

Review for

Distinct structures of interannual variations in stratosphere-to-troposphere ozone transport induced by the Tibetan Plateau thermal forcing

by Yang et al.

Summary:

In their study, Yang et al. consider stratosphere-to-troposphere (STT) ozone transport over the Tibetan Plateau (TP). They distinguish between direct and indirect STT processes, and link the two to the thermal forcing of the TP. They make extensive and excellent use of a STT climatology and meteorological features (e.g., tropopause folds) provided by the atmospheric dynamics group of ETH, and combine these with their own meteorological analysis, mostly considering jet streams and TP thermal forcing.

The study is certainly of high interest, as the TP is a hotspot of cross-tropopause mass and ozone transport. The manuscript is (mostly) very well written and follows a clear storyline. First, the monthly variation in STT frequency is studied. Then, the effect of TP thermal forcing on STT frequencies is assessed, where the corresponding jet stream variability as a key driver for STT due to the thermal forcing is determined. To this aim, a singular-value decomposition (SVD) is performed to get the 'correlation' between two meteorological fields. In a next step, the ozone STT fluxes are studied, in relation to the TP thermal forcing. Finally, the meteorological drivers for STT fluxes and how they relate to the TP thermal forcing is determined. To this aim, the large-scale circulation over the TP is studied, and it is also determined how the frequency of tropopause folds varies in response to a varying TP forcing. The manuscript concludes with a nice schematic figure that summarizes the key findings.

It was fun reading the manuscript, in particular to see how the text is very well structured and leads the reader step-by-step to the answers of the key questions raised in the introduction. I can definitely recommend publication of the paper with minor revisions. There are only few specific comments that the authors could address to improve readability.

Specific comments:

- The term 'Tibetan Plateau thermal forcing' is used in the abstract and also in the introduction (L62), but there it is not clearly defined. Possibly, the authors could add a few sentences that introduces the meaning of 'thermal forcing' more clearly. This might be important, as the TP thermal forcing is a key aspect of the study.
- L28-29 [This study ... environment]: I think I understand what the authors mean, but it could be phrased more clearly.

- L35: 'Its abundance being...' -> 'its abundance in the troposphere being'

- Figure 1: The STT frequency seems to be strongly linked to the strength and position of the jet streams around and over the TP. I wonder whether it would be worthwhile to show the seasonal cycle of the jet streams in addition to the seasonal cycle of the STT frequency. For example, in Figure 1 one could get (most likely) remove the detailed country(canton boundaries, and instead overlay some wind speed contours. In this way, the close link between jets and STT frequency could be highlighted.

- L146: 'The STT exhibits a prominent seasonal cycle with monthly changes'. -> What does 'with monthly changes' exactly mean? I assume that this reflects a slight 'language uncertainty' (not being native English speakers?), although the text is mostly well written and clear. Still, at some places a further language editing could help to make the text more concise and clearer.

- L160: Similarly, 'with the underlying meteorological mechanisms' is not clear. Which meteorological mechanisms?

- In Section 3.2 the authors might make clearer that the SVD-based analysis does not yet imply a cause-effect relationship. It is, as far as I understand, only a measure of 'correlation' between two fields. The text, however, already points to such a cause-effect relationship. This will only later in the text be justified when the jet variability is 'explained' by the thermal forcing.

- L203: 'and upper tropospheric vortex processes play a significant role' -> It is not completely clear to me what 'vortex processes' the authors are referring to. Some further explanations (more explicit naming of processes) would be helpful.

- In Section 3.2, a distinction is made between direct STT (with intense vertical transport) and indirect STT (with longer-range transport). I wonder whether this relates also to the STT process that is discussed in detail in the following study:

Škerlak, B., Pfahl, S., Sprenger, M., and Wernli, H.: A numerical process study on the rapid transport of stratospheric air down to the surface over western North America and the Tibetan Plateau, Atmos. Chem. Phys., 19, 6535–6549, <https://doi.org/10.5194/acp-19-6535-2019>, 2019.

At least, it seems to me that the important distinction between direct and indirect STT is also addressed in this numerical study. If so, the authors might want to refer to this study; if not, of course, there is no need to include it. I think it would be worthwhile to include some additional studies regarding direct/(indirect) STT, as the discussion in L202-215 is certainly very plausible, but it is also somewhat more speculative than other parts of the paper.

- The analysis in Section 3.4 about meteorological mechanism is very nice, and clearly addresses some of my earlier concerns about cause-and-effect vs. simple correlation. Possibly, the authors can earlier in the manuscript already point to this section where good reasons for a cause-effect relationship is made.