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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Characteristics of the tropical tropopause inversion layer using high-resolution temperature profiles retrieved from COSMIC GNSS Radio Occultation" *by* Noersomadi Noersomadi et al.

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Reply to the comments by the Reviewer #2

Comments to "Characteristics of the tropical tropopause inversion layer using high-resolution temperature profiles retrieved from COSMIC GNSS Radio Occultation" by Noersomadi Noersomadi et al.:

This study investigated the characteristics of the tropopause inversion layer using the high vertical resolution GNSS-RO data. It gave more details of the TIL sharpness

and depth compared to previous studies, including the climatological mean and the intraseasonal to interannual variations. In particular, this work gives a special focus on two different longitude regions (the Maritime Continent and the Pacific Ocean). It extended previous work by related the interannual and intra-seasonal variations of the TIL to ENSO and MJO, respectively. It is well laid-out and well written. However, there are still some problems need to be fixed before publication. We appreciate the reviewer for providing constructive comments to our manuscript. We show below our responses to the individual comments.

Introduction The most relevant previous work to my understanding is Grise et al. 2010. Grise et al. 2010 already presented a global survey of the TIL strength (including annual cycle, horizontal distribution and interannual variations related to QBO) using the GPS-RO data with a vertical resolution also 0.1 km. However, it is not introduced in the introduction. It would be necessary to introduce results from Grise et al. 2010 and clearly describe what kind of improvement does this study want to have compared to them. We add the following statements in P2 L12-16: "Using routine radiosonde sounding data, a strong mean inversion at the tropopause in the midlatitude was analyzed by Birner et al. (2002) and Birner, (2006). Grise et al. (2010) conducted a global survey of the TIL characteristics, including annual cycle, horizontal distribution and interannual variations related to the stratospheric Quasi Biennial Oscillation (QBO) using the Global Positioning System Radio Occultation (GPS-RO) data."

We also add the statements citing Birner (2006) and Grise et al. (2010) in P2 L23-26. "Birner (2006) found that the mean N2 shows enhanced values near the extratropical tropopause compared to the extratropical lower stratosphere. Furthermore, Grise et al. (2010) found that the largest magnitudes of N2 found between $10° - 15°$ latitude in both hemisphere during northern hemisphere (NH) winter season."

We add the following sentences in Section 3 (P6 L23-26): "We found the maxN2 at range $11 - 12.0 \times 10-4$ s-2 above CPT height in the two longitude regions. Note that Grise et al. (2010) reported that the zonal mean maxN2 value above the LRT and CPT heights was ∼8.0 × 10−4 s−2 using CHAMP dataset (see fig.2 in Grise et al, 2010). The different values found in this study are probably due to the use of data of higher effective vertical resolution."

We also add the following sentences in P6 L30-34: "The results shown in Fig. 3 uncover the detail structure of N2 above CPT in the specific longitude regions compared to the results by Grise et al. (2010) that showed the mean N2 over 0−1 km layer above LRT. The vertical propagation of equatorial waves (Kelvin waves and/or gravity waves), as the results of convective forcing, modulates the tropopause (Tsuda et al., 1994; Randel and Wu, 2005; Kim and Alexander, 2015; Kim et al., 2018). The MJO activity was also found to control the tropopause variability (Kim and Son, 2012; Pilch Kedzierski et al., 2016)."

P2L12: "A very low temperature in the TIL", TTL should be better here

We follow your suggestion in P2 L18.

P3L6-10: I think it is now commonly known that the vertical resolution of the GPS/GNSS-RO data is up to 0.1 km. This sentence misleads the authors with a impression that the vertical resolution of GPS/GNSS-RO data is 1 km. Please rephrase this paragraph here. There are two fundamental retrievals of GPS-RO data called the wave optics (WO) and the geometrical optics (GO). We have mentioned the definitions of both the WO and GO in Section 2.1. The vertical resolution by GO is limited about 1-2 km (Kursinski et al., 1997), while the effective vertical resolution by WO or radio holographic method up to 0.1 km (Gorbunov, 2002). We used GPS-RO retrieved using WO (FSI) up to 30 km in the present study (Tsuda et al., 2011; Noersomadi and Tsuda, 2017). We think the reviewer referred to the wetPrf products provided by CDAAC. It is true the wetPrf products provide 0.1 km grid resolution, but the effective vertical resolution at 10-20 km altitudes of cosmic2013 is 0.5 km. For more details, please see the improved atmospheric data inversion called NEWROAM in the CDAAC webpage (https://cdaac-www.cosmic.ucar.edu/cdaac/doc/overview.html).

We add the following statements in P3 L28-30: The actual effective vertical resolution of RO measurements increases in regions of increased refractive gradients such as inversion layers at the top of the boundary layer or the tropopause.

Data P3L35-40: To my experience, the cosmic data from CDAAC should has data available for 0.1 km vertical resolution, e.g. wetPrf. Also note, most of studies as I know (Randel et al. 2007; 2010; Grise et al., 2010; Kedzierski et al., 2016 etc.) using cosmic data from the CDAAC and has vertical resolution of 0.1 km. I am not sure whether it is true that the cosmic2013 smoothed the data over a 0.5 km scale. Please check that carefully. Noersomadi and Tsuda (2017) investigated the three GPS-RO products, two by UCAR (i.e. COSMIC version 2010 and re-processed data version 2013) and one by RISH (hereafter we refer to cosmicfsi in the present study). Noersomadi and Tsuda (2017) showed that COSMIC version 2010 indicated mixture of vertical resolution (0.1 – 1 km), while COSMIC version 2013 fixed the resolution at 0.5 km in the UTLS (see their result in fig. 3). Detailed explanation about the retrieval of COSMIC re-processed data version 2013 can be found in Zeng et al (2016). Randel et al. (2007, 2010), Grise et al. (2010), and Kedzierski et al. (2016) did not mention the specific data version/product that they used. In this study, we used the cosmicfsi data product whose vertical resolution is 0.1 km near the tropopause (Noersomadi and Tsuda, 2017).

Figure 1: For the cosmic2013 data. The GPS-RO data is well known to be very accurate with high vertical resolution. From the Figure shown in Figure 1, the temperature profile is heavily smoothed. I strongly doubt for the results shown here. Please check carefully whether you are using the correct type of product from the cosmic2013 data.

Figure R1 Comparison of the T profles on December 17, 2011, between the radiosonde at Jakarta Indonesia (black line) and nearby COSMIC GPS-RO by cosmicfsi (blue line), atmPrf cosmic2013 (red line), and werPrf cosmic2013 (green line), respectively.

Figure R1 is a revised version of fig. 3 of Noersomadi and Tsuda (2017) by changing the atmPrf version 2010 profile to wetPrf version 2013. Figure R1 shows that both atmPrf and wetPrf of cosmic2013 indicate smoothed temperature profiles near the tropopause compared to our cosmicfsi data product. The wetPrf data is 0.1 km gridded data, but the actual, effective resolution is 0.5 km as described by Sokolovskiy et al. (2014) and Zeng et al. (2016).

TIL definition: There has been a lot of definitions to TIL strength, sharpness or thickness. Beside the authors mentioned, please also include Randel et al. 2007; 2010 and Wang et al. 2013 for the TIL definition using the temperature gradient. Randel,W. J.,Wu, F., and Forster, P.: The Extratropical Tropopause Inversion Layer: Global Observations with GPS Data, and a Radiative Forcing Mechanism, J. Atmos. Sci., 64, 4489, doi:10.1175/2007JAS2412.1, 2007. Randel, W. J. and Wu, F.: The Polar Summer Tropopause Inversion Layer, J. Atmos. Sci., 67, 2572–2581, doi:10.1175/2010JAS3430.1, 2010. Wang,W., Matthes, K., Schmidt, T., and Neef, L.: Recent variability of the tropical tropopause inversion layer, Geophys. Res. Lett., 40, 6308–6313, doi:10.1002/2013GL058350, 2013. We add the following statements in P5 L13-17: "Grise et al. (2010) showed minor differences in the zonal mean N2 profile relative to LRT and CPT in the tropics. Randel et al. (2007; 2010) and Wang et al. (2013) investigated the TIL using the temperature gradients. Schmidt et al. (2005) and Son et al. (2011) defined the TIL with respect to the LRT height; more recently, Gettelman and Wang (2015) and Pilch Kedzierski et al. (2016) used the definition with respect to LRT height."

Definition of the TIL thickness: I don't know whether it is necessary to have new definitions of TIL sharpness and thickness since there have been so many kinds of definitions. If the authors feel it is necessary, please address the reason clearly here. In particular, why a 80% is used for the dH. Are there any physical or statistical reasons? Otherwise, I would suggest to using the existed definitions, for example, the maximum of N2 above the tropopause for the TIL sharpness. We add the following sentences in P5 L33-37: "We will focus on seasonal variation of S-ab and dH in Section 3.3. We have analyzed how the results change quantitatively when using the difference be-

tween maxN2+1 and minN2−1 instead of averaging along ±1 km relative to CPT as was done by Kim and Son (2012), with effectively higher vertical resolution dataset. In order to obtain dH we need to define the corresponding N2 value. Considering the stable N2 value in the lower stratosphere as 6.5 $\times 10^{-4}$ s^{-2} and the maxN2 as 10.5 $\times 10^{-4}$ s^{-2} (Fig.2 right panel), the threshold of N2 should be larger than 65% of maxN2. We choose 80% as the threshold."

Results: For the global distribution and seasonal variations of the N2 and TIL, it would be very helpful to have some comparison to previous work like Grise et al. 2010. Please describe clearly whether the results are consistent with each other and what are new findings from the previous work. We have modified the structure of the manuscript focusing on the N2 relative to CPT.

Please see replies to the first comment by the reviewer.

Regarding the comparison with previous studies, we add the following statements in P7 L41 – P8 L6: "Large S-ab values are found along the equatorial region, while low OLR regions show latitudinal variation with season. Local and seasonal variability of horizontal structure of tropopause sharpness presented in this work is consistent with previous studies which attributed it to equatorial waves activity (e.g. Grise et al., 2010; Son et al., 2011; Kim and Son, 2012). However, we found different quantitative results in particular over the Western Pacific because of our use of maxN2+1 and minN2–1 instead of averaging N2 within ±1 km relative to CPT by Kim and Son (2012), and also because of the use of data of higher effective vertical resolution. Maximum static stability just above the tropical tropopause could also be associated with divergence flow as demonstrated by Pilch Kedzierski et al. (2016)."

Figures 5 and 7. The values of N2 above the tropopause is not clear. Please update the color map used for these figures. We have revised the manuscript by removing some figures (including Figs. 5 and 7 of the original manuscript) and updating the figures number. We also update the color map of the Fig.3, 4, 6.

Thank you very much again for your very valuable comments and suggestions.

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Please also note the supplement to this comment:
https://www.atmos-chem-phys-discuss.net/acp-2018-1182/acp-2018-1182-AC2-supplement.pdf

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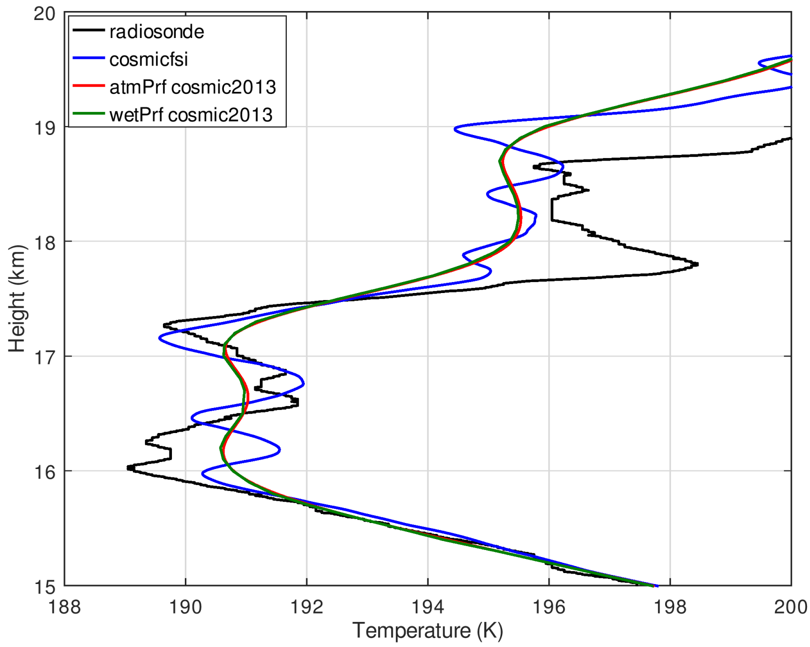

Fig. 1. Comparison of the T profles on December 17, 2011, between the radiosonde at Jakarta Indonesia (black line) and nearby COSMIC GPS-RO by cosmicfsi (blue line), atmPrf cosmic2013 (red line), and werPrf c