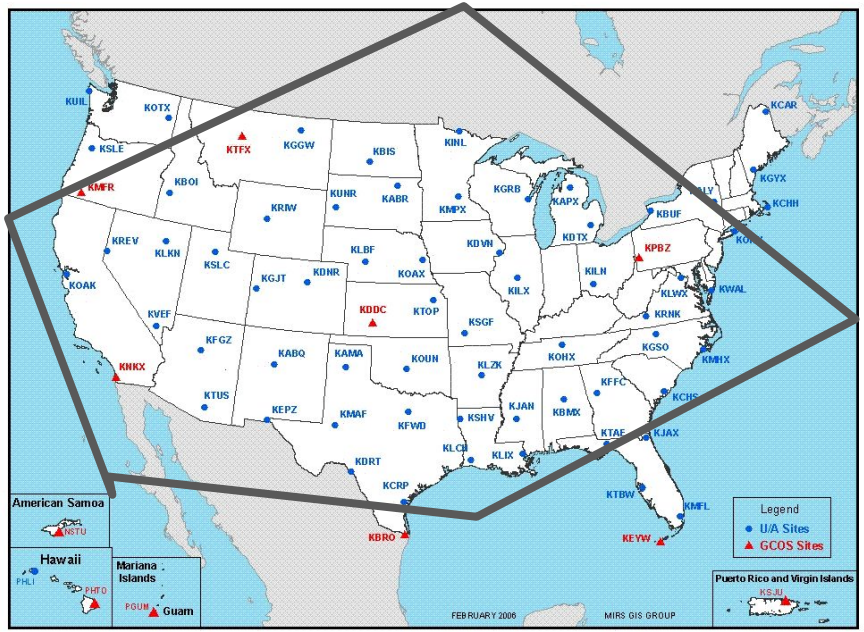
AR Recon Campaign 2022-2023

39 AR IOPs (5 Nov 2022 – 14 Mar 2023)

First (longest) AR Sequence: 13 flights (6-18 Jan 2023)

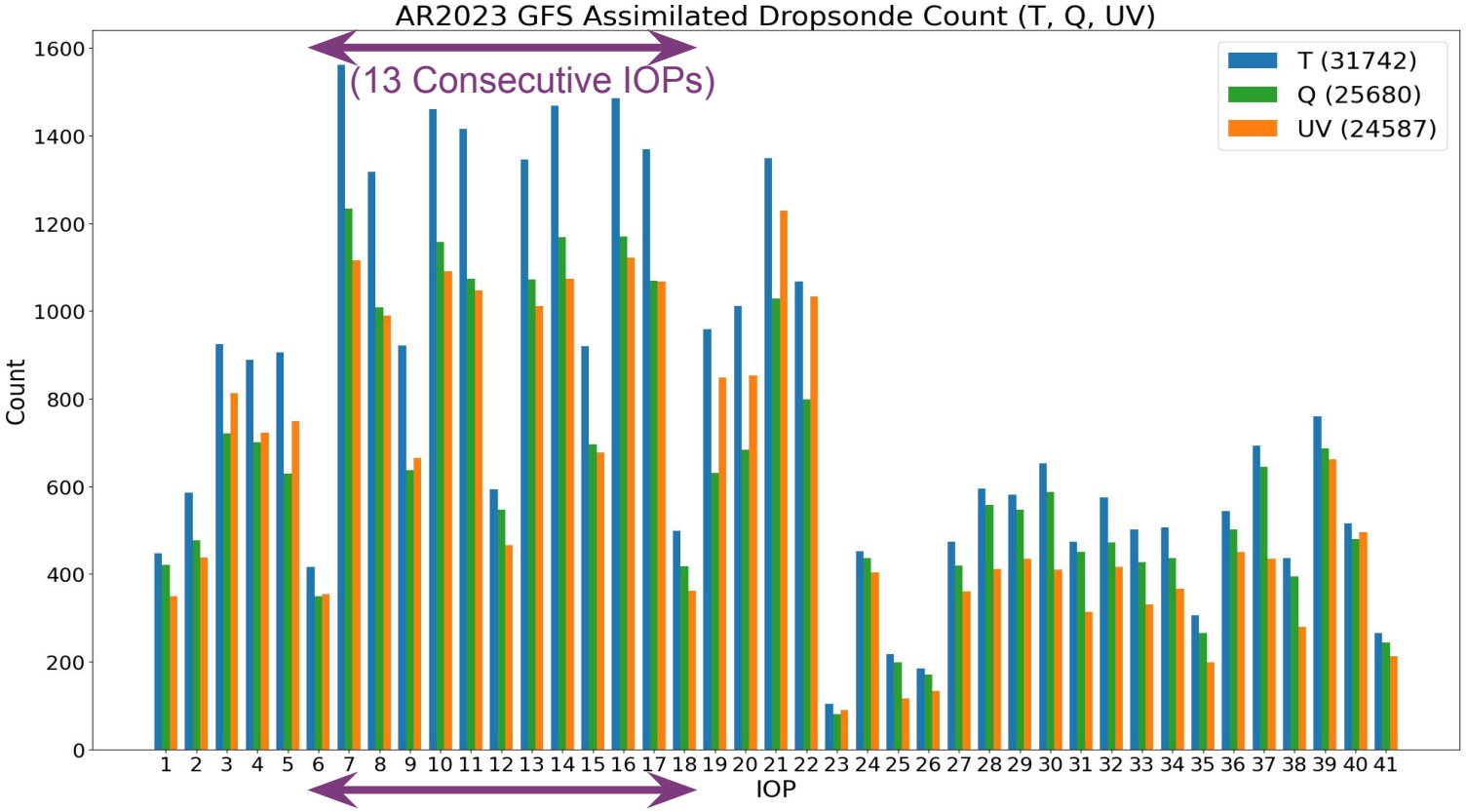
3 WSR IOPs (3, 4, 14 Mar 2023)





AR Recon Dropsondes Counts

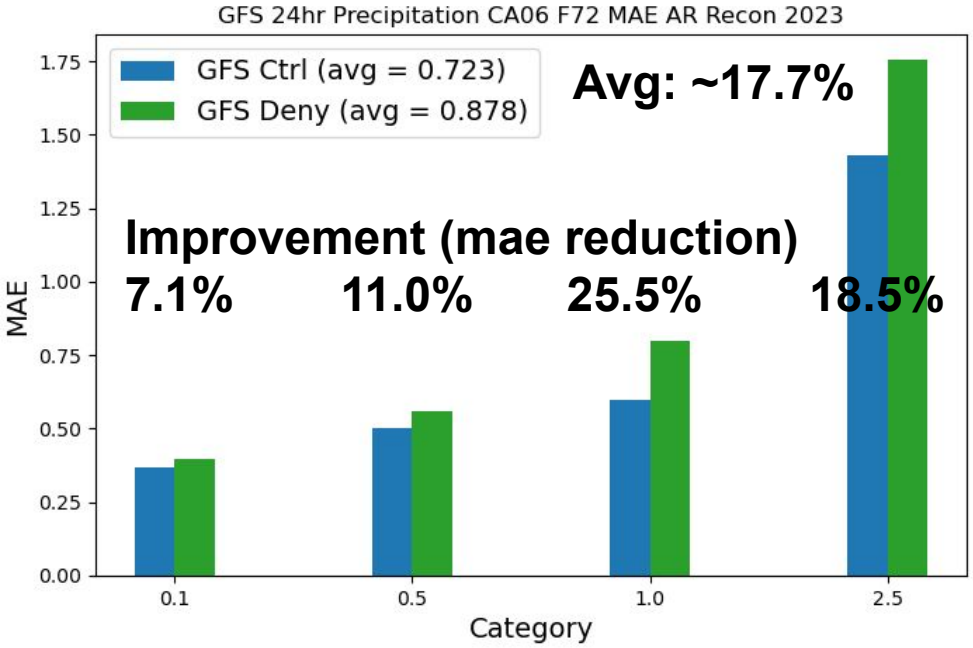
2023: 39 AR IOPs and 2 WSR TESTS (40-41)

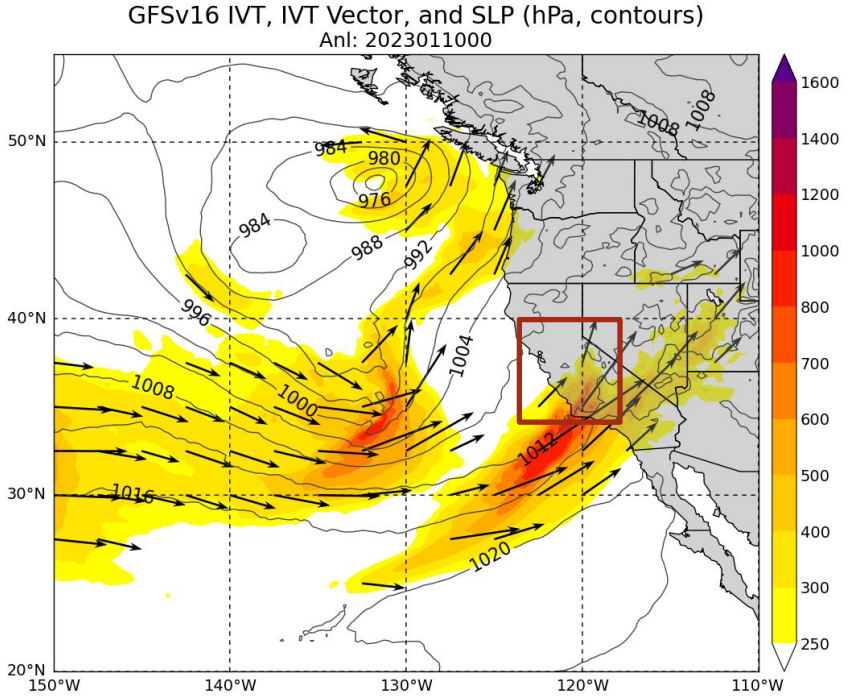


IOP 6-18

F48-F72 precipitation MAE

34N-40N,124W-118W





F48 MAE Improvement (%) 30N-45N,130W-115W	IVT	IWV	MSLP
	-4.5	-6.9	-10.9

Positive impacts from the assimilated **dropsonde obs** for CA precipitation, IVT structures, and the field of MSLP, wind and moisture.

Summary and Future Plan

- GEFS products are important and useful for AR Recon field campaign.
- 66 GEFS/CMC ensemble sensitivity products were prepared and submitted for the planning of 2022-2023 winter ARR/WSR (AR IOP 1-39; & 2 WSR IOPs).
- The metric of precipitation has been used mostly, with the addition of IVT, MSLP and Temperature-850hPa.
- The dropsonde data from AR Recon help improve GFS analysis and forecast for moisture, wind, and AR landfall, and the precipitation forecast over the U.S. West.
- GEFS/CMC ensemble sensitivity tools will replace the current WSR tools when GEFSv13 becomes operational.
- Further enhancements of the sensitivity tools will be tested and implemented for the upcoming AR Recon IOPs.

Thanks for your attention

Acknowledgements: AR Recon Sensitivity Team, especially Ryan Torn

Questions?

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Ensemble Sensitivity for AR Recon

- https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/AR2023ens/

Ensemble Sensitivity for WSR Recon

- https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/WSR2023ens/