Response to comment by Anonymous Referee #1

This study provides a systematic characterization of Rossby wave activity during the 25 sudden stratospheric warming (SSW) and 31 strong polar vortex (SPV) events that occurred in the period 1979-2021 using space-time spectral analysis. The results reveal the Rossby wave behaviors during two situations of stratosphere-troposphere coupling. Overall, this study is very interesting and worth of publication on WCD. I only have some few concerns or comments.

General comments:

The significance of some results are not robust due to limited composite samples used here. Although the authors made efforts to comprehensively analyze these cases, I think they may use the ensemble runs derived from SNAPSI (Hitchcock et al., 2022) to support the key findings during SSW events, particularly for the 'rule-of-thumb' proposed by the authors. The authors may compare differences in the wave activities during control runs and nudged runs.

Thanks for your general and specific comments and your time spent reading the paper. We agree that the use of ensemble runs could enhance the robustness of our results, as also pointed out in the outlook of our section 7. At the same time, we would like to stress that even the limited number of 31 SPV events and 25 SSW events identified in the ERA5 dataset for the period from 1979 to 2021 yielded in significantly different spectral patterns of Rossby waves between SSWs and SPVs in the stratosphere (cf. Fig. 3 and 5), and to some extent even in the troposphere (cf. Fig. 4 and 6). As also highlighted in several places in the manuscript (e.g., L.243 ff., L.263 ff., L331 ff.), the tropospheric response to stratospheric extremes appears to be more complex than the stratospheric one which is likely due to additional factors influencing tropospheric Rossby wave behavior (e.g., baroclinicity, adiabatic forcing) and not because of the limited number of events. Thus, the use of ensemble runs would probably not increase the robustness in the tropospheric response.

Additionally, we acknowledge that using ensemble runs derived from SNAPSI, could help attributing the effect of stratospheric extreme events on specific harmonics of Rossby wave spectra in the troposphere. However, this dataset includes only ensemble runs for 3 events, so some results might be very event-specific. The limitation of only 3 different events being represented in SNAPSI would therefore not really help with the sample size. Furthermore, our way of performing space-time spectral analysis requires time intervals of 60 days (see section 2.2). This could limit the data of spectra even further in context of ensemble runs derived from SNAPSI. Lastly, the analysis of the SNAPSI dataset would likely address a different set of research questions, as those proposed in the introduction of our manuscript (L60-62).

In addition, as the authors said, using 48 m/s as a threshold value is arbitrary. I suggested replacing it with 1 standardize deviation of zonal wind climatology as the threshold to select SPV events.

It is a good idea to use exceedance of 1 std of 60N zonal mean zonal wind as alternative definition of SPV events instead of the, on first sight, arbitrary value of 48 m/s. Our motivation for defining SPV events as times when zonal mean zonal winds exceed 48 m/s was motivated by making results comparable to existing literature about SPVs (Oehrlein et al., 2020; Scaife et al., 2016; Smith et al., 2018). These authors motivated the definition as an analogous way to the SSW definition of Charlton and Polvani (2007a), stating that the threshold of 48m/s is chosen as it is exceeded with the same frequency as the lower SSW threshold (Scaife et al., 2016). Since we aim to compare the impact of SSWs and SPVs respectively, it seemed like this analogous definition would be the fairest way of doing so.

Thus, even though 48 m/s might seem a rather arbitrary value, the motivation for choosing this specific threshold actually considers the variation, and could be seen as a modified way of standard deviation.

Specific comments:

L6: concomitant -> simultaneous

Thanks for pointing this out, we will change this.

L44: complicated -> complex

Good point, we will modify the following part in L44: "…analysis is complicated by…" → "… analysis becomes even more complex by…".

L83: 'SSW events' should be 'SPV events'.

Thanks for highlighting this. We actually meant SPV events here, as the whole paragraph aims to motivate the definition of SPV events. The definition of SSW events by Charlton and Polvani (2007a) is widely accepted and based on the physical threshold of a reversal of zonal winds. This connects well with the warming occurring simultaneously in the polar stratosphere due to the thermal wind balance.

L163: What do you mean about this sentence 'periods around SSW and SPV events are not excluded'? Please clarify it.

We mean that our resampling procedure considers the whole data set, including the times when SSWs and SPVs occurred. We just wanted to highlight this detail, since for certain research questions, one might exclude the dates of anomalies in the data set for assessing their statistical significance (see also comment of reviewer 2 on line 163).

L181:The words 'rapidly' and 'rapid' are not appropriate. The description of 'transient wave' is enough to describe the faster wave than stationary wave.

Thanks for suggesting a different phrasing here. We will adapt this in our manuscript.

L191: 'We not here that also' -> 'Also note that'

Good point. We will change that.

L237: This may be related to stronger stratosphere-troposphere coupling over the North Atlantic Ocean. Please refer to Garfinkel et al (2013) and Zhang et al. (2022).

Thanks for providing the additional references. We will add them in the manuscript.

L258: Is the positive anomaly caused by the internal variability or the sample error of composite cases? Does it also appear in large-ensemble experiments? Please see my general comments.

The composite for the 31 SPV events shows significantly positive anomalies for eastward propagating waves (Fig. 6). Our significance assessment using random resampling indicates that that the positive anomalies are larger than some internal variability. Regarding the positive anomalies observed already before the onset of SPVs (Fig. 6a), we understand this as an effect of coupling between upper troposphere and stratosphere and thus a speed-up of the polar vortex. Furthermore, our choice of onset day as date with maximum zonally averaged

winds for SPVs (see section 2.1) can explain signals observed before this date, since the threshold of 48 m/s is already exceeded prior to that date.

L325:It is confused why the heat flux co-spectra with higher-wavenumber westward propagating waves for SSW events are so noticeable at 10hPa in the upper stratosphere at which there only occurs wave 1 and 2. Please give more explanations.

Thanks for highlighting this point. These synoptic-scale features are likely due to the break-up and shredding of the polar vortex during the onset of SSWs. We will refer to this even earlier in context of Fig.3 (L224).

L356:This sentence should correspond to Fig. 11a and d.

Thanks for spotting this mistake. We will fix it.

L366: Fig.11b should be Fig.11a

Thanks for this suggestion. We actually refer here to the weak negative anomaly for eastward propagating waves in Fig. 11b contrasting the positive anomaly in Fig. 11e. So, Fig. 11b is indeed meant here.

References:

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