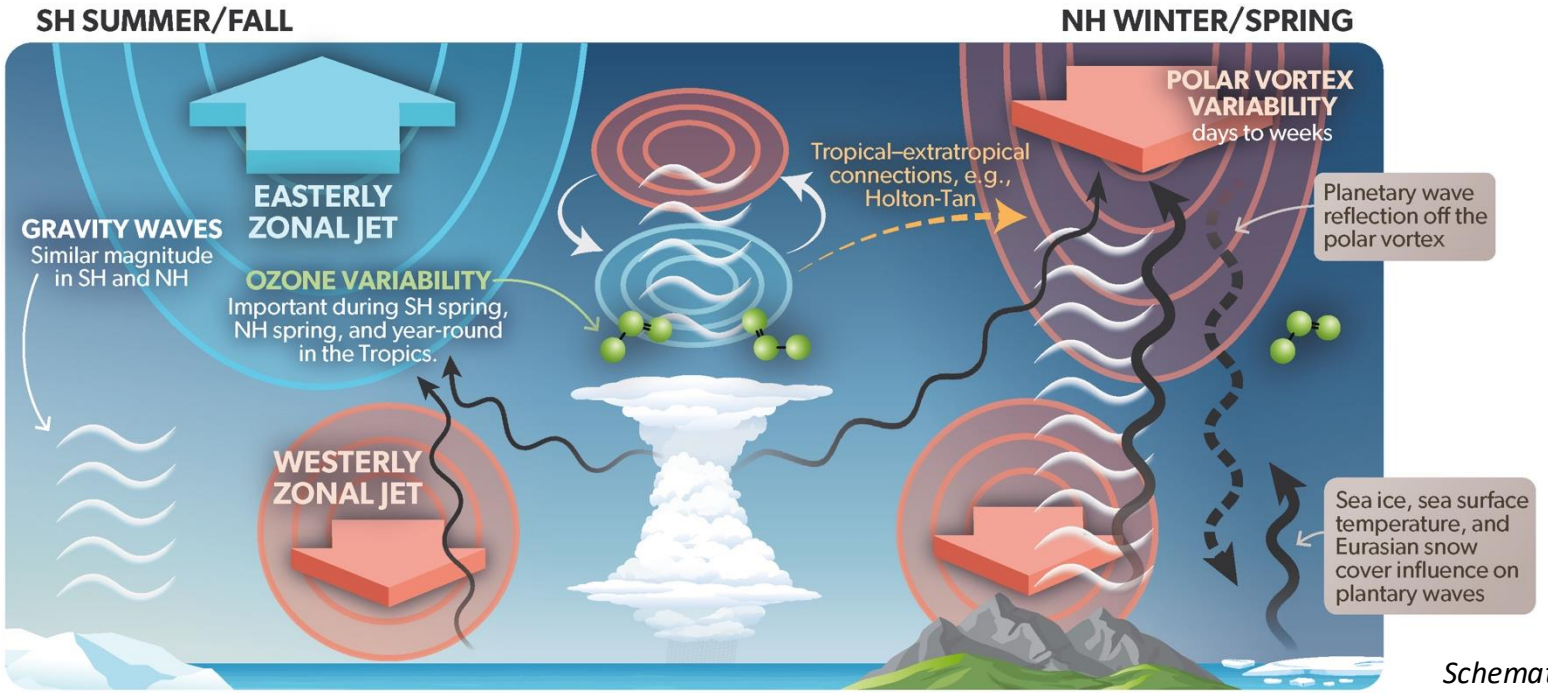
APARC-SNAP study on the role of biases in the stratosphere on S2S predictability

Chaim I. Garfinkel, Zachary D. Lawrence, Amy H. Butler, Blanca Ayarzagüena

Co-authors: Etienne Dunn-Sigouin, Irina Statnaia, Alexey Karpechko, Gerbrand Koren, Marta Abalos, Blanca Ayarzagüena, David Barriopedro, Natalia Calvo, Alvaro de la Cámara, Andrew Charlton-Perez, Daniela Domeisen, Javier García-Serrano, Neil P. Hindley, Martin Jucker, Hera Kim, Robert Lee, Simon Lee, Marisol Osman, Froila Palmeiro, Inna Polichtchouk, Jian Rao, Jadwiga H. Richter, Chen Schwartz, Seok-Woo Son, Masakazu Taguchi, Nicholas L. Tyrrell, Corwin Wright, and Rachel Wu

Subseasonal-to-Seasonal S2S Prediction Project

APARC Atmospheric Processes And their Role in Climate



Schematic by Chelsea Thompson/NOAA
For Butler et al. 2024, submitted

SNAP –Stratospheric Network for the Assessment of Predictability

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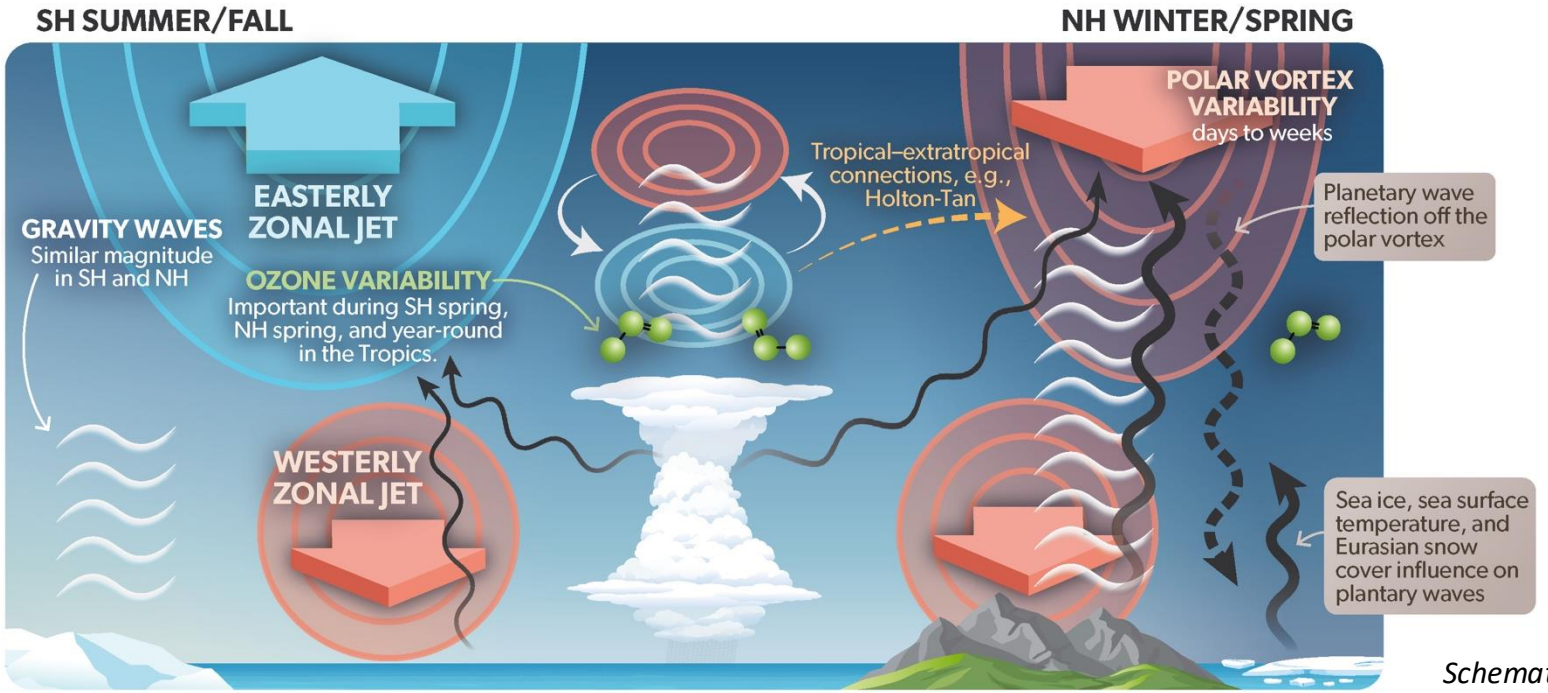

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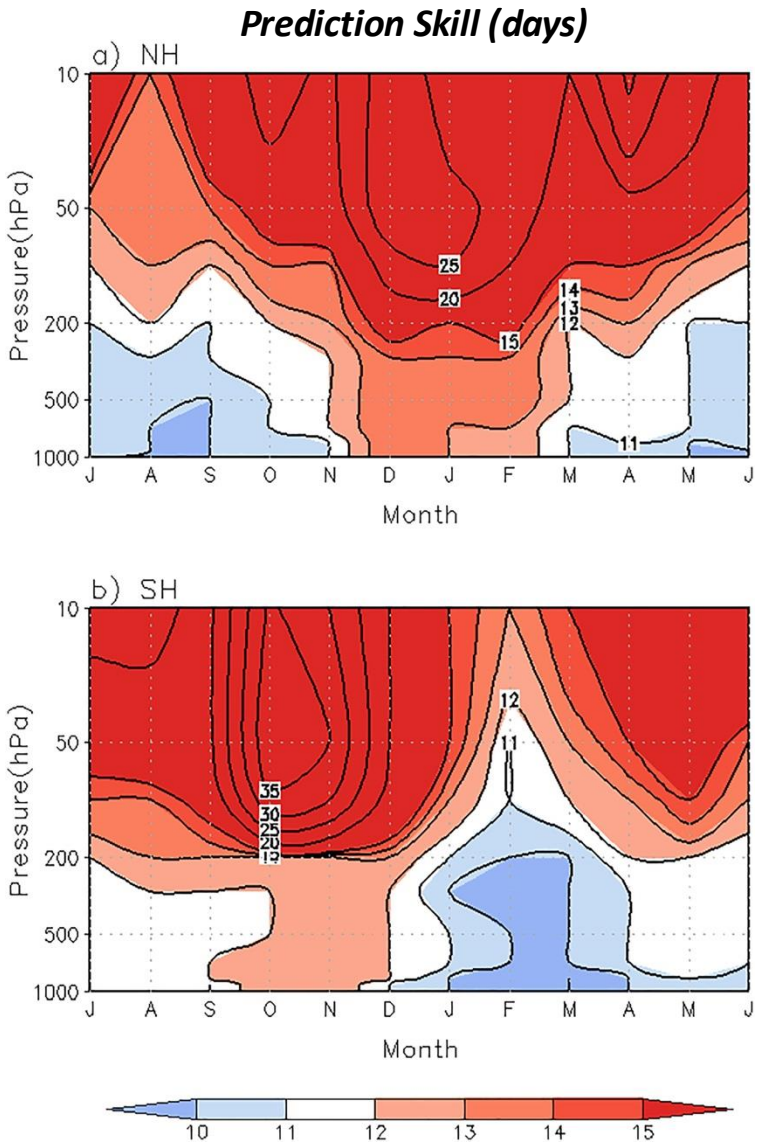
The stratosphere is one of the only sources of persistent signal in the atmosphere on S2S timescales



- Skillful forecasts of extratropical geopotential heights in the stratosphere extend to lead-times ~2-3x longer than in the troposphere.
- Extended prediction skill in the troposphere is found in NH winter and SH spring, during periods of active stratosphere-troposphere coupling.
- Following stratospheric polar vortex extremes, anomalies in the lower stratosphere can persist for weeks to months, with an impact on extremes.

Son et al., 2020

SNAP –Stratospheric Network for the Assessment of Predictability

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Two main activities:

1. Assessment of operational S2S forecast systems

2. Targeted simulations to isolate the role of the stratosphere for surface extremes, and isolate model biases (SNAPSI)

Prediction Project

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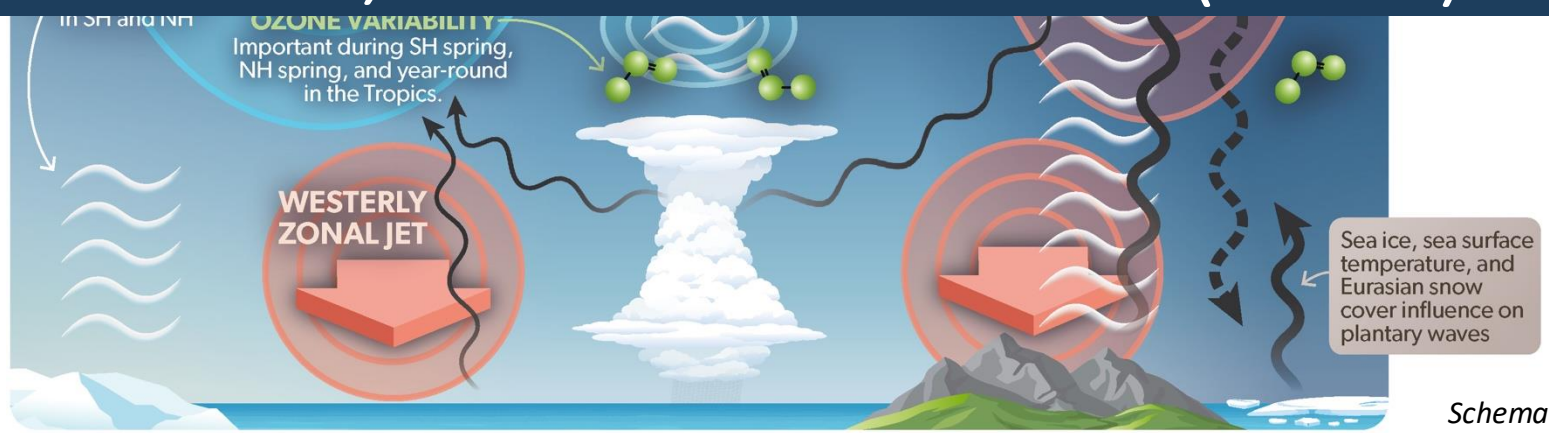

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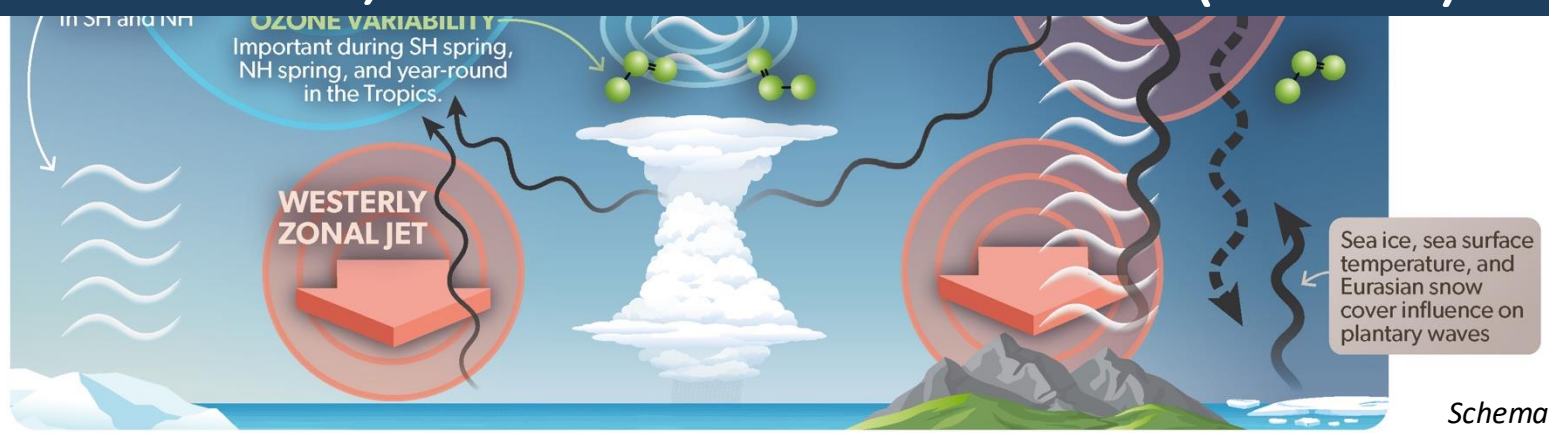

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A process-based evaluation of biases in stratosphere-troposphere coupling in subseasonal forecast systems

Garfinkel et al. 2024, WCD

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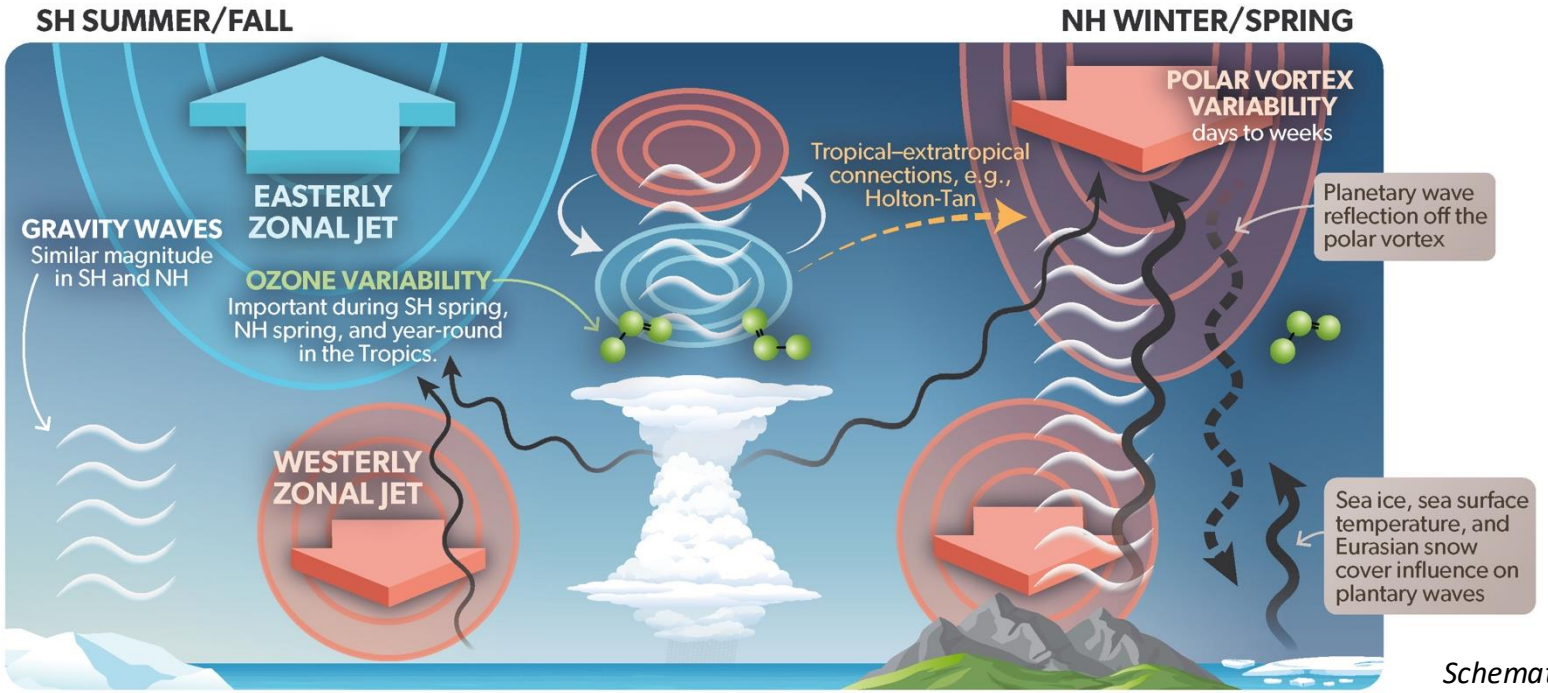

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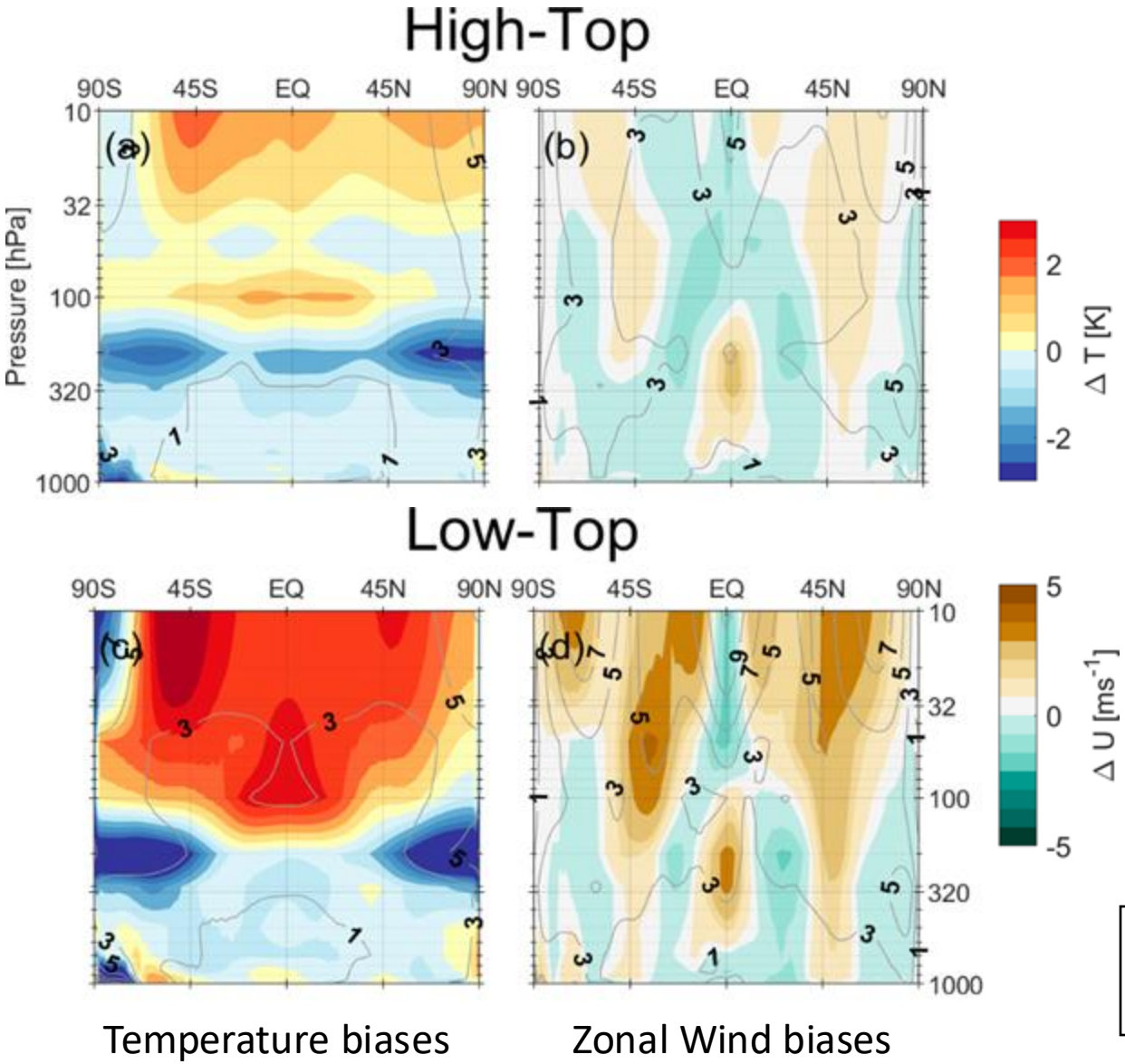
There are known model biases that may affect stratosphere-troposphere coupling



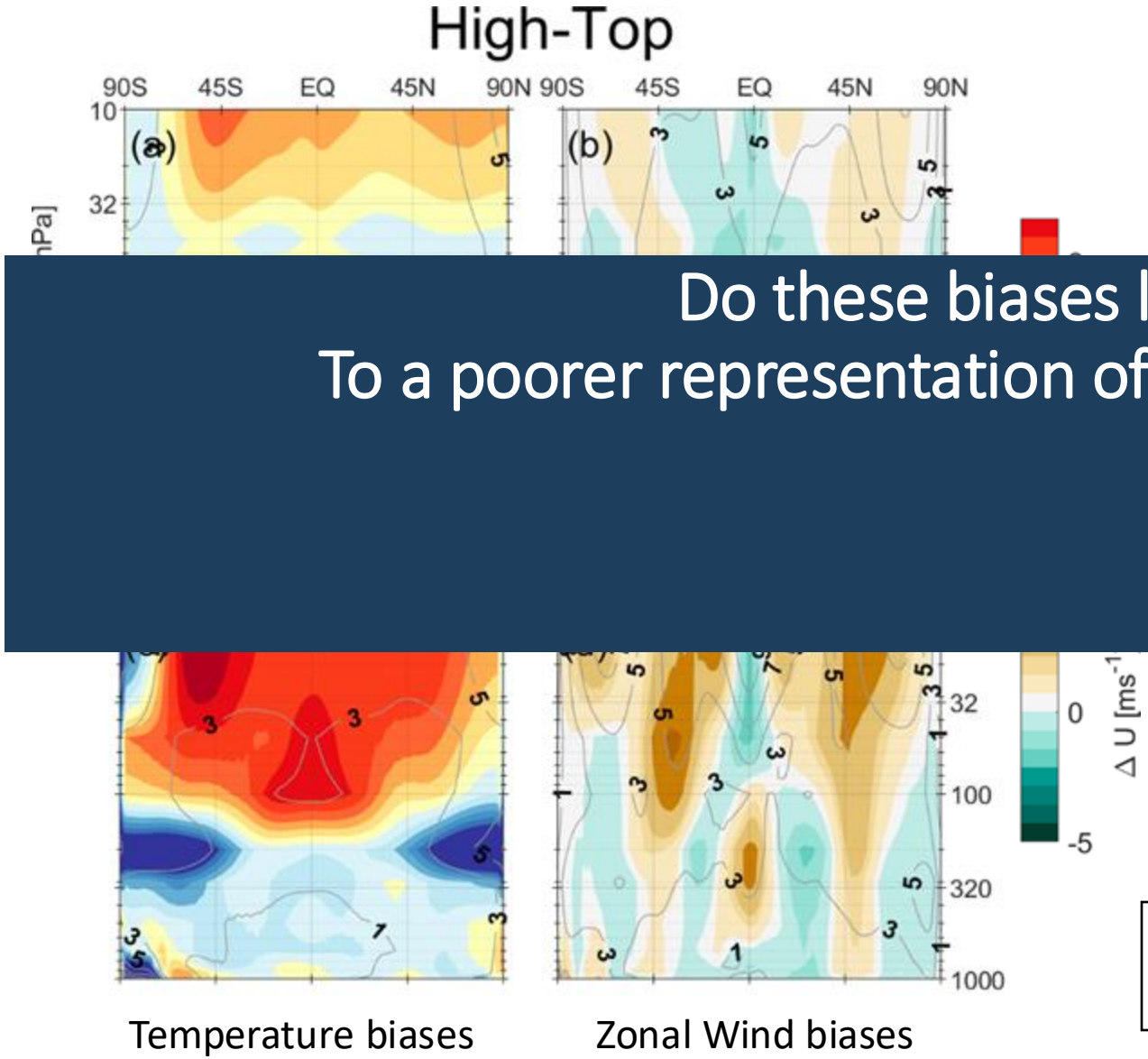
Temperature biases

Zonal Wind biases

- Generally similar week 4 biases across S2S prediction systems:
  1) Polar vortex wind/T bias in winter hemisphere
  2) Extratropical UTLS cold bias
  3) Global-mean stratospheric warm bias
- Models with lower model lid height on average show larger biases

Composites of biases and mean absolute errors at week 4, verified against ERA-Interim, from **Lawrence et al. (2022)**

There are known model biases that may affect stratosphere-troposphere coupling



Temperature biases

Zonal Wind biases

- Generally similar week 4 biases across S2S prediction systems:

Do these biases lead to lower skill?
To a poorer representation of strat-trop coupling processes?

on average show larger biases

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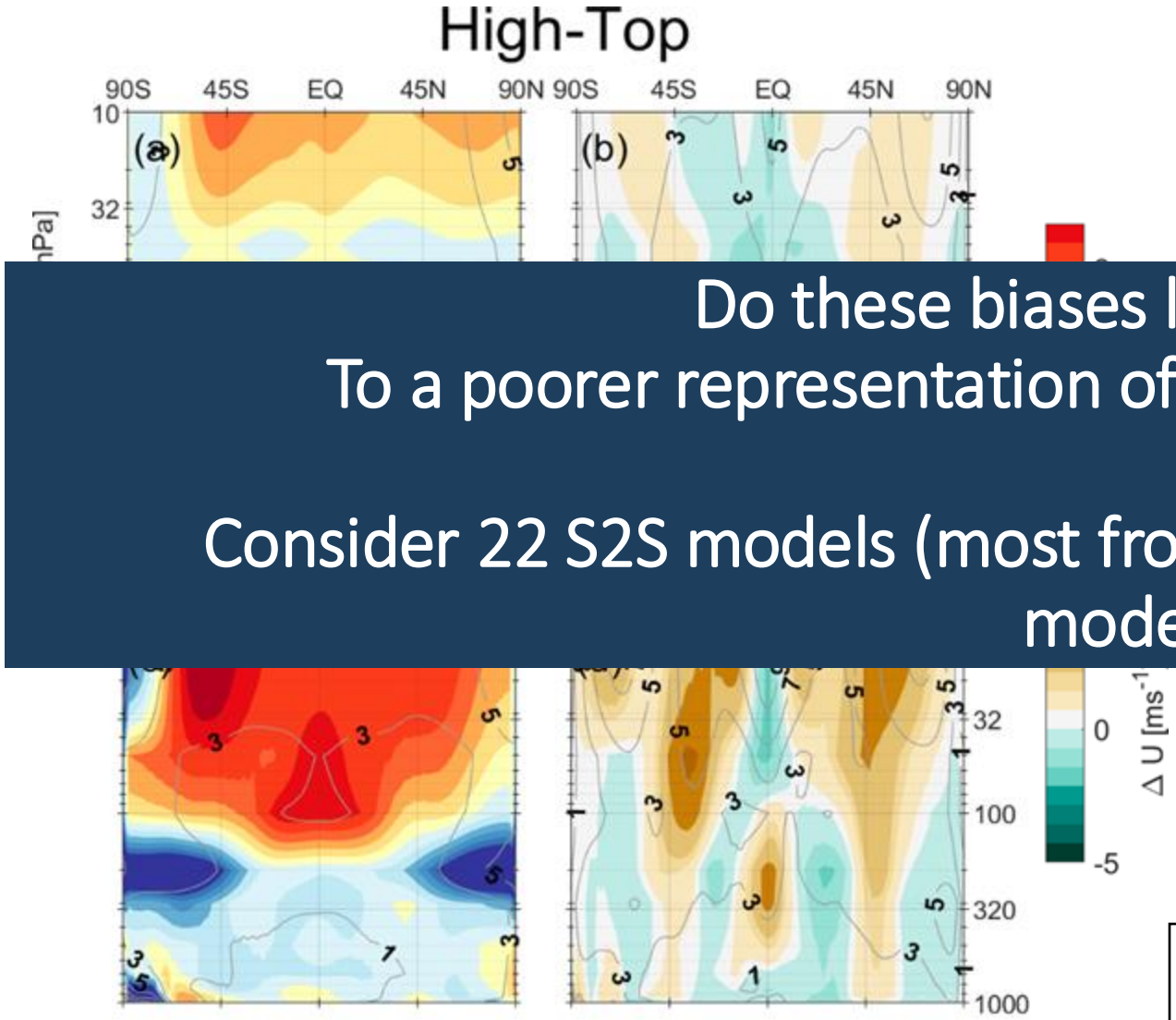
There are known model biases that may affect stratosphere-troposphere coupling



Temperature biases

Zonal Wind biases

- Generally similar week 4 biases across S2S prediction systems:

Do these biases lead to lower skill?
To a poorer representation of strat-trop coupling processes?

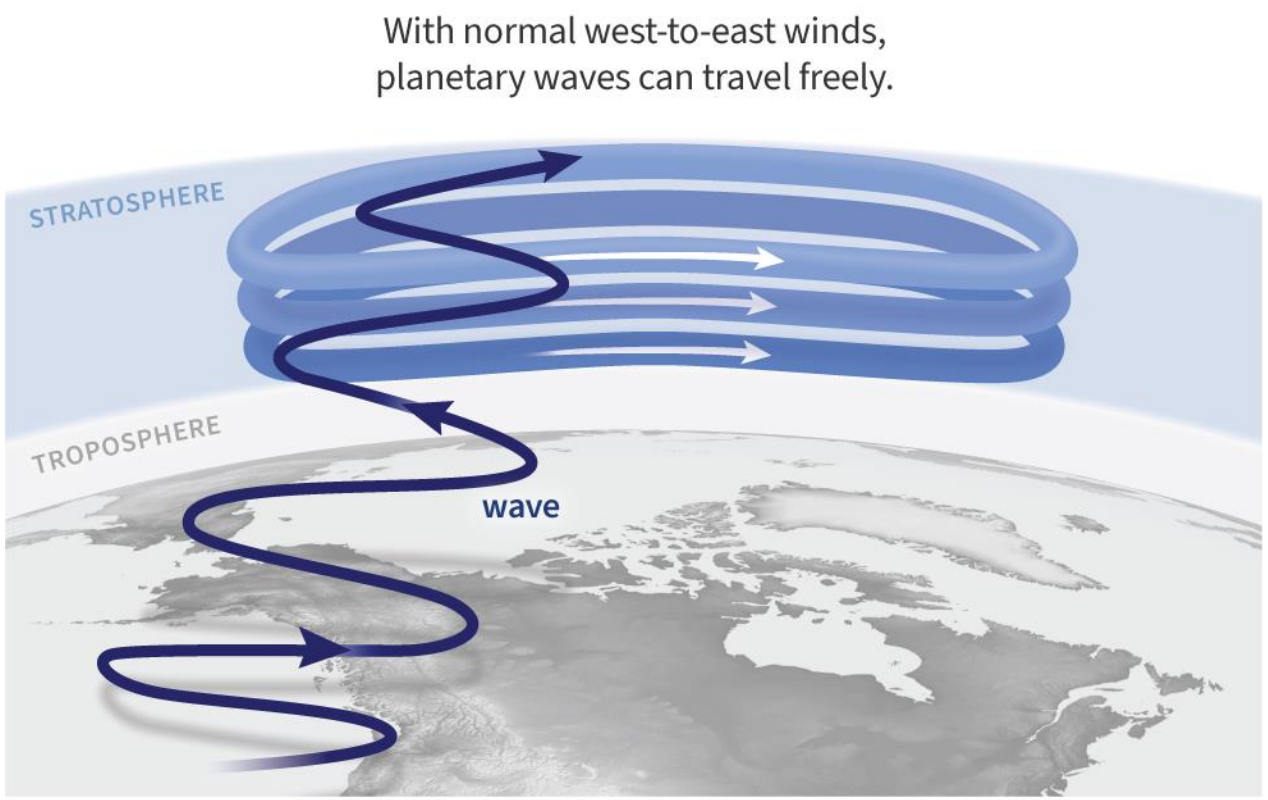
Consider 22 S2S models (most from S2S archive, plus a few US based models)

on average show larger biases

Composites of biases and mean absolute errors at week 4, verified against ERA-Interim, from **Lawrence et al. (2022)**

Breaking stratosphere-troposphere coupling in the NH into upward and downward processes….

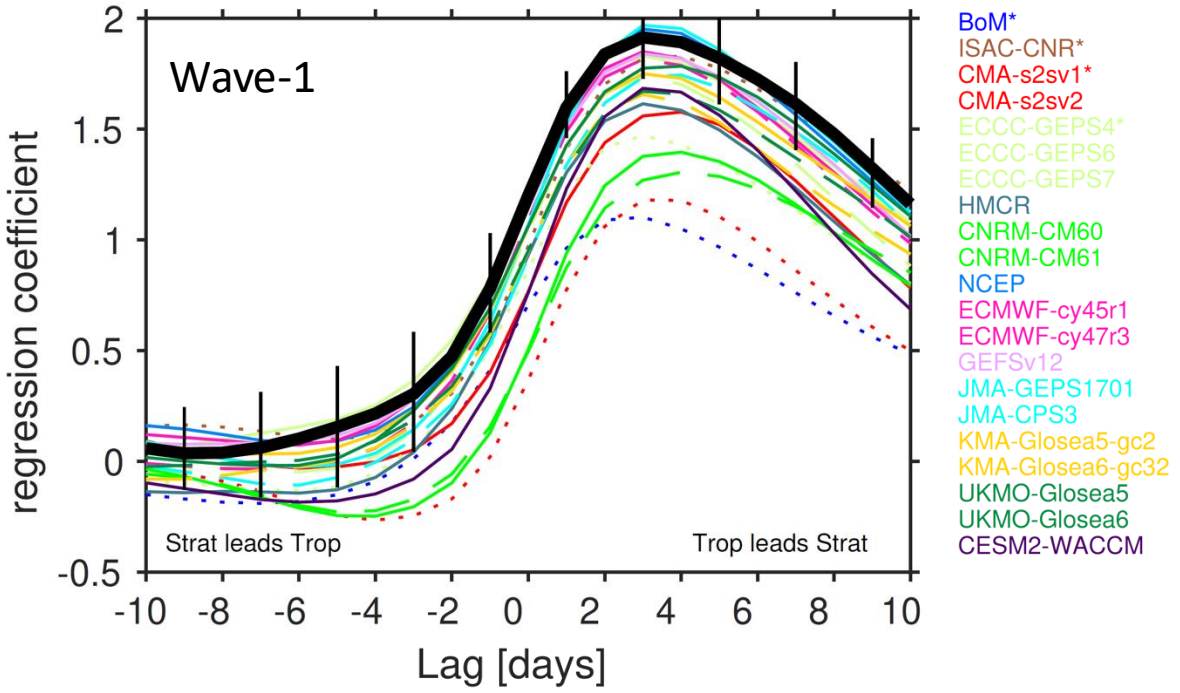
1) Upward flux of wave activity from troposphere to stratosphere



Only the largest Rossby waves (wavenumbers 1-2) can travel into the stratosphere

From the NOAA Polar Vortex Blog on Climate.gov

Regression of 45-75N 500hPa heat flux (days 11-22) with 100hPa heat flux , DJF

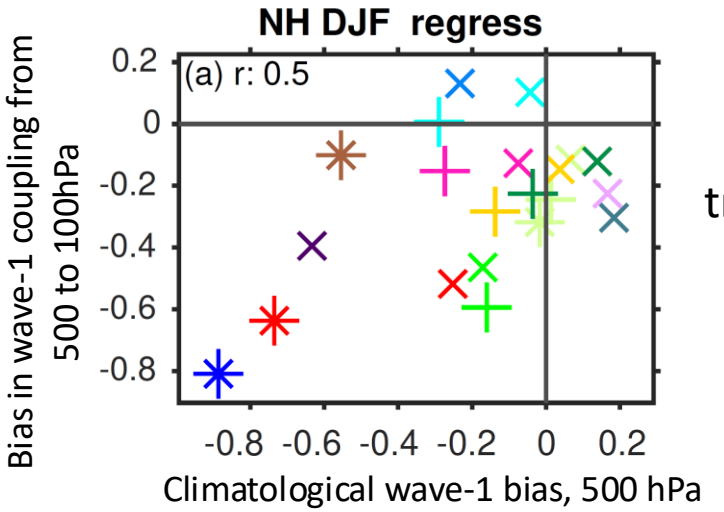


S2S models underestimate upward flux of largest atmospheric waves from troposphere into stratosphere.

Garfinkel et al. 2024, WCD

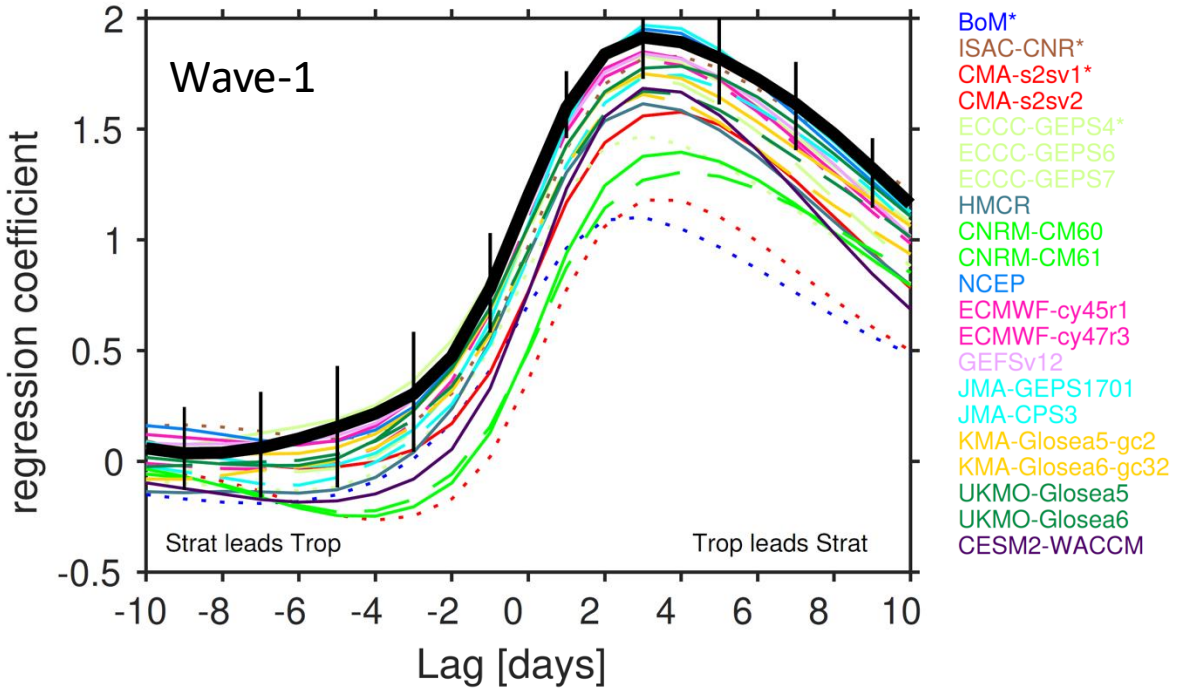
1) Upward flux of wave activity from troposphere to stratosphere

What explains intermodel spread in the regression coefficients?



Models with worse tropospheric quasi-stationary wave-1 biases tend to have too-weak wave-1 upward coupling.

Regression of 500hPa heat flux (days 11-22) with 100hPa heat flux , DJF



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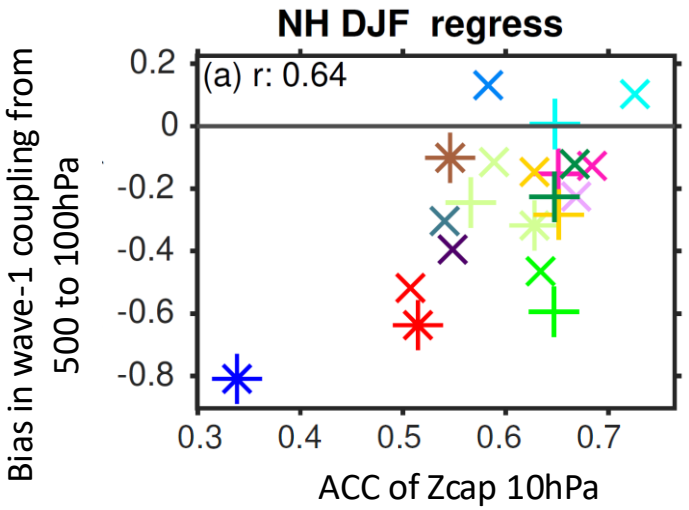
Garfinkel et al. 2024, WCD

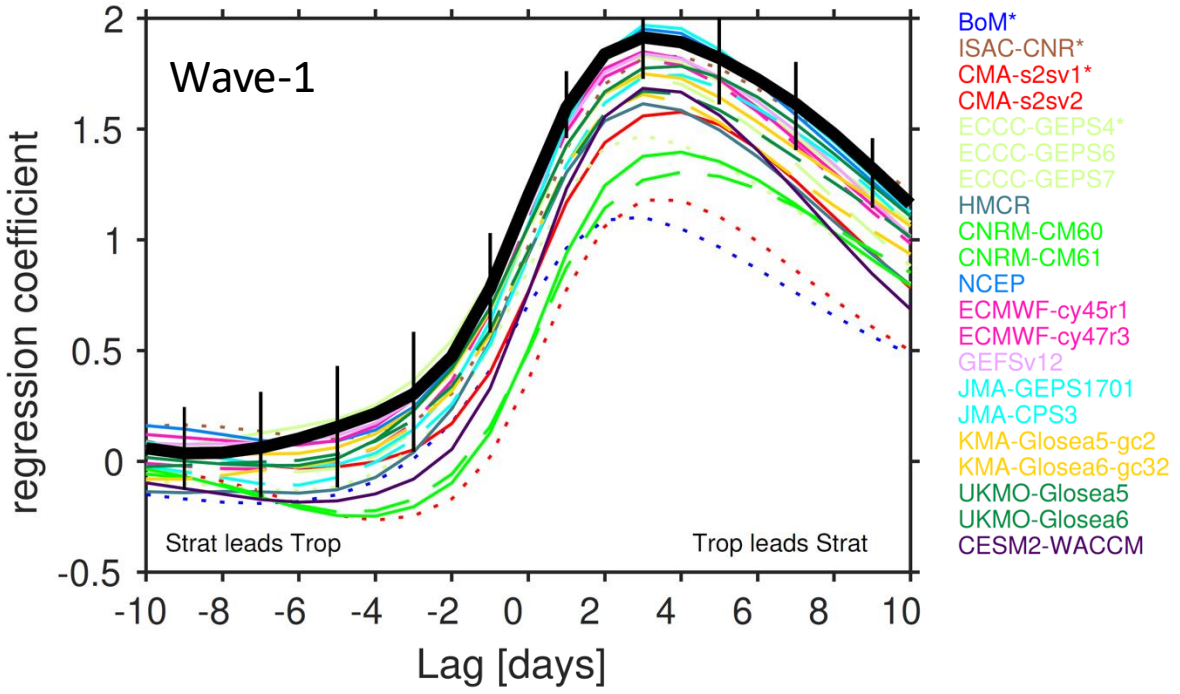
1) Upward flux of wave activity from troposphere to stratosphere

Implications for skill of Zcap10



Models with better wave-1 upward coupling have better stratospheric skill.

Regression of 500hPa heat flux (days 11-22) with 100hPa heat flux , DJF



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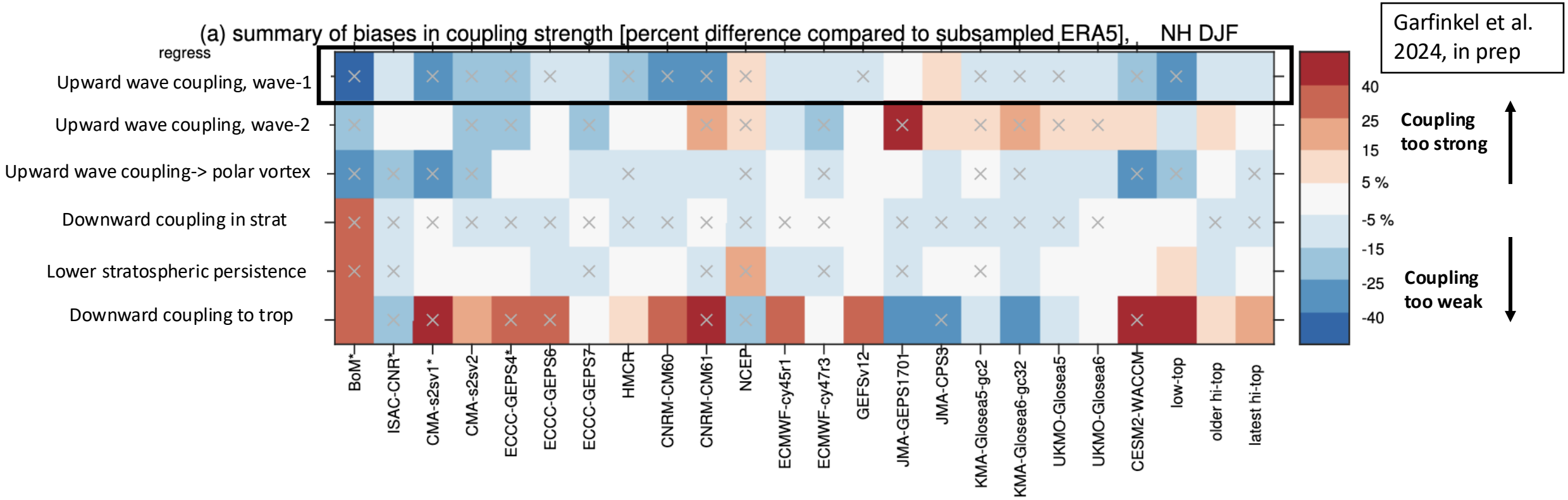
Garfinkel et al. 2024, WCD

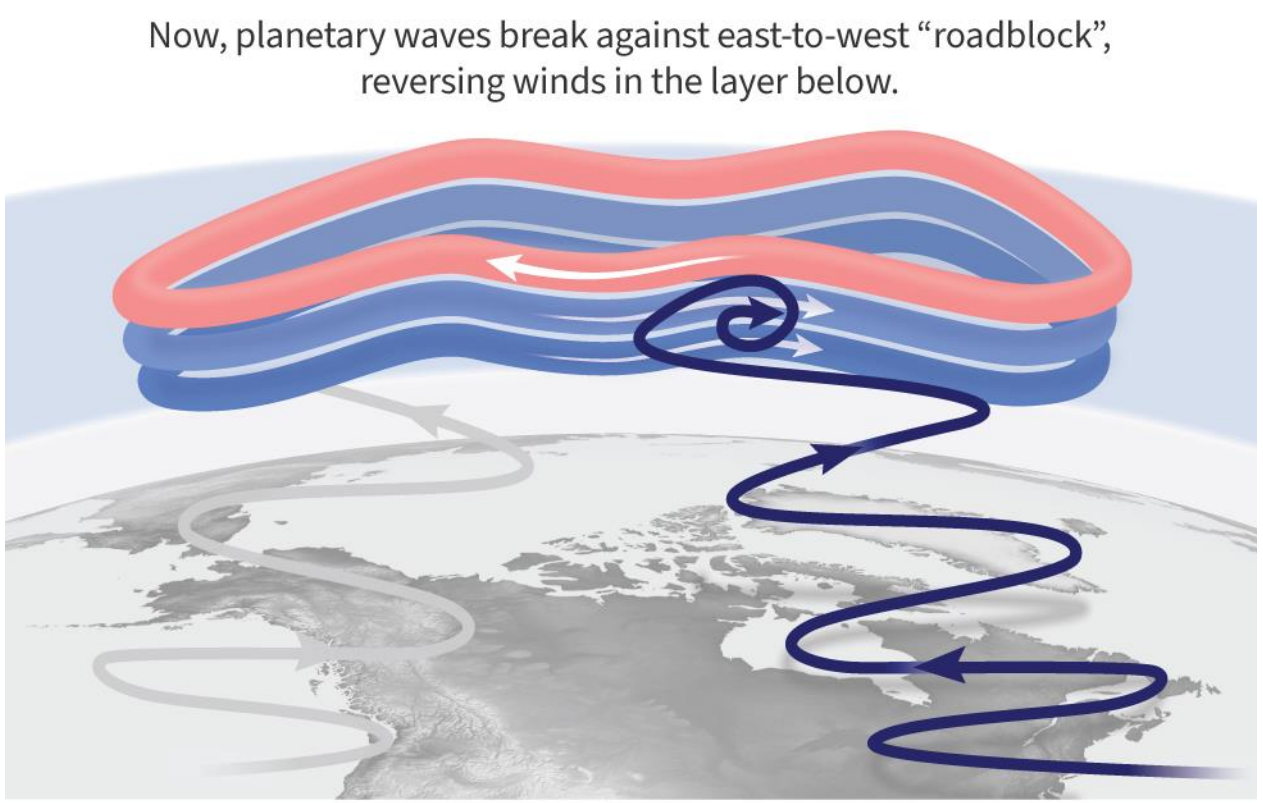
Summary of S2S model biases in stratosphere-troposphere coupling



Garfinkel et al. 2024, in prep

In the NH winter, most S2S models underestimate upward wave coupling and downward coupling within the stratosphere. A few models overestimate downward coupling to the lower troposphere.

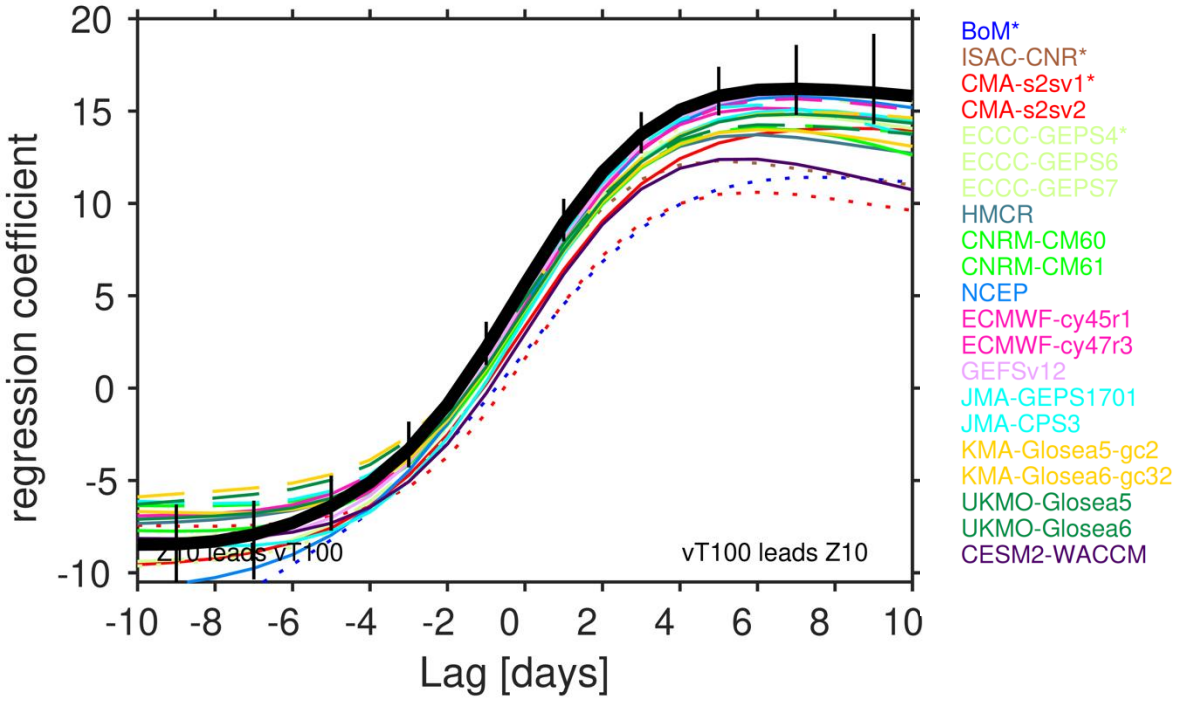
2) Polar stratospheric winds respond to upward flux of atmospheric waves



Combination of stratospheric vortex state and strength/location of tropospheric waves can cause waves to break, depositing easterly momentum and slowing the stratospheric winds.

From the NOAA Polar Vortex Blog on Climate.gov

Regression coefficient of 100hPa heat flux (days 11-22), with polar cap height at 10hPa, DJF

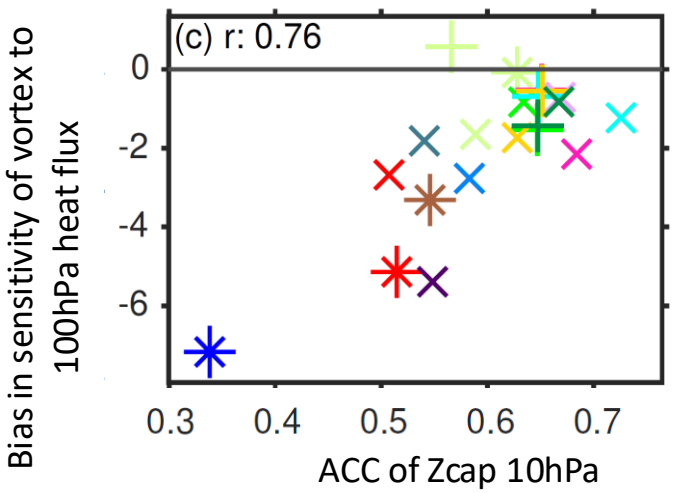


S2S models underestimate sensitivity of polar stratospheric winds to upward wave flux

Garfinkel et al. 2024, WCD

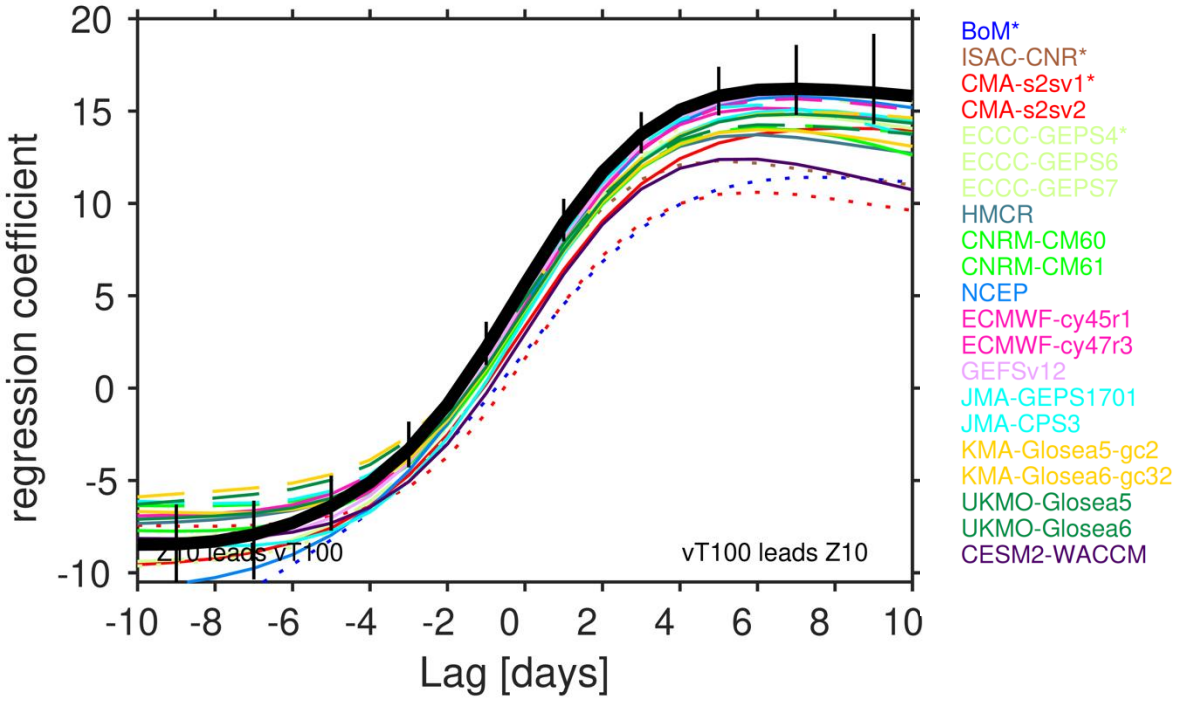
2) Polar stratospheric winds respond to upward flux of atmospheric waves

Intermodel spread in coupling related to skill of Zcap10hPa



Models with better vortex sensitivity have better stratospheric skill.

Regression coefficient of 100hPa heat flux (days 11-22), with polar cap height at 10hPa, DJF



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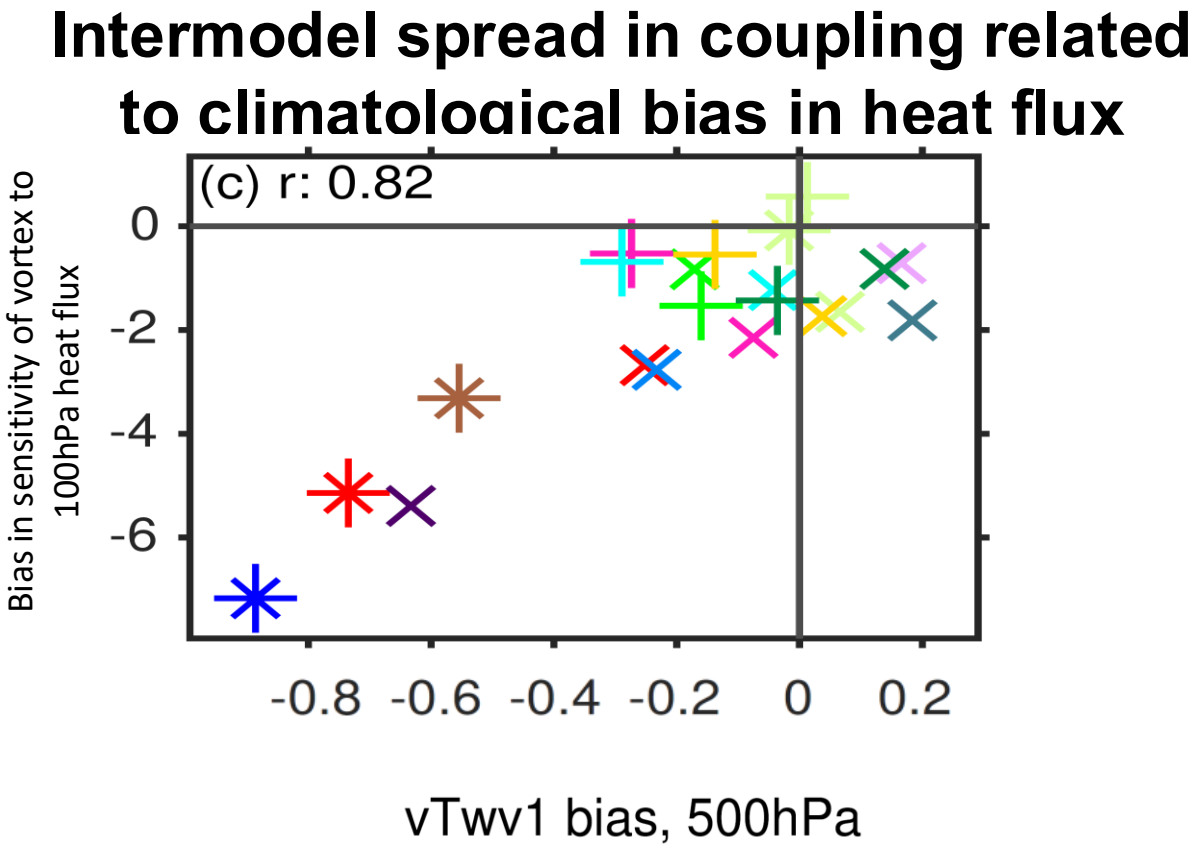

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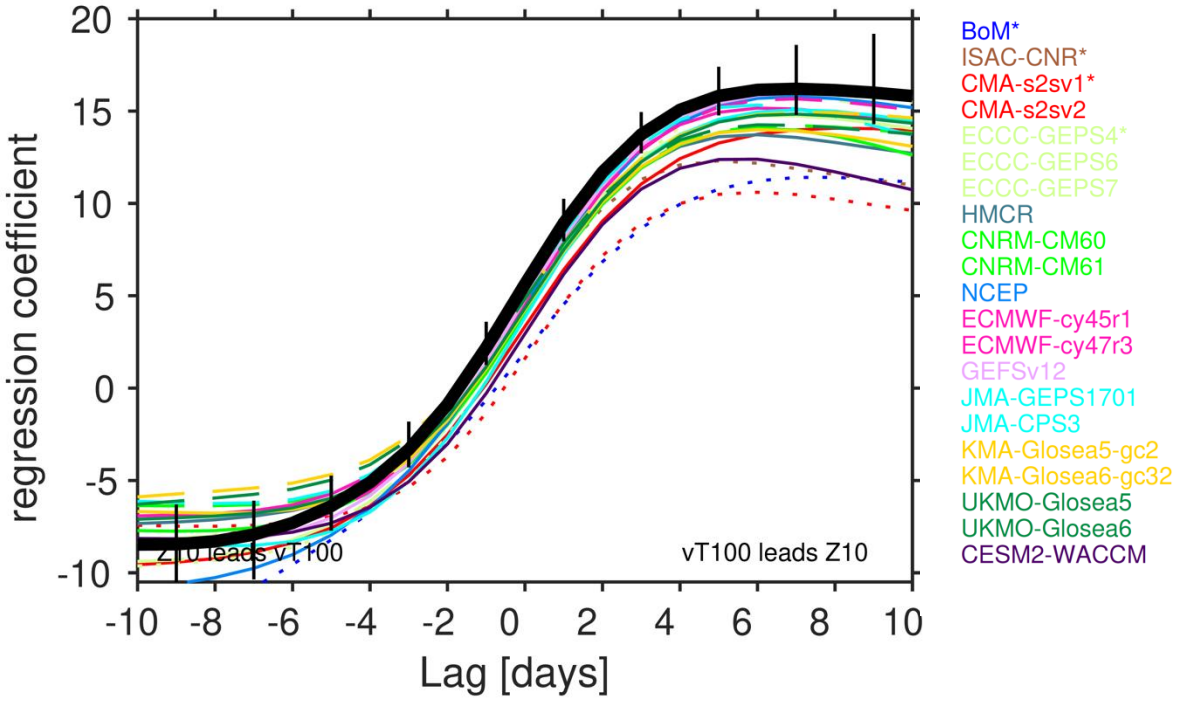
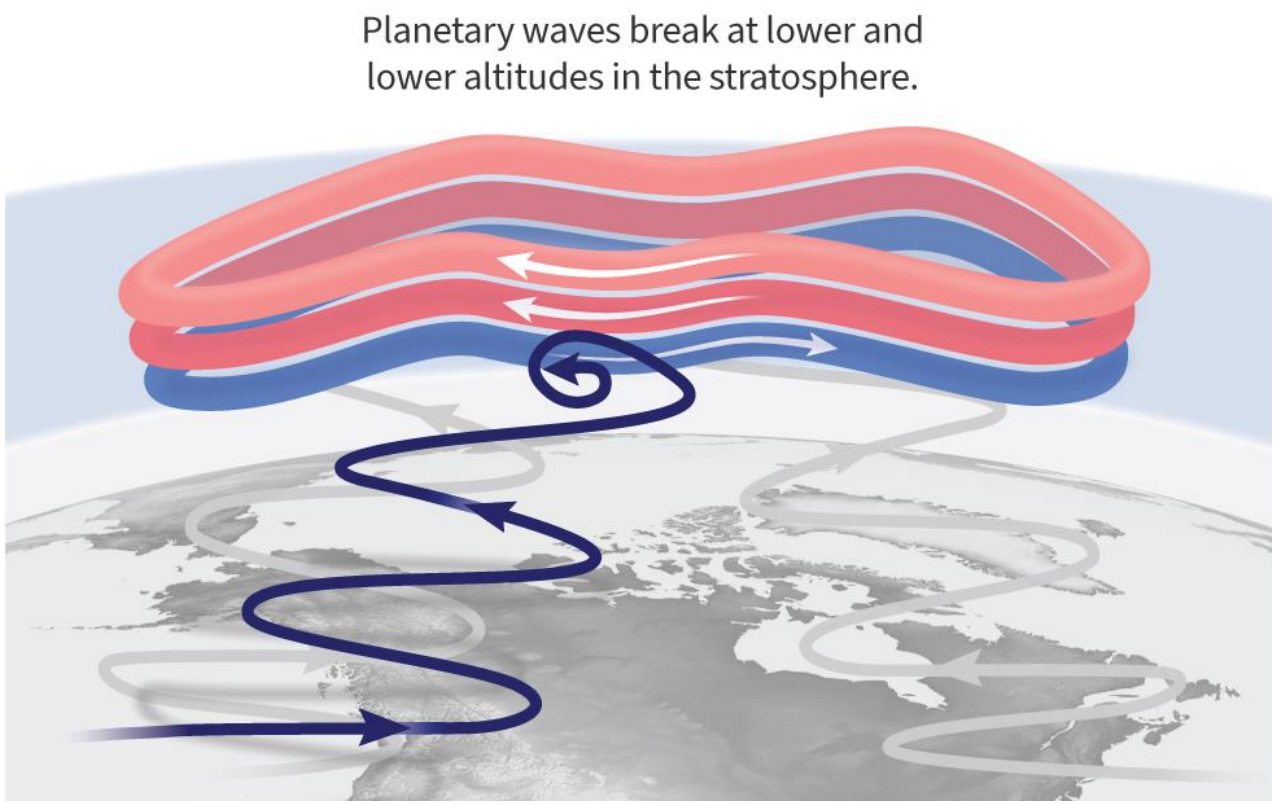


S2S models underestimate sensitivity of polar stratospheric winds to upward wave flux

Garfinkel et al. 2024, WCD

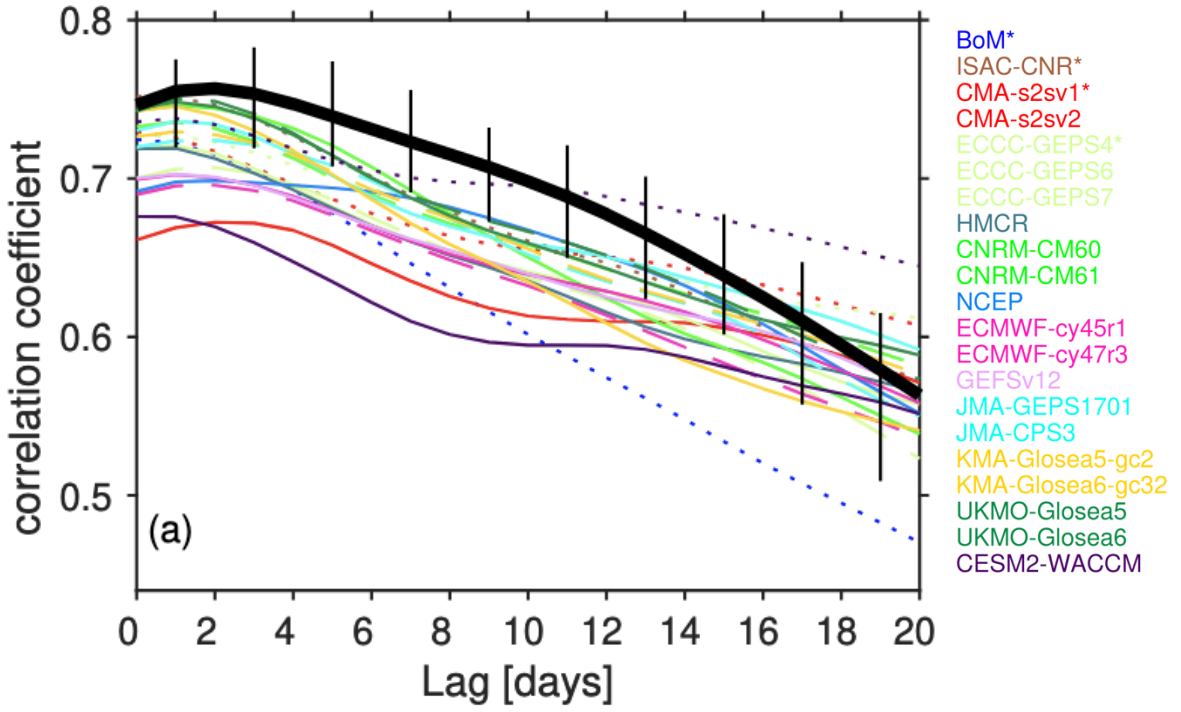
3) Downward coupling from the mid to lower stratosphere



Wave-mean flow interactions drive the downward propagation of anomalies within the stratosphere.

From the NOAA Polar Vortex Blog on Climate.gov

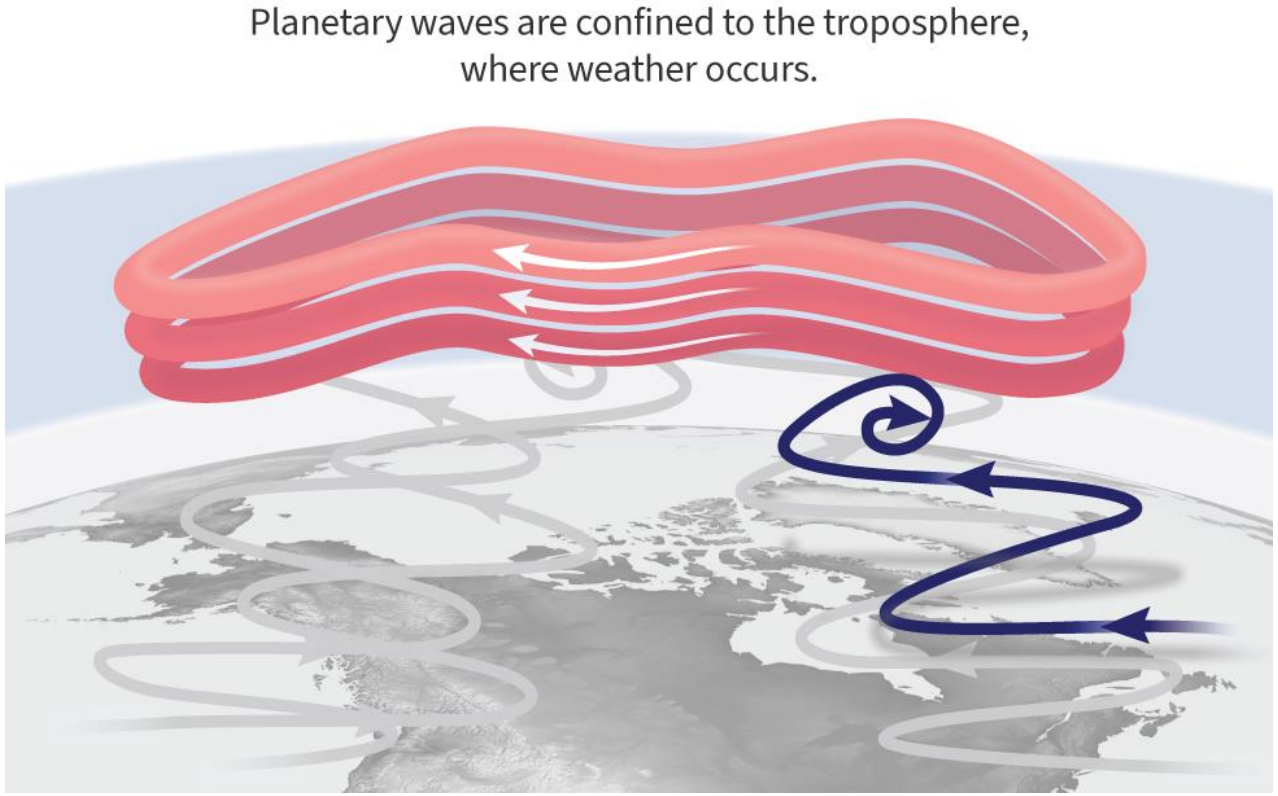
Correlation coefficient of 10 hPa polar-cap height (days 9-12), with 100 hPa polar cap height, DJF



S2S models underestimate magnitude of downward coupling within the stratosphere.

Garfinkel et al. 2024, WCD

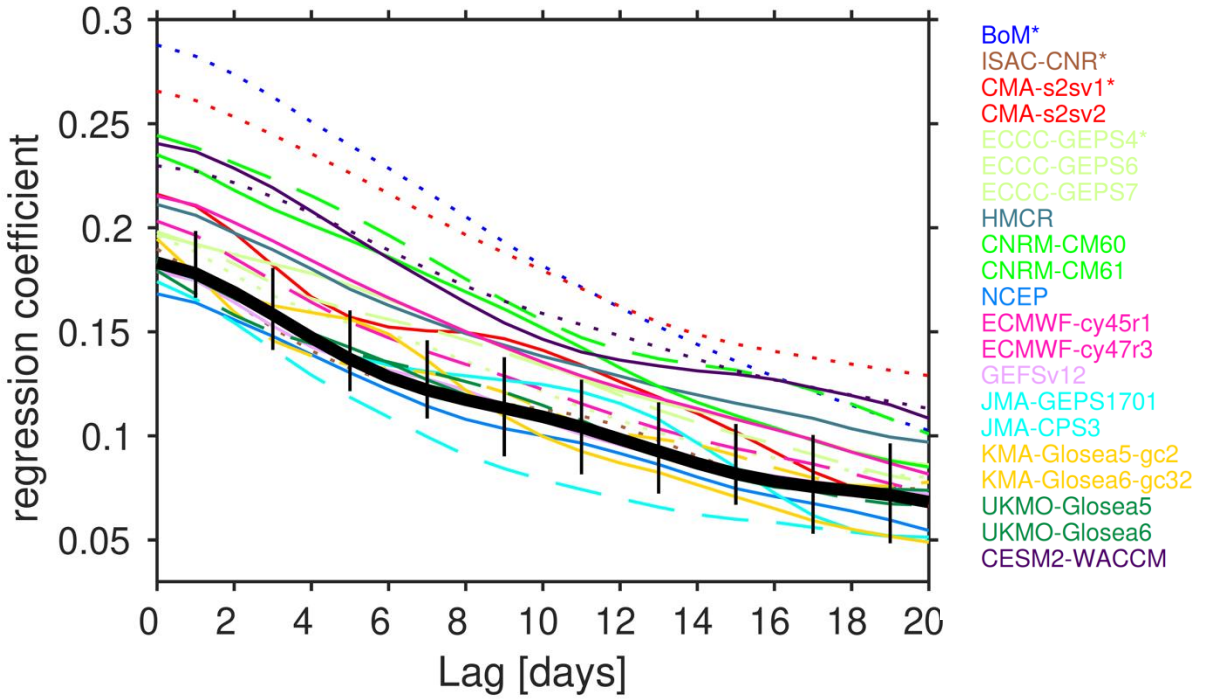
4) Downward coupling from the lower stratosphere to troposphere



Persistent anomalies in lower stratospheric winds likely drive feedbacks with tropospheric eddies that affect weather patterns for weeks to months.

From the NOAA Polar Vortex Blog on Climate.gov

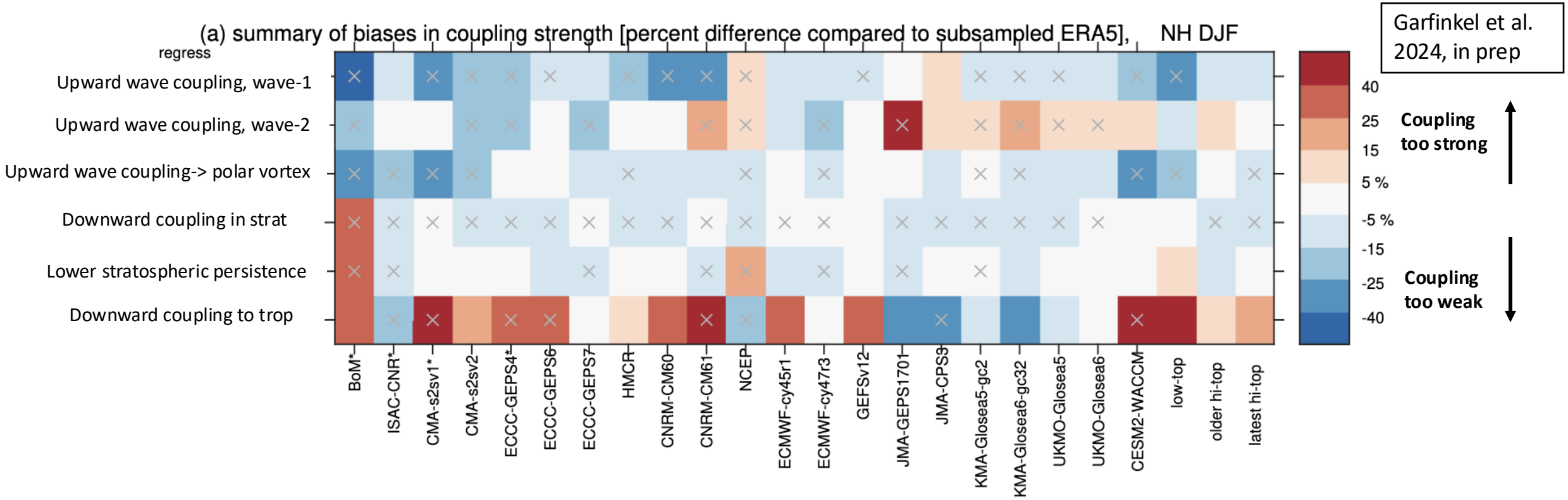
Regression coefficient of 100hPa polar cap height (days 9-12) with 850hPa polar cap height, DJF



Some S2S systems overestimate downward coupling from the lower stratosphere to the surface (in part due to systematic positive bias in variance of 850 hPa polar cap heights)

Garfinkel et al. 2024, WCD

Summary of S2S model biases in stratosphere-troposphere coupling



Garfinkel et al. 2024, in prep

In the NH winter, most S2S models underestimate upward wave coupling and downward coupling within the stratosphere. A few models overestimate downward coupling to the lower troposphere.

Conclusions

- The NH polar vortex in most S2S forecasting systems is insufficiently coupled to tropospheric variability.
- This result is consistent with the too-weak impact of predictable tropospheric modes of variability such as the Madden Julian Oscillation on the stratosphere (Garfinkel et al. 2020, Stan et al. 2022).
- We find that these processes are better captured in models with less bias in the climatological quasi-stationary waves and higher model tops.
- Poor coupling has implications for predictability of the stratosphere. Ongoing work to explore the implications for predictability of surface climate.
- SNAP is interested in engaging with WGSIP/WGNE. Please keep us updated!

Questions/Comments?

Contact: chaim.garfinkel@mail.huji.ac.il