Stratosphere & Stratosphere-Troposphere Coupling Biases in Subseasonal-to-Seasonal Forecast Models: An International SNAP Community Effort

Zachary D. Lawrence
& many others

An International Collaboration

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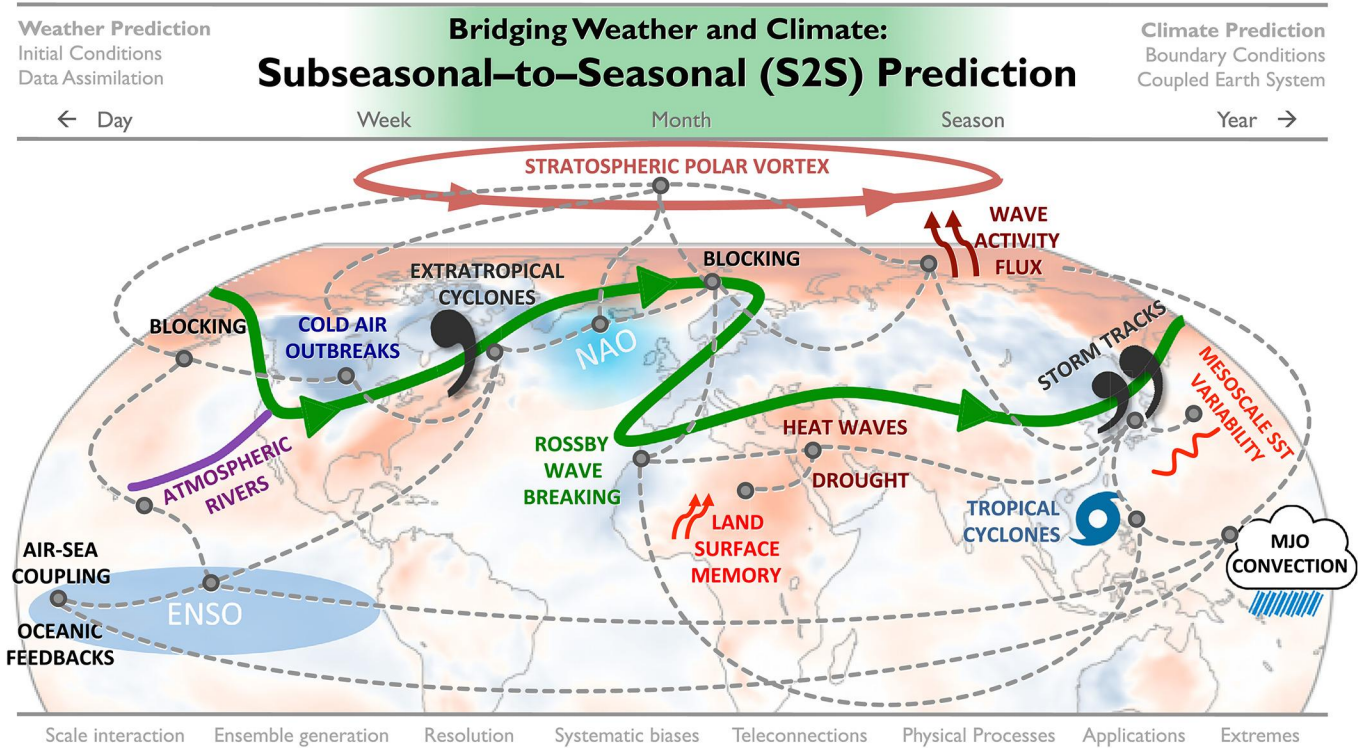
Why focus on the stratosphere and strat-trop coupling?



Increasing number of S2S predictability studies have established that ***the stratosphere can be an important source of improved S2S skill*** in the troposphere.

Problem: Models often struggle to represent the stratosphere. ***Biases can affect strat-trop coupling, and negatively impact S2S forecasts***.

Subseasonal Hindcast Datasets

- Focus primarily on hindcasts in S2S database
  - Not necessarily the most up-to-date model versions
- Where possible, also include results from non-S2S database systems
- Systems with high-top vs low-top models
  - High-top = having a model lid at or above 0.1 hPa with several levels above 1 hPa.
  - Low-top systems are highlighted with *
- Determine biases relative to ERA-Interim reanalysis

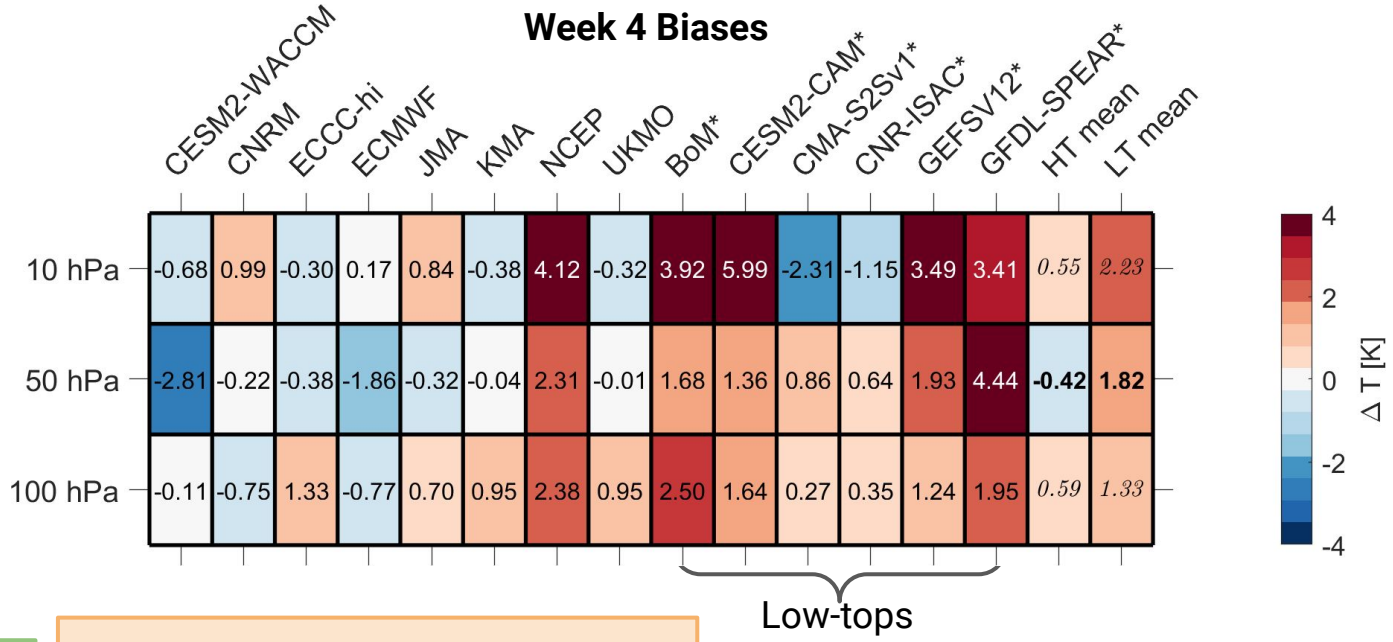
Subseasonal-to-Seasonal S2S Prediction Project

Possible analyses are limited by the S2S Database data only being provided on a sparse set of stratospheric levels (100, 50, and 10 hPa).

Global/Annual-Mean Temperature Biases

To first order, global and annual mean temperatures in the stratosphere are in radiative equilibrium.

Therefore, biases likely to be under radiative control.

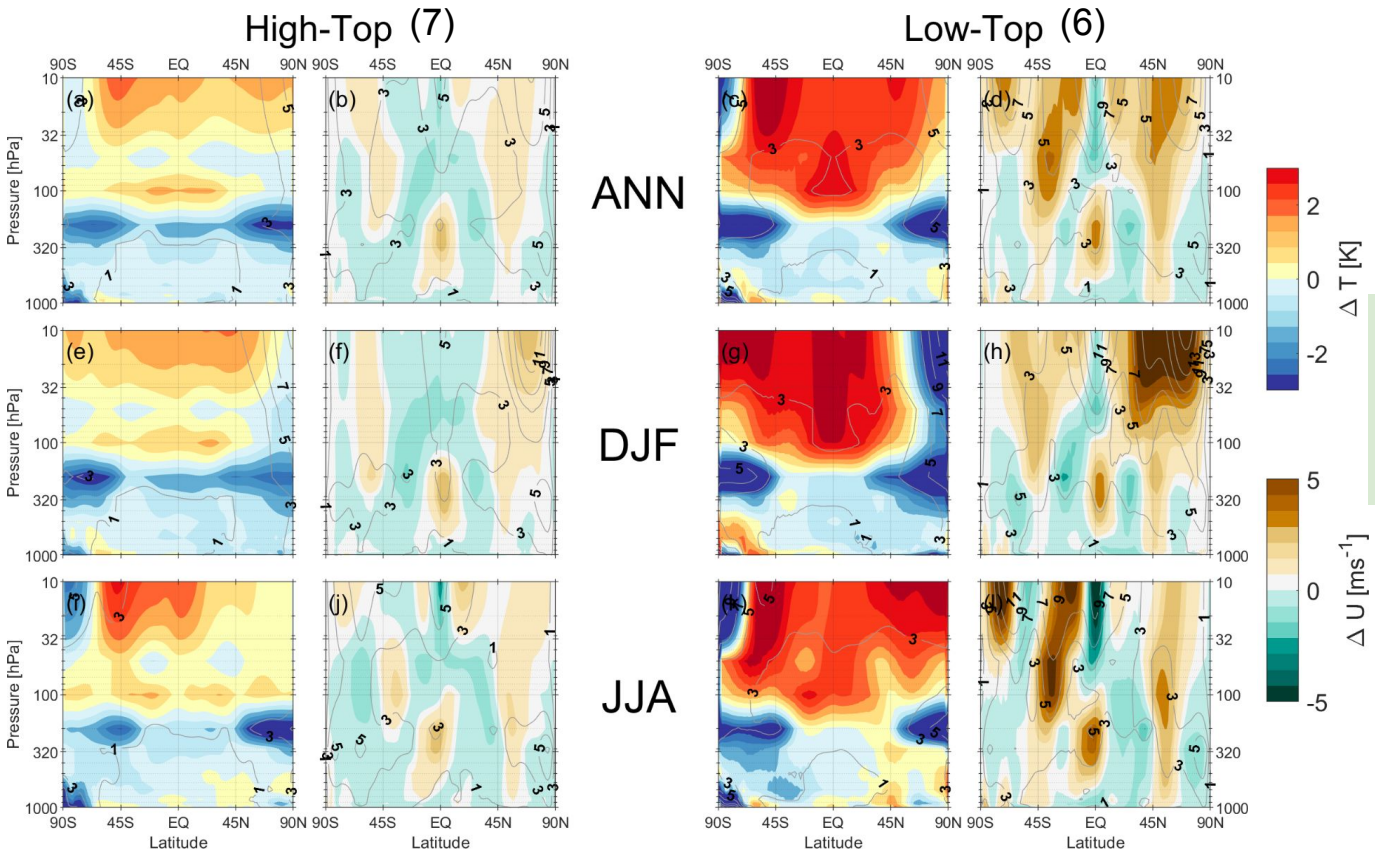


At any given level, ~7-8 systems (out of 15) have absolute biases exceeding 1 K

Global mean warm biases are more common than cold biases. Systems with largest warm biases are BoM, CESM2-CAM, and “NOAA family”

Only systems with cold biases are CESM2-WACCM and ECMWF

Zonal Mean Biases (Week 4)



Low top S2S models:
More pronounced biases + greater errors

Generally similar biases:
(1) global mean warm biases
(2) polar vortex wind/T bias
(3) extratropical UTLS cold bias

Location and structure of biases helps to identify their likely sources

Composites of biases and mean absolute errors at week 4, verified against ERA-Interim

Biases in the QBO

10 hPa tropical winds

50 hPa tropical winds

100 hPa tropical Temps

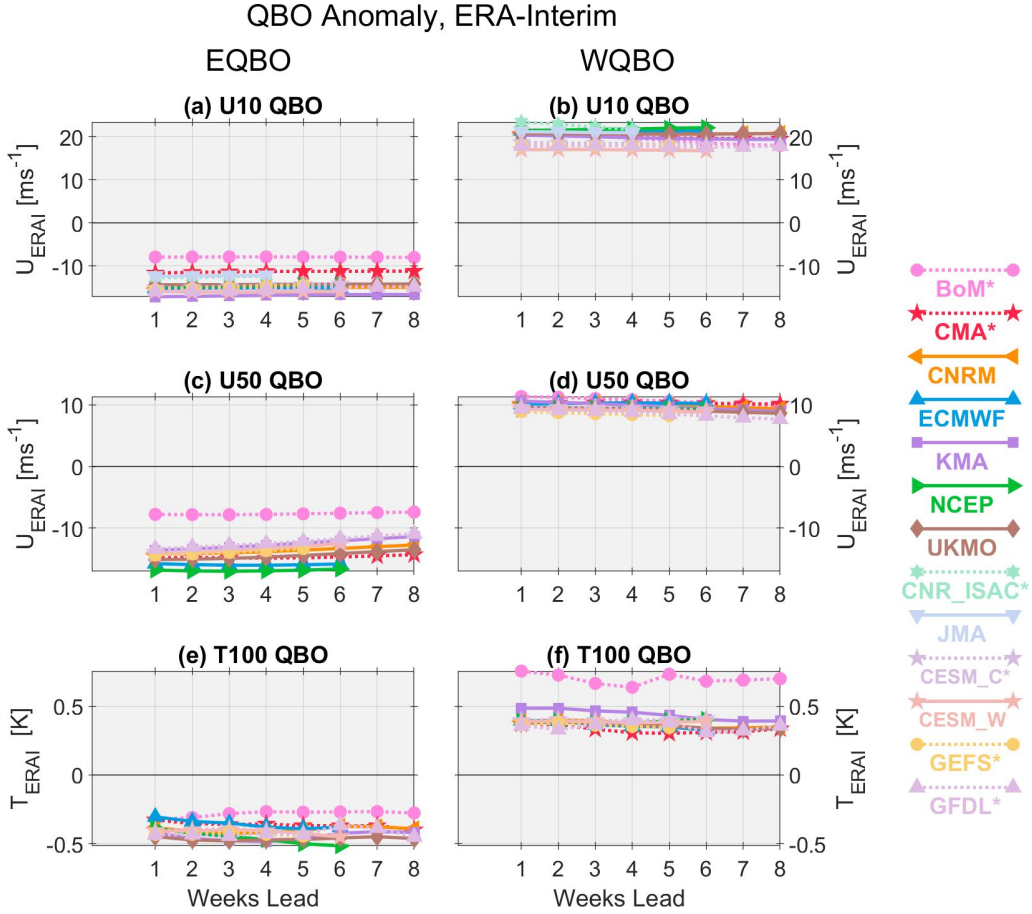


Figure shows QBO-associated anomalies in reanalysis data sampled to match the S2S hindcasts

On S2S timescales, the QBO does not evolve much!

Biases in the QBO

10 hPa tropical winds

50 hPa tropical winds

100 hPa tropical Temps

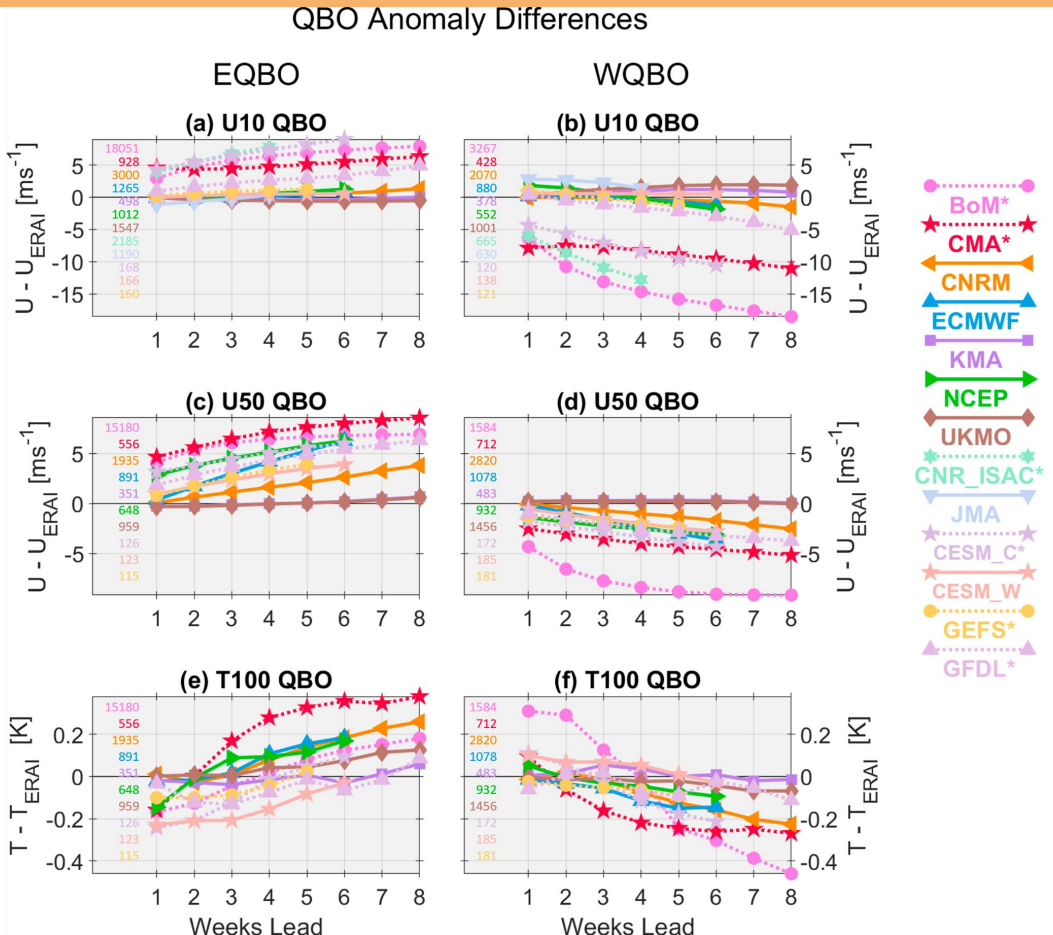


Figure shows differences in anomalies between hindcasts and reanalysis (high-top = solid lines, low-top = dashed lines)

High-top models able to maintain QBO well at 10 hPa, but perform worse in lower strat

QBO anomalies decay quickly for low-top models regardless of level

Biases in Eddy Heat Fluxes

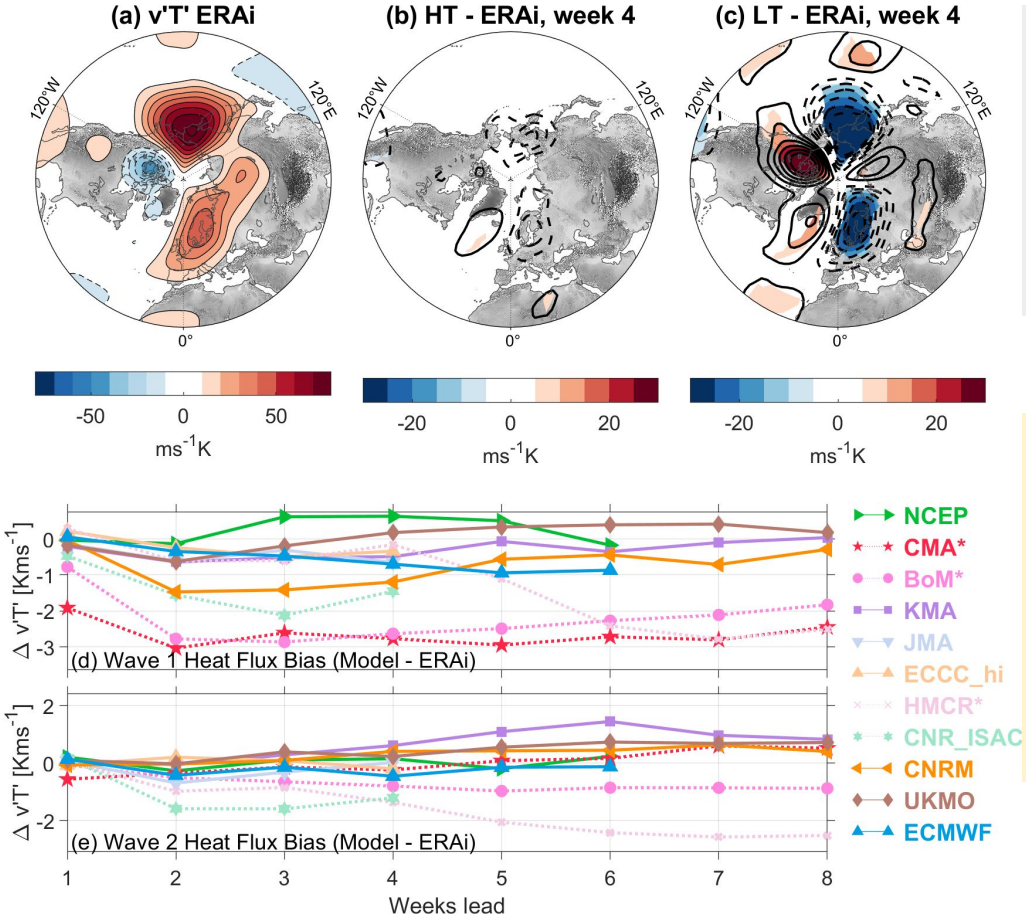
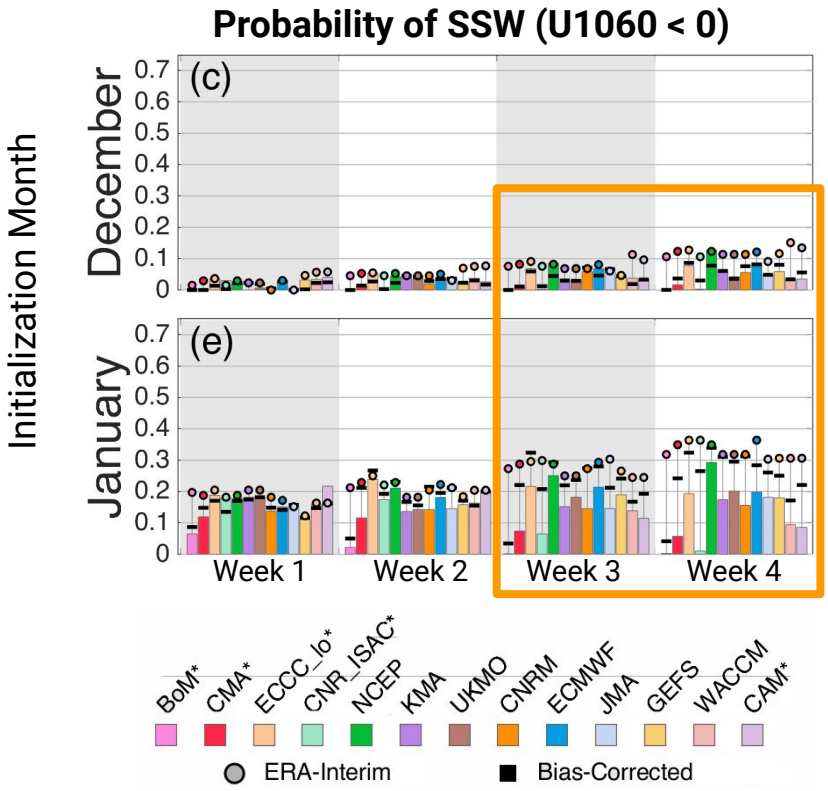


Figure shows maps of 100 hPa eddy heat flux biases for high-top (panel b) and low-top (panel c) S2S models. The bottom two rows show the biases as a function of weekly lead time with high-top models in solid lines, and low-top models in dashed.

Low-top S2S models underestimate the 100 hPa eddy heat fluxes for zonal wavenumbers 1 and 2, suggesting that they have a biased representation of simulated planetary waves.

Sudden Stratospheric Warming Frequency

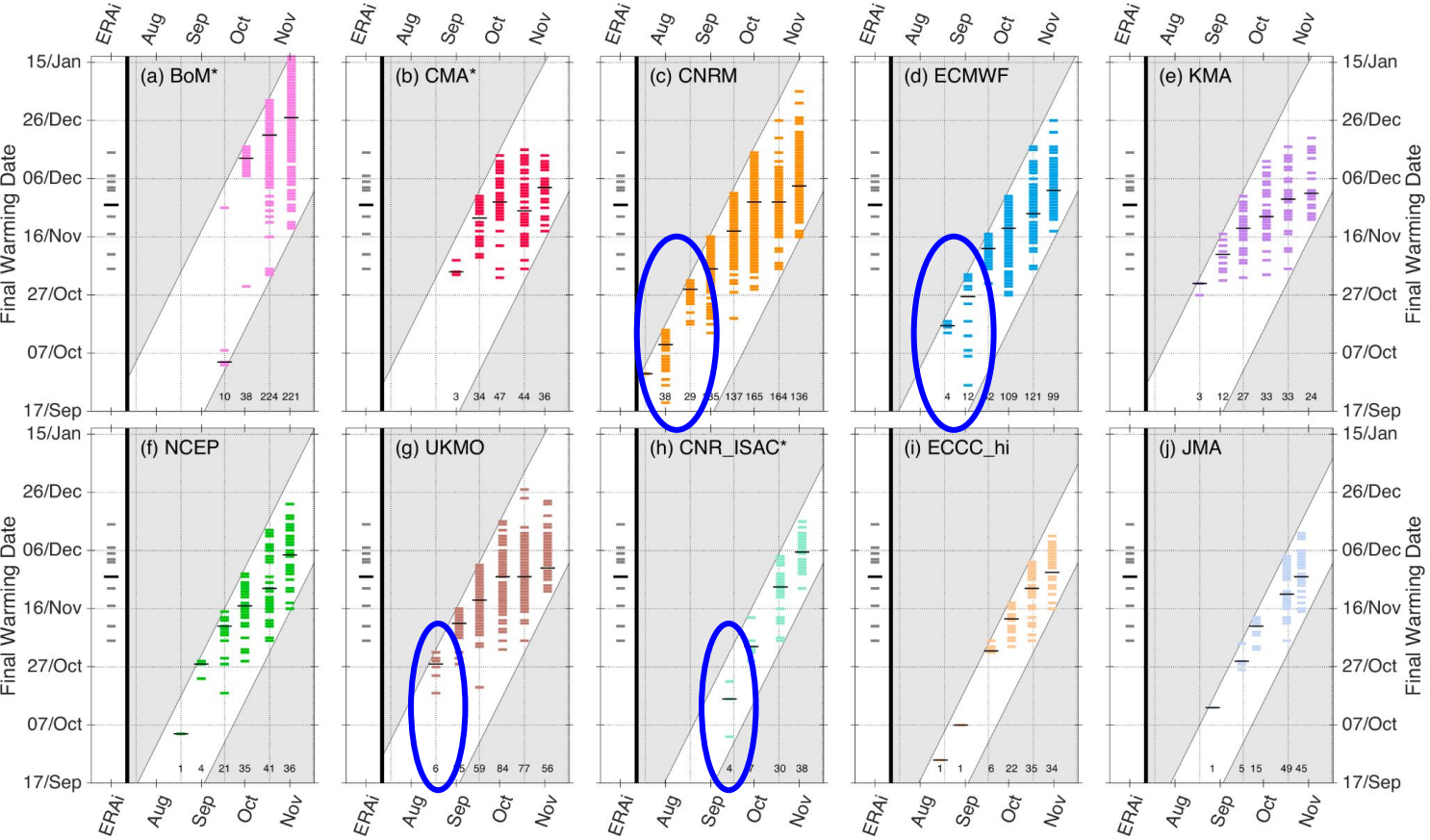


Bars = Average probability of SSW occurring for given initialization month and weekly bin

Circles = Probability determined using ERA-I data subsampled to match each system's sampling of historical record

Virtually all systems underestimate the probability of SSWs occurring @ weeks 3-4, suggesting a relative lack of polar stratospheric variability.

Timing of SH Final Warmings



For early inits in Aug and Sep, many systems simulate early breakdowns of the SH polar vortex at times generally not seen in the historical record.

These (and other) results published in WCD

Weather Clim. Dynam., 3, 977–1001, 2022
https://doi.org/10.5194/wcd-3-977-2022

Quantifying stratospheric biases and identifying their potential sources in subseasonal forecast systems

Conclusions & Future of Project

Findings so far:

- S2S forecast systems can exhibit relatively large biases in both the mean state and variability of the stratosphere
- Biases in systems with low-top models are generally much worse than those with high-top models (high-top systems still aren't perfect)
- Biases can give us hints to their sources and links to other biases. Examples:
  - Good understanding of physical processes for global vs zonal mean biases
  - Polar vortex biases and issues with variability at longer lead times

What's next for the project?

We are working on a second paper that focuses on linking biases to the troposphere, and assesses the impact of biases on forecast skill.

NAM Coupling and Tropospheric Biases

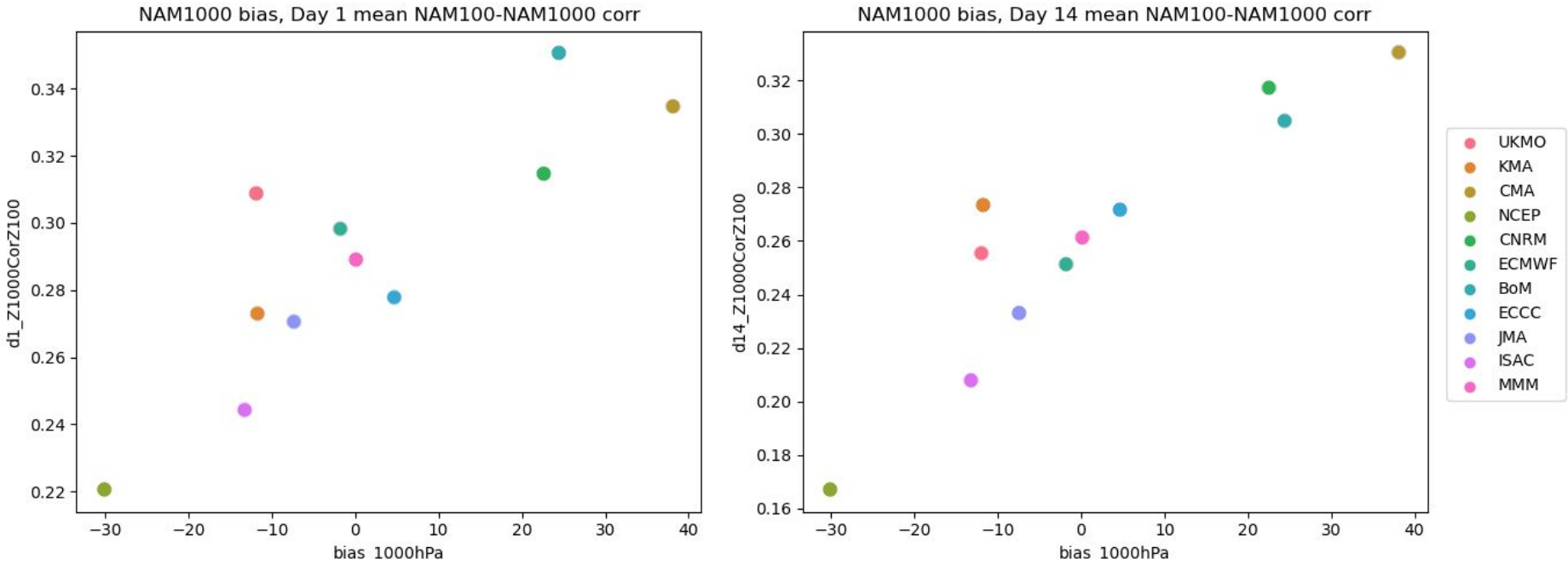


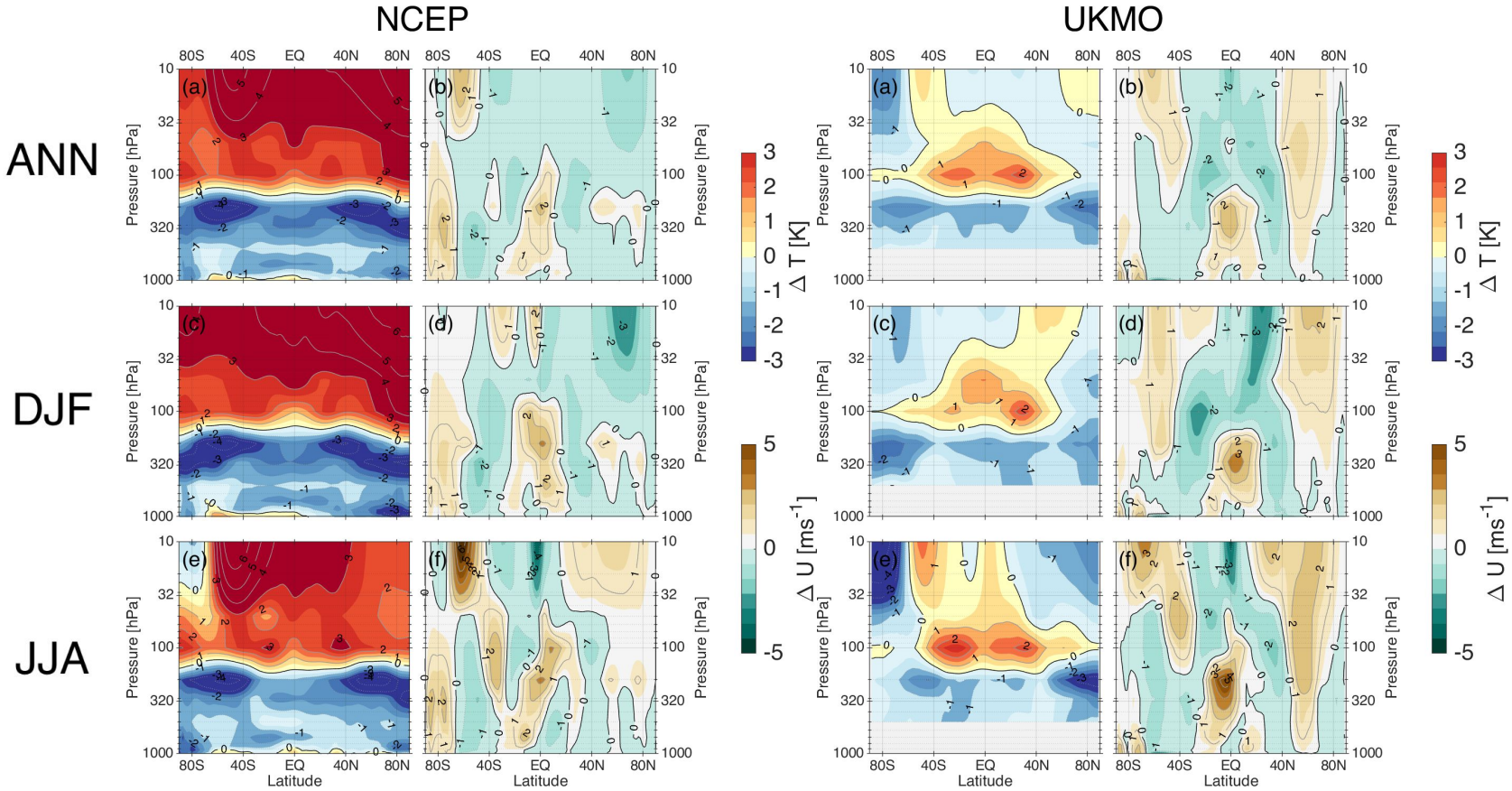
Figure shows the bias in 1000 hPa polar cap heights (x-axes) against the lagged correlation between the 100 hPa NAM and 1000 hPa NAM (y-axes).

The "strength" of downward NAM coupling in the S2S models appears to be linearly related to biases near/at the surface.

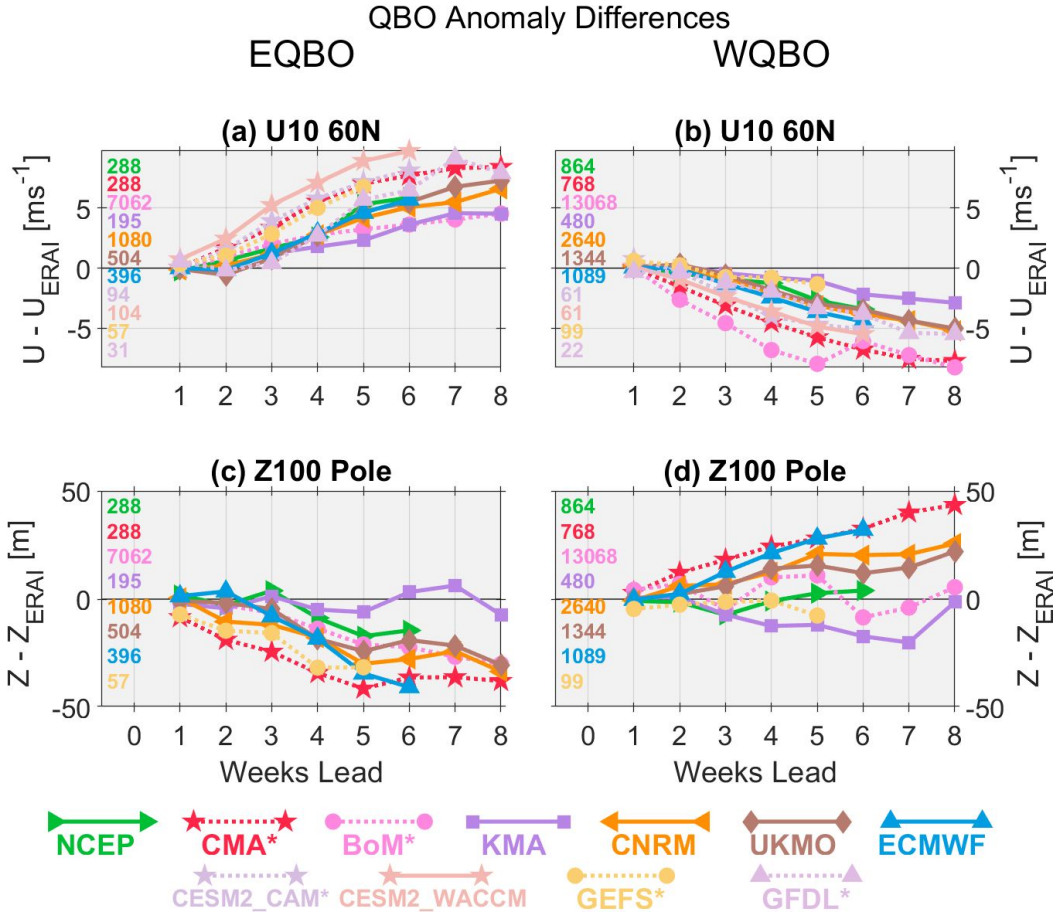
Credit: Alexey Karpechko, Irina Statnaia, Nicholas Tyrrell

Extra Slides

Zonal Mean Biases (Individual Systems)



Holton-Tan Effect



SH Eddy Heat Fluxes (100 hPa)