Responses to Referee #1

We thank the referee #1 for the insightful comments and constructive suggestions. We have addressed all their comments in the revised manuscript. Below are our responses to the referee's critical comments (*Italics*). The page and line numbers in our responses refer to those in the revised manuscript.

1. In reviewers opinion, the reader does not get clear insight into current state of tropospheric modeling after reading the introduction. In addition, the context could contain the view of the empiric models and their quality in broader scope of model types that are commonly used in space geodetic techniques. The title suggests that the scope concerns empiric modeling, however, It could be clearly stated in the text (abstract or introduction).

Authors: To make the introduction more clearly, we rewrote this part to clarify the tropospheric models into 4 types: 1. Ray tracing 2. Single layer parameterization 3. Surface observation parameterization 4. Empirical and climatological model. The proposed model HZWD belongs to the fourth type. In addition, we added the description of the qualities of the empirical models. (Page 2, Line 48 to Page 3, Line 77)

2. The contents would benefit of clear statement, analysis, whether using meteorological parameters is not as efficient as using set of ZWD and coefficients for height correction.

Authors: GPT2w model is the representative empirical model using meteorological parameters. In this paper, we have compared the proposed HZWD model with GPT2w model. We added the comparison about data size of the model parameters for these two models. (Page 13, Lines 251-255) Combining with the precision validations, the HZWD model is more efficient than the GPT2w model using meteorological parameters. (Page 25, Lines 502-503)

3. The manuscript should contain the discussion on the data size that the model consist of with comparison to other models. (P11.220)

Authors: We added the discussion about data size of the model parameters. (Page 13, Lines 251-255)

4. The ZWD as well as its typical modeling error decreases with height reaching small values for top layers. In addition, The variation there is small, which was also shown in the contents (truncating of semi-annual terms for middle and top layers, page 10). The contents would benefit of some reasoning if the improvement is significant facing the above against application in space geodetic techniques that are mentioned in the contents as possible applications (wide area augmentation systems, real-time aircraft navigation and positioning).

Authors: In the application of space geodetic techniques (wide area augmentation systems, real-time aircraft navigation and positioning), the zenith delay errors directly relate to the errors in the height estimates in positioning (Böhm and Schuh, 2013). For instance, at the height above 5 km, the improvement of HZWD model over GPT2W model is about 2 mm, which will result in about 4 mm improvement of height estimates in the above applications. This magnitude of the improvement is quite significant for positioning. We added the corresponding discussions in the paper. (Page 15, Lines 316-318; Page 20, Line 416 to Page 21, Line 418)

P2.56 Citation needed here

Authors: We added a reference to Leandro (2006). (Page 3, Line 68)

P3.61 The reader gets confused if using meteo data or ZWD directly influences the precision of the resulting model.

Authors: The TropGrid model expresses ZWD as a function of water vapor pressure and weighted mean temperature, which involves two variable quantities with individual uncertainties. In TropGrid2, ZWD is directly modeled as an empirical exponential expression with only one parameter, which reduce the uncertainties. To avoid the confusion, we rewrote this sentence as "The improved TropGrid2 model (Schüler, 2014) enhances the efficiency of ZWD calculation by directly modelling ZWD with the exponential function". (Page 3, Lines 70-72)

P3.73-75 Does the quality of the models mentioned here brings any positioning deterioration when comparing to quality of the proposed model?

Authors: According to the Böhm and Schuh (2013), the zenith delay error will result in two times errors in the station height estimates in positioning (Newly added sentence: Page 3, Line 87 to Page 4, Line 88). The commonly used empirical models such as UNB3m and GPT2w has a limitation in ZWD estimation at high heights due to the simple approximations of ZWD vertical variation. The HZWD model has the best accuracy of ZWD estimation especially at high heights, which will improve the positioning precision.

P4.90-93 Is the model proposed in the manuscript in fact comprises of the profiles of coefficients and ZWD. Is it more difficult to attach the profiles of meteo parameters and calculate the ZWD in the model procedure? The reasoning here is not convincing.

Authors: HZWD is an empirical climatological model using piecewise functions to directly describe the ZWD vertical variations in different height intervals. We rewrote the sentences as "With the profiles of water vapour pressure and temperature, one can obtain the accurate ZWD by ray tracing method. However, in practical applications (such as aircraft navigation and positioning and wide area augmentation), we usually uses empirical models for ZWD corrections due to the unavailability of meteorological data profiles. Therefore, it is necessary to develop an empirical ZWD model with high precision". (Page 4, Lines 104-109)

P5.125-127 and P6.152 If the conclusion is that the change is linear, why the model uses quadratic function below 2km?

Authors: Figure 2a shows the changes of **ZWD vertical gradients** with respect to the height and Figure 2b gives the linear fitting of ZWD gradients below 2 km. The linear ZWD vertical gradient is the derivative of ZWD along vertical direction (i.e., $\frac{\partial ZWD}{\partial h}$), thus the ZWD could be characterized using quadratic function. We added a description about the ZWD vertical gradients. (Page 5, Lines 137-139)

P9.187 Figure 5 could be more informative if fitting curves with annual term were added in context of p10.198-203

Authors: The fitting curves of the figure 5 are (w=2π/365.25, x=doy):

z_1=0.2911+0.0237*cos(w*x)+0.0312*sin (w*x)- 0.0006*cos(2w*x)-0.0227*sin (2w*x)
z_2=0.1215+0.0118*cos(w*x)+0.0203*sin (w*x)+ 0.0004*cos(2w*x)-0.0146*sin (2w*x)
z_3=0.0255+0.0031*cos(w*x)+0.0070*sin (w*x)- 0.0019*cos(2w*x)-0.0044*sin (2 w*x)
We added the interpretation in the context as you suggested as "The fittings show that the annual means, and annual, and semi-annual amplitudes of z_1, z_2 and z_3 are distinct. For instance, the cycle fitting results at a grid (0 °N, 0 °E) (Figure 5) indicate that the temporal parameters (i.e., A_0, A_1, B_1, A_2, and B_2) of z_1 are 0.2911 m, 0.0237 m, 0.0312 m, -0.0006 m, and -0.0227 m, respectively; the temporal parameters of z_2 are 0.1215 m, 0.0118 m, 0.0203 m, 0.0004 m, and -0.0146 m, respectively; the temporal parameters of z_3 are 0.0255 m, 0.00031 m, 0.0070 m, -0.0019 m, and -0.0044 m, respectively." (Page 11, Lines 217-223)

P11.220 The statement here should be extended with comparison to other empiric models
Authors: See previous response. We added the comparison. (Page 13, Lines 251-255)

P4. 107 It is not necessary to repeat the description of the symbols that are already described at the same page
Authors: We deleted the repeatable description of the symbols *e* and *T*.

P18.367 precusion -> precision
Authors: Done. (Page 20, Line 413)

P14.296-298 The sentence here is not necessary as bias and RMS are already described at P12.237-238.
Authors: We deleted this sentence from the paper. (Page 16, Line 343)