Interactive comment on "High-resolution Beijing MST radar detection of tropopause structure and variability over Xianghe (39.75° N, 116.96° E), China" by Feilong Chen et al.

Anonymous Referee #2

Received and published: 18 March 2019

In this study, the authors demonstrated the potential of MST radar in detecting the tropopause height (RT) from the radar backscattered echo power profiles by carrying out extensive comparison with the lapse rate tropopause (LRT) derived from radiosonde data and with dynamical tropopause (2 PVU) derived from ERA-Interim re-analysis dataset during the period Nov. 2011 to May 2017 covering all seasons. Com-parison results showed good agreement between Radar and radiosonde and that be-tween radar and ERA data in most of the seasons. The RT determination and comparison with other observations has been already carried out by many other investigators. However, a systematic comparison has been carried out in this paper and the differ-ence in tropopause height is attributed to the sharpness of the tropopause inversion layer (weak / strong). The potential of radar in examining the short-term variability of tropopause useful for wave studies etc and its limitation in detecting tropopause in few occasions are also discussed. In general, the paper is well written and the results are interesting. However, a few concerns need to be addressed, before the manuscript is published.

Response:

Dear reviewer, we really thank you for the helpful and constructive comments, which will be of great useful for this article. We hope that the reviewers will be satisfied with our responses and revisions. Our responses are in different color style (reviewer's comments are shown in black and our response in blue type).

1) RT is determined using the vertical beam echo power data collected in "low mode" operation (which receives strong signal up to 14-15 km). In "middle mode", strong signals can be obtained in the altitude region 7-25 km (as seen in Fig.8). Also, the "first tropopause" and "second tropopause" (based on WMO definition of LRT) are clearly evident in the mean effective data acquisition data obtained from middle mode operation (Fig.8). I strongly believe, that if "middle mode" vertical beam data is used, the strong gradients in radar echo power could be discernible corresponding to the altitudes of first and second tropopause. The authors can examine this aspect for available dataset in middle mode observations and compare with the first and second tropopause derived from radiosonde data.

Response:

Yes, you are right. Really thanks for your valuable comments. It is necessary to explain here the concerns about the radar tropopause detection using middle mode data.

Firstly, the middle mode data is not appropriate to be used to detect the clear tropopause structure (both the first or the second tropopause). Figure R1 (shown below) shows the middle mode observation results of the altitude-time intensity plot of radar backscattered echo power on February 2014. The month is the same as that in Figure 3 of the manuscript. Indeed, the first tropopause structure can be seen with middle mode observations, but the boundary is unsharpness and too coarse to identify the clear tropopause height, at least (especially) compared to the Figure 3 in the manuscript. In addition, also is the most important feature, the second tropopause is barely detected by middle mode results. The limited altitude resolution (600 m) and the limited radar transmitted power are likely the main causes.

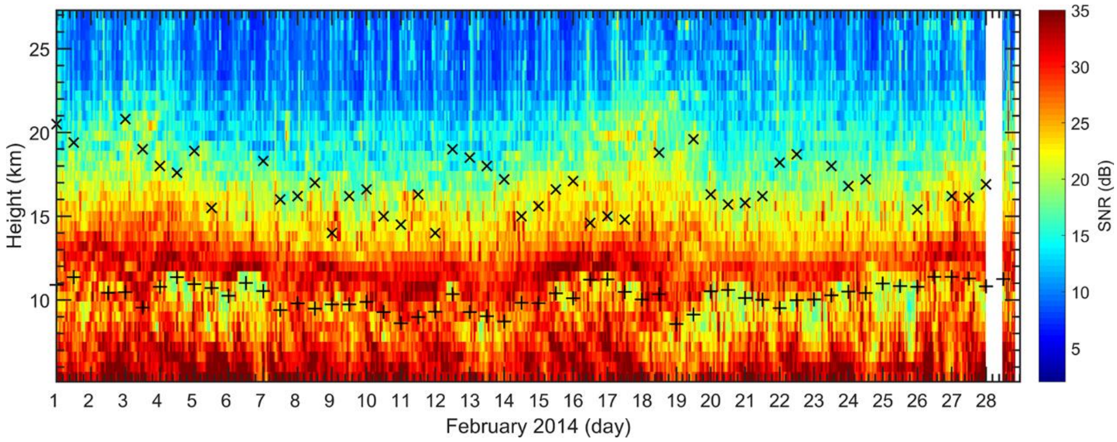

Figure R1. Middle mode observation results: Altitude-time intensity plot of radar backscattered echo power for February 2014. '+' indicates the first tropopause; and 'x' denotes the higher second tropopause derived from radiosonde data.

Secondly, why the "first tropopause" and "second tropopause" appeared to be clear in the mean effective data acquisition rate (profile) obtained from middle mode operation (Fig.8)? We believe that this is largely because the data acquisition rate is the statistical result of five-year dataset, even if the height resolution is relatively low (600 m), the 5-year statistics are enough to amplify the impact of changes in atmospheric states (such as the static stability) around the transition region (between the troposphere and the stratosphere) on the data acquisition rate.

Finally, some responses regarding to the second tropopause:
Considering that the mechanism of the formation of second tropopause (Pan et al., 2004; Randel et al., 2007; Pan et al., 2009), the inversion height of ~16km (or higher) over the radar station is the second tropopause with tropical characteristics. Anyhow, no matter whether the inversion layer at ~16 km is the first tropopause or the second tropopause, such tropical featured higher tropopause will not be considered and studied here by both the RT definition and LRT definition. Indeed, the routine presented higher tropopause (second tropopause near 16km) in different seasons throughout the year is

worthwhile for studying. However, due the relatively poor altitude resolution for middle mode data, it is not appropriate to be used to detect high resolution tropopause structure over Beijing MST radar station, especially for the statistical study. The case observation of the second tropopause near 16 km (or higher) using the middle mode data is worthy of future study.

Therefore, we explain in many places that this study only focuses on the first tropopause below 16km, no matter whether it exists or not. For example, one sentence has been modified in the introduction section of the revised manuscript: 'In the present study, we focus only on the first tropopause (below 16 km) which will be referred to as 'tropopause' hereafter'.

Pan, L. L., Randel, W. J., Gary, B. L., Mahoney, M. J., and Hintsa, E. J.: Definitions and sharpness of the extratropical tropopause: A trace gas perspective. Journal of Geophysical Research, 109, D23103, doi:10.1029/2004JD004982, 2004.

Pan, L. L., W. J. Randel, J. C. Gille, W. D. Hall, B. Nardi, S. Massie, V. Yudin, R. Khosravi, P. Konopka, and D. Tarasick: Tropospheric intrusions associated with the secondary tropopause, Journal of Geophysical Research, 114, D10302, 2009.

Randel, W. J., Seidel, D. J., and Pan, L. L.: Observational characteristics of double tropopauses. Journal of Geophysical Research, 112, D07309, 2007.

2) Radar provides a vertical resolution of 150 m in "low mode" and 600 m in "middle mode" and "1200 m" in "high mode" and the temporal resolution is about 30 minutes. In the present study, RT derived from the vertical beam data in low mode is compared with the dynamical tropopause (2PVU) derived from potential vorticity obtained from ERA-interim reanalysis The comparison results shows large deviation between the two. Fine resolution radar data is compared with the coarse resolution ERA dataset. What is sanctity in comparing these two datasets.

Response:

Dear reviewer, really thanks for your comments. The difference in height resolution between radar and reanalysis data is unlikely to be one reason for the large difference between RT and PVT. There are also differences in resolution between radar and radiosonde data. At least, the difference in height resolution is not the main point. The interesting features from the comparison results between RT and PVT are that: the RTs agree reasonably well with the PVTs with the correlation coefficient of 0.72 and 0.76 respectively, during winter and spring (Fig. 6a and 6b). In contrast, the consistency for summer (Fig. 6c) is relatively bad and with correlation coefficient of only 0.33.

Whereas, in contrast, previous research about the RT and PVT results over polar regions by Alexander et al., (2013) reported that the comparison between the RT and PVT showed the similar good agreement during both summer and winter.

The possible causes of the larger offsets during summer (Fig 6c) is discussed in the revised manuscript. Following sentences in the revised manuscript (discussion section) have been added: ‘The existing cyclones or anticyclones in the upper-troposphere (Wirth, 2000), of course, may also be an important cause of the significant asymmetric differences (most of the scattered points deviate significantly from the 1:1 line). This asymmetric differences, that is most of the RT are located higher than the 2PVU tropopause height, suggest that the 2PVU surface is not the best measure of a dynamical tropopause over Beijing during summer-time.’.

Alexander, S.P., Murphy, D.J., and Klekociuk, A.R.: High resolution VHF radar measurements of tropopause structure and variability at Davis, Antarctica (69◦ S, 78◦ E), Atmos. Chem. Phys., 13, 3121-3132, 2013.

Specific/Minor comments

Line 28 : replace "good capability of Beijing MST radar" with "potential of Beijing MST radar "

Response:

Really thanks for pointing out the flaw. The corresponding sentence has been replaced.

Lines 108, 246, Fig. 8: Is this the "data acquisition rate" of backscattered echo power received?. Effective data acquisition rate for different modes of radar operation are shown? How is this parameter estimated. Give details.

Response:

Really thanks for your comments. Data acquisition rate indicates the effective wind data. It has been corrected in the 3.3 section and the figure caption in the revised paper.

Lines 165-168: The method of identifying dynamical tropopause from potential vorticity is to be added. ERA-interim reanalysis data does not have fine vertical resolution. But the dynamical tropopause determined from the above is compared with RT derived from higher vertical resolution radar backscattered echo power. Hence, the larger difference in tropopause height is expected between the two methods.

Response:

Dear reviewer, the difference in height resolution between radar and reanalysis data is unlikely to be one key reason for the large difference between RT and PVT. There are also differences in resolution between radar and radiosonde data. At least, the difference in height resolution is not the main point. The possible causes of the larger offsets during summer (Fig 6c) is discussed in the revised manuscript:

‘The existing cyclones or anticyclones in the upper-troposphere (Wirth, 2000), of course, may also be an important cause of the significant asymmetric differences (most of the scattered points deviate significantly from the 1:1 line). This asymmetric differences, that is most of the RT are located higher than the 2PVU tropopause height, suggest that the 2PVU surface is not the best measure of a dynamical tropopause over Beijing during summer-time.’.

Line 181: delete "fine-scale"

Response:

Really thanks for pointing out the flaw. It has been corrected in the revised manuscript.

Line 190-191: ".......the RT is well defined as the first layer with enhanced echo power..."

Response:

It has been corrected in the revised manuscript.

Line 209: replace "good capability" with "potential"

Response:

It has been corrected in the revised manuscript.

Line 217: "sharpness of tropopause" is affected by cyclonic /anticyclonic systems. Explain. Are radar measurements carried out during such systems. please clarify.

Response:

Dear reviewer, we didn’t demonstrat that the sharpness of tropopause is affected by cyclonic /anticyclonic systems. The results form Figure 5 indicate that the larger (weaker) tropopause sharpness contribute to lower (higher) difference between the RT and LRT.

Line 237, 246: what is "effective data acquisition rate?: Middle mode observation in Figure 8 shows two distinct peaks corresponding to the mean of first and second tropopauses based on LRT definition by WMO. Then why the data obtained from this mode (middle mode) is not used for the extensive comparison of first and second tropopause derived from radiosonde dataset, which is not so far studied extensively.

Response:

Really thanks for your comments. Data acquisition rate indicates the effective wind data. It has been corrected in the 3.3 section and the figure caption in the revised paper. Firstly, no matter whether the inversion layer at ~16 km is the first tropopause or the second tropopause, such tropical featured higher tropopause will not be considered and studied here by both the RT definition and LRT definition. Secondly, the middle mode data is not appropriate to be used to detect the clear tropopause structure (both the first or the second tropopause, please see Figure R1 above). Detailed responses about the issue of second tropopause are given above.

Lines 247-249: Correct this sentence (message not clear).

Response:

Really thanks for your comments. It has been corrected in the revised manuscript.

Line 272: "....radar-derived winds are combined...." what does it mean?

Response:

Really thanks for pointing out the flaw. The corresponding sentence has been corrected in the revised manuscript and modified to 'With the absence of temperature measurements, zonal and meridional winds are applied to demonstrate the evidence of diurnal or semidiurnal modulation by tidal'.

Line 289-290: correct the sentence

Response:

Really thanks for pointing out the flaw. The corresponding sentence has been corrected in the revised manuscript.

Line 293-294: what are the system problems that makes RT identification difficult?

Response:

The corresponding sentence has been cahgned to 'Apart from the system problems (e.g. the damage of T/R module)' in the revised manuscript.

Lines: 297-298: correct the sentence

Response:

It has been corrected in the revised manuscript.

Line 300: In this case, the temperature inversion is observed at 16 km...

Response:

Detailed responses about the issue of second tropopause are given above. In order to avoid the potential misguidance and to fit in with the main research focus of this paper, we have indicated in many places that the research focus of this paper is the first tropopause below 16km (as long as it exists).

For example, one sentence has been modified in the introduction section of the revised manuscript: 'In the present study, we focus only on the first tropopause (below 16 km) which will be referred to as 'tropopause' hereafter'.

In addition, the figure 12 and the figure caption have also been modified accordingly:

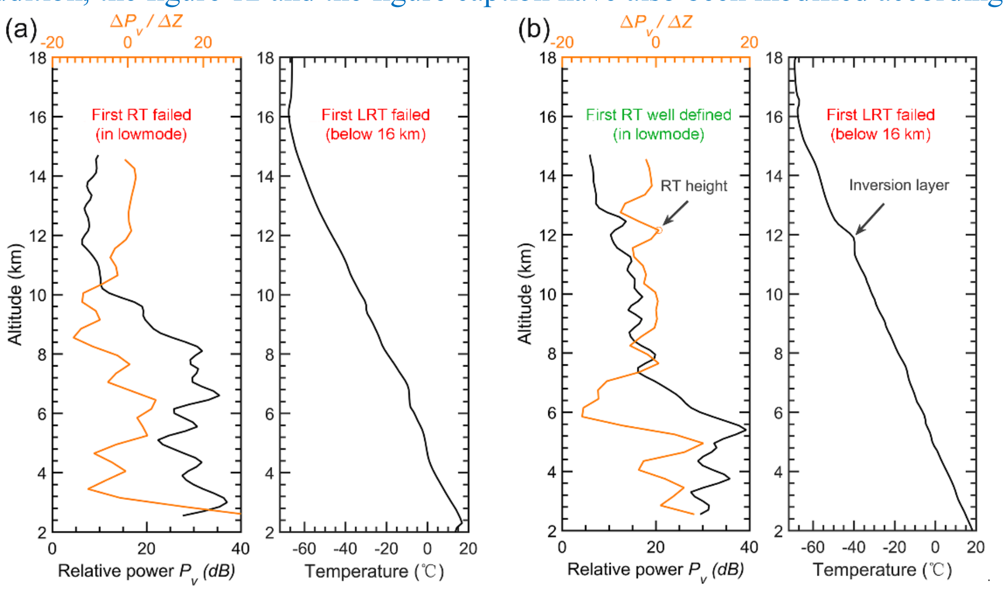

Figure 12. Example profiles of radar echo power and radiosonde temperature that (a) both the RT and LRT definitions fail due to the continuing decrease in temperature on 00 UTC 7 July 2012 and (b) the temperature inversion layer failed to meet the LRT definition but well defined in RT definition on 12 UTC 02 August 2012. Please note that we only consider the conditions below 16 km.

Line 307-308: Correct this sentence....

Response:

Really thanks for pointing out the flaw. The corresponding sentence has been corrected

Line 311: ..difficult in identifying the thermal tropopause from radiosonde profiles ..

Response:

Really thanks for your comments. It has been corrected in the revised manuscript.

Line 313: ...altitude extent of inversion layer is too thin to meet the WMO criterion...

Response:

Really thanks. It has been corrected in the revised manuscript.

Line 316: delete "Need to highlight again that"

Response:

Really thanks. It has been deleted in the revised manuscript.

Line 324: inconsistency between the RT and PVT

Response:

Really thanks. It has been corrected in the revised manuscript.

Line 326-327: Confirm whether radar measurements are carried out during cyclones/anticyclones in the upper troposphere (which period/season). Is the asymmetric differences in tropopause heights mainly due to the above conditions or due to difference in vertical resolution of radar and ERA dataset.

Response:

Dear reviewer, the difference in height resolution between radar and reanalysis data is unlikely to be one key reason for the large difference between RT and PVT. There are also differences in resolution between radar and radiosonde data. At least, the difference in height resolution is not the main point. Because the differences during spring and winter is not so bad as that during summer. The possible causes of the asymmetric differences during summer (Fig 6c) is discussed in the revised manuscript:

'The existing cyclones or anticyclones in the upper-troposphere (Wirth, 2000), of course, may also be an important cause of the significant asymmetric differences (most of the scattered points deviate significantly from the 1:1 line). This asymmetric differences, that is most of the RT are located higher than the 2PVU tropopause height, suggest that the 2PVU surface is not the best measure of a dynamical tropopause over Beijing during summer-time.'.

Wirth, V.: Thermal versus dynamical tropopause in upper-tropospheric balanced flow anomalies. Quarterly Journal of the Royal Meteorological Society, 126(562), 299-317, 2000.

Thank you again for your help with improving the paper.

Best regards