Review of manuscript WCD-2022-18: "**Stratospheric Wave Reflection Events Modulate North American Weather Regimes and Cold Spells**", by Messori et al.

This study presents physically interpretable regional impacts of the stratospheric wave reflections on tropospheric circulation anomalies. The main result is that the stratospheric reflection event exhibits a systematic tropospheric evolution from a Pacific Trough regime to an Alaskan Ridge regime, which favors low temperatures over the North America. I find the results interesting and have the potential to trigger other follow-up studies. The manuscript is logically structured and carefully written. However, additional work is required to further clarify the causal relationship between the wave reflection and tropospheric circulation changes, the potential influence of tropospheric internal variability, and other dynamical aspects. Thus, I will recommend major revisions.

General comments:

1. My main concern is the true causal relationship between the wave reflection events and the changes in the tropospheric circulation. You showed that the tropospheric imprints of the stratospheric wave reflection are mostly (on averaged) associated with a regime transition from a Pacific Trough (PT) to an Alaskan Ridge (AkR) (e.g., Figure 10). The question here is which comes first. How often stratosphere can be considered a cause of extreme tropospheric events and how often troposphere is considered as the cause of the extreme tropospheric events, which also triggers the stratospheric reflection events. It remains elusive in this paper. As shown in Fig. 10, the PT regime already exists prior to the occurrence of the reflection event and its transition to the AkR regime may not necessarily be related to the reflection event – it could be also triggered by other forcings in the troposphere (e.g., remote forcing from the tropics, blocking etc.). Also, the fact that you see reflection events here could be due to the favorable tropospheric conditions associated with PT, but it does not mean that wave reflection is the cause of the regime transitions or tropospheric changes. Can you address this causality issue? This should be better described and explored.

2. Please keep in mind that the amplitude of the upward propagating waves reflected back into the troposphere decreases with altitude due to the density effect (exp -z/H). Therefore, the wave energy is reduced when it reaches the surface (i.e., damping effect). The question now is how much the energy transferred by the downward planetary wave reflection can explain changes in tropospheric circulation? This could clarify whether the wave reflection event is the cause of the temperature/circulation changes in the troposphere. Another possibility is that the impact of the wave reflection on tropospheric circulation is indirect and requires interaction with synoptic transient eddy forcing via direct effects on baroclinicity and baroclinic eddies (Lubis et al., 2016, 2018; Smy and Scott 2008; Thompson and Birner 2012). Lubis et al., (2016) and Lubis et al., (2018) found the importance of

synoptic-scale eddy-mean flow interaction in shaping the tropospheric response to downward wave reflection event.

- Lubis, S. W., Matthes, K., Omrani, N.-E., Harnik, N. & Wahl, S. Influence of the quasi- biennial oscillation and sea surface temperature variability on downward wave coupling in the northern hemisphere. *J. Atmos. Sci*., 73, 1943–1965 (2016).

- Lubis, S. W., Matthes, K., Harnik, N., Omrani, N., and Wahl, S. Downward Wave Coupling between the Stratosphere and Troposphere under Future Anthropogenic Climate Change. *Journal of Climate* 31, 10, 4135-4155 (2018).

- Smy, L., & Scott, R. The influence of stratospheric potential vorticity on baroclinic instability. *Quart. J. Roy. Meteor. Soc*., 135, 1637–1683 (2009).

- Thompson, D. W. J. & Birner, T. On the linkages between the tropospheric isentropic slope and eddy fluxes of heat during Northern Hemisphere winter, *J. Atmos. Sci*., 69, 1811-1823 (2012).

3. It is well established that negative vertical wind shear results in a reflective layer, with a refractive index $n^2 = 0$ (Harnik and Lindzen, 2001). However, in some cases this condition may also involve a reversal of the zonal-mean zonal wind, with a refractive index $n^2 = \infty$, and a wave absorption (e.g., Kodera et al., 2016). Thus, the downward pointing wave activity vectors ($v'T' < 0$) in the presence of critical layers does not necessarily mean a linear reflection, if conditions are not linear (Plumb, 2010). For example, the reflective SSW events can be viewed as a mixture between reflective SSW and linear reflection events (e.g., Kodera et al., 2016). The reflective SSW events may involve over-reflection rather than linear reflection because a critical surface formed is embedded by two opposite signs of PV gradient, thus they should be studied separately (Harnik and Heifetz, 2007). My questions are:

- Did you separate the reflective events from the SSW events?
- From the total 44 events, how many reflection events are preceded or followed by the SSW events?
- If you exclude these events, will you have the same temperature responses to a reflection event?
- Especially in Fig. 6(f), the cold anomalies extend further south and are reminiscent of the impact of SSW events. Just make sure that this response does not mix with the SSW events. Please clarify.

Harnik N. and E. Heifetz, 2007. Relating Over-Reflection and Wave Geometry to the Counter Propagating Rossby Wave Perspective: Toward a Deeper Mechanistic Understanding of Shear Instability. J. Atmos. Sci.64 2238-61.

4. Given the fact that the downward stratospheric wave reflection has a significant impact on the cold spell events, it is important to understand the role of natural and

anthropogenic forcings in controlling the variability of such events. Previous studies showed that the natural and anthropogenic forcing (including ENSO, QBO, GHG and ODSs) can significantly influence large-scale circulation that favors downward wave reflection events and the associated surface impacts (e.g., Lubis et al., 2016; Lubis et al., 2018). This should be discussed in the introduction or in the discussion part.

5. The use of v'T' anomaly, instead of total field, as a measure of vertical wave propagation should be used with caution. Especially in Fig. 1a, the region over the North America (inside the polygon) is not only dominated by the climatological mean of negative eddy heat flux. This means a negative RI value does not always indicate downward wave propagation, but a weakening of upward wave propagation. Could you check if the results are robust if you use the total field v'T'? Also check the sensitivity of the results with respect to the size of the regional boxes.

6. What are the dynamical explanations behind the too persistent (prolonged periods) of wave reflection events (Fig. 3)? What causes the negative wind curvature (shear) to persist for such a longer period? Also, the formation of reflective layers does not guarantee that you will always have a reflection event. Without a narrow meridional wave guide channeling the upward wave flux to the reflecting surface, the upward wave propagation most likely disperses in the meridional direction. To answer this question, you most likely need to analyze the wavegeometry (m^2 and l^2) of those 44 reflection events (see in Perlwitz and Harnik 2003, Shaw et al., 2010, and Lubis et al., 2016).

Minor comments:

Title: I would suggest slightly modifying the title as "Stratospheric **downward** wave reflection events…... ". The *reflection* can be either in the vertical or horizontal direction.

L24-26: Planetary wave patterns are also large-scale meteorological patterns. Please modify this.

L50: It would help the readers to understand what factors controlling the downward wave reflection events. See general comment #4.

L52: *"One potential reason is the difficulty in diagnosing reflection events (see the discussion in Matthias and Kretschmer, 2020)."* I don't think this is the main reason. I think the main reason is the underlying dynamics that are still unclear, especially from the perspective of eddy-mean flow interaction (e.g., baroclinic eddy feedback in the presence of the downward reflection) and energy transfer (e.g., Harnik 2009, Lubis et al., 2017).

L55-59: "*Matthias and Kretschmer (2020) introduced a simple index to identify wave reflection events based on anomalous lower-stratospheric poleward eddy-heat flux over Siberia and Canada*". Matthias and Kretschmer (2020) in fact used the same measure of downward WAF as originally used by Kodera's back in 2008 (see **Figure 2a** in Kodera et al., (2008), with the same level (i.e., 100 hPa) and the same regional locations associated with the upward and downward WAF). It would be nice to acknowledge the work of Kodera et al., (2008) too here.

- Kodera, K., Mukougawa, H., and Itoh, S. (2008), Tropospheric impact of reflected planetary waves from the stratosphere, Geophys. Res. Lett., 35, L16806, doi:10.1029/2008GL034575.

L74: Why October and November are excluded from the analysis? It would be great to argue this from dynamical perspective of downward reflection events (see the seasonality of DWC in Shaw et al., 2010, Lubis et al., 2017 etc).

L102: I would specifically mention that your work only focus on the impacts over the North America sector.

L111: Can you check the sensitivity with respect to the size of the regional boxes used to define the index.

L128: " *..while negative values indicate downward propagation*." Add the following sentence at the end of this "(assuming the wave-activity density is positive definite)".

L134: It may be not true for the whole domain over North America since you are using the anomalous eddy heat flux. See my general comment #5.

L147: "*Finally, following Matthias and Kretschmer (2020) we apply a persistence criterion of 10 days*". Would be the results sensitive with the choice of this threshold? Please clarify.

L164: "*we analyze the tropospheric evolution associated with the 44 reflection events*". How many events are related to SSW event? Please see my general comment #3.

Figure 6. Can you explain dynamically how does the wave reflection event cause a stretching tropospheric jet, hence a severe cold spell over North America? Can you quantify this? I think the elongation of tropospheric jet (i.e., wavier) is of importance to the cold spell over North America, which may provide useful insight to the forecast of cold spells over North America.

L260-L265: I am afraid that your signals are mixed with the SSW events. Please do check. See my general comment #3.

L321-L323: Do you have any cases where a downward reflection event is not preceded by the PT regime, but still have a strong influence on surface temperature? Or a case when you have reflection but there is no significant impact on the surface temperature. I am wondering whether the PT regime is a robust tropospheric precursor of the downward reflection event.

L325: Very good point but without exploring this, it remains elusive if wave reflection events are the main cause of the cold spells.

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