Interactive comment on "Local and Remote Response of Ozone to Arctic Stratospheric Circulation Extremes" by Hao-Jhe Hong and Thomas Reichler

Anonymous Referee #1
Received and published: 16 September 2020

The paper presents an analysis of stratospheric ozone anomalies associated with sudden stratospheric warmings (SSW). vortex intensification events (VI), as well as FW events at the end of the corresponding winters. MERRA-2 data is used and both the Arctic and the Tropics are examined. The transport mechanisms are examined using the Transformed Eulerian Mean formalism. The paper is very well written, the methods are valid and the interpretation of the results is correct. I only have minor comments that should be addressed before publication.

Minor comments

• General: I find interesting the approach of interpolating the time axis in order to get common composited times for the SSW/VI event and for the FW. It helps bring out the outstanding ozone feature during the FW following VI events. However, I am not convinced by the terminology "the event's duration" referring to the lapse time between the event's central date and the FW. The final warming terminates the winter season, and while this indeed terminates the VI events, the SSW ends when the vortex recovers, not when it breaks down.

Yes, we agree that "event duration" can be misleading. In the revised manuscript we now use "period" to better describe the time between the central date and the FW.

• L134-138: I understand that S does not provide information on the photochemical changes as it is obtained as a residual and there are likely important numerical errors that prevent closing the budget, especially in a reanalysis system, where assimilation increments are included. However, you could check if the expected behavior is found in the S anomalies when referring to changes in photochemistry, e.g. for VI events in the polar region (L252-254) and in the tropics (L325-326).

We performed the suggested analysis. Over the Arctic (Fig. R1) and in the upper stratosphere (above 10 hPa), the source term *S* is mostly anticorrelated with temperature *T*, as expected. Interestingly, during VIs and over the Arctic, there is some indication for chemical ozone depletion, consistent with previous studies (Isaksen et al., 2012; Manney et al., 2011, 2020). However, *S* over the Tropics (Fig. R2) does not follow this pattern and largely opposes the tendencies due to the vertical advection (Fig. 5g and 5h). We now mention this in the manuscript at line 255:

L255: *"We also examined the source term S (not shown) and find negative tendencies in the lower stratosphere (10 – 100 hPa) during and after the onset of VIs, indicative for temperature-driven heterogeneous ozone depletion as suggested by previous studies (Isaksen et al., 2012; Manney et al., 2011, 2020). In the upper stratosphere, S is as expected mostly anticorrelated with T."*

Reference

Manney, G. L., Livesey, N. J., Santee, M. L., Froidevaux, L., Lambert, A., Lawrence, Z. D., Millán, L. F., Neu, J. L., Read, W. G., Schwartz, M. J., Fuller, R. A.: Record-low Arctic stratospheric ozone in 2020: MLS observations of chemical processes and comparisons with previous extreme winters, Geophys. Res. Lett., 47, e2020GL089063, https://doi.org/10.1029/2020GL089063.

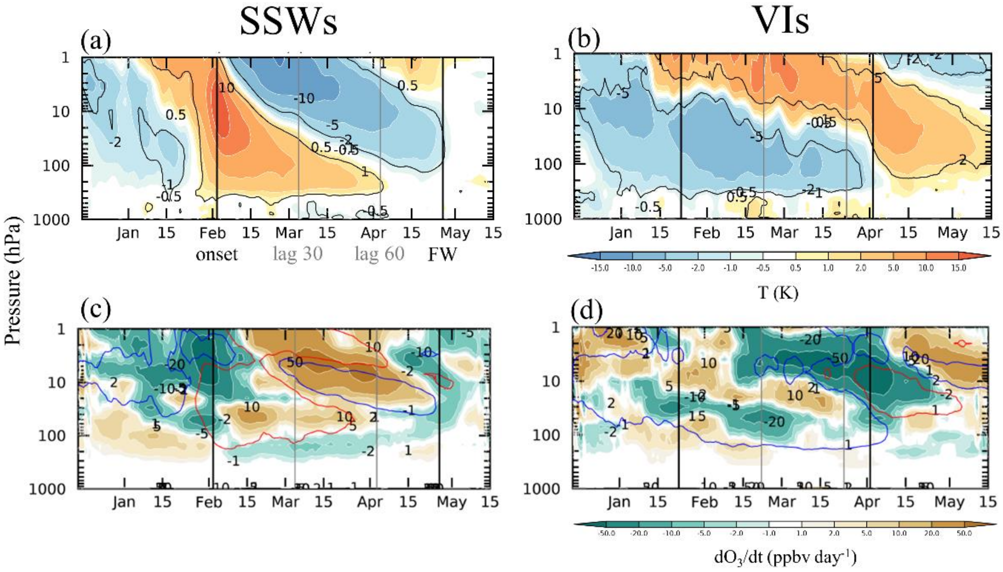

Figure R1. Composite anomalies for (left) SSWs and (right) VIs over the Arctic. Shown are time-height cross-sections for (a-b) temperature (K) (65°N-90°N) and (c-d) ozone tendency associated with *S* (ppbv day^{-1}).

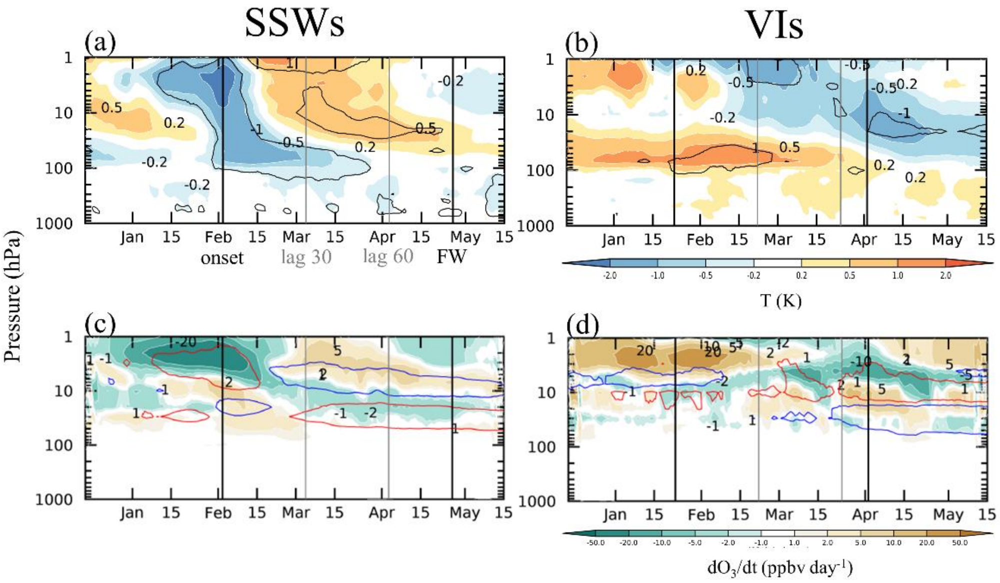

Figure R2. As Fig. R1, except for the Tropics (±15°).

• Sections 3.1 and 4.1. Several of the features described in these sections have been previously shown in the article of de la Cámara et al. 2018 JGR (https://doi.org/10.1002/2017JD028007), such as the tropical upwelling or the wave activity for SSW composites, in both reanalysis and model data.

We thank the reviewer for pointing this out. We now reference the paper to support its results.

• L157: "one-tailed t-Student test". This should be a two-tailed test, since the sample anomalies could be overestimating or underestimating the population anomalies (i.e. the null hypothesis is $\mu = 0$, not $\mu \leq 0$). This is important since for a 95% confidence level for the 8 VI events, $t_{0.025,7} = 2.365$ should be used instead of $t_{0.050,7} = 1.895$.

We agree with the reviewer. In the revised manuscript, we now use for the figures a two-tailed t-test at the 95% confidence level. Note that our results suggest that the anomalies of temperature and ozone during VIs are still significant after the change.

• L241-242: The small role of photochemical effects hypothesized here against the findings of Sagi et al. (2017) is consistent with the photochemical term shown in de la Cámara et al. (2018) ACP. Note that this paper does show the transport and chemistry relative contributions referred to L353-355 in a CCM, and that these CCM transport results are overall consistent with your reanalysis results.

We also compared our ozone tendency results with de la Cámara et al. (2018). Although we use a different vertical system, the two results are quite consistent with each other in most of the stratosphere for SSW events. We followed your advice and changed our paper in two locations:

L241: *"Overall, this indicates that the decrease in mid-stratospheric ozone after SSWs is mainly of dynamical origin, consistent with de la Cámara et al. (2018). We note that this does not support the ideas of Sagi et al. (2017), who argue that the ozone decrease is due to chemical reactions involving NOx species."*

L353: *"Nevertheless, it would be interesting to evaluate the relative contributions from the dynamics and the chemistry in changing ozone during SSWs and VIs, using output from a range of coupled chemistry climate models (CCMs), similar in spirit to de la Cámara (2018) for SSWs using the WACCM model."*

• L304: These values are much lower than their Arctic counterparts, what is the relative TOC change?

Fig. R5 shows the SSW and VI composites for column ozone as in Fig. 2 and Fig. 5. The blue lines in Fig. R5 are the percent column ozone anomaly with respect to climatology. The result suggests that changes in column ozone amount to 10%-12% of climatological values over the Arctic, while the ozone anomaly over the Tropics amount to only 0.5%-1%.

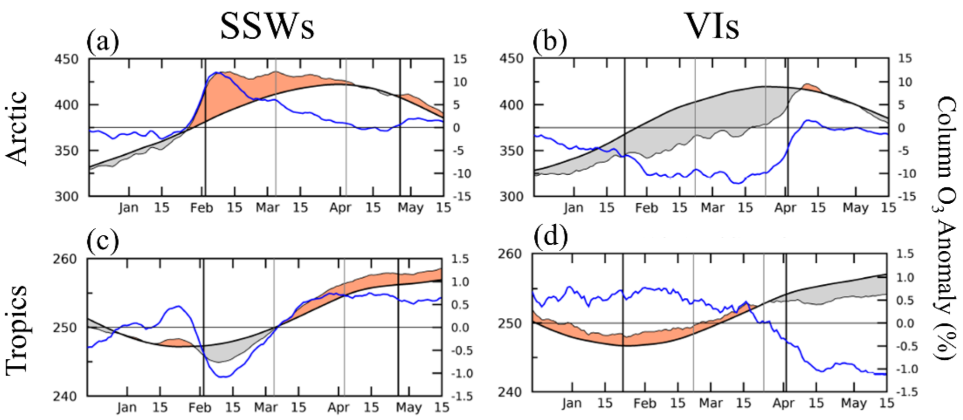

Figure R5. Column ozone composites (left) SSWs and (right) VIs. Blue line (right axis) represents the percentage of column ozone anomaly with respect to climatology.

We now add this information to our paper by adding/modifying the following sentences:

L301: *"… during SSWs and VIs. The variations in tropical column ozone are rather small and amount to only ~0.5 – 1% of the climatological values, which can be compared to the 10 – 15% changes seen over the Arctic. Nevertheless, the changes in tropical ozone are quite coherent and persistent. For SSWs, …"*

L303-305: *"SSWs are followed by a small reduction in tropical column ozone by ~2.5 DU (~ -1 %) and an increase by ~1-2 DU (~ 0.5 %) after mid-March, which persists until late spring."*

L310: *"During VIs (Fig. 5b), there are small tropical column ozone anomalies, which are mostly positive (~1 DU or 0.5%) and only become negative (~2 DU or 1%) after the FW."*

In the revised manuscript, we also replaced the column ozone tendency line (green lines in Fig. 2a-2b and Fig. 5a-5b) with the percentage of ozone anomalies (as in Fig. R5).

Technical

• L35 onward: Consider changing "transports" to "transport" throughout the paper?

This has been corrected.

• L125: change "p-coordinates" to "pressure coordinates"

This has been corrected.

• L341: "spectacular" Perhaps a more scientific term could be used (sudden/abrupt)?

We now use the word “remarkable” instead.