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Atmospheric Measurement Techniques Discussions

Interactive comment on "Characteristics of tropopause parameters as observed with GPS radio occultation" *by* T. Rieckh et al.

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Manuscript title: Characteristics of tropopause parameters as observed with GPS radio occultation

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We thank the referee for the thorough review and all comments. We have carefully considered the suggestions and will update the manuscript accordingly. We have answered all comments below (for easier comparison the referee comments are included

in italic).

1 Main Comment

Overall I find this paper to be straightforward and very well written. My main concern is that most of the presented results are really just confirmation of what is already known. Many of the more recent tropopause studies (as referenced) also use GPS RO data, although from other retrievals. It is therefore not clear, what new insight comes from the present analysis. Figures 3-6 repeat what has already been shown in previous studies, but for only one out of the 12 years of available data. The ENSO related variability is demonstrated based on only one cold and warm phase, respectively. It is not clear how these results cary over to the longer data record. Figures 10 and 11 include some novel ways of characterizing the stratospheric influence on tropopause height and temperature. One relevant reference for this that I didn't see listed, is: Son et al., Intraseasonal variability of the zonal-mean extratropical tropopause height, J. Atmos. Sci., 64, pp 608-620, 2007. Son et al. show how stratospheric temperatures have a strong influence on tropopause height, which seems relevant for the SSW related analysis here. In summary, I think the authors need to much more clearly state in what way the present analysis adds to the existing state of the art. Additional analysis and/or discussion may be required to make this contribution sufficiently novel to allow publication.

Within the discussion phase we have processed our RO data set until the end of 2013. In the revised paper we will present the whole record from September 2001 to December 2013, which is a significantly longer observational time series than in previous studies on this object.

We agree that a lot of figures of the discussion paper showed results only for one out of many years of available data. To fully take advantage of the whole RO record,

(i) we additionally calculated statistics of tropopause characteristics, (ii) investigated longitudinal variability in a more transparent way, and (iii) analyzed ENSO- and QBO-related variability by applying multiple linear regression.

1. To fully exploit the longer data set we will remove Figure 4 of the AMTD manuscript and add new figures showing the statistics of tropopause characteristics (tropopause altitude and temperature) calculated from the whole RO record. For this purpose, we will show box-whisker plots including information on mean, median, standard deviation, 25 and 75 quartiles, and extremes for 5° latitudinal bands. Figure 1 exemplarily shows this statistics (calculated from 2001 to 2013) for tropopause altitude in January. Discussion will be included in Section 3.1 ("Latitudinal characteristics").
2. To investigate longitudinal variations in a more transparent way, we use the full RO record (2001 to 2013) to calculate averages for 5° latitude × 10° longitude bins for each month for all years (i.e. long-term monthly means). We will replace Figure 5 of the AMTD manuscript by a map showing spatial variability of long-term monthly mean tropopause altitudes for different months. Figure 2 exemplarily shows such a map for tropopause altitude in January. Related discussion will be included in Section 3.2 ("Longitudinal characteristics"). Figure 6 of the AMTD manuscript will be removed.
3. For a better representation of ENSO- and QBO-related variability, we performed multiple linear regression analysis of tropopause altitude and tropopause temperature. ENSO and QBO proxies were regressed onto monthly inter-annual anomalies for the time range 2007 to 2013. During this period warm ENSO (El Niño) events occurred early 2007 and 2009/2010 and cold ENSO (La Niña) events in 2007/2008, 2010/2011, and 2011/2012. Neutral ENSO conditions were observed in 2008/2009 and in 2012/2013. The number of RO measurements per month was sufficient to perform multiple linear regression analysis for 5° latitude

× 10° longitude grid boxes. This allows to gain more insight on spatial ENSO and QBO patterns in tropopause parameters using observational data.

We will replace Figures 8 and 9 of the AMTD manuscript by maps showing the regression coefficients of ENSO and QBO. Figure 3 exemplarily shows ENSO and QBO regression maps for tropopause temperature. Plots and related discussion will be included in Section 5 ("Inter-annual variability").

2 Minor Comments

(a) Tables: *To me, the Tables are not needed, as they merely repeat the information given in Figures 3 and 4.*

We agree with the reviewer and will remove the tables in the revised paper.

(b) Page 4694, line 14: *Temperature and wind fields are to a good approximation coupled through the thermal wind balance – in that sense neither "influences" the other, they are simply reacting to the underlying large-scale dynamics in a consistent way. You could simply say something like "due to variability in the subtropical tropopause break"*

Thank you for this input, we will change the sentences to:

Page 4694, lines 12 to 14: "In the transition zones (20° N/S to 40° N/S), individual profiles reveal varying tropopause altitudes from 7 km to 17 km due to variability in the subtropical tropopause break."

Page 4700, lines 14 to 16: "Larger deviations are found between 20° and 30° in hemispheric winter, when variability in the subtropical tropopause break leads to large variations in the H_T distribution."

Page 4708, lines 5 to 6: "Variability in the subtropical tropopause break leads to a large spread in the H_T and T_T distribution in the 20° to 30° latitudinal band during winter."

(c) Page 4695, line 3: *Arguably, most of the troposphere-to-stratosphere transport occurs within the upwelling branch of the Brewer-Dobson circulation, which due to adiabatic cooling and freeze-drying also sets the water vapor amount. Deep convection can certainly have an impact, but is usually not considered to be the dominant process.*

We will change this sentence to: "In the tropics, exchange between troposphere and stratosphere is mainly determined by the upwelling branch of the Brewer-Dobson circulation (BDC). Tropical cross-tropopause transport is the main source for water vapor in the stratosphere and plays an important role in stratospheric chemistry and its radiative budget (*Fueglistaler et al.*, 2009)."

(d) Page 4696, lines 24-28: *In many ways the present analysis also concentrates on the broad scale spatio-temporal mean structure, so I don't fully understand this motivation. Yes, Figures 3-6 show individual data points, but there are so many of them, that the predominant structures don't look very difference from monthly averaged contours. Also, it's not clear to me why the authors choose to look at the mean and median only, if they'd like to gain more insight into the distributions? Mean and median alone are certainly not sufficient to characterize a distribution.*

Thank you for pointing that out. To take advantage of the whole RO record we enhanced the analysis. We will add figures showing the statistics of tropopause altitude and tropopause temperature including latitude-resolved information on mean, median, standard deviation, 25 and 75 quartile and extremes. As an example, Figure 1 shows a box-whisker plot for tropopause altitude.

Furthermore, we will replace Figure 5 of the AMTD manuscript by a map showing long-term monthly mean tropopause altitude for 5° latitude × 10° longitude bins for different months. As an example, Figure 2 shows long-term monthly mean tropopause temperature for January.

Figure 6 will be removed.

(e) Page 4700, line 5/6: *slightly confusing — tropopause height is primarily a function of surface temperature, tropospheric lapse rate, and stratospheric temperature (which is in part set by the Brewer-Dobson circulation, see e.g. Birner (2010)) baroclinic waves actually act to lift the tropopause in the extratropics by lowering the lapse rate.*

Thank you for this input, we will rewrite this sentence to:

"This pattern results from combined effects of the troposphere and the stratosphere. While the surface pressure and tropospheric lapse rate determine these basic latitudinal characteristics (e.g., *Held*, 1982; *Thuburn and Craig*, 1997), stratospheric dynamics can also significantly raise or lower tropopause height (e.g., *Son et al.*, 2007; *Birner*, 2010)."

(f) Page 4707, line 2: *suggest to insert "can" before "increase" – 50 K do not happen for every SSW*

We will change the sentence to: "During SSW events, stratospheric temperatures can increase by up to 50 K within a couple of days, which affects T_{T}."

(g) Figures 5, 6 : *the circles / ellipses on the plots need to be explained*

The plots will be substituted by maps showing 5° × 10° binned data, as depicted in Figure 2.

(h) Figure 7: *I found showing two full cycles somewhat confusing – how about adding just 3 months on either side of the annual cycle (start in Oct, end in March), that way things should look clear, but one is not mislead into thinking there is a semiannual cycle. If the plot is left as is, it would help to draw a vertical line at January (middle of panels).*

Thank you for this idea. We will change the plot and show two extra months on both sides.

(i) *Citation of Son et al. (2007)*
We will include this reference.

References

Birner, T. (2010), Residual circulation and tropopause structure, *J. Atmos. Sci.*, *67*, 2582–2600, doi:10.1175/2010JAS3287.1.

Fueglistaler, S., A. E. Dessler, T. J. Dunkerton, I. Folkins, Q. Fu, and P. W. Mote (2009), Tropical tropopause layer, *Rev. Geophys.*, *47*, doi:10.1029/2008RG000267.

Held, I. M. (1982), On the height of the tropopause and the static stability of the troposphere, *J. Atmos. Sci.*, *39*, 412–417.

Son, S.-W., S. Lee, and S. B. Feldstein (2007), Intraseasonal variability of the zonal-mean extratropical tropopause height, *J. Atmos. Sci.*, *64*, 608–620, doi:10.1175/JAS3855.1.

Thuburn, J., and G. C. Craig (1997), GCM tests of theories for the height of the tropopause, *J. Atmos. Sci.*, *54*, 869–882, doi:10.1175/1520-0469(1997)054<0869:GTOTFT>2.0.CO;2.

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 4693, 2014.

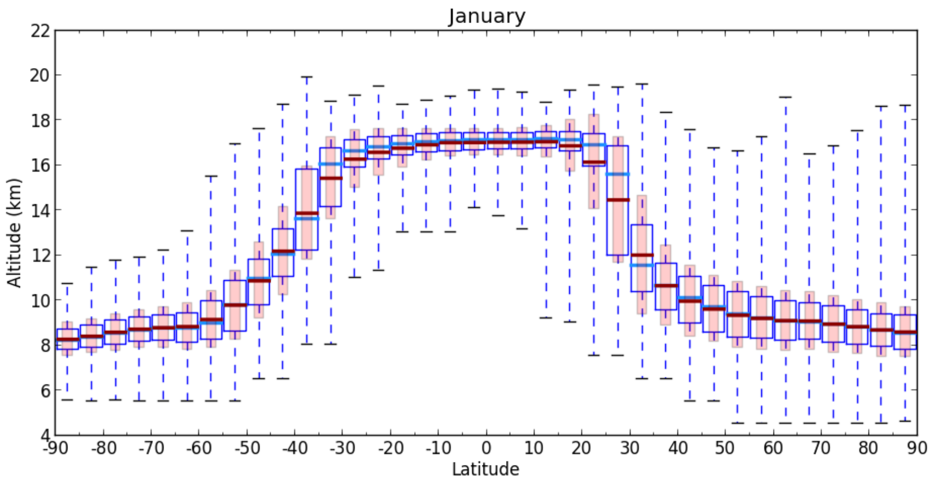

Fig. 1. Statistics of first tropopause altitudes as a function of latitude for 5° zonal bands for January.

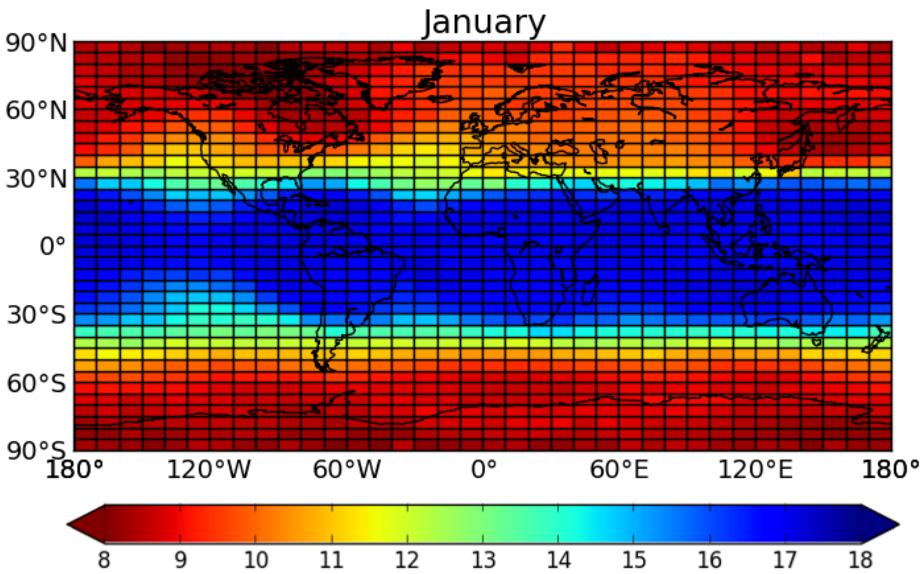

Fig. 2. Long-term monthly mean (2001 to 2013) first tropopause altitude (km) for January calculated for 5° latitude x 10° longitude grid boxes.

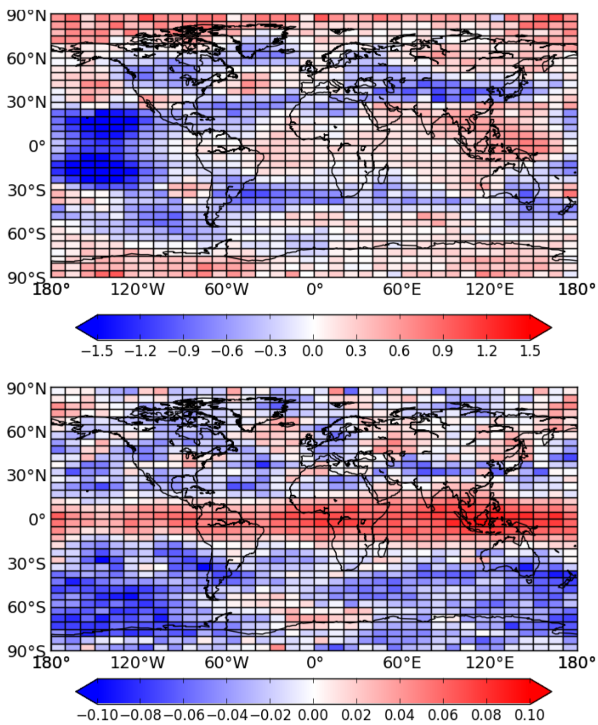

Fig. 3. ENSO regression map (top) and QBO regression map (bottom) of tropopause temperature.