Review: How do different pathways connect the stratospheric polar vortex to its tropospheric precursors?

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Summary

This analysis identified and examined the pathways of troposphere-stratosphere coupling at the seasonal timescale in ERA5 and ICON model. The results highlight tropospheric precursors of stratospheric extended winter circulation and the timescales of their influence. The authors make use of the NAM index to identify the coupling mechanisms and regions: the Ural area and the extended Aleutian area. Furthermore, the authors develop a precursor index based on the MSLP difference between these two regions and show that it is mostly correlated with the subsequent NAM in the stratosphere, which highlights the importance of coupling. Moreover, vertical Plumb fluxes are investigated to identify pathways of coupling. In the Ural area vertical planetary waves propagation transmits signal from the troposphere to the stratosphere, whereas for the Aleutian region the pathway seems to be different. The geopotential anomalies in the upper layers seem to play a greater role.

The research is timely and novel as it discusses the mechanisms of the stratosphere-troposphere coupling at the subseasonal-to-seasonal timescales which can be an important source of predictability. However, as the authors mention, there is great variability across individual events. Overall, the manuscript presents results in a well-constructed way. I have some major and minor comments presented below and I recommend this manuscript for publication after addressing the comments.

Major comments

- As the Plumb flux is formulated using a quasi-geostrophic assumption, I would suggest using the wave activity flux by Takaya and Nakamura (2001). This flux is defined for the case of a zonally varying basic flow and focuses on the wave activity associated with planetary waves, as the wavy anomalies are considered to be embedded in the basic flow that includes the climatological planetary waves. The basic state in the Northern Hemisphere in winter shows inhomogeneities that can modulate the propagation of planetary waves.

- Regression coefficients in Figs. 2 and 6 have very different magnitudes and provide limited information as for the meaningful *effects* of this regression. While the results are meaningful for the non-hatched areas, it would be good to provide the effect-size by adding R^2, which shows the explained variance ratio in the dependent variable.

- In part of the analysis (Figs 4 and 5) you show the difference between high (80th percentile) and low (20th percentile) precursor index. I do not fully understand the purpose of showing the difference and not high/low index separately. It seems to me that this would be more clear for interpretation. Please, provide more explanation of your choice or maybe show the results separately for high and low index.

Minor comments

L77: The length of the model simulations is a bit shorter than the length of the ERA5 period chosen for the analysis. I think it would be more straightforward to take the same periods of time for the intercomparison reasons.

L112-113: Why did you choose to limit the showed correlation coefficients to the 10% largest? Might this result in the loss of information?

Fig.1 c, d: The font of the longitude labels and colorbar seems too small to me.

L129-130: Would it be better to use ensemble means for the intercomparison reasons?

Fig.2: It seems that "@100hPa" at the x-axis label is wrong.

L161-162: Please, consider adding that these areas are also shown in Fig.1.

L171: It seems interesting that "the negative correlation between January precursor index and February NAM is not statistically significant in the ERA5 data, but highly significant in the ICON ensemble simulations." Do you have any explanation for this?

L175: "The two components of the precursor index were also analysed individually": I guess this is not shown?

L179: Please, provide the sample sizes of composites. Are the same samples used also in Section 3.2?

L218: Did you test your results using the wave activity flux at different heights? Why did you choose to use 100hPa in the study?

L255-258: "This signal reaches the tropopause without a time lag but is disconnected from the main stratospheric signals, which emerge east of the Ural region and propagate west- and eastward throughout time. Thus, a high-pressure anomaly in the Ural area is connected to positive stratospheric geopotential anomalies that are a clear indication of a weakened stratospheric polar vortex." This explanation seems confusing to me, as in the first part you mention that the signal is disconnected, but then the anomalies are connected at different heights. I suggest the authors to rewrite this part more in a more clear way.

L261-262: The ICON ensemble is somewhat in agreement, but it also have strong negative correlations, how would you explain this? At least, this is worth mentioning in text.

Fig. 7 and 8: Please consider adding briefly heights to the b,c,e,f captions