Dear associate editor and referees，

Thank you for your careful reviews. Followings are our responses to your comments.

Responses to Associate Editor

Dear Associate Editor,

Thank you very much for your positive comments.

We have revised our manuscript carefully. Many sentences are rewrote and many errors are revised. The missing white spaces have been added throughout the manuscript.

We address all the error sources of GPS-PWV in line 289~325. And the calculation of ZHD is discussed in particular (line 313~325). After these discussions and experiments, we point out that the GPS-PWV's error reduction due to the more precise T_m estimation can be very limited. When the σ_{P_s} is larger than 5 hPa, most of the pQ values are smaller than 10 % while the error associated with the calculation of ZHD can contribute more than 80 % of the GPS-PWV's error."

Responses to anonymous referee #3

General comments

We have revised the language of our manuscript carefully. Many sentences are rewrote and many errors are revised. We actually employed the 1 by 1 degree resolution GPT2w model for the comparisons in our manuscript and we mentioned this in line 225.

Detailed comments
1. Remove the paragraph in lines 53 to 55, including equation 5. You do a better error budget on page 20.
Response: Thank you for suggestions. We delete the corresponding paragraph.

2. Lines 68 to 71 contain a statement about Tm models not including current observations not being accurate enough. You must either give references or own examples to substantiate the statement. Otherwise remove it. (It is not a question whether your own model is better, but whether there are examples models like the GPT2w model should not be used in near real-time GNSS meterology.)
Response: We actually studied the performance of the GPT2w model in a typhoon case. Details can be found in our previous study (Jiang et al., 2016). We add this reference to our manuscript. (Line 67)

3. Line 72. Your text says Tm it is related to several surface parameters, according to several studies. It would be good to mention at least one in addition to Ts. If you do not know another surface parameter to which Tm is strongly coupled, rephrase the sentence.

Response: The surface air humidity is claimed to be related to Tm by some papers (e.g. Yao et al., 2014). However the relationship is weak. We mention this in line 69~72.

4. Line 74. Don't use "x" as a sign for multiplication in a formula, just write 0.72 Ts + 70.2 [K].

Response: Revisions have been made throughout the manuscript.

5. Line 89 Why "4 degrees x 5degrees", not "4 degrees x 5 degrees"? (found several places in the manuscript)

Response: These missing white spaces have been added throughout the manuscript.

6. Table 1. Include GPT2w in this table, to provide a comprehensive overview of the resolution of the different models, the information upon which they are based, etc.

Response: Detail information have been added in table (1). (Line 95)

7. Line 157 The full sentence doesn't read well.

Response: We rewrite this sentence to "Unreliable regression analysis results may be derived if the Ts and Tm data both have small variations". (Line 155)

8. Line 175. Maybe the spatial variations are "large" rather than "complicated"?

Response: Revision has been made. (Line 174)

9. Line 190. I guess you mean better than previous "models" not "studies"?

Response: Revision has been made. (Line 189)

10. Equation 7. Again the "x" is not necessary. Similarly the dots for multiplication inside the sines and cosines are not necessary.

Response: Revision has been made.

$$T_m = aT_s + b + m_1 \cos\left(\frac{doy}{365.25} 2\pi\right) + m_2 \sin\left(\frac{doy}{365.25} 2\pi\right) + n_1 \cos\left(\frac{doy}{365.25} 4\pi\right) +$$
$$n_2 \sin\left(\frac{doy}{365.25} 4\pi\right) + p_1 \cos\left(\frac{hr}{12}\pi\right) + p_2 \sin\left(\frac{hr}{12}\pi\right)$$

11. Line 224. You probably mean "In addition,..", not "In contrast,.."

Response: Revision has been made. (Line 223)

12. Figure 6. Make a test if using 2 K as minimum value of the color scale for RMSE reveals better the variations in RMSE between the different models (and regions).

Response: Thank you for your suggestions. We replot the figures in figure 6 according to your advices. (Line 257-260)

13. Line 269. I think you mean to "find" or "identify" the best Tm model, not to verify it. You verify or validate all the Tm models, afterwards you find or identify the best, at the location of each RS.

Response: Revision has been made. (Line 271, 282, and 421)

14. line 304. pQ is measured in %, a drop of 0.2 doesn't sound dramatic to me.

Response: Revision has been made. "At some sites pQ drops more than **20 %** from pQ_{Bevis} to $pQ_{Varying.}$" (Line 310)

15. Line 407 - 408. What are "comprehensive error sources"? You probably mean that the GPS PWV errors are of the order 1 to 5 mm, with only part of that error being due to errors in Tm, up to 30 % at specific sites.

Response: We rewrite this sentence to "The differences between the GPS-PWV and the radiosonde PWV are approximately 1~5 mm. Some differences decrease 1~2 mm in the wetter conditions by using more precise T_m models. However, the error reductions of GPS-PWV due to the T_m models are very limited overall. This means that the other error sources, as we described in section 4.3, occupied the errors of GPS-PWV." (Line 424-430)

16. Notice that one writes 30 %, not 30% (common error in the manuscript).

Response: We correct such errors throughout the manuscript.

References:

Jiang, P., Ye, S. R., Chen, D. Z., Liu, Y. Y., and Xia, P. F.: Retrieving Precipitable Water Vapor Data Using GPS Zenith Delays and Global Reanalysis Data in China, Remote Sensing, 8, 10.3390/rs8050389, 2016.

Yao, Y., Zhang, B., Xu, C., and Yan, F.: Improved one/multi-parameter models that consider seasonal and geographic variations for estimating weighted mean temperature in ground-based GPS meteorology, J. Geodesy, 88, 273-282, 10.1007/s00190-013-0684-6, 2014.

Responses to David Adams

General comments

1. The English has improved substantially over the last version, but there are still many grammar errors and awkward sentences.

Response: We have revised the language of our manuscript carefully. Many sentences are rewrote and many errors are revised.

2. Firstly, the error reduction (if we can even call it that) due to their model is very small. You need to address all of the sources of errors associated with PWV, including, very importantly, the calculation of ZHD. Even if you cannot quantify directly these errors, you need to recognize that they exist and that they may be very large compared to your improvement in the Tm model.

Response: We address all of the error sources of GPS PWV in line 289~325 and list their values in table 4 based on the summaries of other studies. We also mention the errors of ZHD calculations can be very large in line 313~325.

3. These tiny error reductions of 2mm to 1mm in PWV could very easily be attributed to errors in ERA-Interim or radiosonde temperature and humidity profiles. And because there is no standard baseline PWV value against which to judge this error reduction for a given locale, it is difficult to draw conclusions about the improvement due to the author's time-varying global gridded Ts - Tm model.

The authors have fastidiously avoided mentioning one of the largest sources of errors -- errors in Ps in the calculation of ZHD. An error of 1mb in the surface pressure in their equation (1) is 2.5 times as large as an error of 1 degree C in temperature using the Bevis Ts -Tm equation, $T_m = 0.72 T_s + 70.2$. Why is this problematic? Let´s first assume that local barometers measure pressure perfectly, which of course isn´t true, but not much we can do about this. Now, more importantly, the inherent uncertainties in surface pressure measurements in ERA-Interim interpolated to a local site can lead to the errors I mention above (2.5 times as large as surface temperature errors). Of equal importance, error in antenna height relative to the height of the pressure measurement can introduce large errors. Snajdrova et al. (2005) found that 10 m of height difference approximately causes a difference of 3 mm in the ZHD. Now imagine GPS PWV calculated with an interpolated surface pressure from ERA-Interim over very complex terrain where errors could easily be greater than 100m.

Likewise, as I insisted in my previous review. The authors have not even mentioned the fact that ZHD doesn't take into account existing water vapor the atmospheric column. This error is small, but in the deep tropics the mass of water vapor can be near 4% of the total column mass.

Response: We discuss the errors of Ps in line 313~325. Based on Ning's summary, the uncertainty of Ps is 0.2 hPa when the surface barometer is calibrated routinely and equipped together with the GPS antenna. We enlarged it to 0.5 hPa in consideration of the possible worse performance of the surface barometers. However, we described the situations that the Ps's errors can be very large in line 318~325, and the error reductions due to our Tm models would be very limited in such cases.

4. Considering all of these sources of errors I mention about, the small reduction (assumed) in error due to your model

is not particularly notable considering that substantial errors in surface pressure can be associated with reanalysis or radiosonde data. Finally, the authors need to be more critical of ERA-Interim. I have worked with these data and seen how poor they are over regions of complex terrain, for example, in the North American Monsoon region.

Response: We mention the overall precision improvements of GPS-PWV introduced by the more precise Tm models can be very limited in our conclusions (Line 428~429). And we also mention the deficiencies of ERA-Interim in line 336~339.

Minor Comments

1. Line 39 Write "GPS observations require some kinds of meteorological elements to estimate PWV ..."
Response: Revision has been made. (Line 39)

2. Line 43 Write "are the latitude"
Response: We rewrite the sentence. (Line 43)

3. As I noted in my previous review, you need to clarify what ZHD is. And the fact that it ignores water vapor in its calculation. This is a small error (maybe more important ~4% of total mass in equatorial regions), but you need to mention it.
Response: We add the description about this error source in line 314~317.

4. Line 67. "these models independent of real meteorological observations." As I mentioned in my previous review, this is not typically true. NWP models are most often initialized and constrained with some form of real-world observations. So they are not independent in this sense.
Response: What we tried to express is that these models require no current meteorological observations which are expected to be observed together with the GPS data. To express our meaning more clearly, we rewrite the sentences to "T_m at any time and any location can be estimated from these models. These models are often independent of the current meteorological observations which are required to be observed together with the GPS data."   (Line 64~66)

5. Lin 71 Write "weather prediction."
Response: Revision has been made. (Line 68)

6. Line 83 "without high-precision specific T s -T m equations." Clarify what you mean here.
Response: We rewrite the sentence to "Aside from this, some other vast areas have no specific high-precision Ts-Tm model, for example over the oceans." (Line 81-82)

7. Line 84. Write "Significant differences exist between oceanic and terrestrial atmospheric properties, especially near the near the surface and within the boundary layer, in general."

Response: Revision has been made. (Line 81~82)

8. Line 89-90 "However, the Ts -Tm relationship has time variations and can produce residuals in the static Tm estimations (Yao et al., 2014a). Such residuals are not fixed in Lan's model."
It is not real clear what you are trying say here. Lan´s model (Lan et al. 2016) is static and there for doesn´t include time variation in Ts-Tm as does Yao et al. (2014) estimation. This is what I think you want to say.
Response: We rewrite the sentences to "Actually the Ts-Tm relationship has time variation (Yao et al., 2014a). However, Lan's model is static and does not consider the time variation." (Line 82~83)

9. Line 94-95 Write "...smoothing of the data, then assess their precision,..."
Response: Revision has been made. (Line 89~90)

10. Line 110 Write "are from the earth´s surface to the top of the troposphere"
Response: Revision has been made. However, we replace your "the top of the troposphere" by our "the top level of the profile data". We think this replacement can express us more precisely. (Line 106).

11. Line 120 Write "...observations must be available,..."
Response: Revision has been made. (Line 116)

12. Line 125. As I stated in my previous review, you need to say something about the quality of ERA-Interim, particularly for regions with sparse observational data. Humidity can be very poor in ERAInterim and your integral depends on it.
Response: We add the description about the deficiencies of ERA-Interim in line 336~339.

13. Line 129 Write " ...should be integrated through the entire atmospheric column
Response: Revision has been made. (Line 126)

14. Line 146. You should state here that these two are not independent even though you explore it later. Radiosondes are assimilated into ERA-Interim, so you need to state this explicitly.
Response: We mention the relationship between the radiosondes and ERA-Interim in line 146~147.

15. Line 158 "Unreliable regression analysis results may be derived by both the Ts and Tm with small variations." What are you saying here?
Response: We rewrite the sentence to "Unreliable regression analysis results may be derived if the Ts and Tm data both have small variations." (Line 155)

16. Line 159 "is quietly obscure". This sounds very poetic, but I am not sure what you mean.
Response: We rewrite the sentences to "As the blue dots show, the T_s-T_m relationship is weak in the areas near the equator.

It is because that the entire variation ranges of T_s and T_m are both below 10 K" (Line 157~158).

17. Line 190 " Attributed to no spatial or temporal smoothing of any data in our study, the precision and resolution of our static model, with no RMSE larger than 4.5 K, is clearly better than previous studies (Lan et al., 2016)." Rewrite this sentence, it is not very clear.

Response: We rewrite the sentences to "Meanwhile, there is no RMSE larger than 4.5 K in the results of our model. The precision and the resolution of our static model is clearly better than previous models (Lan et al., 2016). It is because that we performed no spatial or temporal smoothing of the data during the data processing." (Line 188~190)

18. Figure 5 is not very attractive. Neither is Figure 4. The small numbers are a bit of a distraction.

Response: We delete the numbers in figure 4 and 5.

19. Line 338 and throughout. PWVs should just be written PWV

Response: Revisions have been made throughout the manuscript.

20. Line 349 Some relative RMSEs were remarkably reduced. For example, at the ALIC site which is located in Australia with mean PWV of approximately 23 mm, the relative RMSE dropped from 1.97% of PWV BTm to 1.10% of PWV VTm . THIS IS NOT REMARKABLE!

Response: We delete the sentence "Some relative RMSEs were remarkably reduced", and we add a sentence "We found that some relative RMSE could reduce more than 2 % from PWV_{BTm} to PWV_{VTm}" in line 367.

21. Line 353. "It is attributed to the wetter atmosphere in summer than in the winter." Why would the error be larger just because the atmosphere is wetter? You need to give a physical reason as to why this should be the case.

Response: We rewrite the sentences to "It is because that the T_m's variations in summer are not modeled well by both Bevis model and the latitude-related model. Furthermore, the higher PWV values in summer enlarge the PWV differences." (Line 369~370)

22. Line 409 "However, at some special sites, such differences could decrease by more than 30% in wetter conditions" This is a bit misleading, your small error can decrease by 30%.

Response: We rewrite the sentences to "The differences between the GPS-PWV and the radiosonde PWV are approximately 1~5 mm. Some differences decrease 1~2 mm in the wetter conditions by using more precise T_m models" to avoid the possible misleading" in line 427-428. Corresponding revision has been made in the abstract in line 25.