Advances and Challenges In Atmospheric River Forecasting

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The “UFS-AR” project

A project funded by the NOAA “Water in the West” appropriation aimed improving forecasting of atmospheric rivers (read: heavy precipitation events).

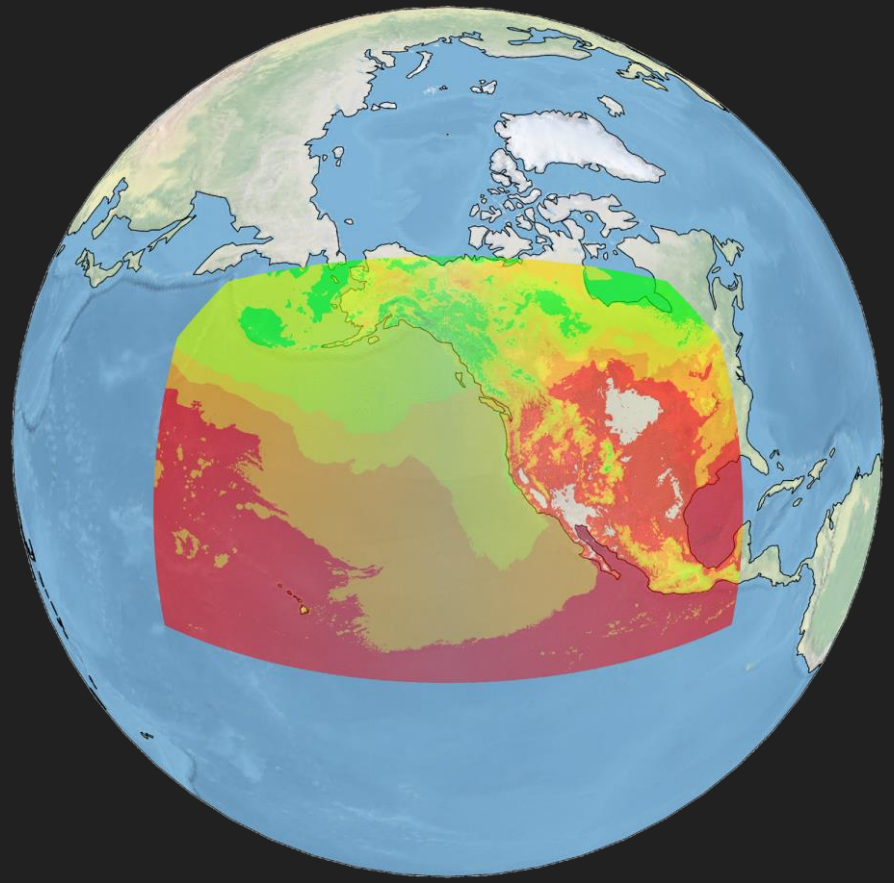
Motivation

- Decision makers need greater lead time, precision on landfall, and accuracy of precipitation estimation.
- Western region forecasters rely upon multiple models to forecast atmospheric rivers.
- NOAA wants to improve atmospheric river forecasts.

Project objectives

- Create a prototype application of the NOAA Unified Forecast System (UFS), dubbed UFS-AR, that improves upon current operational and nonoperational models.
- Evaluate and compare UFS-AR and other AR models for forecasting landfalling ARs and precipitation events over the U.S. West Coast, focusing on winter 2022–2023.
- Conduct testbed forecasting experiment under the Hydrometeorological Testbed, using winter 2022–2023 as a test case.
- Apply social science to assess stakeholder AR forecast experiences.

The “UFS-AR” project



Model configuration (currently under development)

- UFS-based 13-km global model, with 3-km nest over the Pacific and western U.S.
- Data assimilation, including shift from GSI to JEDI.
- Improved/refined model physics suitable for high-res nesting in global model.

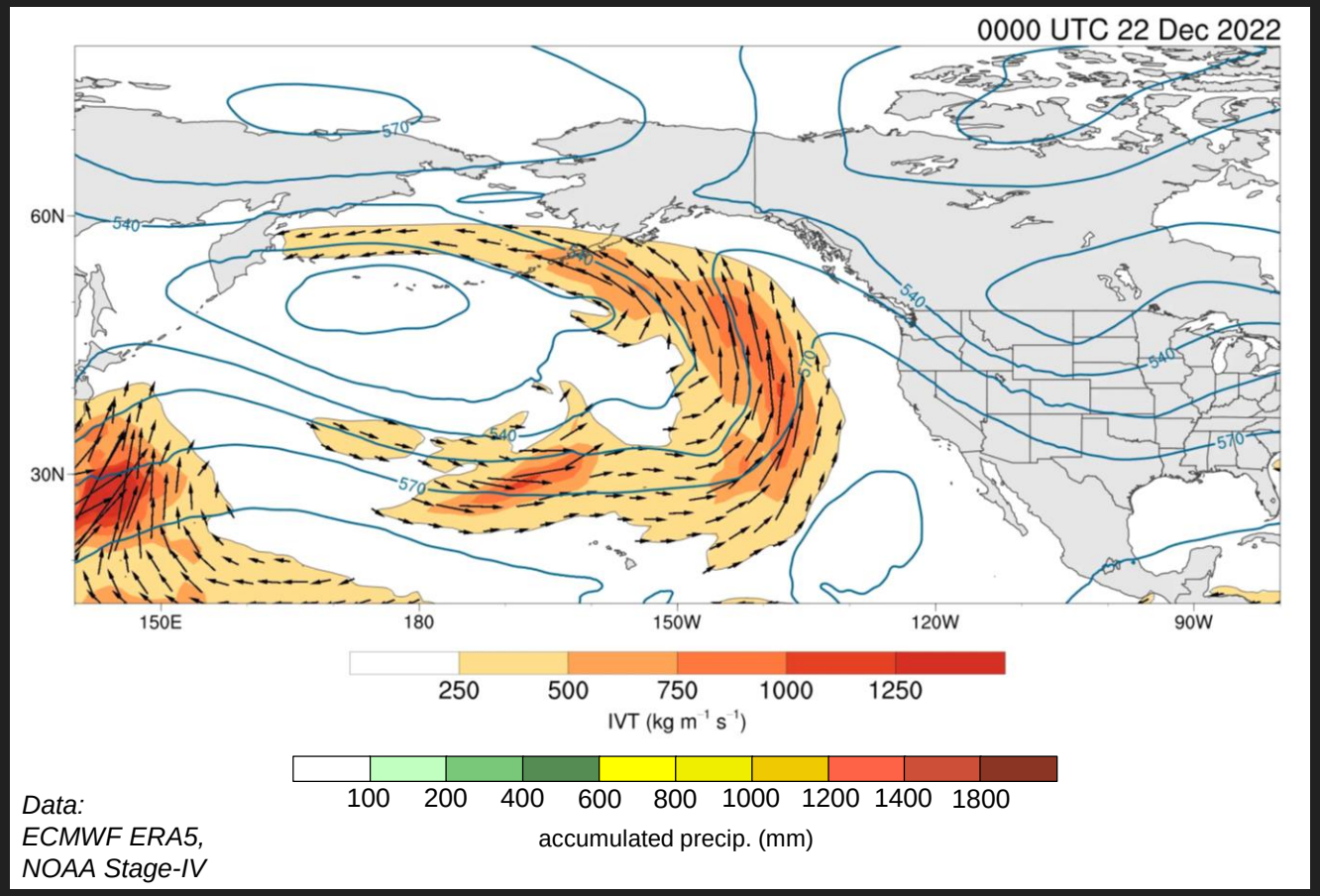
Experimental design

- *Eventually* - Retrospective medium-range (out to +10 days) forecasts for two periods of frequent landfalling ARs and heavy precipitation: Dec–Jan 2022–23; Feb–Mar 2023.
- *Currently* – Prototype forecasts for six selected cases are in progress.

Forecast evaluation/verification for winter 2022–2023

- Evaluate and intercompare forecast skill for various deterministic operational (NOAA GFS, ECMWF IFS) and nonoperational NWP models (UFS-AR prototype, CW3E/Scripps “West-WRF”, NOAA/EMC “AR-AFS”) as well as machine-learning weather models.
- Apply grid-point and object-based methods to evaluate forecasts, focusing on integrated water vapor transport (IVT) and precipitation over the east Pacific/U.S. West Coast.

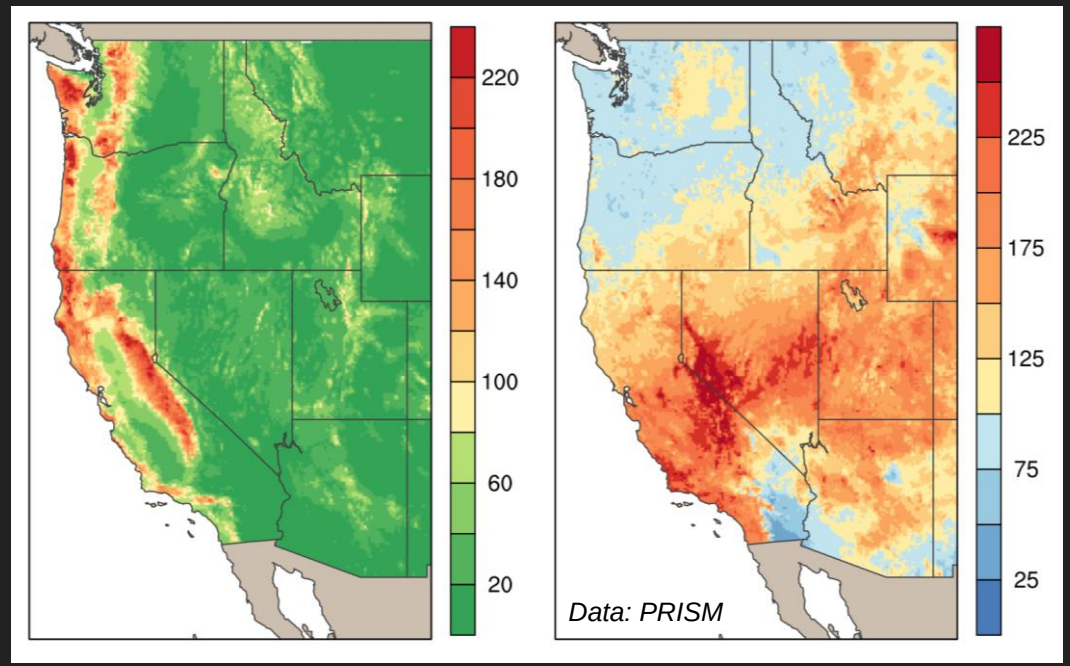
Overview of winter 2022–2023



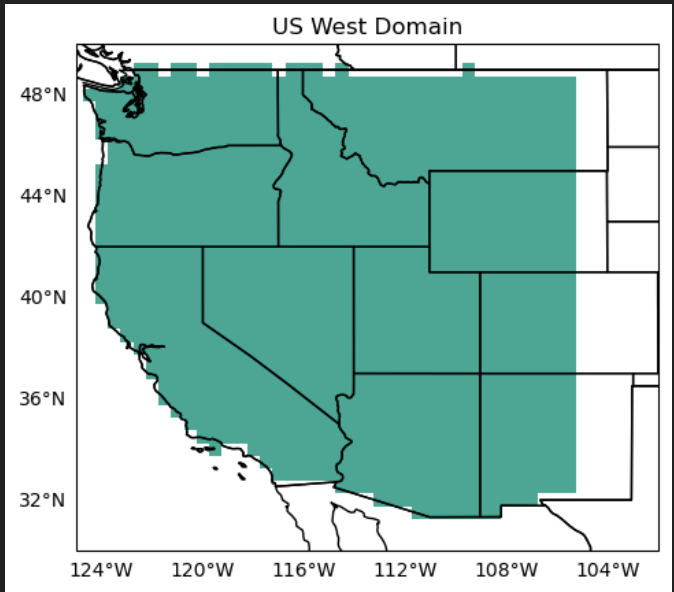
Data:
ECMWF ERA5,
NOAA Stage-IV

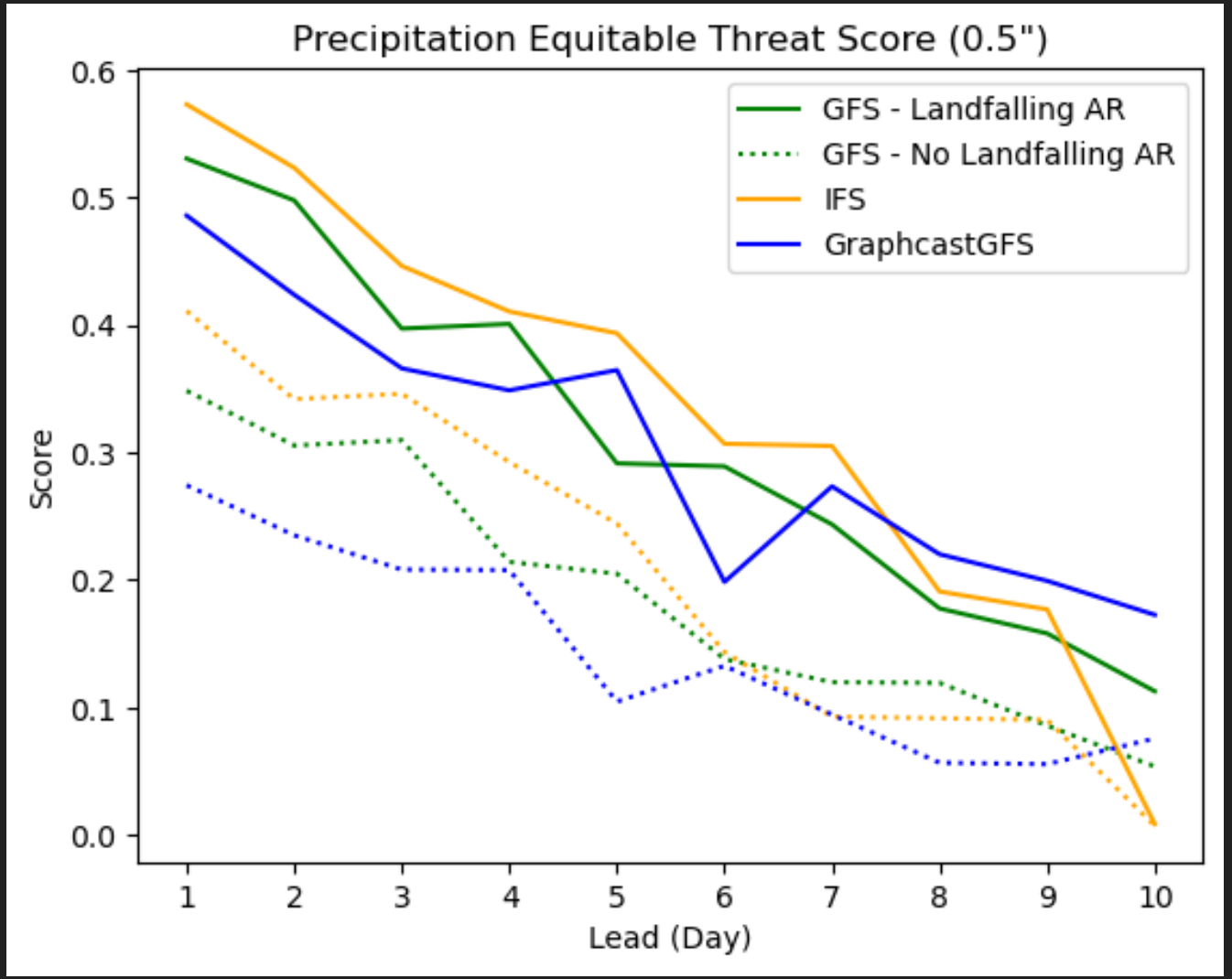
Total precipitation for Nov 2022 – Mar 2023 (cm)

Precipitation as a % of 1982–2021 average



Motivation

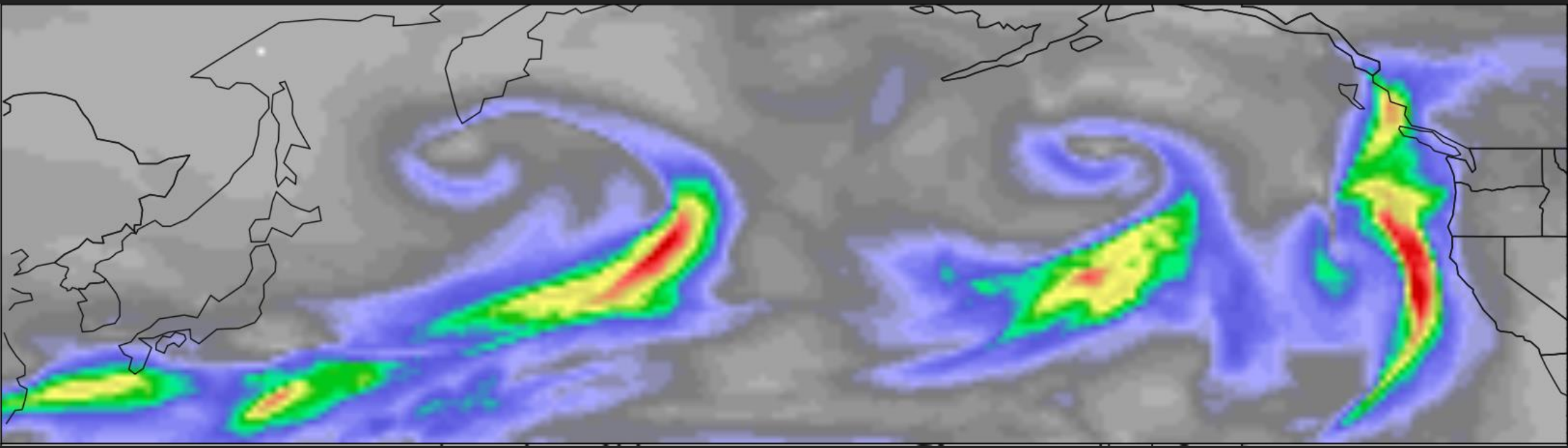




- Atmospheric Rivers are an important driver of Western US rainfall.
- Increasing their predictability at longer lead-times would be a huge boon to decision makers.

Atmospheric Rivers

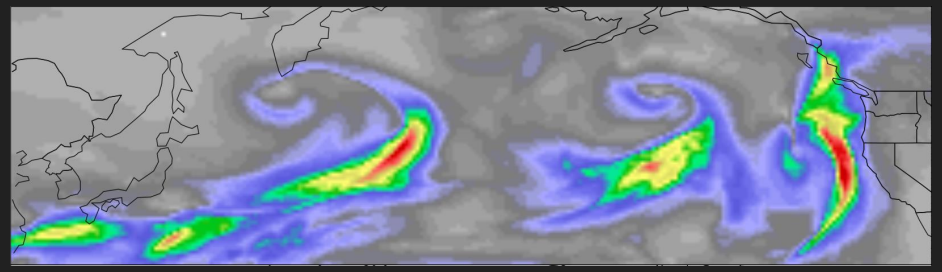
- Atmospheric Rivers (ARs) are narrow transitory corridors with elevated Integrated Vapor Transport (IVT)
- Responsible for most of the poleward water vapor transport in the extratropics
- Often found within the warm sector of an extratropical cyclone

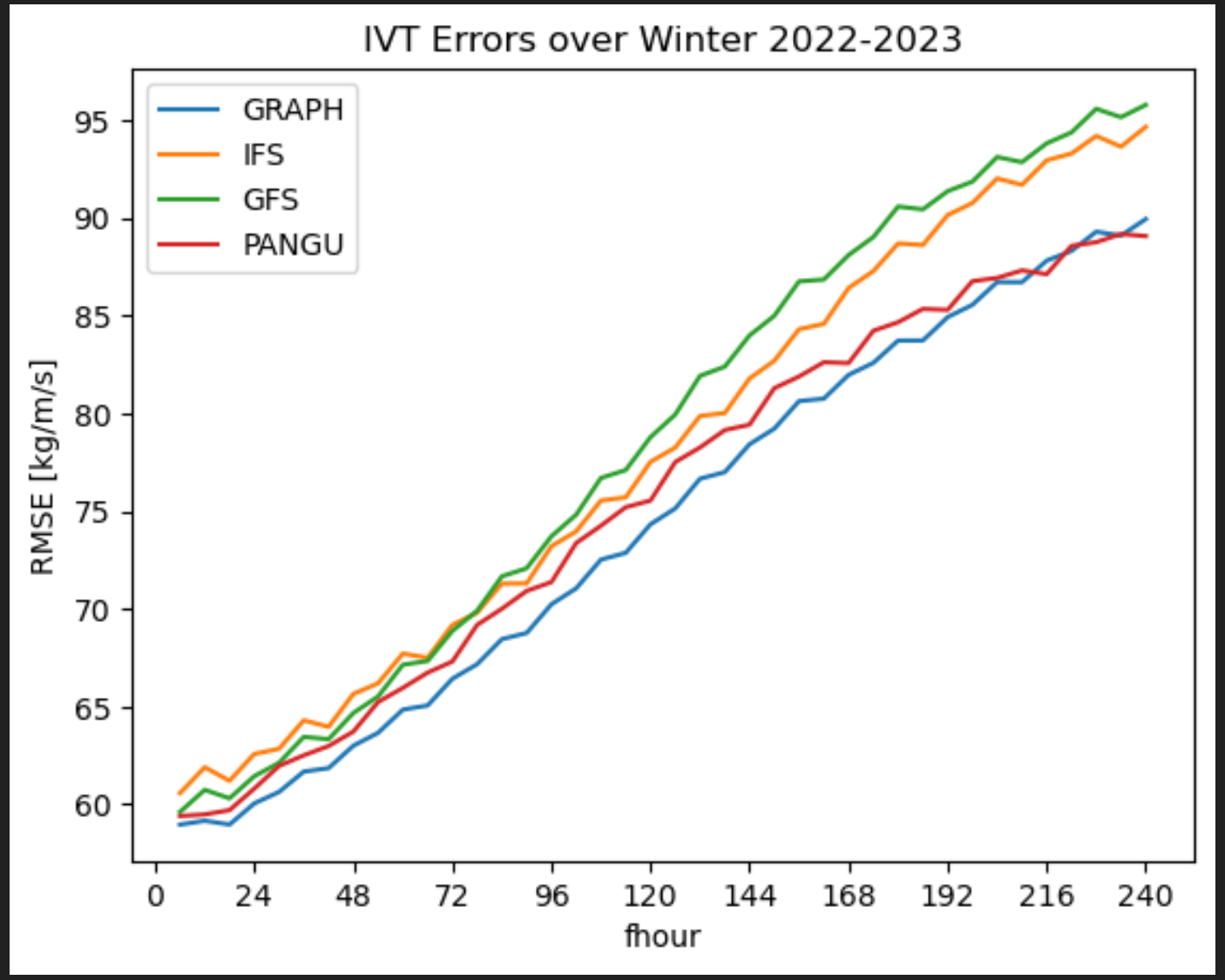


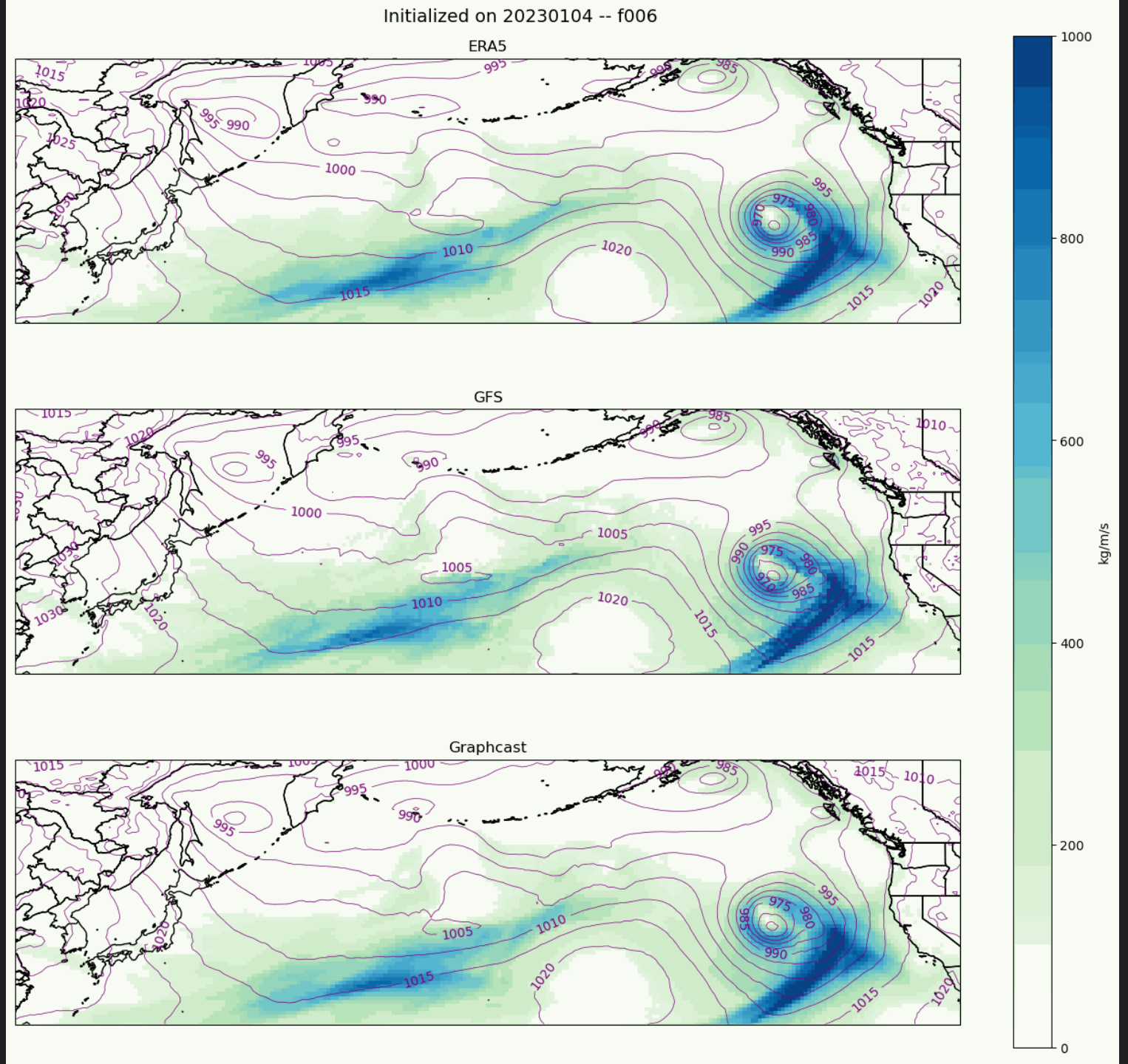
Details

Is IVT Well Forecast by MLWP?

- Root Mean Square Error of IVT over the North Pacific Basin
- The MLWP models outperform the NWP models



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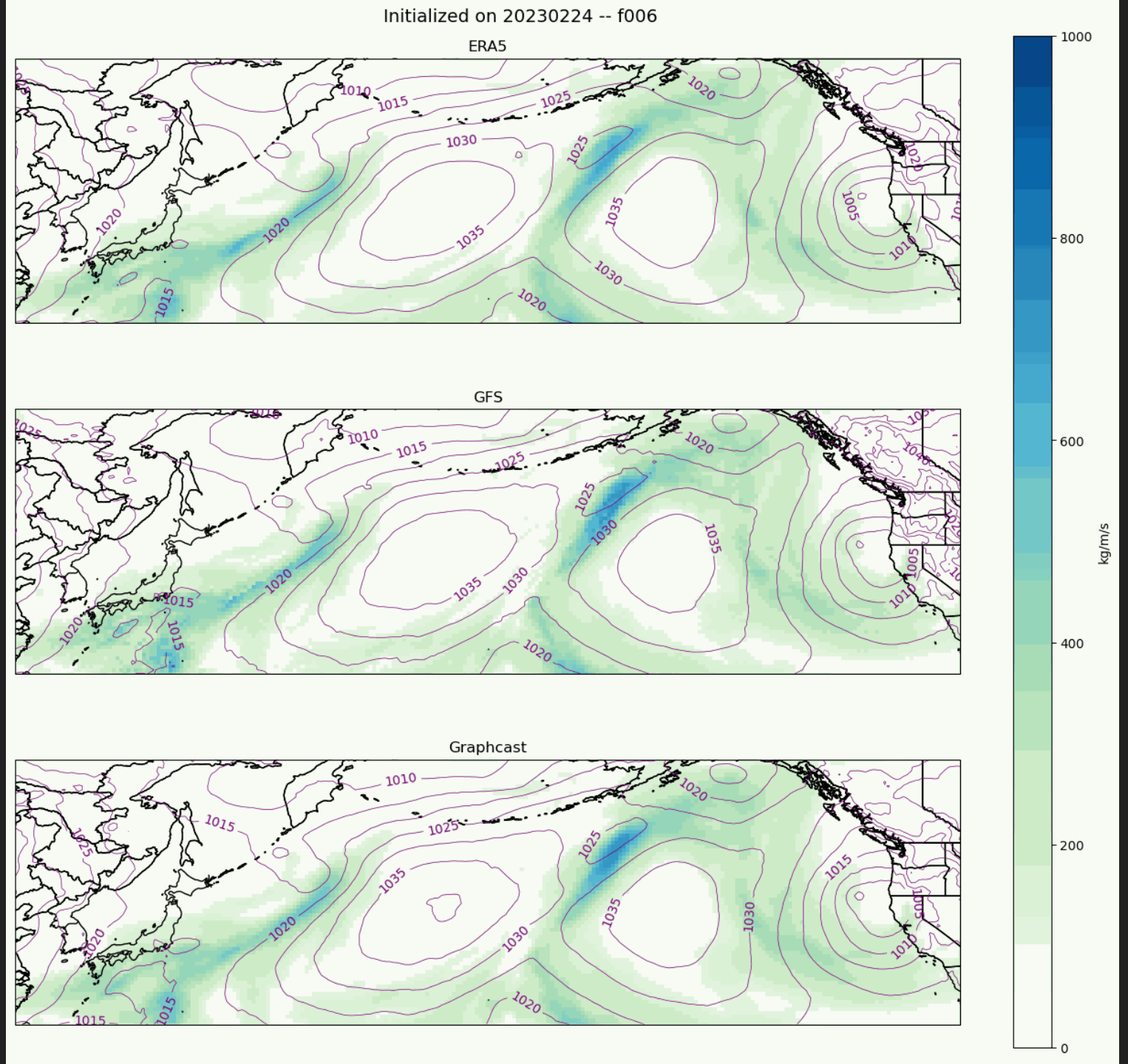
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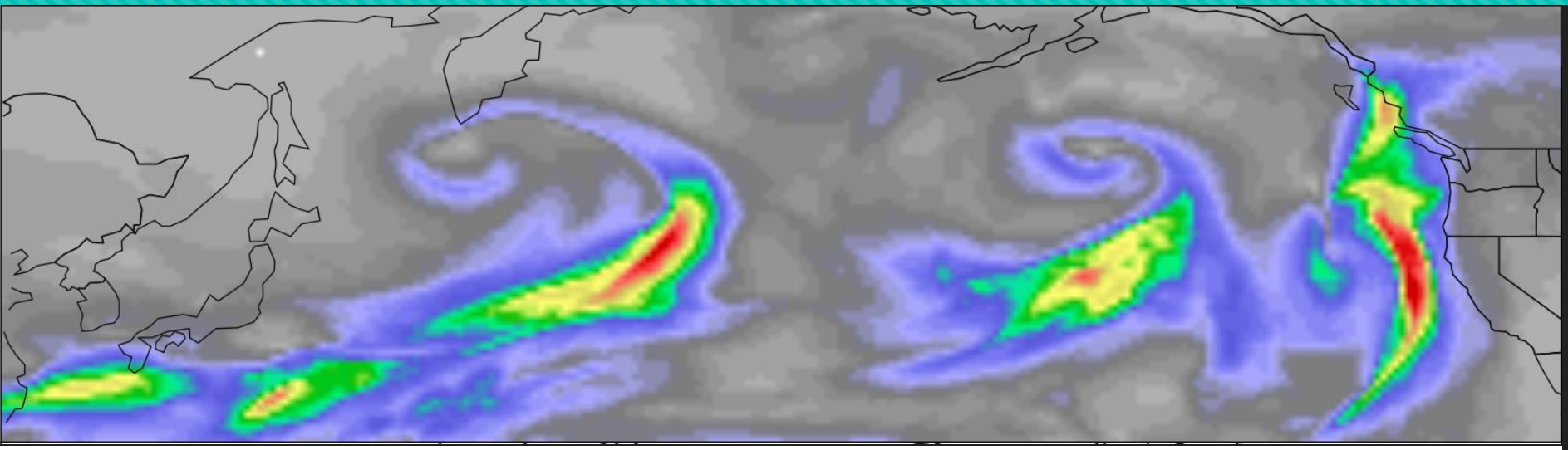
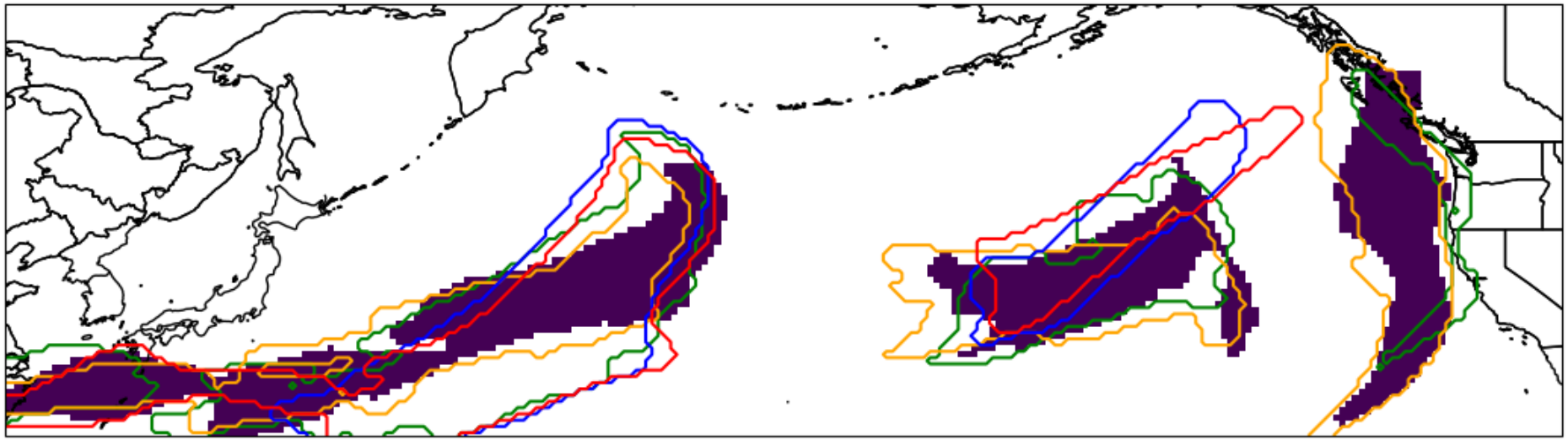
Object Based Evaluation

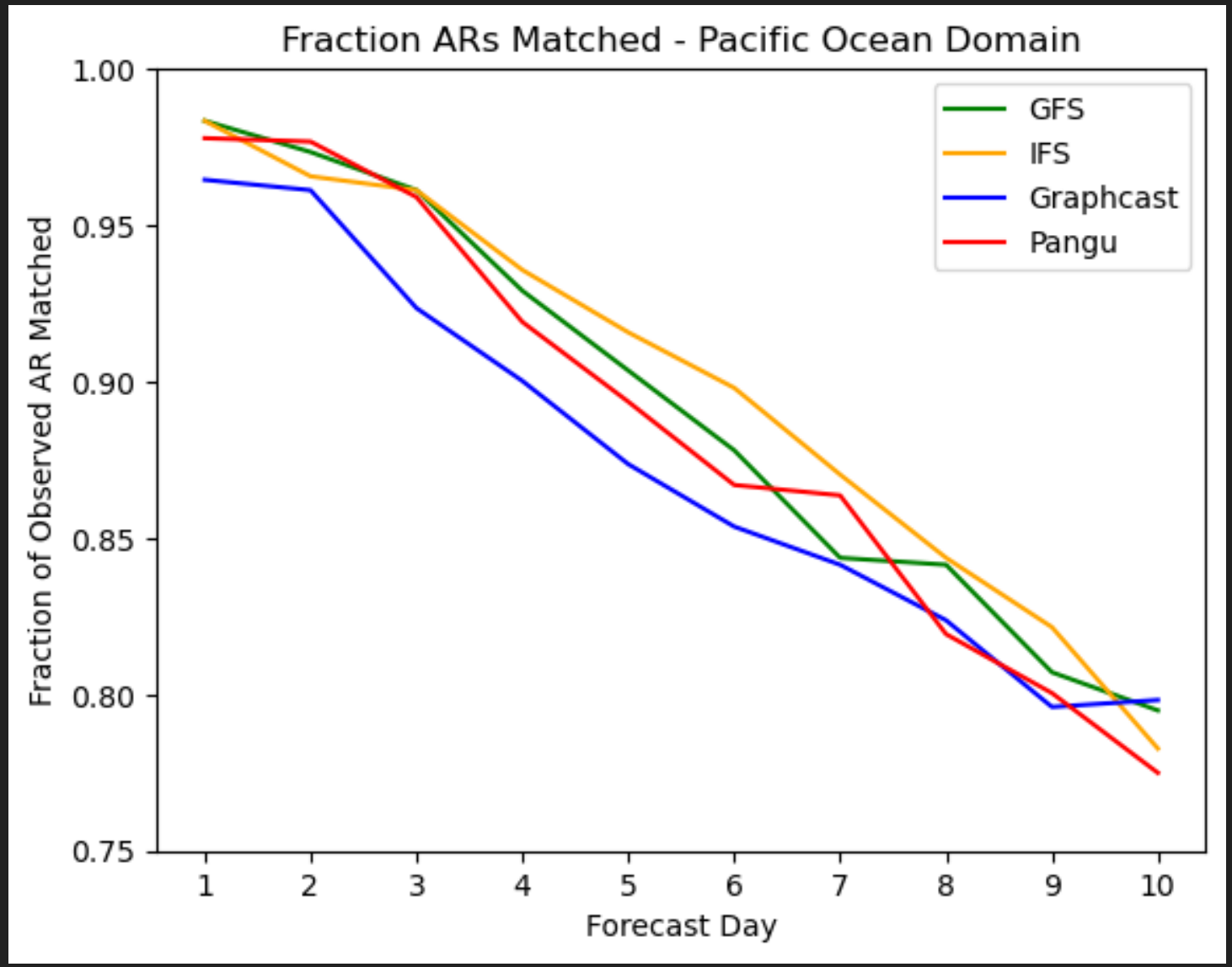




- Five Day Forecast, initialized on Jan 29, 2023 00z
- Top – IVT from ERA5
- Bottom – Mode output
  - Shading – ERA5
  - Green – GFS
  - Orange – IFS
  - Blue – Graphcast
  - Red - PanguWeather

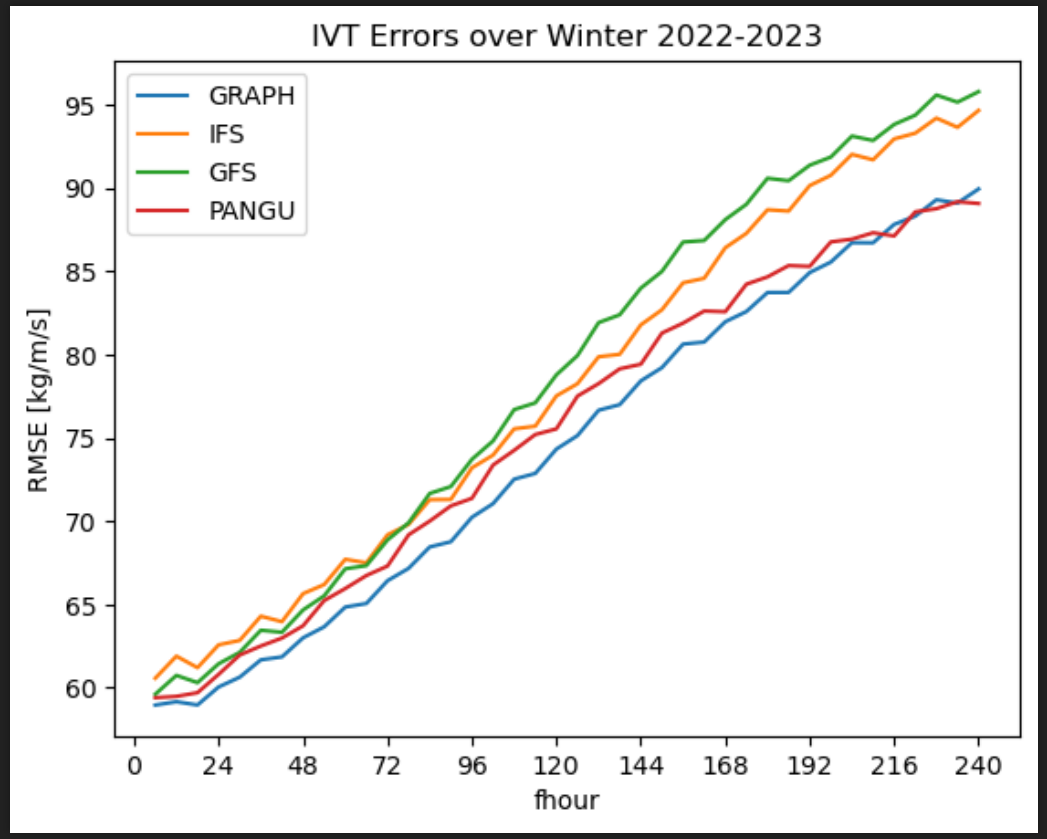
How Many Observed ARs are Matched

- Based on many factors the MODE software matches forecast objects with Observed objects
- At most lead times the MLWP models match fewer observed ARs than the NWP models.

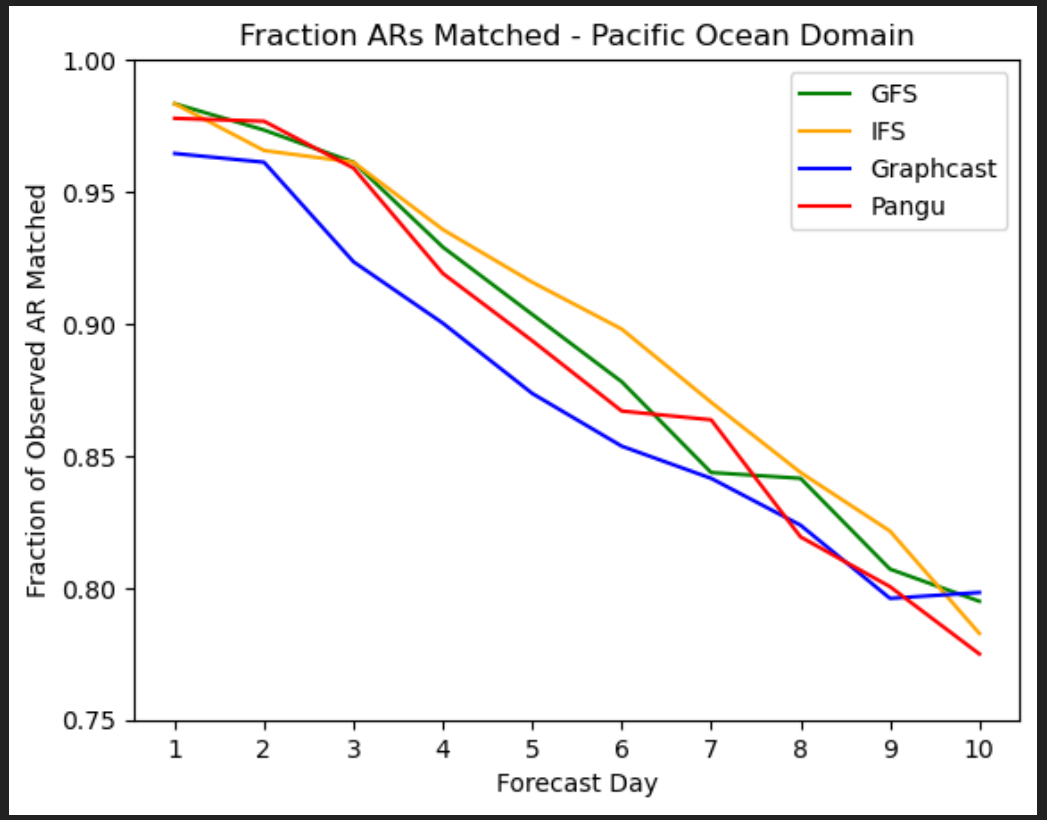


Raw Field vs Object Based

Difference in Raw IVT

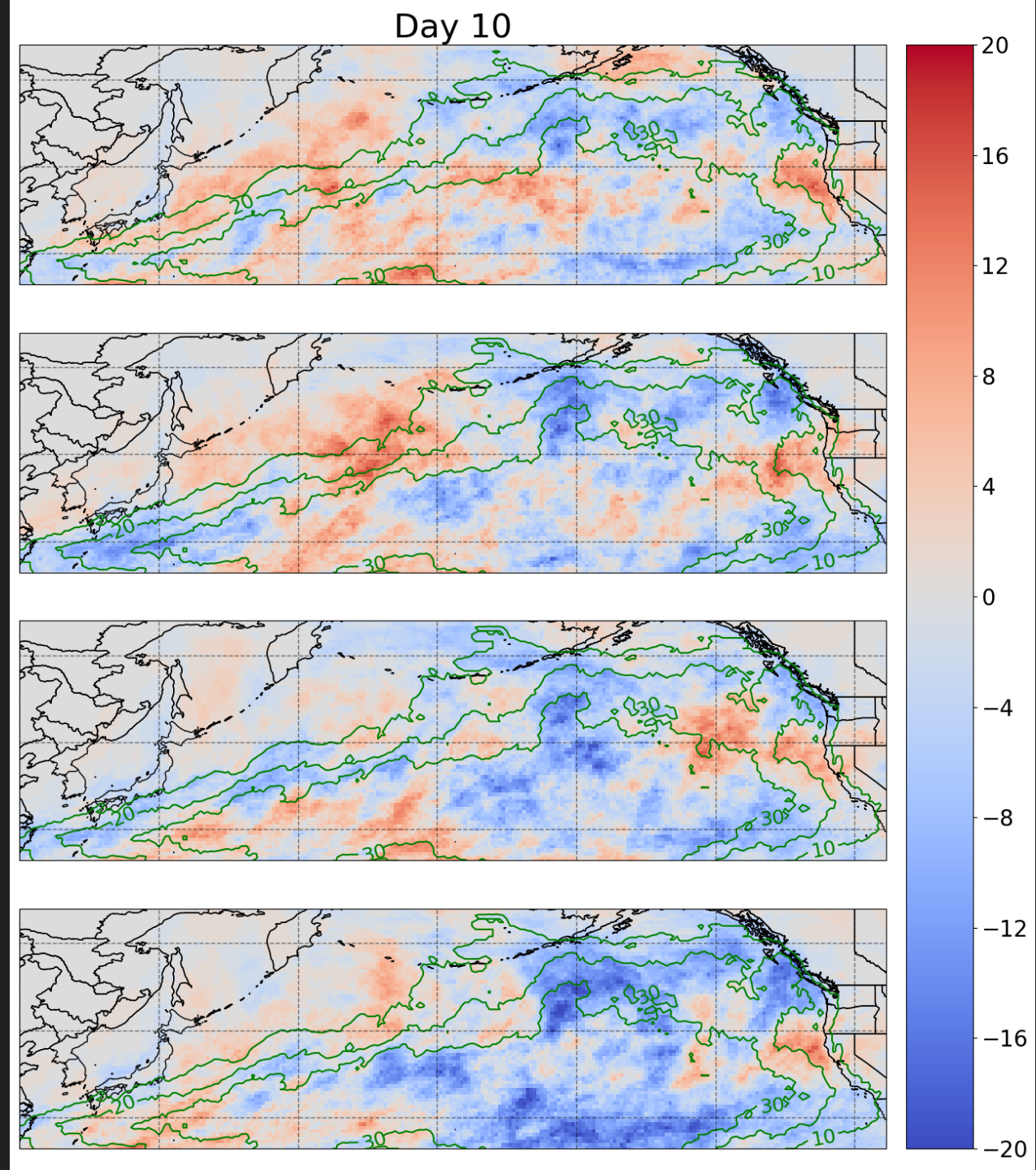


Difference In Matched AR Objects



Basin View of Detected ARs

- The thin green lines represent the number of observed ARs at each grid point.
- There is substantial noise in the number of ARs found at each grid point over the course of the season.
- Each model shows positive bias just off the coast of Northern California / Southern Oregon



Raw Field vs Object Based

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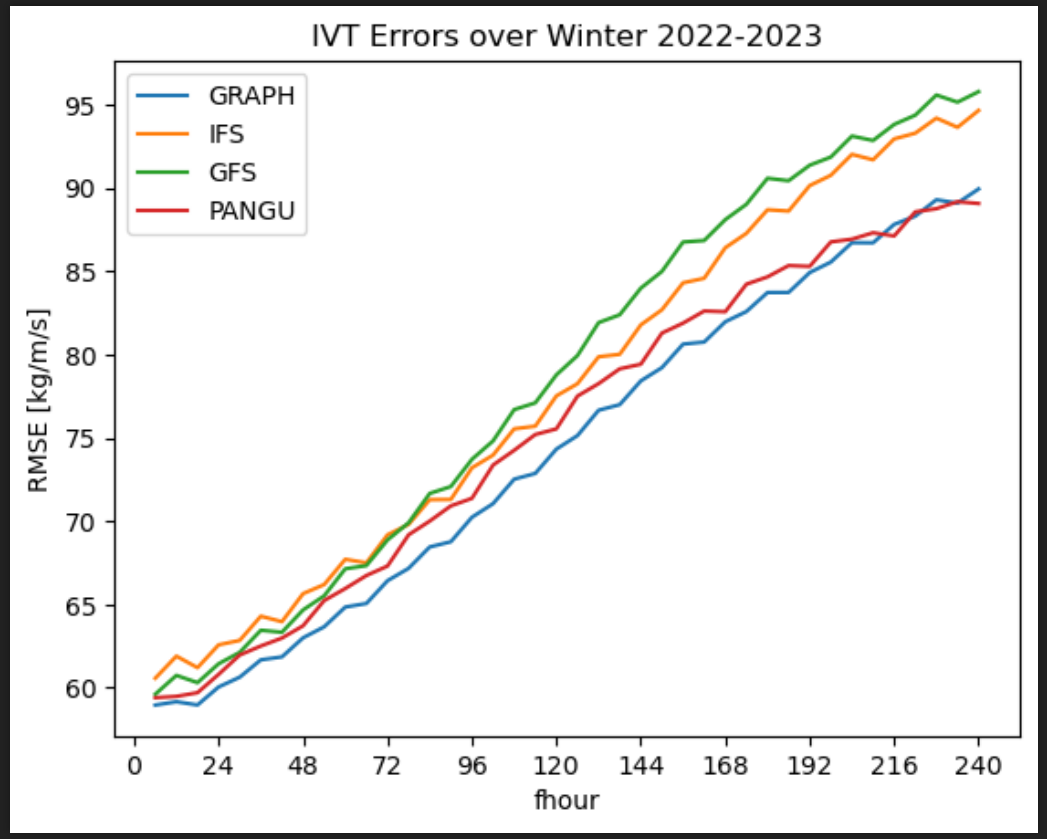
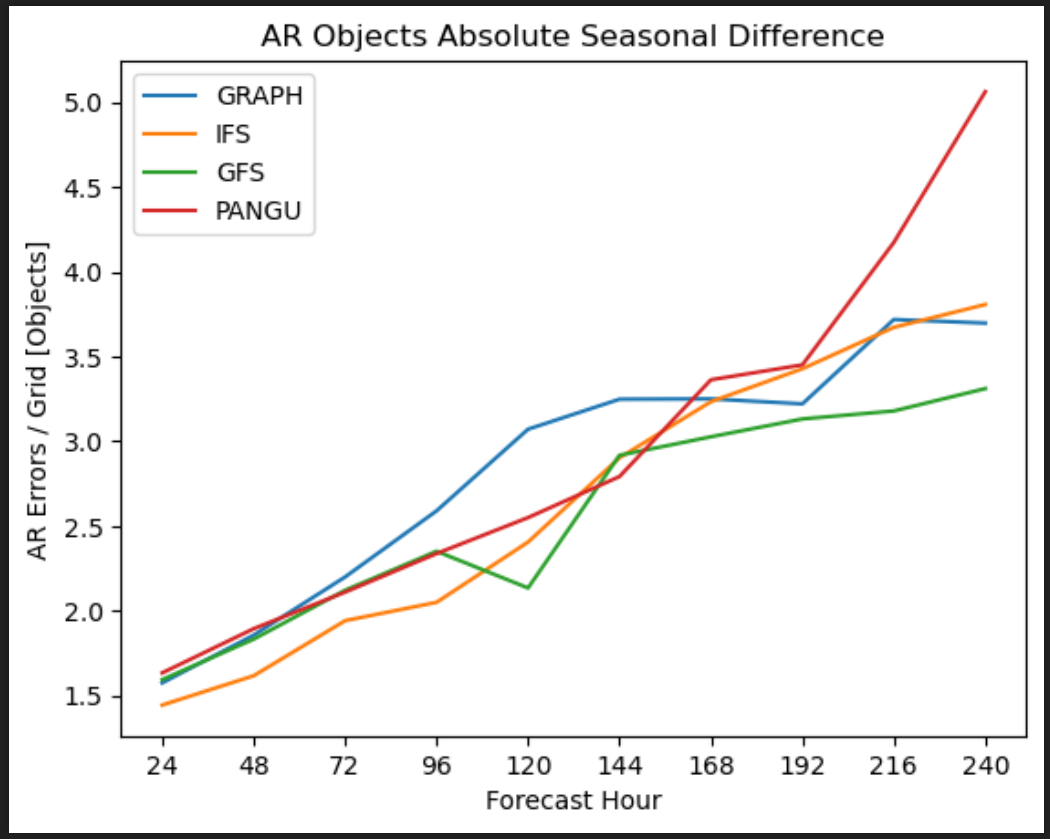
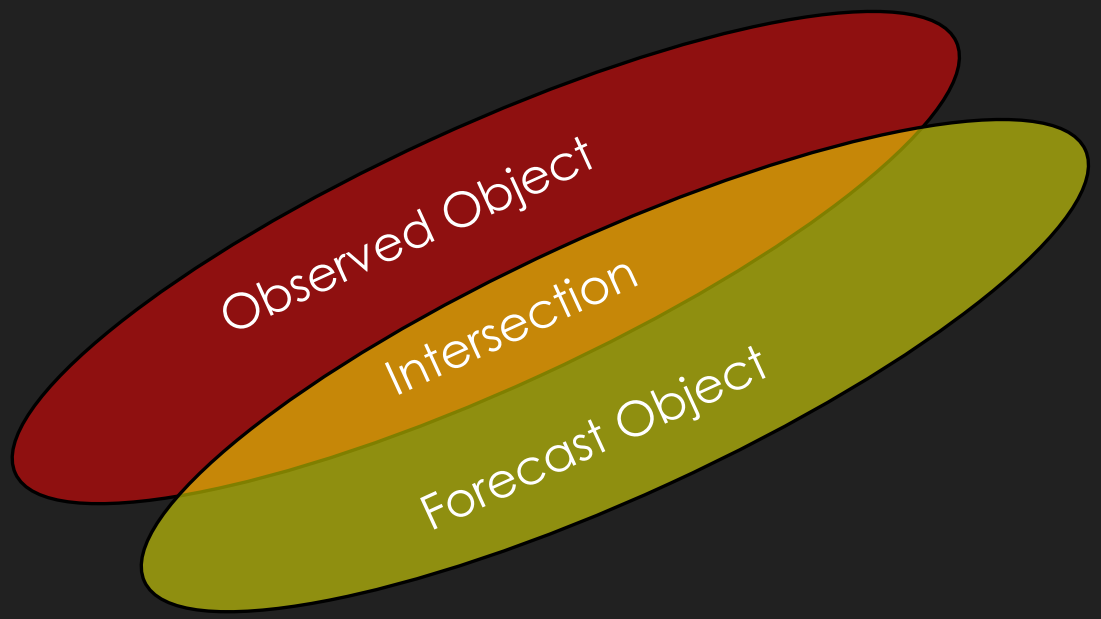


Difference In Detected ARs



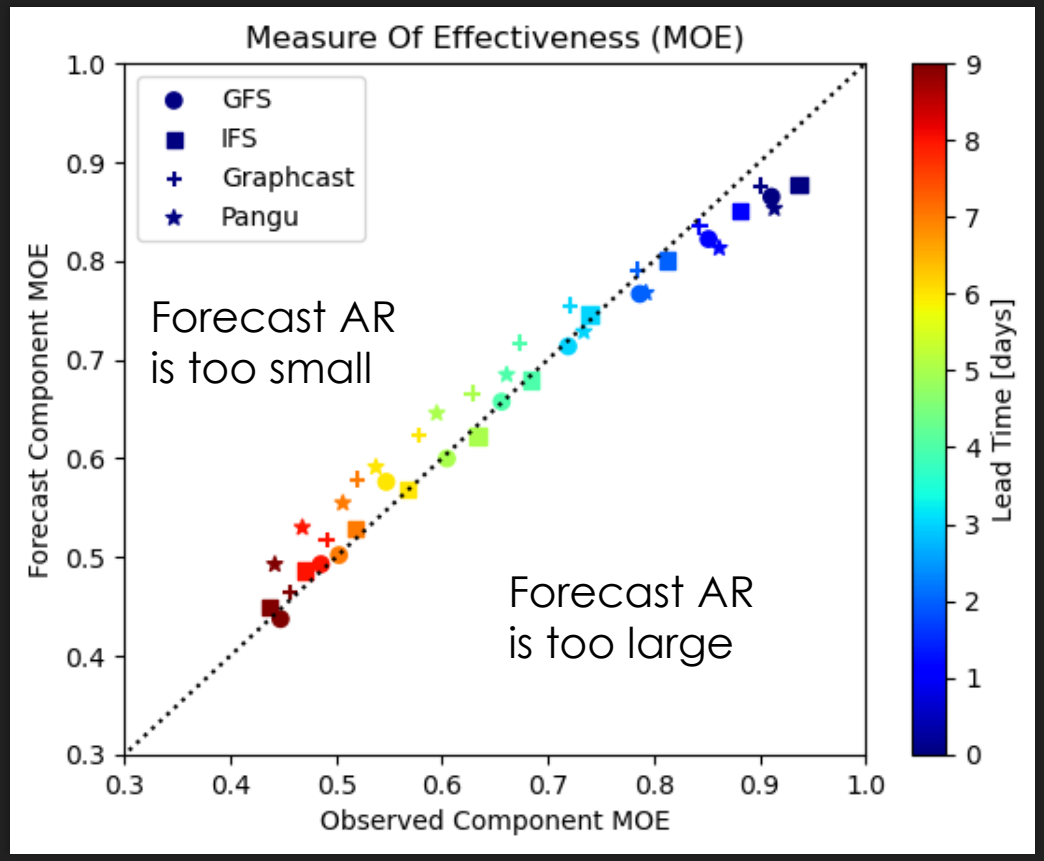
Measure of Effectiveness



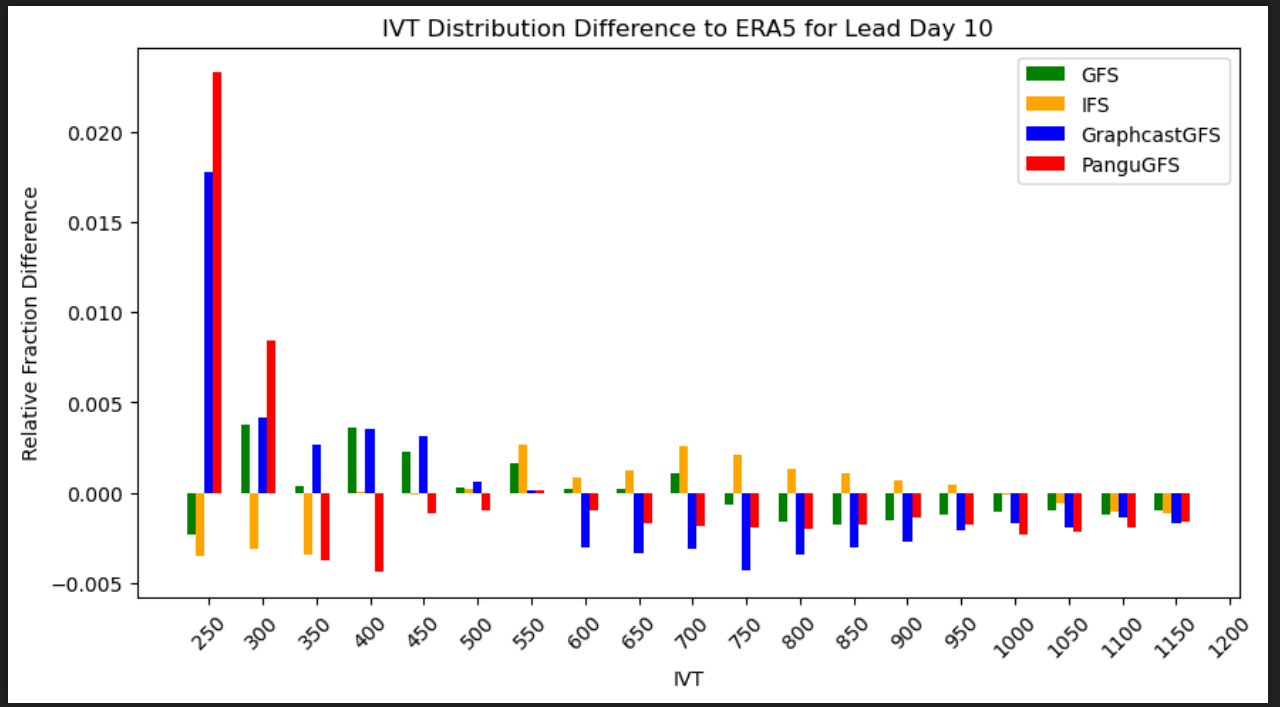
- $MoE = \left(\frac{Intersection}{Observed}, \frac{Intersection}{Forecast}\right)$
- Compares the area of each object with the area of intersection
- If you plot MoE on an (X,Y) plane a perfect forecast will sit at (1,1) in the upper right-hand corner
- If the forecast is the same size as the observation than the MoE will fall on the 1:1 line.

Differences Within Matched & Detected Objects

Difference In AR Size



Difference in IVT Distribution



Final Thoughts

- MLWP models are capable of producing realistic ARs but are more likely than NWP models to miss observed ARs
- MLWP models produce ARs that are, on average, too small and too weak compared to observed ARs
- Caveat – This is based on one season of data, work to expand this analysis as far backwards as possible is under way.

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