Response to interactive comments on "The tropical tropopause layer in reanalysis data sets" by Tegtmeier et al.

We thank the reviewer for his/her comments which have helped us to improve the paper in revision. Comments are reproduced below, followed by our responses in *italics*.

Anonymous Referee #4

This paper evaluates data quality of multiple atmospheric reanalyses focusing on ther- mal characteristics of the tropical tropopause layer (TTL). The comparisons are made against long-term archives of radiosonde and GNSS RO data, which provide the most accurate temperature measurements in the TTL. Purpose of the paper is very clear, methods are reasonable, and results are well organized. It provides valuable information on reanalysis data sets and is recommended for a publication in ACP after considering several minor issues listed below.

Minor issues

1. The title is too broad. The analyses focus mainly on long-term mean features and inter-annual variability of the TTL, while the title gives an expectation that it will cover overall aspects of the TTL. Annual cycle and intra-seasonal variation are also features of the TTL, particularly for dehydration processes. A more detailed title is required if authors decide not to include these features. One suggestion is making this paper as "part 1" covering long-term structures and inter-annual variability and left annual cycle and intra-seasonal variability for a future study (as this paper already has enough material, I think. . .).

We agree that the title was too broad and have changed it to 'Temperature and tropopause characteristics from atmospheric reanalyses in the tropical tropopause layer'. We make it clear from the onset that we focus on climatological and long-term characteristics by adding this information at the beginning of the abstract.

2. This is also related to comment #1. The temperature bias peaking near the equator and its potential connection to Kelvin waves (Figs. 6-8) are interesting results. This part is worth to be further investigated (even in a different paper) as it provides noble information for researchers studying the dehydration process based on reanalyses. Particularly, this feature could be "seasonally" different because temperature and circulation structures in the TTL undergo strong seasonality. The same is true for the Kelvin source over central Africa.

We agree with the reviewer that the evaluation of the seasonal cycle would be an interesting addition and should be covered in a future follow-up study. We have added a remark to the summary section.

3. Please provide some details describing how the CPT/LRT and their properties are calculated in this study. Several methods have been used to estimate properties of the CPT, and the results could be sensitive to the selected method, particularly for data set with coarse vertical resolution. This information will be helpful for readers to better understand the results provided in this paper.

We have added the following text to the manuscript 'We derive the cold point and lapse rate tropopause characteristics for each reanalysis using model-level data between 500 and 10 hPa at each grid point at 6-hourly temporal resolution. Zonal and long-term averages are calculated by averaging over all grid points, and represent the final step of data processing.

For our calculations, the cold point tropopause is defined as the coldest model level. The lapse rate tropopause is defined as the lowest level at which the lapse rate decreases to 2 K km^{-1} or less, provided that the average lapse rate between this level and all higher levels within 2 km does not exceed 2 K km^{-1} (World Meteorological Organization, 1957).'

4. Given the accuracy and vertical resolution of ERA5 described in section 3, CPT temperature trend from ERA5 would be most reliable. It will be very useful if this information could be added in Fig. 12. (just suggestion)

At the moment, we have only acquired the 6 hourly data sets from ERA5 (used to calculated the cold point tropopause) for the period 2000 to 2017. We can also access a data set on the 37 standard CFMIP pressure levels for the time period 1979 to 2017, but the lower vertical resolution will impact the cold point tropopause. Therefore, we have decided to include long-term changes of ERA5 in a follow-up study that focuses on a detailed comparison of ERA-Interim and ERA5 and will evaluate long-term changes over different time periods (i.e., extending to 2018).

5. Dynamical aspect (e.g., upwelling) in the TTL is not covered in this paper. Some discussion may be beneficial (but not necessary).

We agree that a discussion of the dynamical aspects of the TTL would very interesting. However, this would require a large amount of additional material and is beyond the scope of the manuscript. Such a discussion can be found in the TTL chapter of the upcoming S-RIP report (currently under review) and related paper publications.

Technical comments

P3L20: Pan and Munchak (2011), Pan et al. (2018) could be good references for this paragraph

We have added the references to the manuscript.

P3L37: 0.5 km is roughly 5 hPa at this level, 5 hPa maybe more consistent.

Thanks for pointing this out. We have changed the text to 7 hPa.

P10L29: "near 100 hPa (ERA-Interim; -0.82 K)". This is correct in Fig. 4 at ∼96 hPa, but could look inconsistent with Fig. 3 (right panel) as it shows ∼ -0.4 K at 100 hPa. Better to mention that it is on a model level, not 100 hPa.

We have changed the text according to the suggestions.

Fig. 4: Average on pressure level could be a bit misleading as it shows a smooth CPT. Additional figure on tropopause relative coordinate (e.g., Birner et al. 2002) could be useful.

We have decided to keep the current version of Figure 4, which aims at identifying reanalysis biases on the respective model levels. Tropopause-based averages would have the disadvantage to be affected by cold point altitude biases. Therefore, biases in a tropopause-based figure would belong to different model levels mixed up in the same tropopause-relative level.

P12L1: "comes at the expense . . . tropopause". This expression could be a bit misleading because there is no clear causality.

We have changed the sentence to phrase this more carefully.

P13L5: "with respect to the zonal mean" => in meridional direction?

Yes, this phrase fits better. We have changed the sentence.

Fig. 7: ERA5 could provide an important clue on this issue as it has a good vertical resolution, but it is missing in the figure.

We have added ERA5 to the figure. It shows very similar structures when compared to the observations.

Fig. 8: Is the left figure different from that in Fig. 7?

Only the colour bar is different in order to contrast the comparison of CFSR over the whole time period better with the comparison during times of high Kelvin wave activity.

P17L24: datasets => data sets Fig. 10: RAOB is used for the first figure, but IGRA is used for the second figure. It will be helpful if an explanation is provided why authors made this choice. Periods ('.') are missing in several section titles and figure captions.

For consistency reasons we decided to rely on the radiosonde data sets used in Wang et al., 2013, where the authors provide detailed evaluations of the temporal variability and trends of radiosonde temperature in the TTL. Wang et al. (2013) use the unadjusted quality-controlled radiosonde data set IGRA for the cold point and several independently adjusted radiosonde temperature data sets RATPAC, HadAT, RAOBCORE, and RICH for temperatures at 70 and 100 hPa. The motivation for evaluating interannual variability of cold point temperature, height and pressure only from the unadjusted temperature profiles is that temperature adjustments can change the location of the cold point tropopause in a profile. Therefore, we show RAOBCORE in the top panel at 70 hPa and IGRA in the lower panels for the cold point. The interannual anomalies at 70 hPa are shown only for RAOBCORE for a better clarity of the figure, while the other data sets are mentioned in the text. We have added a detailed explanation to chapter 2.1 (Observational data sets) to make clear which data sets are used at which levels for which reasons.

References

Birner, T., A. Dornbrack, and U. Schumann, 2002: How sharp is the tropopause at midlatitudes? Geophys. Res. Lett., 29, 1700.

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Pan, L. L., Honomichl, S. B., Bui, T. V., Thornberry, T., Rollins, A., Hintsa, E., & Jensen, E. J. (2018). Lapse Rate or Cold Point: The Tropical Tropopause Identified by In Situ Trace Gas Measurements. Geophysical Research Letters, 45(19), 10-756.