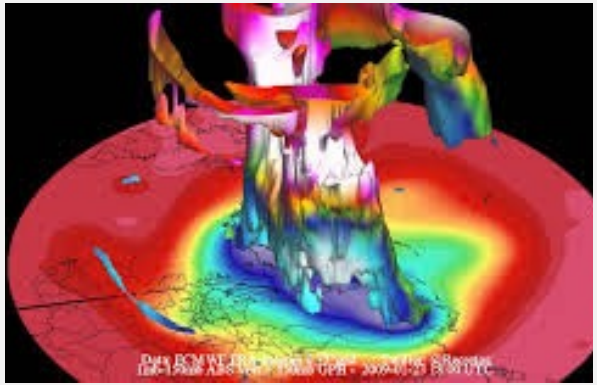
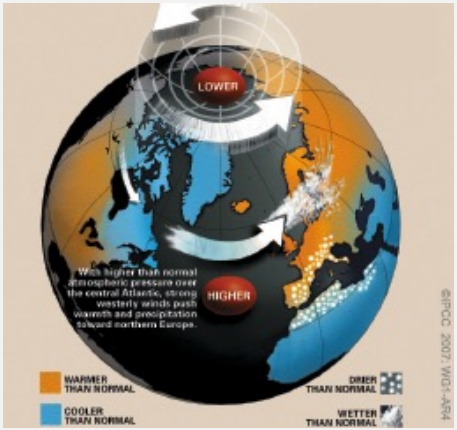
Overview of Current Understanding of the Role of Stratosphere-Troposphere Interactions in S2S Prediction



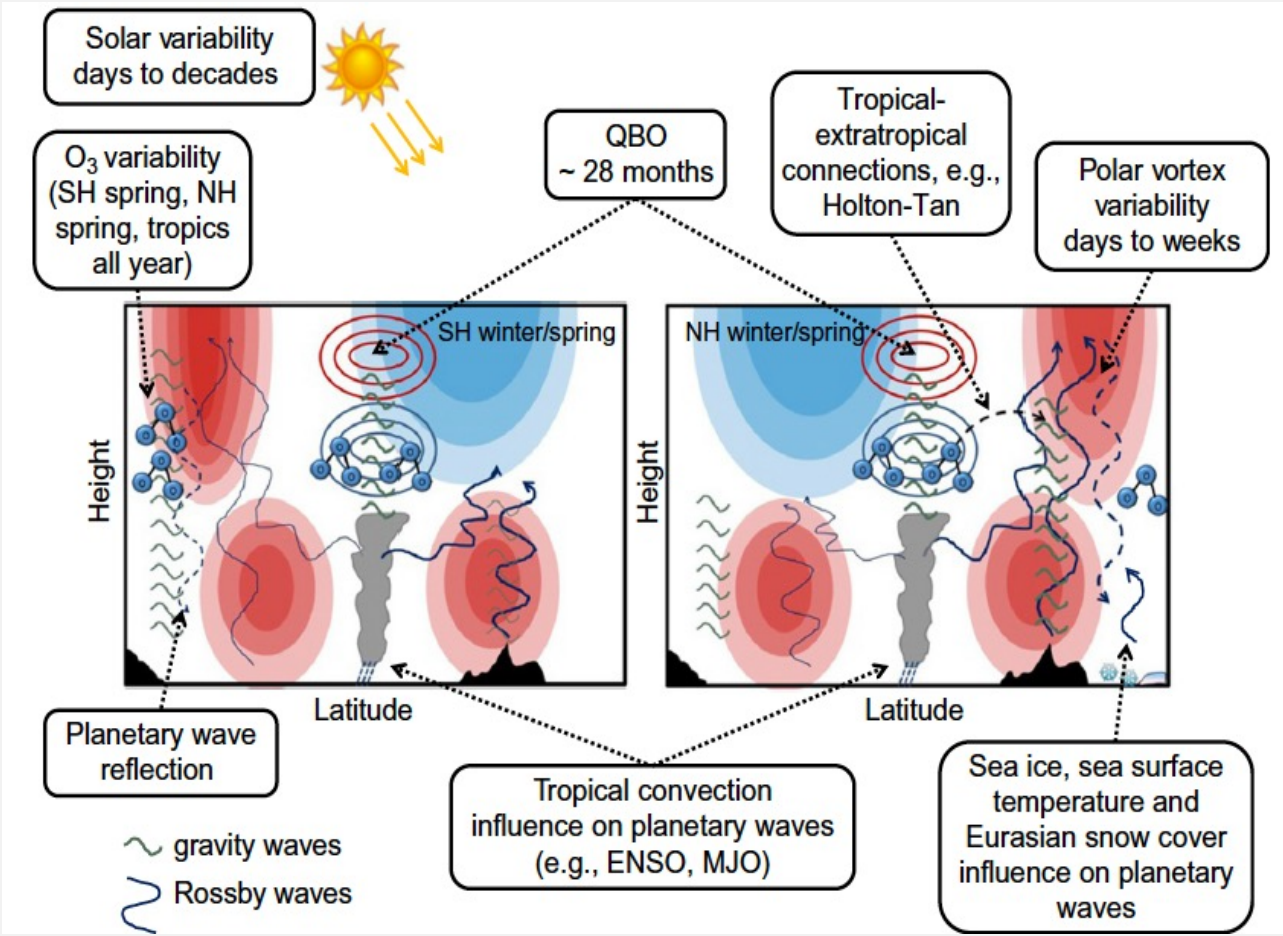


Jason C. Furtado, *School of Meteorology, University of Oklahoma*

2022 US CLIVAR Summit

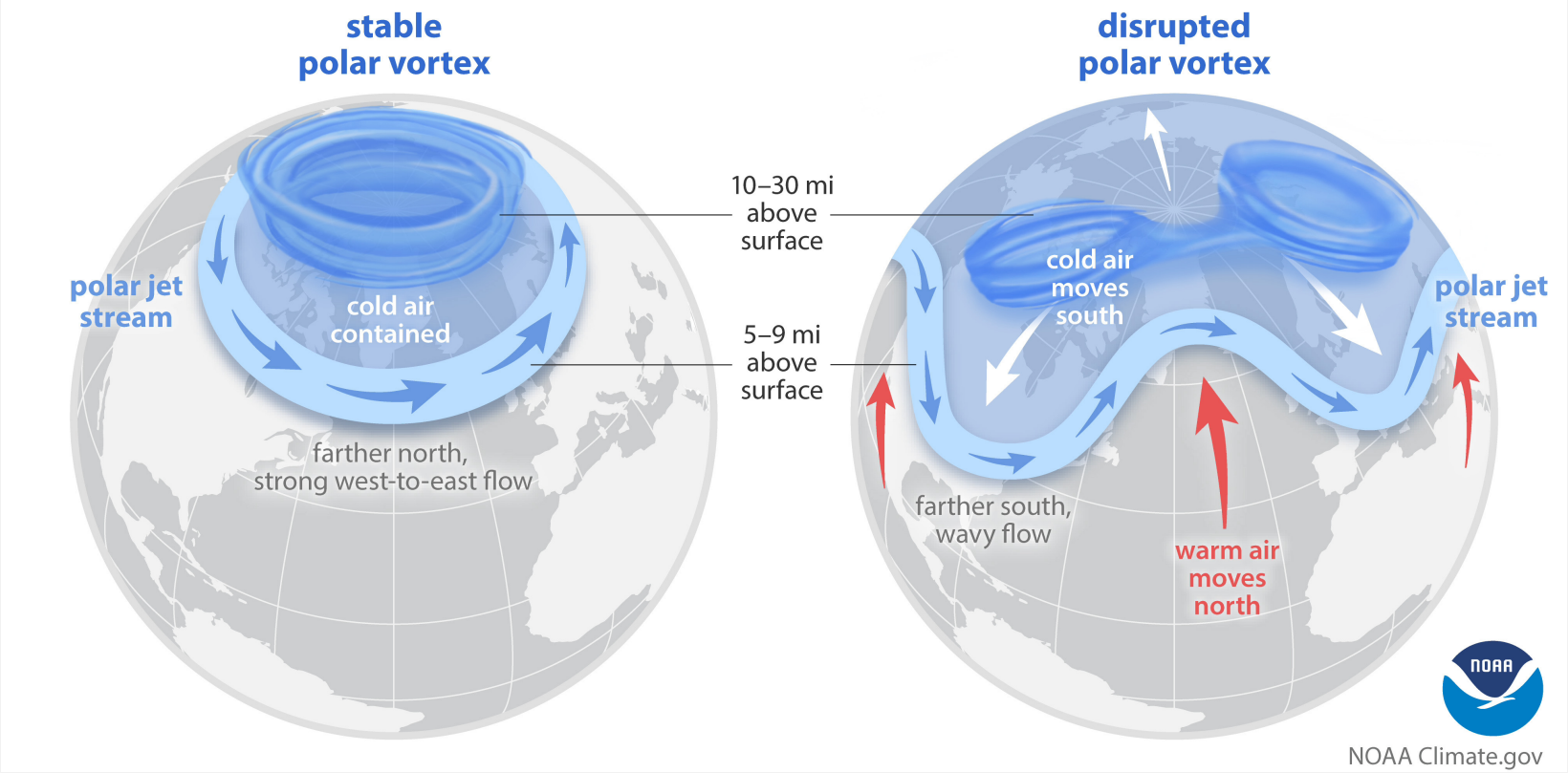
15 March 2022

Relevant Stratosphere-Troposphere (S/T) Coupling Phenomena

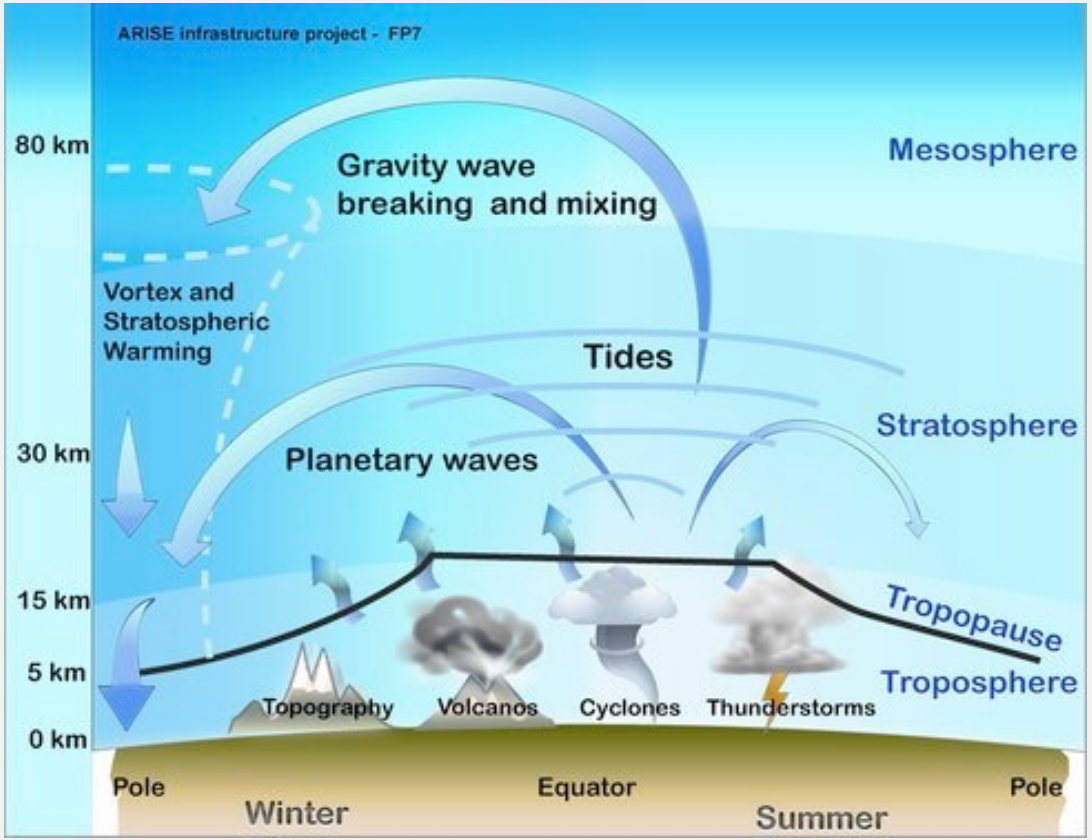


Butler et al. [2019]

The Polar Vortex



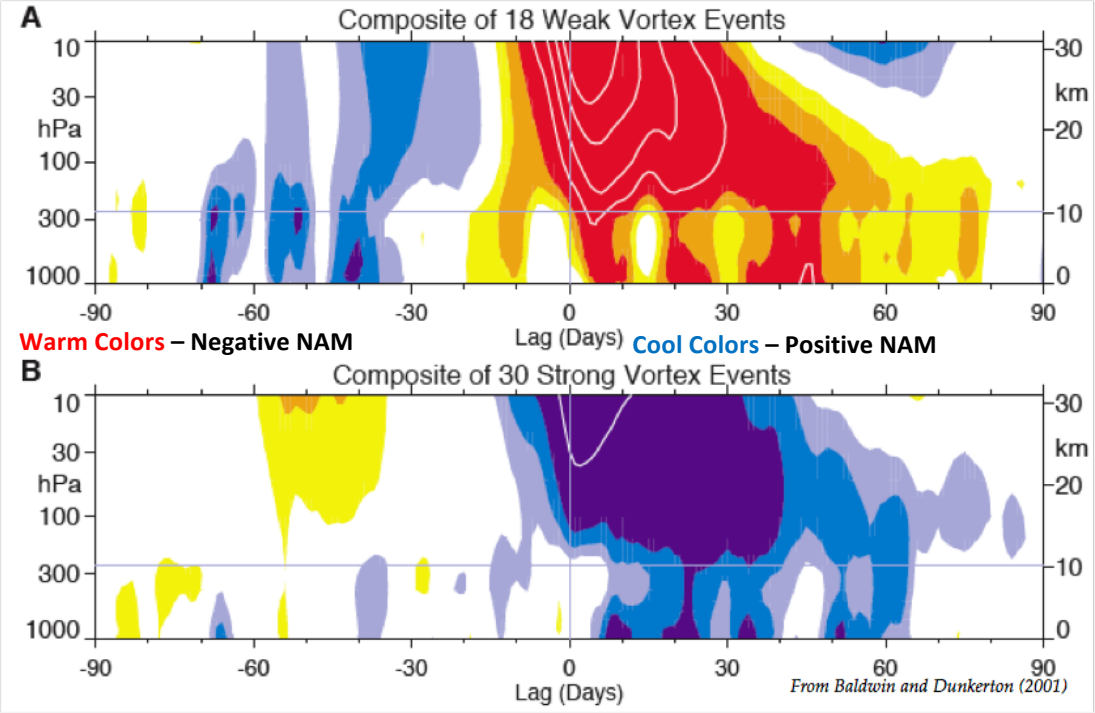
The Stratosphere & Tropospheric Wave Driving



http://arise-project.eu/science.php

Using the Stratosphere For S2S Forecasting

VORTEX STRENGTH defined by height anomalies over the pole at 10 hPa



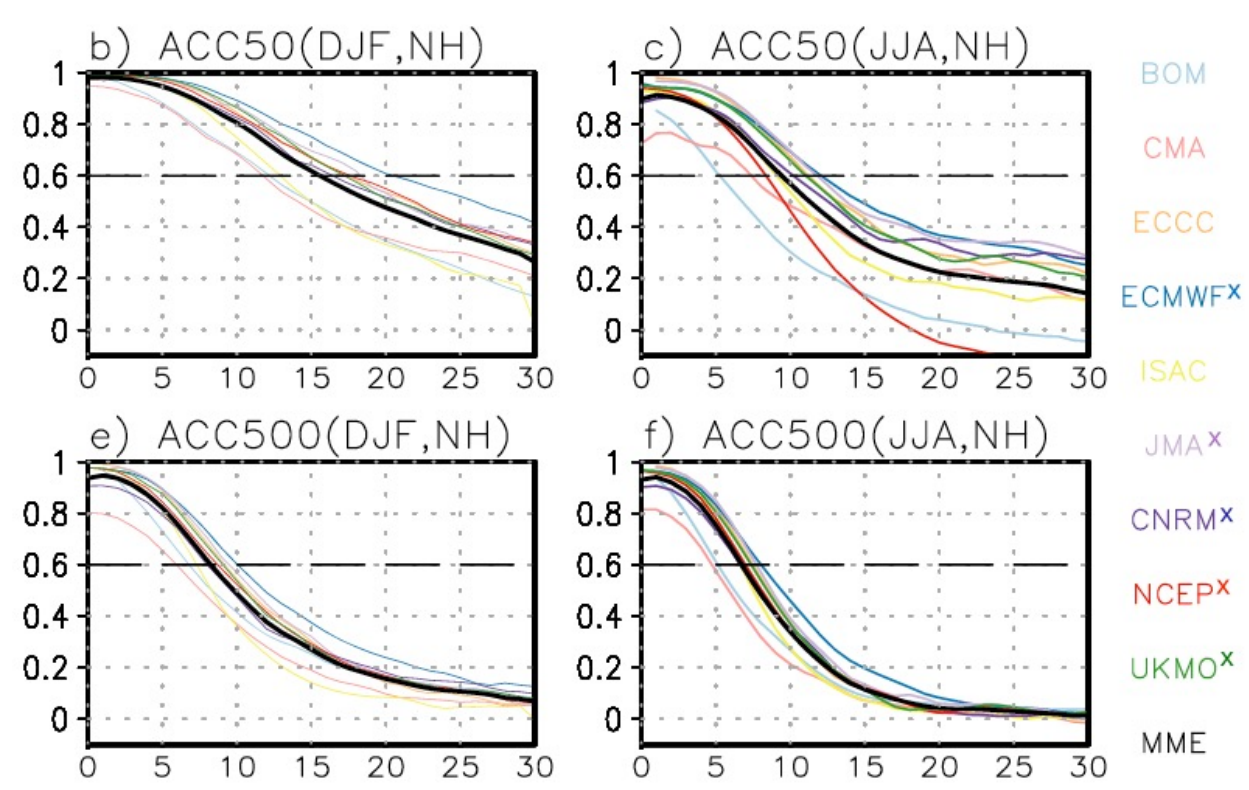
1. Same-signed circulation anomalies can propagate downward into the troposphere.
2. Anomalies in the lower stratosphere/ troposphere <u>persist for weeks beyond the initial stratospheric anomaly.</u>

Main Questions

1. What is the current state of stratosphere and S/T coupling prediction in operational S2S forecast models?
2. What are some known biases in the models that limit the use of the stratospheric information in S2S predictions?
3. What processes need to be better understood to advance our use of S/T coupling in S2S predictions?

(#1) S/T Coupling Prediction in S2S Forecast Models

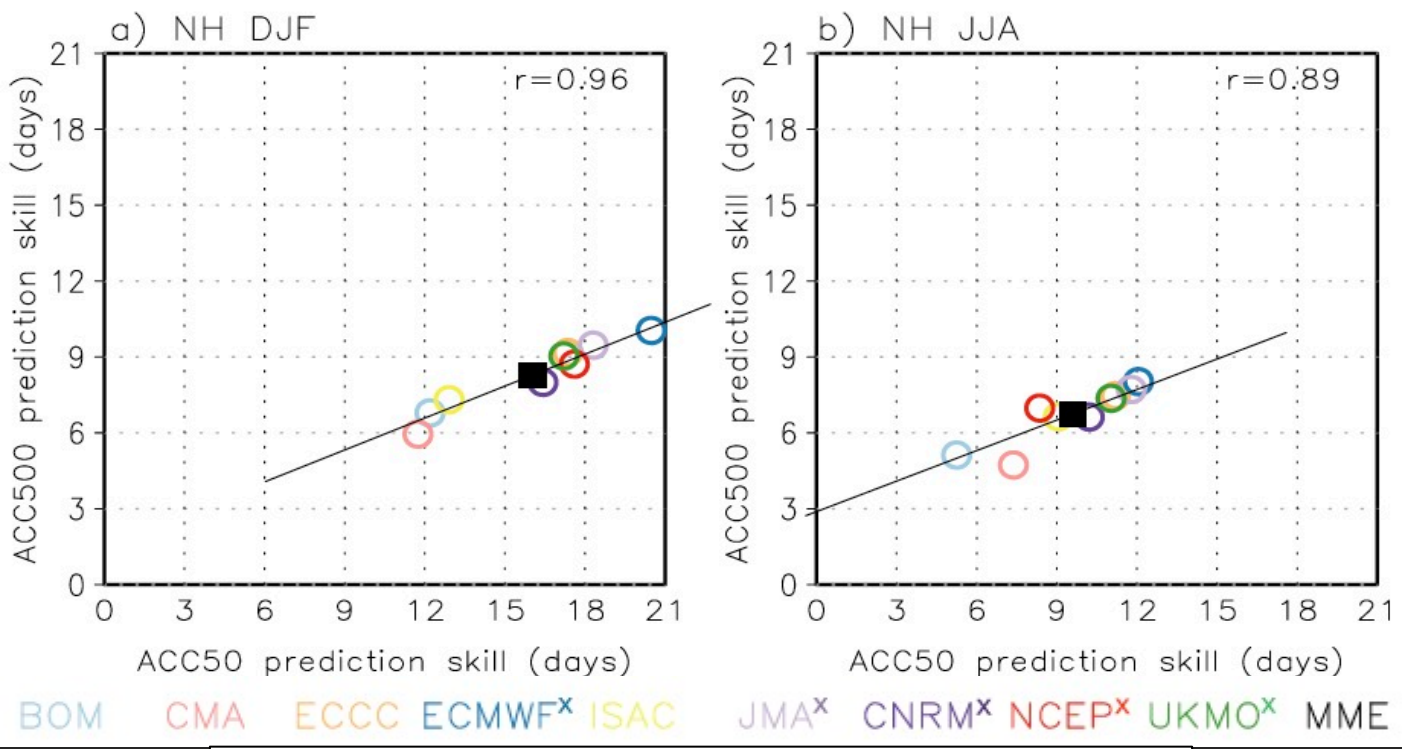
Predictability of Stratosphere vs Troposphere



- The stratosphere has longer memory than the troposphere, especially during boreal winter (**active S/T coupling season**).

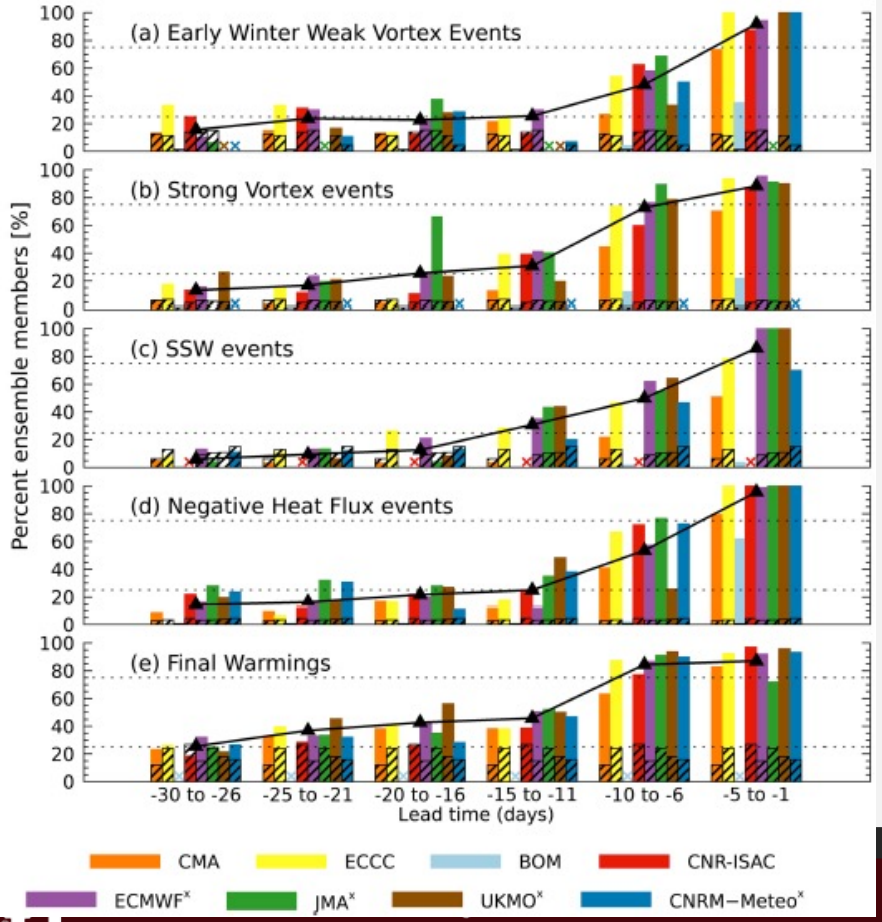
Models: *S2S Prediction Project Database*
Hindcasts from 1980s – 2010s
Domeisen et al. [2020a]

Tropospheric Prediction Skill Linked to Stratosphere



Models: *S2S Prediction Project Database - Hindcasts from 1980s – 2010s*
Domeisen et al. [2020a]

Predicting Stratospheric Extreme Events

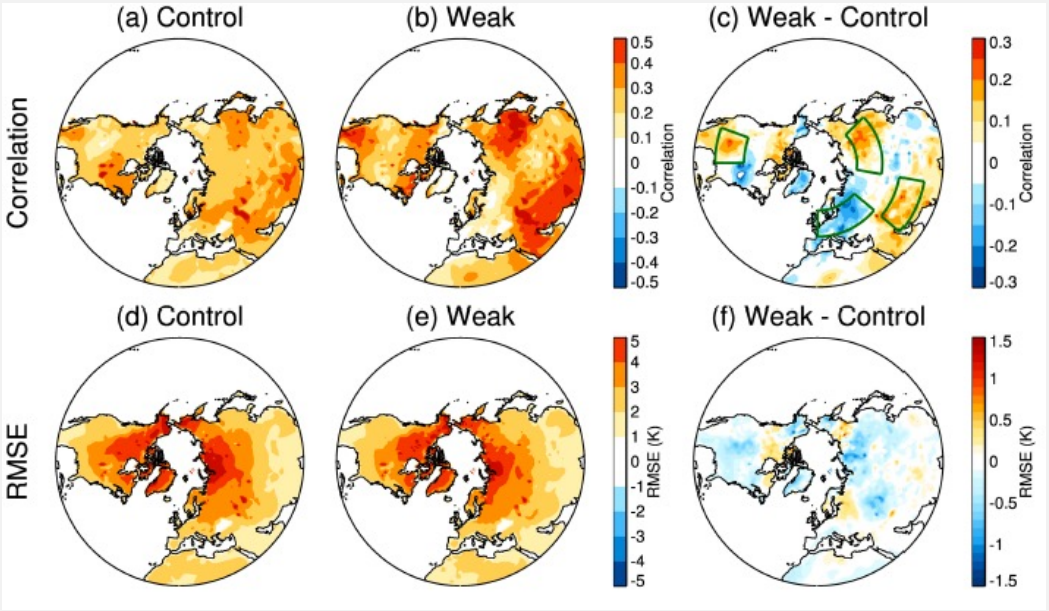


- Most stratospheric extreme events only predictable up to 10 days ahead of time.
- *Final warmings* (demise of the polar vortex) are an exception – maybe Week 2 or Week 3 lead times?

Models: *S2S Prediction Project Database*
Hindcasts from 1980s – 2010s
Domeisen et al. [2020a]

Skill For Surface Weather – SSW vs. No SSW

Week 3-4 Forecast Skill – 2-m Temperature



- ***Increase*** in ACC in some regions (US S. Plains, East Asia); ***decrease*** in others (Europe)
- General ***decrease*** in RMSE for hindcasts with weak vortex.

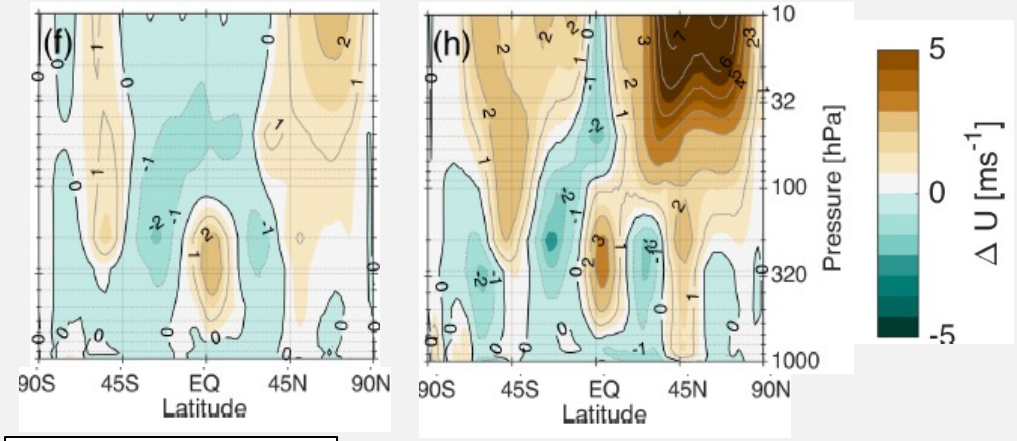
Models: *S2S Prediction Project Database*
Hindcasts from 1980s – 2010s
Domeisen et al. [2020b]

(#2) S/T Coupling Biases in S2S Operational Models

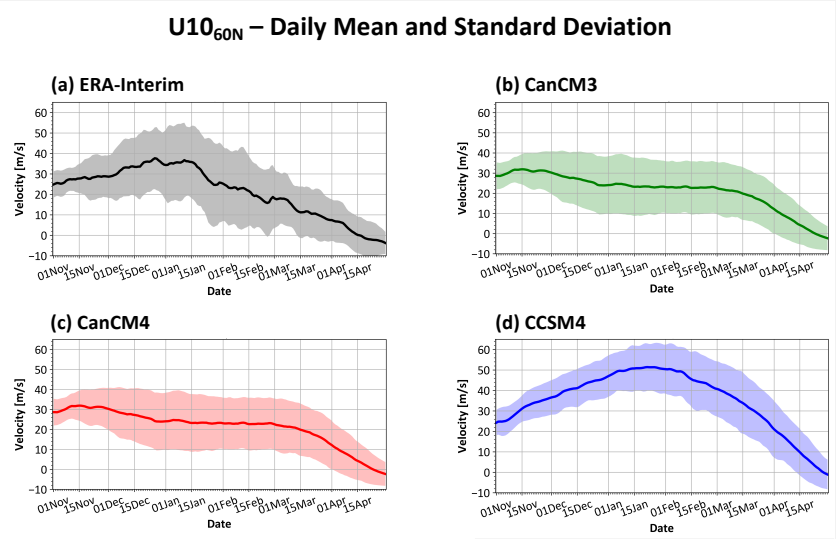
Biases in Polar Vortex Climatology

DJF Zonal-Mean U (Model – Reanalysis)

High Top *Low Top*



Lawrence et al. [2022]

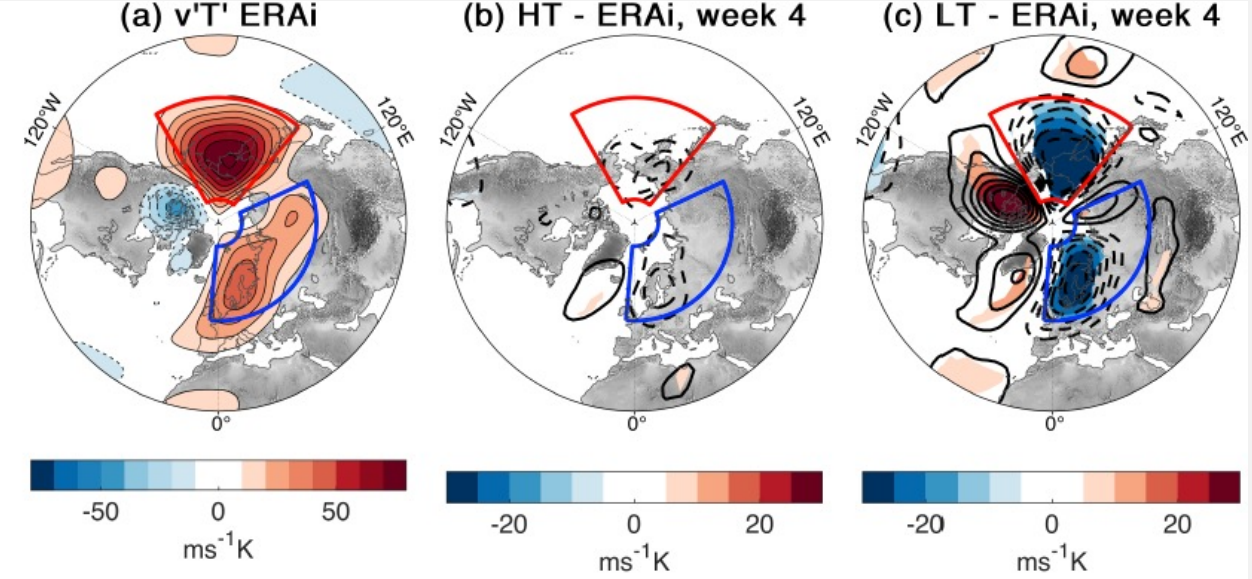


Models: NMME Phase 2
Furtado et al. [2021]

Less variability in simulated polar vortex vs. reanalysis

Vertical Wave Propagation (v'T' at 100 mb)

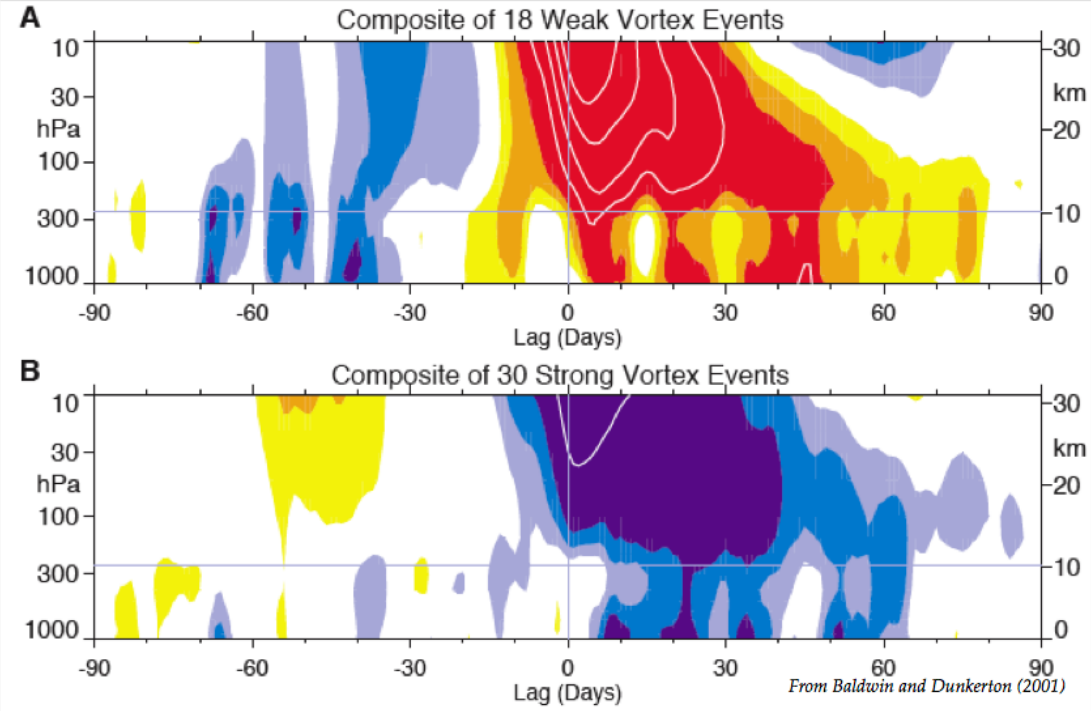
- Larger negative biases in low-top models.
- Less heat flux = less wave driving = less variable polar vortex



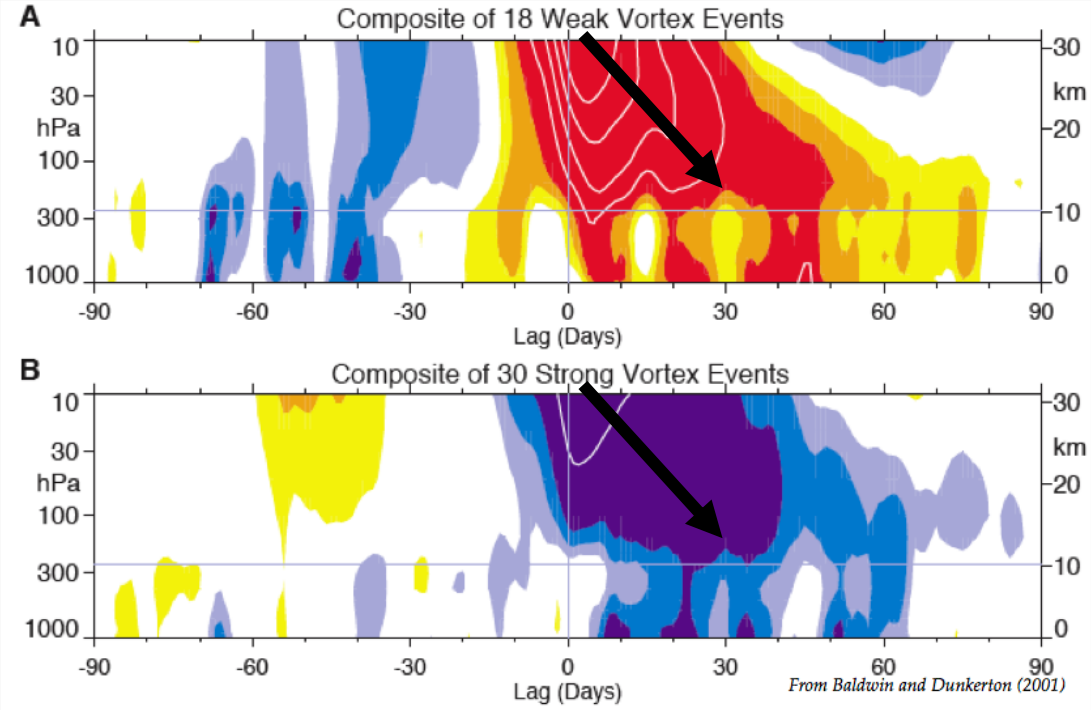
High-Top Models: CESM2-WACCM, CNRM, ECCC, ECMWF, GEFSv12, JMA, KMA, NCEP, UKMO
Low-Top Models: BoM, CMA, CNR-ISAC, CESM2-CAM, GFDL-SPEAR,
Lawrence et al. [2022]

(#3) Work to Do with S/T Coupling for S2S Predictions

(A) Predicting The "Downward" Coupling

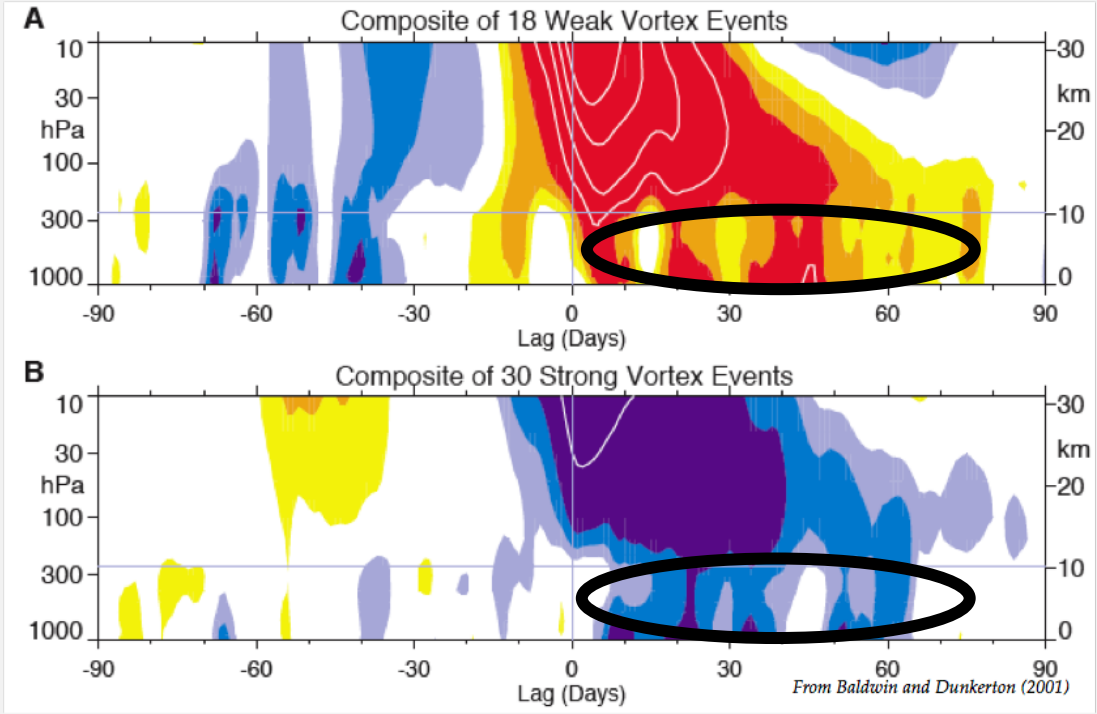


(A) Predicting The "Downward" Coupling



- Likely due to descent of critical layer ($u < 0$) from subsequent wave breaking; "downward control" [e.g., *Haynes et al.* 1991].

(A) Predicting The "Downward" Coupling

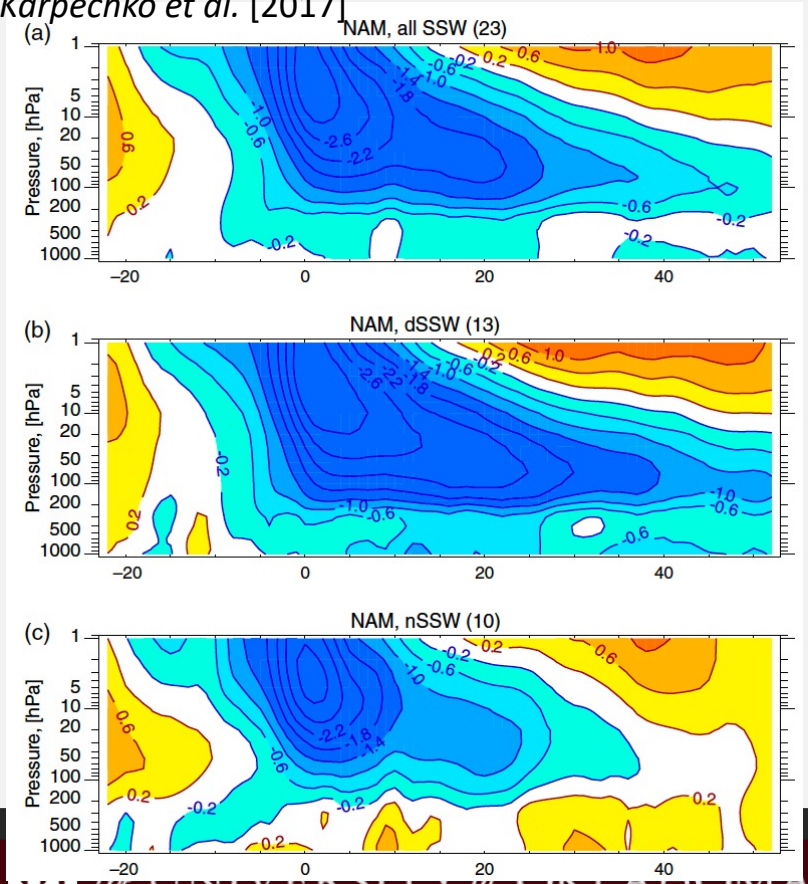


- Likely due to descent of critical layer ($u < 0$) from subsequent wave breaking; "downward control" [e.g., *Haynes et al.* 1991].

- Likely from reorganization of tropospheric eddies, changing momentum fluxes and shifting the polar jet [e.g., *Thompson et al.* 2006].

(A) Predicting the "Downward" Coupling

Karpechko et al. [2017]

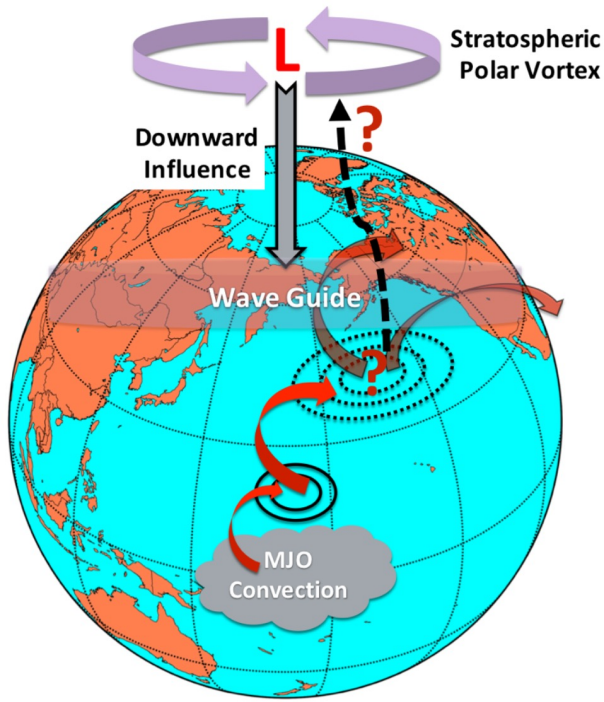


- Slightly more than half of observed major SSWs downward-couple into the troposphere.
- **WHY?**
  - The troposphere must be "receptive" to stratospheric anomalies [e.g., *Garfinkel et al.*, 2013; *Maycock et al.*, 2020]

(B) Interaction w/ Other Climate Modes

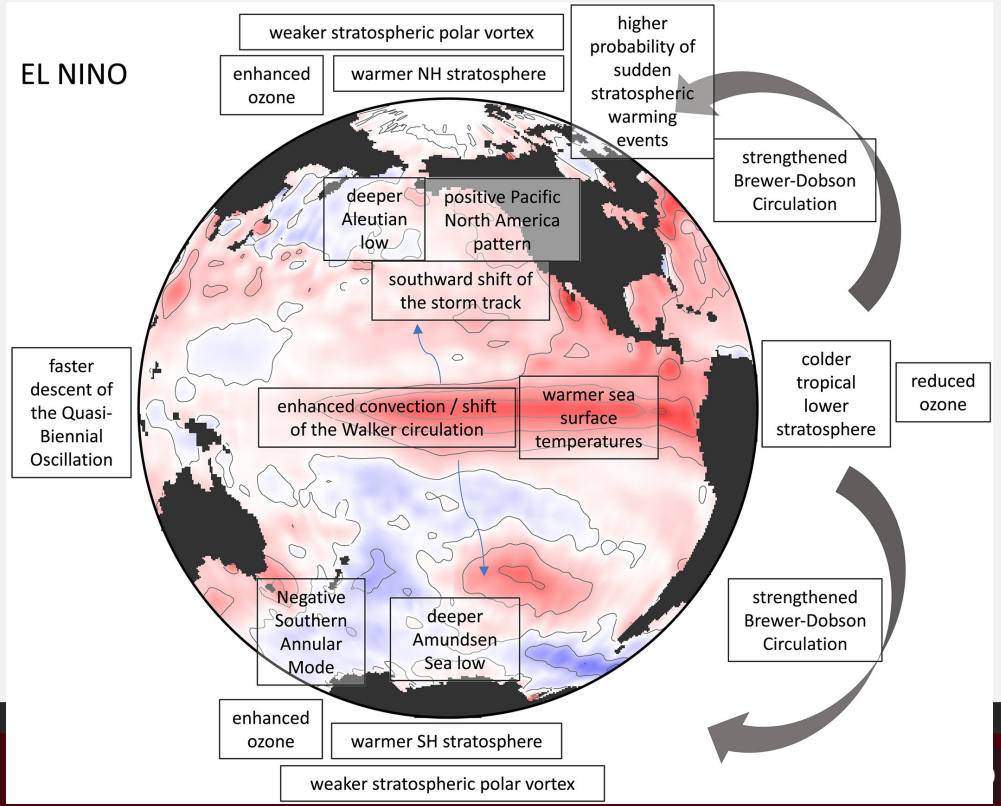
MJO-Stratosphere Interactions

[e.g., *Garfinkel and Schwartz*, 2017; *Green and Furtado*, 2019]



ENSO-Stratosphere Interactions

[e.g., *Butler et al.*, 2014; *Domeisen et al.*, 2019]



Concluding Thoughts

- **Number of vertical levels** and **vertical (stratospheric) resolution** are important for modeling S/T coupling dynamics.
- New push for ***nudging experiments*** (e.g., nudge the stratosphere to climatology vs. reanalysis) to quantify the role of the stratosphere in tropospheric weather predictions [e.g., SNAPSI; *Hitchcock et al.*, 2022; also *Kautz et al.,* 2020; *Huang et al.*, 2022]
- Zonal–mean dynamics and responses → regional-scale variability associated with S/T coupling [e.g., *Kretschmer et al.*, 2018; *Matthias and Kretschmer*, 2020]