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Characteristics of long-track tropopause polar vortices

by M. T. Bray and S. M. Cavallo

Tropopause polar vortices (TPVs) are positive upper-level potential vorticity anomalies intensifying via longwave cooling in the Arctic. They are associated with severe weather events (e.g., cold air outbreaks) when moving out of the Arctic and they play an important role as a pre-cursor to surface cyclogenesis. Hence, understanding the processes driving their genesis and evolution is not only interesting from a scientific point of view but it is also highly relevant from a forecasting perspective. This study focuses on the most long-lived TPVs (i.e., longer than 2 weeks, corresponding to the 95^{th} percentile in a TPV climatology) as unique cases for studying the conditions that favour TPV development. Specifically, the study first presents statistics of basic TPV characteristics such as intensity and size and then moves on to explore the processes leading to their genesis. While most of the TPVs form as splits from a pre-cursor TPV, characteristic patterns of Rossby wave breaking and ridge building are identified to favour TPV genesis in certain regions. Then, the evolution and tracks of these long-lived TPVs are explored. A particularly noteworthy result is the identification of two main pathways of TPVs to exit the Arctic, one via Canada and one via Siberia, as well as the observation that TPVs that exit the Arctic can live on for more than 10 days.

I found the study interesting to read and the results make for an important contribution towards a better understanding of TPVs. The methodology is sound, which applies in particular also to the thorough Monte-Carlo based statistical tests. In addition, the presentation is mostly clear and figures are of high quality. I have a few minor suggestions for improvement that I would like the authors to consider. Other than that, I am convinced that this study will make for a valuable contribution to WCD.

General comments:

- While the introduction gives a comprehensive exposition of the current knowledge about TPVs, there are some unnecessary jumps between topics and I suggest the authors re-arrange some of it. For example, the paragraph about impacts (L42ff) is squeezed in between two paragraphs that are concerned with the processes driving the formation and intensification of TPVs. Furthermore, genesis of TPVs and their subsequent intensification should be discussed in separate paragraphs. Finally, I think that the introduction could more strongly point out the gaps of knowledge that motivate studying long-lived TPVs.

- I find the diversity of synoptic configurations leading to the genesis of non-split TPVs fascinating and Figs. 4-6 (as well as those in the appendix) are very helpful for illustrating this diversity. However, I am not sure whether the way they are arranged now is ideal. I found myself switching back and forth several times between Figs. 4-6. Instead of arranging the panels chronologically by event with separate figures for different times relative to

genesis, I'd suggest to present events for each of the three categories in separate figures with panels corresponding to different relative times next to each other.
In addition, I would find it more intuitive if the schematic Fig. 7 was presented before the case studies. This would also help to streamline the section, the four typical patterns are explained twice – first in the context of the cases and second when explaining Fig. 7.

- An especially interesting result of this study is that TPVs that exit the Arctic can live on for many days and eventually move back to the Arctic, where they may re-intensify. The pathways sketched in Fig. 12 suggest that such TPVs travel along the main storm tracks in the North Atlantic and the North Pacific. Hence, I am wondering how unusual it is for a TPV to "survive" a passage through these regions? I imagine that a TPV approaching the main storm tracks will inevitably catch up with a baroclinic zone and then start to interact with it, i.e. trigger surface cyclogenesis. Could you say something about whether the long-lived TPVs are less often involved in surface cyclogenesis than ordinary TPVs and if so why? One way to approach this would be via TPV centred composites similar to Fig. 9 showing surface fields. Alternatively, also a matching of the TPV tracks with a cyclone data base could shed some light on this.

- I would have wished some more discussion of the results in the context of existing climatologies of stratospheric cutoffs and the processes that cause their genesis and demise (e.g., Portmann et al. 2021 and references therein), which are certainly related to the processes governing TPVs – at least once they have left the Arctic.

Specific comments:

(1) L12: The sentence beginning with "Notable differences emerge … " is a bit vague. Either remove or specifically state what the differences between long-lived TPVs in summer vs. winter are.
(2) Abstract: I'd find it worth to mention the main exit pathways from the Arctic of the long-lived TPVs as this results is directly relevant in terms of impact.
(3) L35: Start a new paragraph here since the formation of TPVs is a new topic.
(4) L58: Suggest to connect this paragraph to what is previously said about the dynamical processes and splitting of the vortices.
(5) L71 and also L375, L412: "low-shear" → "low shear" to be consistent with the rest of the paper
(6) L78: Suggest to remove the sentence "Thus, we hope…" or move it to the conclusion.
(7) L103: "the set … were created" → "the set … **was** created"
(8) L104: The reference to Dee et al. (2011) should be moved to the mention of the ERA-Interim in the previous sentence.
(9) L105: Are these always year-round climatologies or do they take the seasonal cycle into account?
(10) L132ff and Fig. 1: I undestand the distributions in (a) and (b) are per track. It is less clear to me in (c) – (f): are these distributions for all track points or only the extrema along the tracks? Please specify.

(11) L148: With “low shear”, do you mean vertical or horizontal shear? To me vertical wind shear appears particularly detrimental for a TPV due to baroclinic interaction.

(12) L155: A high lysis frequency in the storm track regions is also found for stratospheric cutoffs (see Portmann et al. 2021).

(13) L162: No need to put the sentence “Note that when…” in brackets. I find this information relevant.

(14) L166: To what end? Do you mean to shed light on the split vs. non-split TPV genesis events?

(15) L203: How is the sorting of the non-likely split TPVs done? Is it based on visual inspection?

(16) L237: “method of genesis” sounds odd

(17) L275: I don’t understand what you mean by “This feature of the composites is likely a reflection of mainly TPVs that form nearer to the mid-latitudes…”

(18) L270ff and Fig. 9: On what level are the winds? I assume it is the 2pvu tropopause. In any chase this should be specified.

(19) L317: What do you mean by “flow regime”?

(20) L322: “into two regions” → “**in** two regions”

(21) L326ff: This is a very interesting and – to me at least – surprising result. I would have expected that TPVs, once they exit the Arctic, will inevitably interact baroclinically with the lower troposphere and as a result decay.

(22) L421: “objective set **of** TPV genesis mechanism”

(23) L411: I suggest to streamline this last paragraph.

References:

Portmann, R., Sprenger, M., and Wernli, H.: The three-dimensional life cycles of potential vorticity cutoffs: a global and selected regional climatologies in ERA-Interim (1979–2018), Weather Clim. Dynam., 2, 507–534, https://doi.org/10.5194/wcd-2-507-2021, 2021.