Response to reviewer 1

We are very grateful for the review work of the Reviewer #1 who has provided constructive comments.

We have examined all the comments and suggestions made carefully and relevant revisions have been made accordingly. The following are our responses and further explanations item-by-item:

(1) Although many latest studies [2][3][4] used a linear function to describe the vertical variation of Tm, a nonlinear function has already been used by Yao et al. 2018[1]. Thus, it is not the first attempt using a nonlinear function. Although this reference is included in the reference list, I cannot see any further discussions with their study. Their work has a very significant correlation with your study.

We agree with the comments made. This research is concentrated on developing a blind model that considering the nonlinear variation of Tm in the vertical direction and is independent of any other data sources. The nonlinear variation trend was found by Yao et al. (2018) and a nonlinear function integrating the linear function and the trigonometric function was proposed. However, a reference Tm at a specific height (Tm_0, h_0) that can be obtained from atmospheric profiles or other empirical models, is required as the input of the proposed model, which means that Tm cannot be determined by the model independently. Thus, it is not compared with our new model in the manuscript. Only three state of the art open-access blind models that can provide Tm directly were utilized in this research.

(2) It is good to compare GGNTm with GTrop and GWMT_D, since GTrop and GWMT_D stand for the state-of-the-art blind Tm models. However, results of GPT3 are redundant and even meaningless. In fact, GPT3-Tm is GPT2w-Tm and many studies [1][2][3][4] have clearly pointed out the defect of GPT2w-Tm and the accuracy of GPT2w-Tm has been discussed for several times. I think just a few sentences can describe the defect of GPT3-Tm (GPT2w-Tm) and citing results of GPT2w-Tm in other references (e.g. reference [4]) is enough.

We thank the reviewer for the comments about the inclusion of GPT3 in the comparison. We mostly agree with the reviewer to reduce the length of the discussion. Relevant revisions have been made to condense this part of the description (according to the reviewer's suggestions).

(3) I`m very curious that if the height of the GNSS user site is lower than the height of the grid points, will unpredictable results be produced.

Our new model is expressed as:

$$Tm = a + bH + cH^2 + dH^3$$

The first coefficient, a, is the empirical Tm value at the sea level at the grid point. Thus, the height of the grid point is set to zero, this means that the heights of most user sites are greater than the grid points. A radiosonde station that is located below the sea level ("Atyran" station, No. 35700) was also taken as the reference data for the evaluation of

the new model, and no obvious underperformance results were found (from GGNTm).

(4) The geopotential heights cannot be converted directly to the ellipsoidal heights.

Thanks for pointing this out. Yes, this is right. Although the geopotential heights cannot be converted to the ellipsoidal heights directly, an approximate conversion was conducted in this research. The equations given by Nafisi et.al. (2012) and Yilmaz (2008) were used for the conversion.

In addition, relevant revisions have been made in the revision in response to other technical corrections mentioned by the reviewer.

Finally, the reviewer is thanked again the careful review work and the constructive suggestions made.

Reference:

Landskron, D. and Böhm, J.: VMF3/GPT3: refined discrete and empirical troposphere mapping functions, J. Geod., 92(4), 349–360, doi:10.1007/s00190-017-1066-2, 2018.

Nafisi, V., Urquhart, L., Santos, M. C., Nievinski, F. G., Bohm, J., Wijaya, D. D., Schuh, H., Ardalan, A. A., Hobiger, T., Ichikawa, R., Zus, F., Wickert, J. and Gegout, P.: Comparison of Ray-Tracing Packages for Troposphere Delays, IEEE Trans. Geosci. Remote Sens., 50(2), 469–481, doi:10.1109/TGRS.2011.2160952, 2012.

Yao, Y., Sun, Z., Xu, C., Xu, X. and Kong, J.: Extending a model for water vapor sounding by ground-based GNSS in the vertical direction, J. Atmospheric Sol.-Terr. Phys., 179, 358–366, doi:10.1016/j.jastp.2018.08.016, 2018.

Yilmaz, N.: Comparison of different height systems, Geo-Spat. Inf. Sci., 11(3), 209–214, doi:10.1007/s11806-008-0074-z, 2008.