Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2018-1182-AC3, 2019

Atmospheric Chemistry and Physics
Discussions
Open Access

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.

Noersomadi Noersomadi et al.

noersomadi@lapan.go.id

Received and published: 25 March 2019

Reply to the comments by the Reviewer #3

This manuscript presents global characteristics of static stability in different vertical coordinate systems and closely investigates its characteristics in the tropical tropopause region. The authors use ten years (2007 to 2016) of GNSS RO data from the COSMIC satellite constellation. Data from an FSI RO retrieval are used. These profiles have a much better vertical resolution than profiles from other RO processing centers. The

Printer-friendly version

Discussion paper

tremendous vertical resolution of this data set is exploited by investigating atmospheric characteristics in detail. Spatial, inter-annual, annual, and intra-interannual variability of tropopause sharpness and the thickness of the tropopause inversion layer (TIL) are discussed. In my opinion, this is an interesting study with important scientific results. To a large extend, the manuscript is clearly and concisely written. Exceptions are some parts of the introduction and data description (see minor comment below). More importantly, I have some doubts regarding the vertical resolution of the data set and the conclusions drawn (see major comment below).

We appreciate the reviewer for providing constructive comments to our manuscript. We show below our responses to the individual comments.

1 General comments

1. The vertical resolution of the data set is specified to be 100 m. However, in some sections of the manuscript (mainly in section 3.3), the authors discuss characteristics with a distinctively better vertical resolution. Middle panels of Fig. 10 and also Fig. 13, e.g., show dH characteristics with a 10 m vertical resolution. I doubt somehow that this appropriate. Similarly, the authors find an uncertainty of the thickness of the TIL of 40 m. It is important to add a discussion and prove that these features can really be retrieved with this data set. See also minor comments on the retrieval and the uncertainty of the vertical grid. The vertical resolution of the dataset (i.e. 100 m) can be regarded as the uncertainty of each data point. Averaging a lot of data points with an uncertainty (100 m) would reduce the uncertainty for the average. In other words, this is similar to the standard error of the mean. The uncertainty of the thickness of TIL (40 m) is statistically reasonable. We used 80% of maxN2 within 1 km above CPT. To find the point where N2 at 80% reaching to and decreasing from maxN2, we applied a linear interpolation between the nearest two points within 100 m (Fig. R1). Therefore, it is reasonable that the random values of dH have the uncertainty of the order 10 m (the colormap legend in Fig.6 middle row range between 0.39−0.48 km). Then, we average dH from many profiles.

Figure R1 The diagram of the algorithm to calculate dH from the N2 profile.

2 Minor comments

âĂć I have difficulties in following the logical structure of some parts of the introduction (section 1) and data description (section 2). More specifically, paragraphs 3, 4, and 5 of section 1 (pages 2 and 3), and several paragraphs of section 2 (i.e., the first paragraph of section 2, 2.1, and 2.2, the last paragraph of section 2.1 (concerning the TIL definition)) should be revised. We have revised the logical structure of the introduction. We refer to the Fig. 2 (right panel) for the clear description in P3 L6-9.

âĂć Add some more detailed discussion about the data retrieval. What input data are used for the FSI retrieval? What is the vertical coordinate of your data set (height above ellipsoid, height above geoid, geopotential height)? What is the uncertainty of the vertical grid? Scherllin-Pirscher et al. (2017, doi:10.1002/2016JD025902) also discuss some of these issues. We used the same retrieval provided by CDAAC/UCAR. We modified the sewing height between FSI and GO retrieval to ∼30 km to obtain better vertical resolution in the UTLS (Tsuda et al., 2011; Noersomadi and Tsuda, 2017). The input data is atmPhs (atmospheric excess phase) provided by CDAAC.

We have mentioned in the manuscript that we used geopotential height (P4 L39). "We adjusted T from GPS-RO in the geometrical height domain to the geopotential height used for radiosonde data before performing the comparison."

We add the following sentence (P4 L23-24): "The discrepancy in the CPT altitude between cosmicfsi and the campaign radiosonde dataset was 70 m (mean) and 100 m (median) (Noersomadi and Tsuda, 2017)."

âĂć Introduce all acronyms at their first occurrence. We follow this suggestion.

âĂć Abstract, line 22: It is not clear at this point what "S-ab anomaly (S-ab?)" and "OLR anomaly" refer to. Please rewrite this sentence.

We define the S-ab and OLR anomaly in the abstract.

Printer-friendly version

Discussion paper

âĂć Introduction, page 2, paragraph 3: At least for a non-expert reader, the first two sentences "The vertical profile of N2 across the tropopause (i.e., the sharpness) and the thickness of the layer of maximum N2 above the tropopause have been determined in previous studies using both ground- and satellite-based observations. For example, Bell and Geller (2008) analyzed the twice daily standard radiosonde data from the WMO stations and found that the thickness was âĹij1 km at low latitudes." are not clear. Does "the thickness" refer to the layer between the tropopause and maximum N2 above the tropopause? Please clarify. We explicitly write as “the thickness of the layer of maximum N2 above the tropopause (i.e., between 80% reaching to and decreasing from maximum N2)”. Also, we refer to the Fig. 2 (left panel) for the clear description (P3 L6-9).

âĂć Introduction, page 2, paragraph 4: the better reference for the COSMIC data set is Anthes et al. (2008, doi:10.1175.BAMS-89-3-313). We follow this suggestion (P3 L16).

âĂć Introduction, page 3, paragraph 2: Add the Noersomadi and Tsuda (2017)- reference. We follow this suggestion (P3 L31).

âĂć Section 2.1, page 3, line 27: As far as I know, COSMIC does not provide 1500 to 2000 profiles anymore. Please clarify. We add the following statement in P4 L10-11: “Nevertheless, the number of profiles is significantly decreasing in 2015 and 2016 (60−100 profiles over 10°S–10°N).”

âĂć Section 2.1 page 4, lines 6/7: I do not understand the explanation "caused by different truncations of the GNSS signals in the lower atmosphere". It is true that the penetration depth is different for each RO measurement. It is also true that the penetration depths of the retrieved profiles can be different for different RO retrievals. However, I do not understand the connection between penetration depth and the number of profiles. Is there a specific quality indicator which reduces the number of profiles for cosmicfsi? Please clarify. We have slightly modified the atmospheric data inversion

Printer-friendly version

Discussion paper

called ROAM provided by CDAAC and do not understand details very much. We believe CDAAC used improved atmospheric data inversion (NEWROAM) as mentioned in their webpage (https://cdaac-www.cosmic.ucar.edu/cdaac/doc/overview.html). One possibility is due to different retrieval algorithm and background extrapolation model for L1 and L2 bending angles. We retrieved cosmicfsi using FSI algorithm, while cosmic2013 were re-processed using Phase Matching algorithm (Sokolovskiy et al., 2014; Zeng et al., 2016; Sokolovskiy, personal discussion, 2017). However, discussion on the differences in the retrieval algorithm between cosmicfsi and cosmic2013 is beyond the scope of the present study.

We add the following sentence in P4 L30-32: “The difference in the total number of occultations in the two retrievals is possibly caused by different algorithm and background extrapolation model for bending angles as reported by Noersomadi and Tsuda (2017). Discussion of difference between retrieval algorithm for cosmicfsi and for cosmic2013 is beyond the scope of this study.”

âĂć Section 2.1, page 4, lines 15/16: "which is located within 115 km horizontal radius": Does this number refer to the mean tangent point location? How is it defined? Did you account for the tangent point drift? Please explain. We refer to the distance between the perigee point (tangent point) and the location of radiosonde launch site. We defined the radius as the distance between radiosonde station and the perigee point. We did not account for the tangent point drift. The cosmicfsi and cosmic2013 data show differences of ±0.4 K and less than 100 m for CPT temperature and CPT height, respectively, within the distance of 200 km and the time difference of ±3 hours (Noersomadi and Tsuda, 2017).

âĂć Section 2.2, page 4, line 36 to page 5, line 5: I recommend referring to the right panel of Fig. 2 for this explanation. Furthermore, the figure should include all parameters introduced in this section. We have referred to Fig. 2 (right panel) in the Introduction for the clear description (P3 L6-9). Definition of all TIL parameters are summarized in Table 2. Since we focus on S-ab and dH in the later discussion, we

Printer-friendly version

Discussion paper

emphasize only these parameters in Fig. 2 (right panel). We are afraid that the figure would be too complicated if we included all the parameters. Thus, we would like to keep it as it is.

âĂć Section 3.1, page 5, lines 33/34: "Figure 3a-d...": This sentence is a general statement, which should be made earlier in this paragraph. This figure has been removed in the revised manuscript as suggested by other reviewer.

âĂć Section 3.1, page 6, line 1: "the LRT should be the same as the lowest CPT" and line 40: "the LRT and CPT are at the same location/height". In the tropics, LRT is usually lower than CPT because LRT refers to a specific temperature gradient and CPT to the temperature minimum. Please clarify. We have shortened the text in Section 3.1 to focus on discussing the mean N2 relative to CPT height in the tropics. Thus, these sentences have been removed.

âĂć Section 3.1, page 6, lines 39 to 42: I do not understand this explanation. Please rewrite. We have modified this paragraph (P6 L27-33) as follows. “The profiles of large N2 over 20°N and 20°S in the MC region represent the vertical section of the Kelvin-wave and mixed Rossby–gravity-wave response known as the Matsuno–Gill pattern mode (Matsuno, 1966; Gill, 1980; Grise et al., 2010; Nishimoto and Shiotani, 2012). The results shown in Fig. 3 uncover the detailed structure of N2 above the CPT in the specific longitude regions, being compared to the results by Grise et al. (2010) who showed the mean N2 over $0-1$ km layer above the LRT. The vertical propagation of equatorial waves (i.e., 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).”

âĂć Section 3.1, page 7, lines 15/16: I do not understand the sentence "The level of increasing temperature can be determined as the LRT height when the WMO definition is attained" as the LRT is not determined by increasing temperatures but only a

Printer-friendly version

Discussion paper

temperature gradient threshold. We have shortened the text in Section 3.1 to focus on discussing the mean N2 relative to CPT height in the tropics. Thus, this sentences was removed.

âĂć Section 3.2, page 7, Figure 9: The class widths of several panels of Fig. 9 seem to be either non-equidistant or floating numbers causing rounding errors. Please use well defined and equidistant classes. We have updated Fig.9 and change the figure number into Fig.5 in the revised manuscript.

âĂć Section 3.2, page 7, lines 28/29: Since Fig. 9 shows that mean S-aCPT is smaller than 6:6 × 10-4 s-2 this statement cannot be true. Please clarify. The mean S-aCPT is 6.4 ×10−4 s−2. We modify the sentence (P7 L12) as follows: The values of S-aCPT are mostly in the range 2.8−6.6 × 10−4 s−2 ...

âĂć Section 3.3, page 8, lines 13/14: "The highest values, up to 16 - 18 × 10-4 s-2, are associated with low OLR values...": In DJF, S-ab is clearly above average (17 - 18 × 10-4 s-2) west of South America, where OLR values are about 260 W/m2, defined as "non-convective" on page 8, lines 33/34. Above the convective regions in South America, however, where OLR values are really low, the S-ab only reaches about 14 × 10-4 s-2. So this statement seems to be wrong for the South American region. Please clarify. We add the following sentences in P7 L41 – P8 L9: “Large S-ab values are found along the equator 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 result in particular over the Western Pacific because using maxN2+1 and minN2–1 instead 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). Large S–ab around the 240°–270°E longitude region in DJF is qualitatively related to OLR values of 220–240 W m–2 representing the inter tropical convergence zone (ITCZ). Large S-ab values of 14–16 × 10−4 s−2 are also found over South Asia and near the ITCZ in JJA. Exception is seen over South America where S-ab only reaches ∼14 × 10−4 s−2 associated with OLR values < 220 W m–2."

âĂć Section 3.4, page 9, line 22: How big are the cross-correlations between S-ab and OLR at different lags? We add the following sentence in P9 L13-15. "We have tested for different lags. The cross-correlation between S-ab and OLR become smaller for two month lag (−0.49 and −0.57 over MC and PO regions, respectively)."

3 Figures

We have updated the figures following all the suggestions below by the reviewer, including color map updates, grid line additions, and legend revisions. Note there are also some other comments above.

âĂć I recommend adding a background grid in Figs. 1, 2, 11, 12, 13, 14, 16, 18 âĂć Please also add minor ticks on x-axis of Figs. 11, 14, right panel of Fig. 18, and on y-axis of Figs. 12, 13, 16

âĂć I recommend adding "MC" and "PO" next to the longitudinal information in the figure titles of Figs. 3, 5, 6, 7, 14, 15, 16.

âĂć Please indicate MC, PO, Atlantic, and Indian Ocean in Figs. 4, 7, and 8 (e.g., arrows below the x-axis).

âĂć Indicate MC and PO in the figure legends of Figs. 12, 13 (could be one two panel figure) and also in the right panel of Fig. 16.

âĂć I suggest indicating the LRT and CPT for all data sets in Fig. 1

âĂć Indicate El Nino events 2009/2010 and 2015/2016 in both panels of Figs. 14 and 15.

4 Editorial We have edited following all the suggestions below by the reviewer.

âĂć Page 1, line 15: "in the range" ! "in the range of"

âĂć Page 3, line 8: "Centre" ! "Center"

âĂć Page 3, line 17: "cosmic2013 only" ! "cosmic2013 data only"

âĂć Page 4, line 5: "within a 183-day period" ! "within the 183-day period in 2011/2012".

âĂć Page 4, line 16: According to Table 1, Surabaya station is located at 112.78âŮęE, 7.37âŮęS. Please clarify.

âĂć Page 4, line 18: "less than 30 min": This is only true for the UTLS.

âĂć Page 4, line 21: "within a 183-day period" ! "within the 183-day period".

âĂć Page 6, line 4: "height-longitude" ! "longitude-height"

âĂć Page 6, line 10: "height-latitude" ! "latitude-height"

âĂć Page 6, line 30: "Fig. 6b" ! "Fig. 6c"

âĂć Page 7, line 4: "height-longitude" ! "longitude-height"

âĂć Page 7, line 19: "than in JJA." ! "than in JJA (Fig. 8)".

âĂć Page 7, line 27: "entire latitude range" ! "entire region from"

âĂć Page 10, line 27: "15 April 2012" might be "13 April 2012" Fig. 12 (right panel) does show the data until 15 April 2012.

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

References: Birner, T., Dörnbrack, A., and Schumann, U.: How sharp is the tropopause at midlatitudes?, Geophys. Res. Lett., 29, 1700, doi:10.1029/2002GL015142, 2002. Birner, T.: Fine-scale structure of the extratropical tropopause region, J. Geophys. Res., 111, D04104, doi:10.1029/2005JD006301, 2006. Gettelman, A., and Wang, T.: Structural diagnostics of the tropopause inversion layer and its evolution, J. Geophys. Res., 120, 46–62, doi:10.1002/2014JD021846, 2015. Gill, A. E.: Some simple solutions for heat-induced tropical circulation, Q. J. Roy. Meteorol. Soc., 106, 447–462, 1980. Grise, K. M., Thompson, D. W. J., and Birner, T.: A global survey of static stability in the stratosphere and upper troposphere, J. Clim., 23, 2275–2292, doi:10.1175/2009JCLI3369.1, 2010. Kedzierski, R. P., Matthes, K. and Bumke, K.: The tropical tropopause inversion layer: Variability and modulation by equatorial waves, Atmos. Chem. Phys., 16, 11617–11633, doi:10.5194/acp-16-11617-2016, 2016. Kim, J.-E., and Alexander, M. J.: Direct impacts of waves on tropical cold point tropopause temperature, Geophys. Res. Lett., 42, 1584–1592, doi:10.1002/2014GL062737, 2015. Kim, J. and Son, S. -W.: Tropical cold-point tropopause: Climatology, seasonal cycle, and intraseasonal variability derived from COSMIC GPS radio occultation measurements, J. Clim., 25, 5343–5360, doi:10.1175/JCLI-D-11-00554.1, 2012. Matsuno, T. : Quasi-geostrophic motions in the equatorial area, J. Meteorol. Soc. Jpn., 44, 25–42, 1966. Noersomadi and Tsuda, T.: Comparison of three retrievals of COSMIC GPS radio occultation results in the tropical upper troposphere and lower stratosphere, Earth Planets Space., 69, doi:10.1186/s40623-017-0710-7, 2017. Randel, W. J., & Wu, F.: Kelvin wave variability near the equatorial tropopause observed in GPS radio occultation measurements, Journal of Geophysical Research, 110, D03102. https://doi.org/10.1029/2004JD005006, 2005. Sokolovskiy, S., Schreiner, W., Zeng, Z., Hunt, D., Kuo, Y. -H, Meehan, T. K., Stecheson, T.W., Manucci, A.J., Ao, C.O.: Use of the L2C signal for inversions of GPS radio occultation data in the neutral atmosphere, GPS Solut, 18, 404−416, doi:10.1007/s10291-013-0340-x, 2014. Tsuda, T., Murayama, Y., Wiryosumarto, H., Harijono, S. W. B., and Kato, S.: Radiosonde observations of equatorial atmosphere dynamics over Indonesia: 1. Equatorial waves and diurnal tides, J. Geophys. Res., 99, 10491–10505, doi:10.1029/94JD00355, 1994. Tsuda, T., Lin, X., Hayashi, H., and Noersomadi: Analysis of vertical wave number spectrum of atmospheric gravity waves in the stratosphere using COSMIC GPS radio occultation data, Atmos. Meas. Tech., 4, doi:10.5194/amt-4-1627-2011, 2011. Zeng, Z., Sokolovskiy, S., Schreiner, W., Hunt, D., Lin, J. and Kuo, Y. H.: Ionospheric correction of GPS radio occultation data in the troposphere, Atmos. Meas. Tech., 9,

Printer-friendly version

Discussion paper

335–346, doi:10.5194/amt-9-335-2016, 2016.

Please also note the supplement to this comment:
https://www.atmos-chem-phys-discuss.net/acp-2018-1182/acp-2018-1182-AC3-supplement.pdf

---

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018-1182, 2018.

Printer-friendly version

Discussion paper

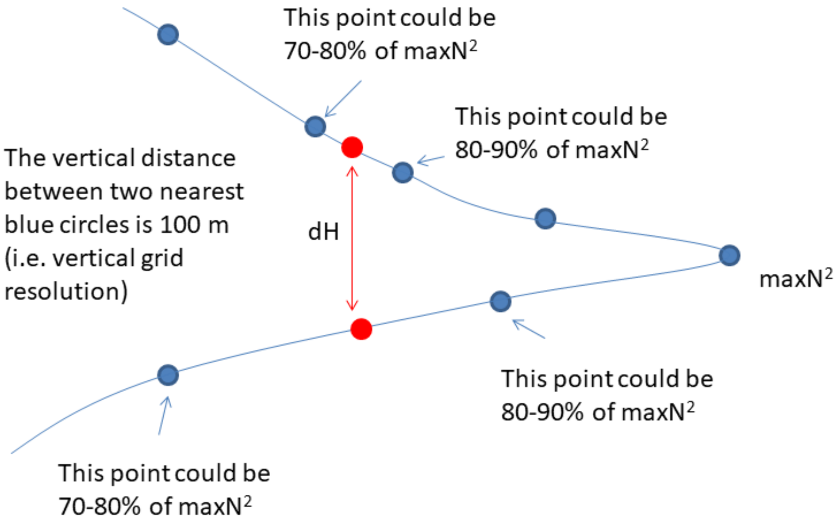

Fig. 1. The diagram of the algorithm to calculate dH from the N2 profile.