IDENTIFYING SUBSEASONAL FORECASTS OF OPPORTUNITY FOR WINTERTIME SURFACE TEMPERATURE EXTREMES THROUGH ML APPLICATIONS OF STRATOSPHERIC VARIABILITY

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S2S Windows of Opportunity and the Stratosphere

- In S2S, seek to find potential windows of opportunity in forecasting.
- Intrinsic predictable skill provided by atmospheric states, systems, and patterns (*Mariotti et al. 2020, Barnes et al. 2021*).
- Focus on stratospheric polar vortex component and its teleconnections to climate modes.

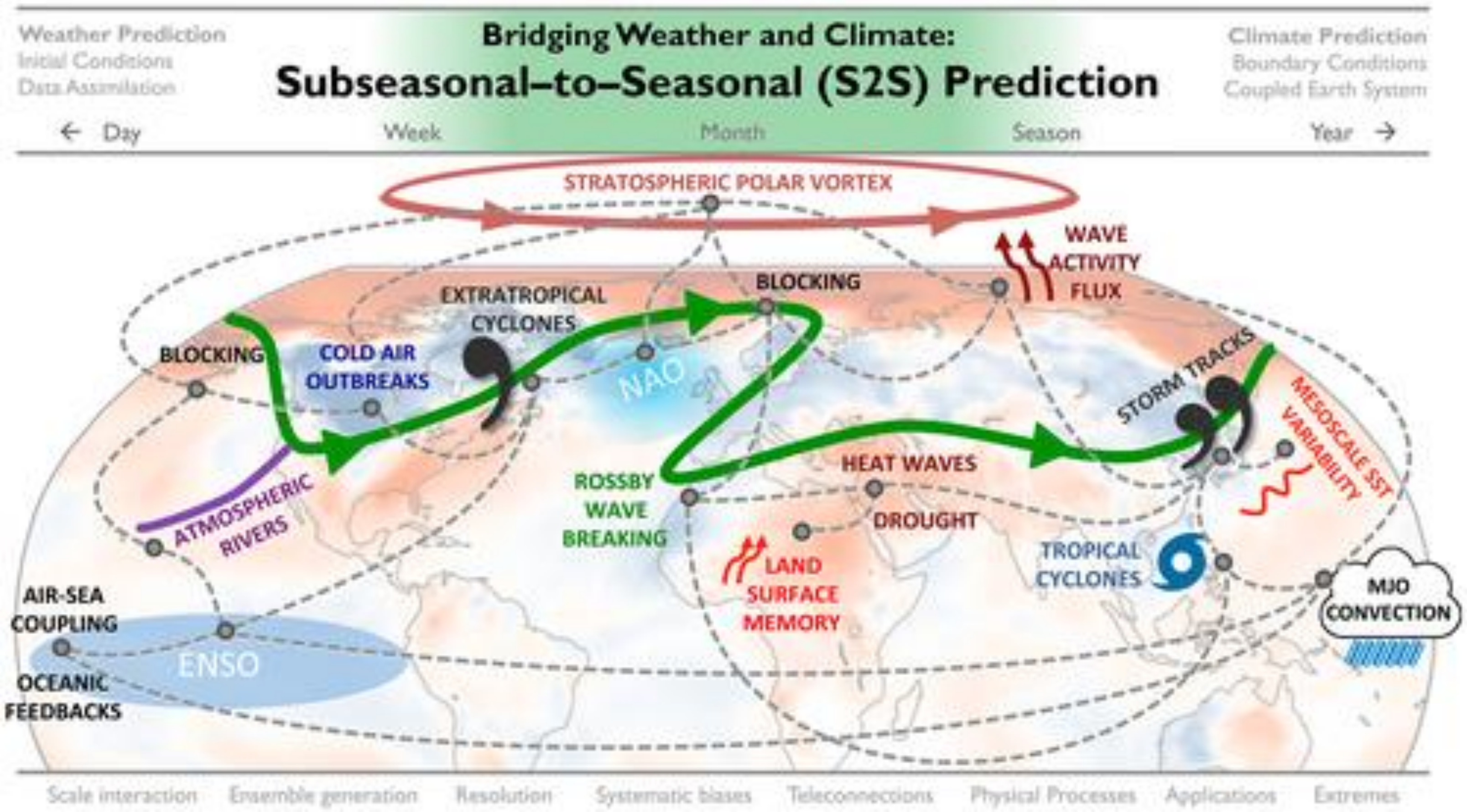
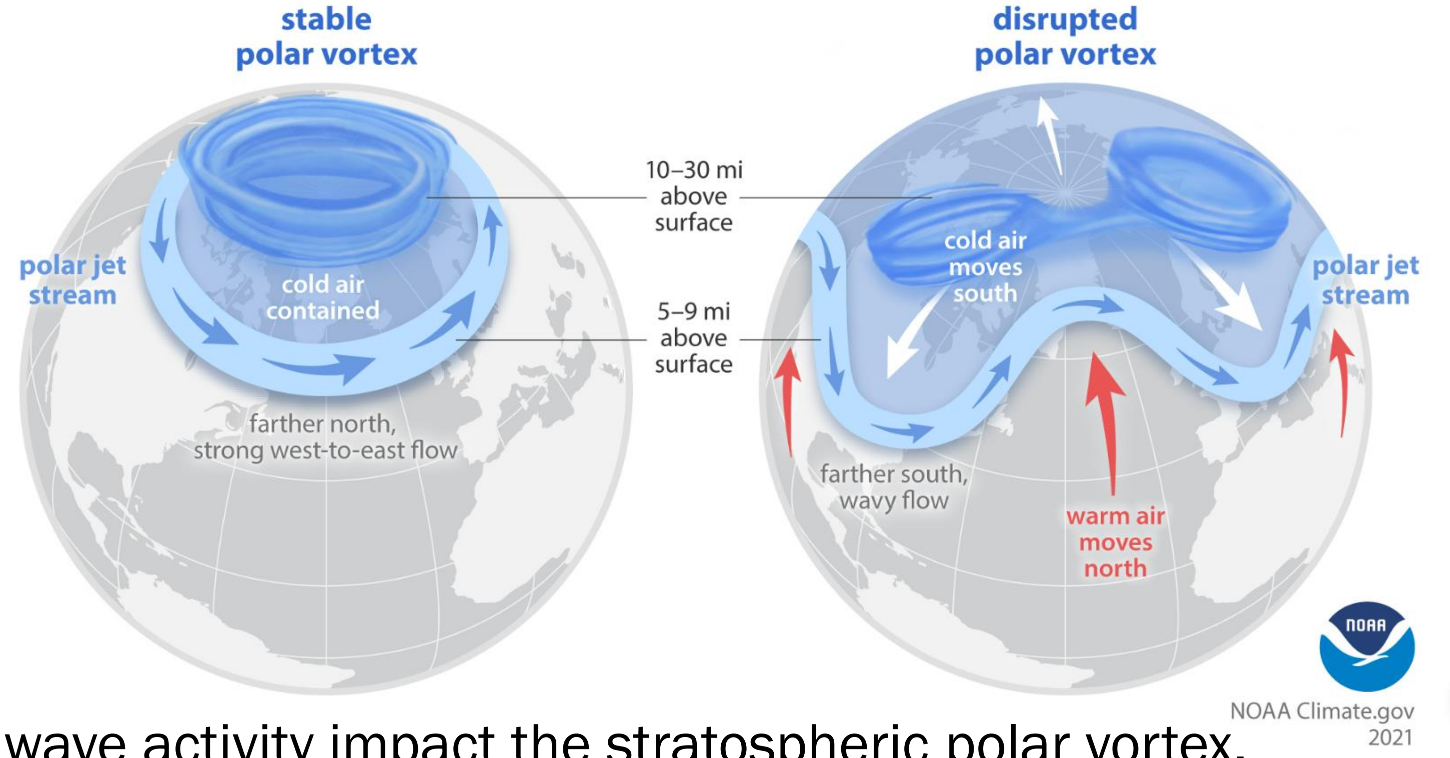


Image Credit: Lang et al. 2020

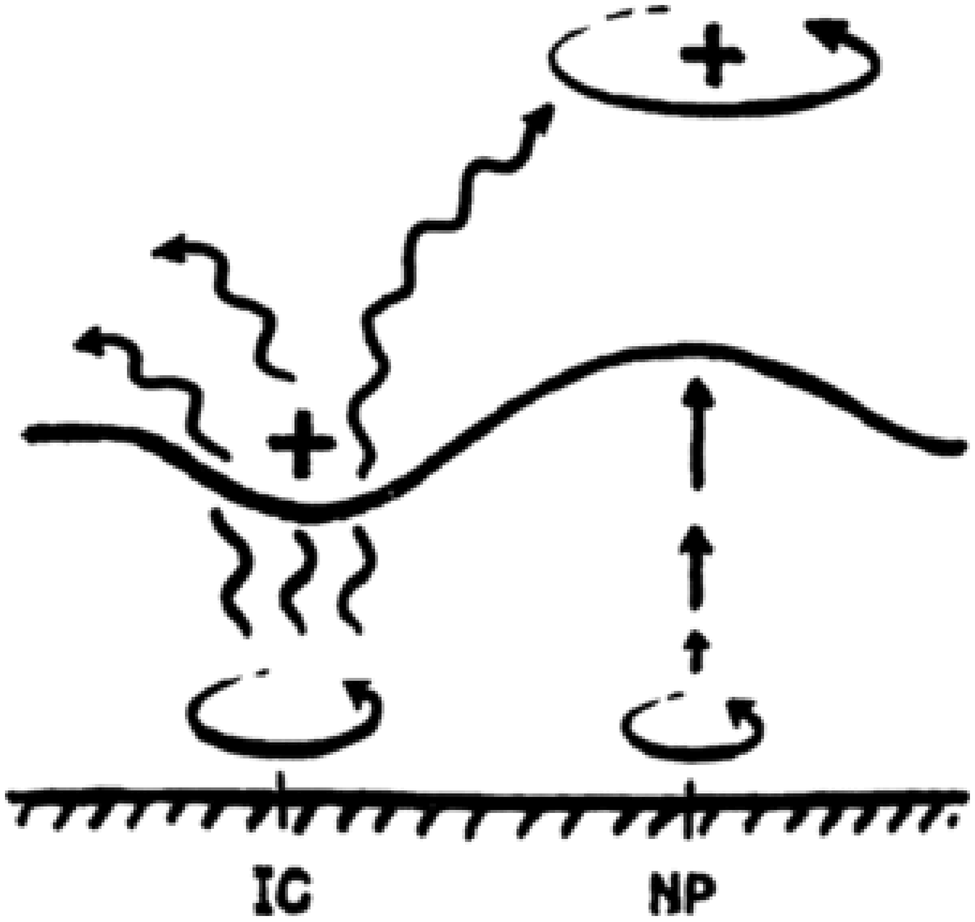
Stratospheric Polar Vortex



- Fluctuations in wave activity impact the stratospheric polar vortex.
  - Decreased = Strong vortex events and increasing of potential vorticity (PV) anomaly.
  - Increased = Sudden Stratospheric Warming (SSW) events and weakening of PV anomaly.
- Induced changes to the strength and location of stratospheric PV anomaly can impact tropospheric flow.

Image Credit: NOAA 2021 (https://www.climate.gov/news-features/understanding-climate/understanding-arctic-polar-vortex)

Stratospheric PV and NAO Signals

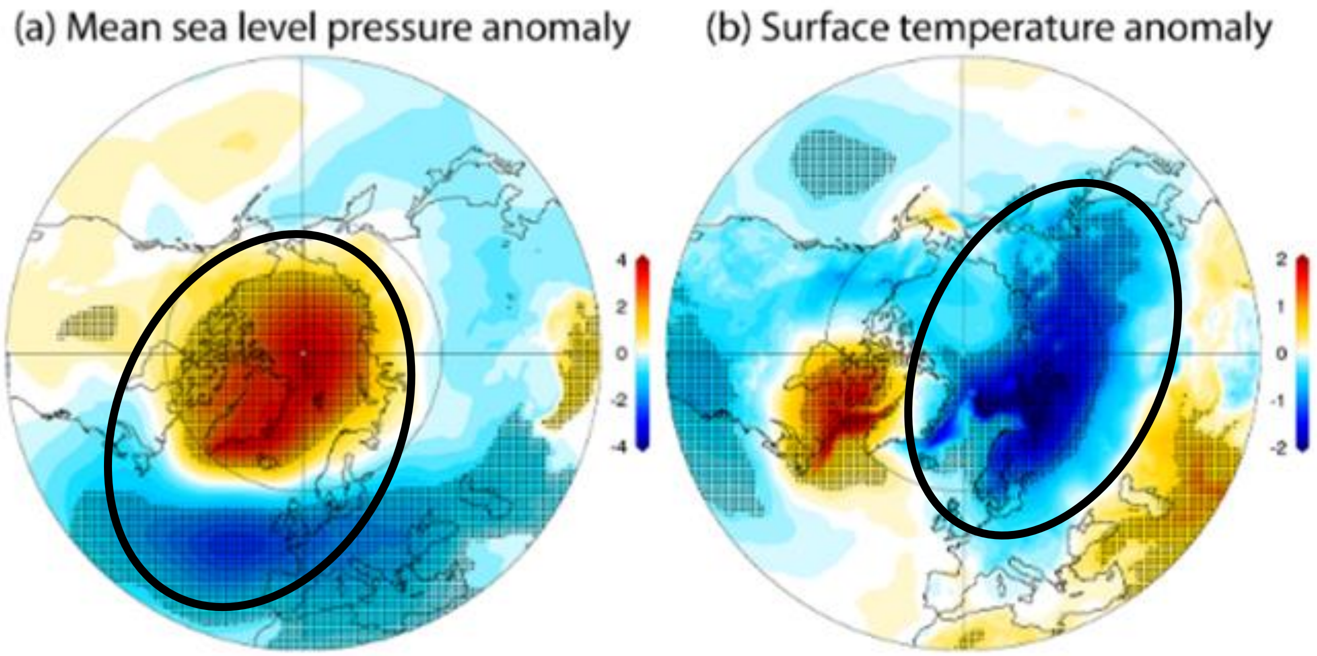


Schematic representing connections between NAO, strength of the stratospheric jet, and height of the tropopause. Strengthening circulation over Iceland (IC) enhances + NAO, lowers the tropopause, and increases the positive PV anomaly over the North Pole (NP). (Ambaum and Hoskins 2002, Fig 1).

- Changes to stratospheric vortex strength are often associated with geopotential height (GPH) anomaly configurations in the North Atlantic that mirror signals of the NAO (Ambaum and Hoskins 2002).
- Visible teleconnection wherein changes to the NAO index induce fluctuations in stratospheric wave activity that are then coupled downward to the troposphere (Ambaum and Hoskins 2002).

Surface Impacts of Stratospheric Variability

- NAO signal



Temperature response

Composite contour plots of the 60 days following historic SSWs noted in JRA-55 reanalysis data for anomalies in ***(a)*** *mean sea level pressure (hPa),* ***(b)*** *surface temperature (K). (Butler et al. 2017; Fig. 4)*

- GPH composite response to SSWs shows strong negative NAO pattern and cold air response in Eurasia.
- Potential source of predictability/window of opportunity

Research Goal

Can we use lower Stratospheric PV and NAO teleconnections to identify window of opportunity scenarios for enhancing predictions of temperature anomaly outcomes at the surface?

In this instance, specifically looking at Northern Europe.

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In this instance, specifically looking at Northern Europe.

- *We know this causal relationship exists, but can we create an ANN model that identifies relevant regions for enhanced predictive skill when evaluated with XAI (Layerwise Relevance Propagation or LRP).*
- *Not necessary to have a model here with high overall accuracy.*

Data & Pre-Processing

- All variables of interest are 2.5° regridded ERA5 data, cold season (NDJFM) 1959/1960 – 2021/2022.
  - <u>Probabilistic Output:</u>
    - ✓ 2m Temperature Daily Anomaly over Eurasia (*10-45°E; 60-75°N*) as binary values (0 for negative, 1 for positive).
  - <u>Input(s):</u>
    - ✓ 500hPa Daily Anomaly GPH over the North Atlantic (*100-10°W; 20-80°N) 4 days lead to temperature.*
    - ✓ 100hPa Daily Anomaly PV over the Polar Cap (*60-90°N*) *14 days lead to temperature.*
      - ✓ *Chosen due to known improvements in forecasts of AO in the troposphere from 10-day lead features in the stratosphere @ 100hPa when compared to troposphere (Baldwin et al. 2003).*
- All data had seasonal climatology removed.
  - Testing and Training data were separated in data preprocessing to ensure that model had no familiarity with testing dataset.

Training/Testing/Validation

For ANN model:

- **Training** → Cumulative 59-year period from 1959/1960 to 2016/2017, only 53 used in each instance of model training.
- **Validation** → Randomly selected 6-year span of dates from the training dataset.
  - Cross-validation/model trained 100 consecutive instances with early stopping implemented if validation loss increased for more than 2 epochs (50 epochs total).
- **Testing** → All values 2017/2018 to 2021/2022.

For identifying forecasts of opportunity:

- Look at the 10% most **confident and correct** predictions wherein the accuracy of predictions greatly exceeds random chance; mirroring the methodology from Mayer and Barnes 2021.

Multi-Input Model Architecture

Input Tensor #1

Daily PVU Anomaly over Polar Cap (60-90°N) @100hPa + 14 days from output

1595 input features

128

Input Tensor #2

Daily GPH Anomaly @ 500hPa over N. Atlantic (100-10°W; 20-80°N) +4 days from output

777 input features

124

Merged Layer

28

Output

Daily 2m Temperature Anomaly Classification over a region in Northern Europe/Eurasia (10-45°E; 60-75°N)

Full Connected, Dense layers for this model. Opted for over alternatives to keep the model simple in the short time frame I was training this.

ReLu activation used for input tensors.
Softmax activation used for output tensors.
L2/Ridge regularizers on each layer.

Multi-Input Model Architecture

Input

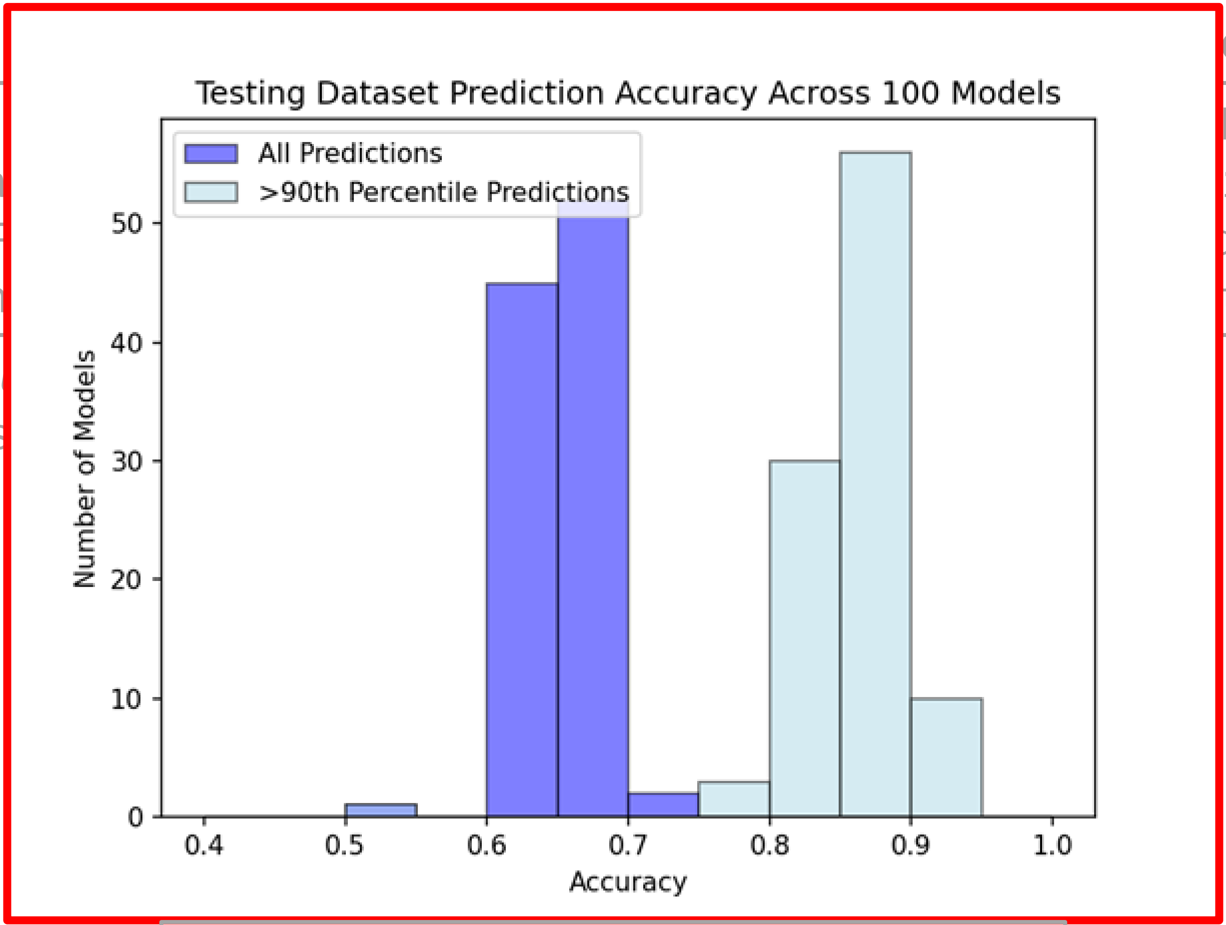
Daily PVU
Polar Ca
@100hP
fron

1595 inp
features

or #2

ly @ 500hPa
100-10°W;
days from
t

777 input
features

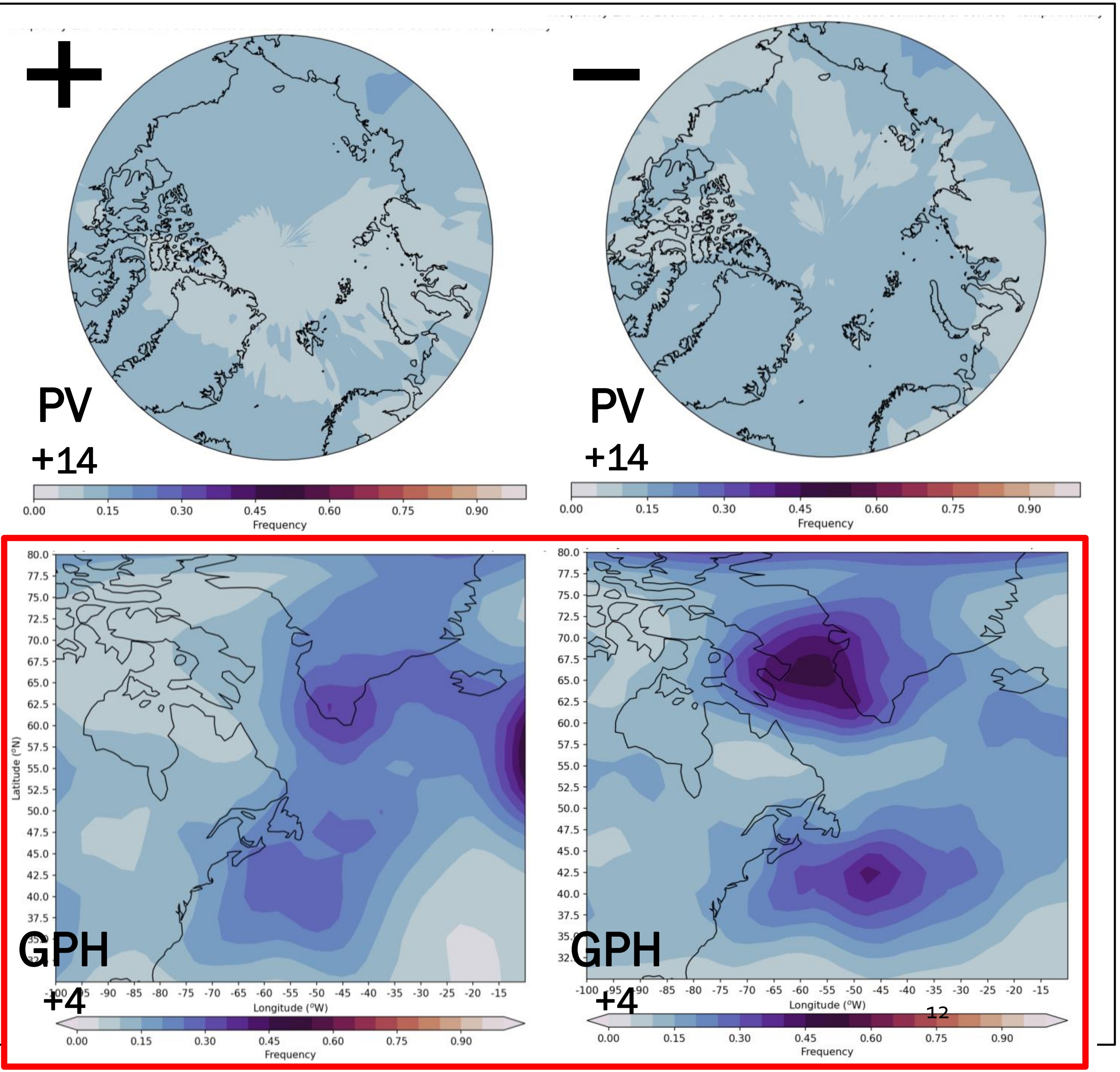


The 10% most confident predictions across 100 trained models on testing data have higher accuracy compared to all prediction accuracies.

Daily 2m Temperature Anomaly
Classification over a region in Northern
Europe/Eurasia (10-45°E; 60-75°N)

LRP on Multi-Input Model

- GPH (**bottom**) has different regions of LRP frequency depending on whether it is a positive or negative temp anomaly.
  - Generally, highlights areas of the N. Atlantic/Greenland for relevance. Consistent with NAO.
  - Also favors an area off the Eastern Coast of N. America. Unsure what this may be. (*Blocking pattern? Weather regime?*)



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- GPH (**bottom**) has different regions of LRP frequency depending on whether it is a positive or negative temp anomaly.
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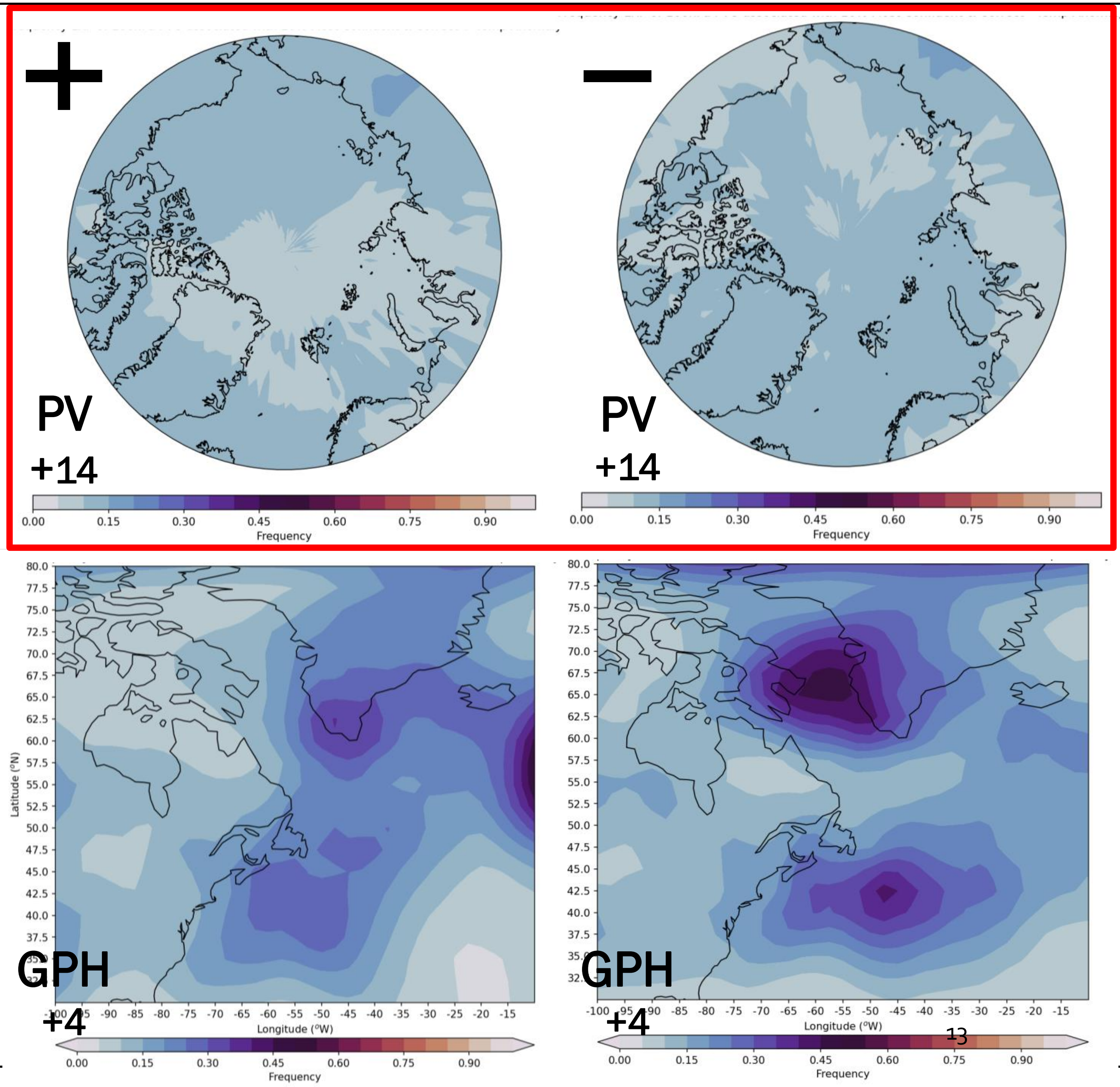
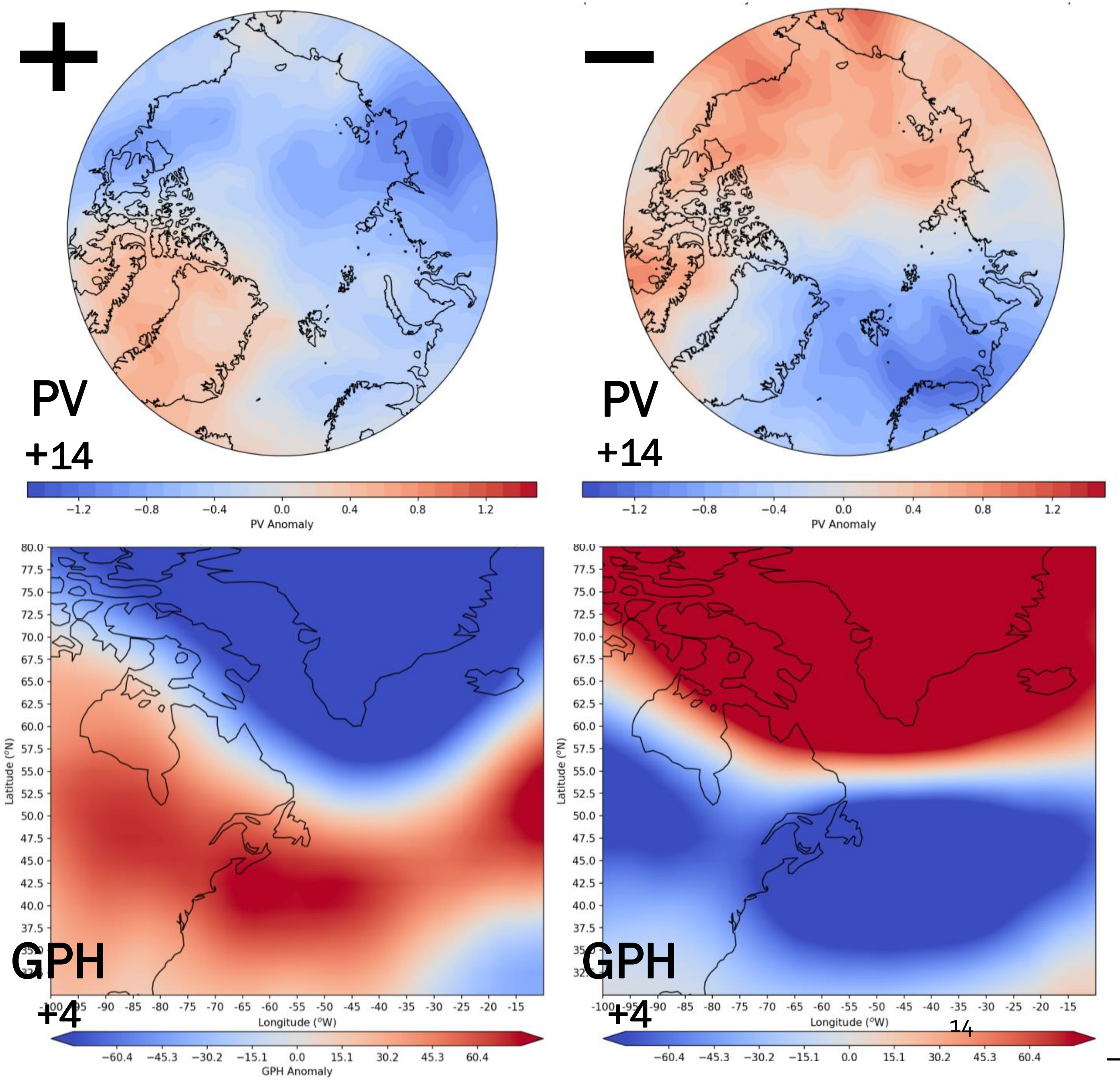
- PVU (**top**) overshadowed by GPH for relevance in this model's decision making likely due to the robustness of GPHs synoptic-scale connections with temperature changes.



Composites

For these 10% most confident and correct predictions …

- Model recognizes a strong NAO signal in GPH anomalies (**bottom**).
    - + NAO for positive temp anomalies.
    - - NAO for negative temp anomalies.
- Lower stratospheric PV signals 14 days out from the predicted anomaly (**top**) correspond accordingly.
    - Again, consistent with NAO.
    - Signal is less obvious with negative temp anomalies and is deviated away from Iceland/Greenland toward our forecast area.



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PV Only Model

Wanted to see probabilistic forecasts of tropospheric temperatures based on just S2S scale PV which …

Output

Daily 2m Temperature Anomaly Classification over a region in Northern Europe/Eurasia (10-45°E; 60-75°N)

Multi-Input Model Architecture

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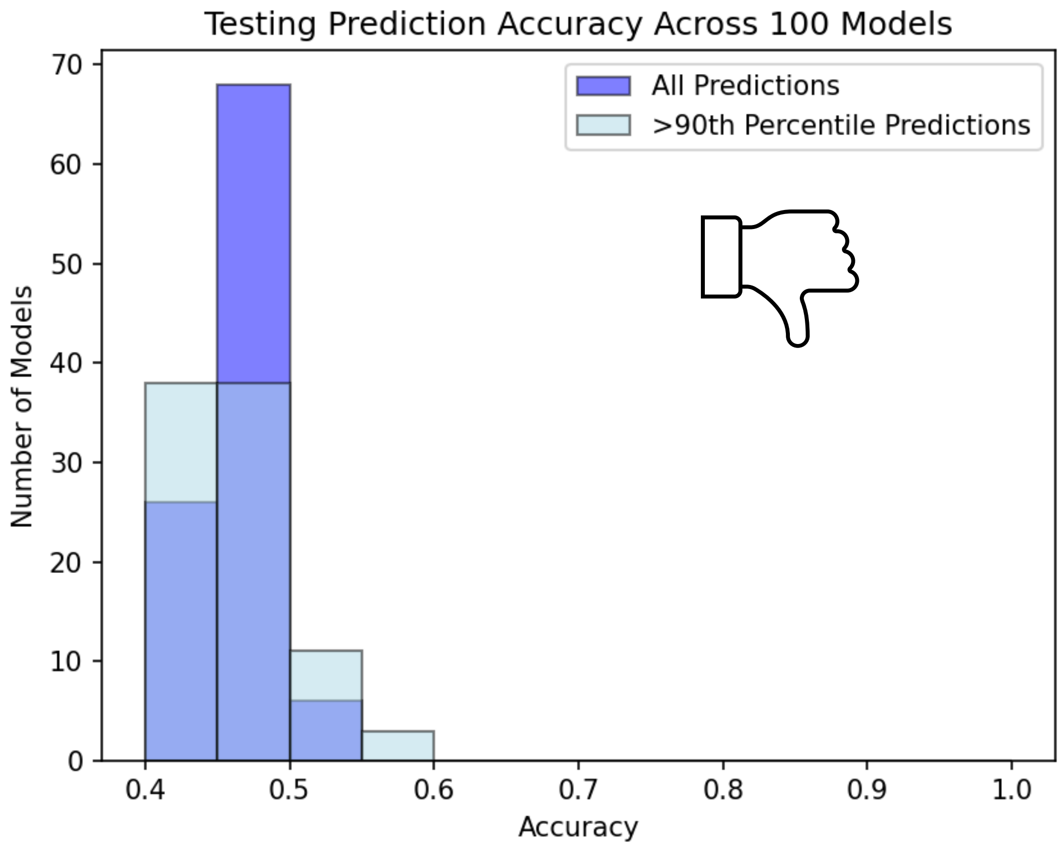
PV Only Model



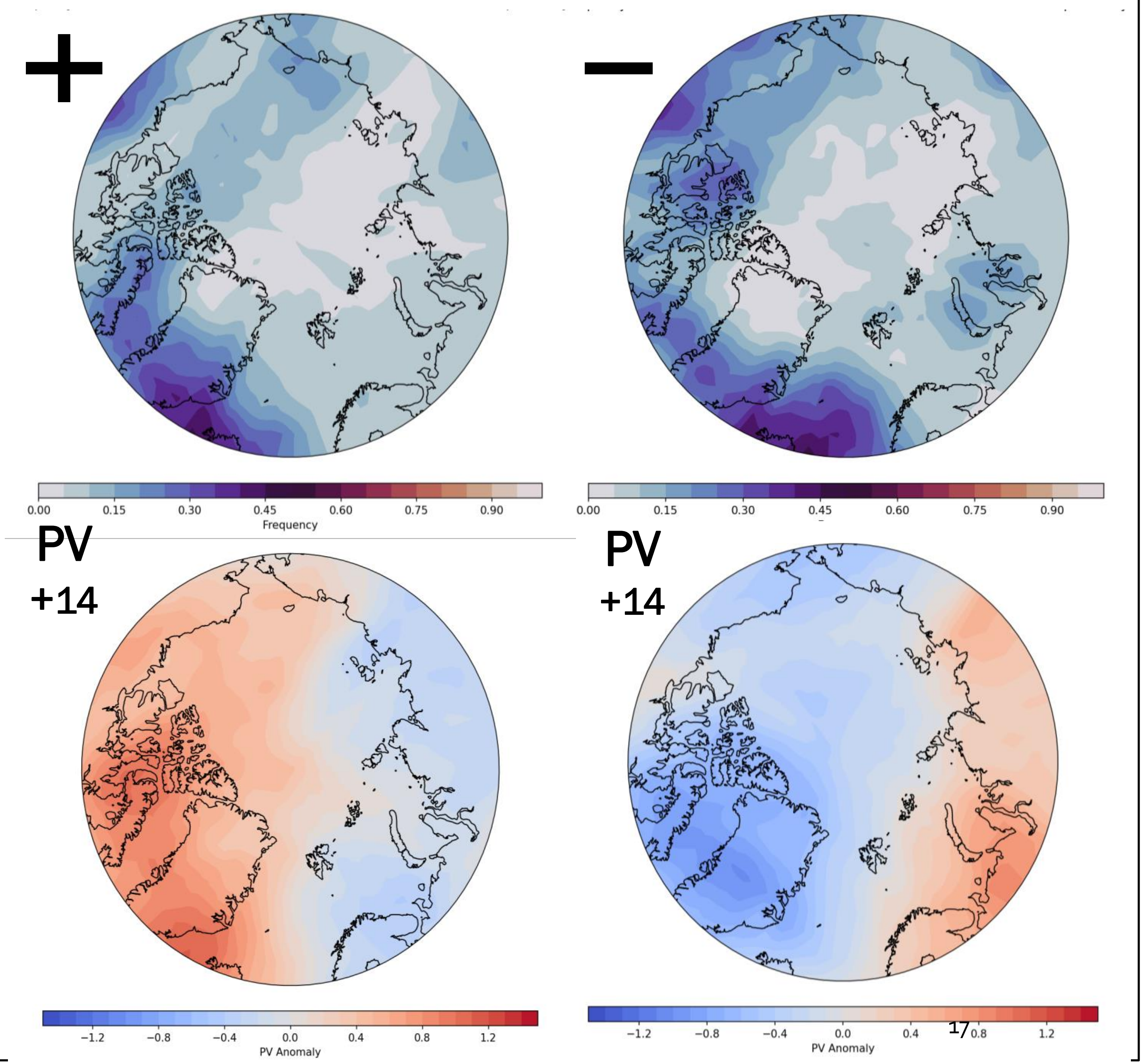
Extremely poor model performance, even for the 10% most confident predictions across 100 trained models on testing data.

Daily 2m Temperature Anomaly Classification over a region in Northern Europe/Eurasia (10-45°E; 60-75°N)

PV Only Model
LRP and Composites

For the few 10% most confident and correct predictions …

- LRP plots (**top**) show N. Atlantic primarily as the most frequent source for the model's decision making across both signs of temperature anomalies.
- Vaguely reminiscent to NAO signals +14 lead in composites (**bottom**).



Conclusions & Next Steps

Conclusion:

- From preliminary analysis with this model, we can observe stratospheric PV features which may provide subseasonal forecasts of opportunity related to the synoptic scale perturbations of the NAO, but the model does not actually use them to predict.

Next Steps:

- There is room to improve this model. Want to promote the usage of the subseasonal features in its decision making and increase model accuracy at longer leads.
  - This is what I plan to explore next; open to suggestions. (e.g., different stratospheric metrics, model architectures?)
- Ultimately want to transition into seeing whether similar features related to NAO teleconnections persist for other temperature regions.
- And whether these features can be replicated by AI weather forecast models.

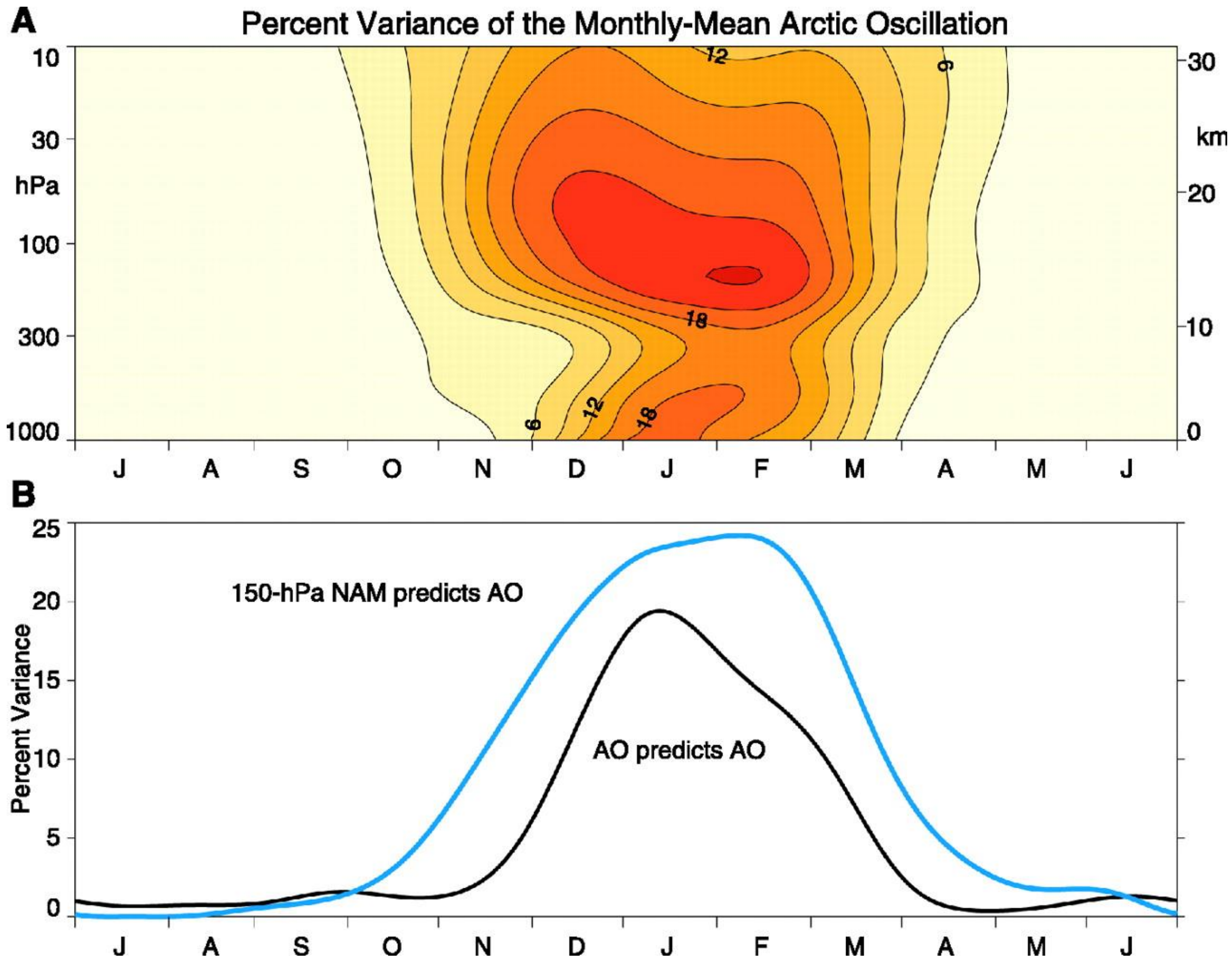
Thank you for listening!

With additional questions contact Elena M. Fernández; emfernandez@albany.edu.

EXTRA SLIDES

Why PV @ 100hPa?

- @ 100hPa the stratospheric AO signal, mirrored through PV, is better at predicting the tropospheric AO response at 10-day lead than corresponding tropospheric signals.
- With downward stratospheric influence, we choose to look at 100hPa PV at the S2S scale (+14 days) which has a known relationship with GPH NAO response @ 500hPa (+4 days).

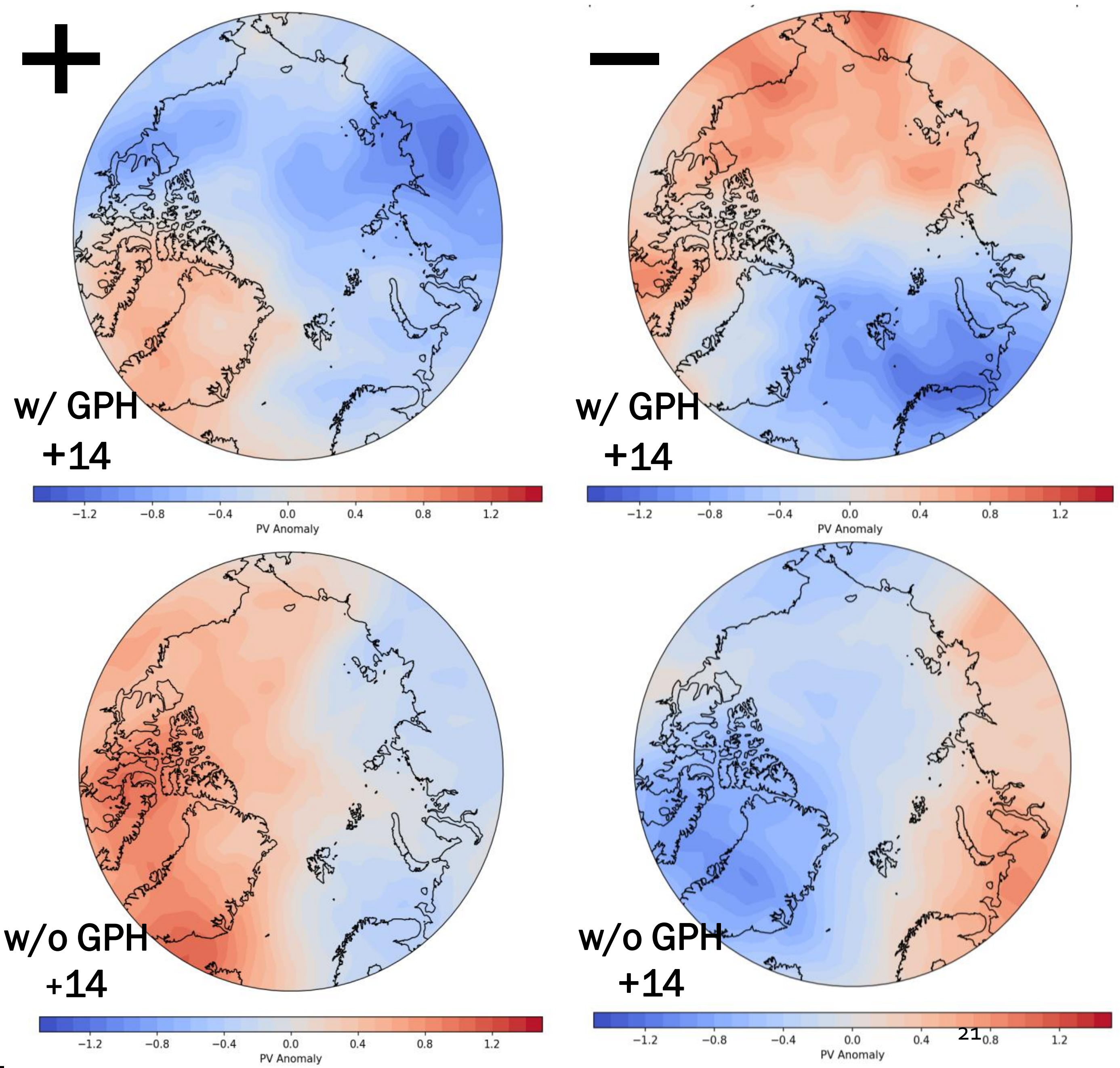


*(**A**) Predictability of monthly mean AO after 10-day leadtime. Obtained via linear regression between daily NAM and monthly-mean AO beginning after 10 days. (Figure 2, Baldwin et al. 2003)*

Compared to PV Only Model

- More clearly defined NAO signal in the full model (**top**) when compared to the PV-only composites **(bottom).**

- Most noticeable for positive temperature anom predicitions, likely to due the favoring of synoptic GPH signals in the full model's decision-making and highlighting short-term fluctuations to NAO signals.



Model Performance & ACC for Forecasts of Opportunity