Here, we give the comments from referees, as well as the responses to all comments, and the changes made in the revised manuscript based on the comments.

1. Referee 1:

General

With interest I have read the responses from the authors to the first round of reviews. I find that all my comments are dealt with. Not all of them are handled as I have suggested, but that is the responsibility of the authors. I still think that the conclusions are somewhat overrated and that more could be done. A main issue is the use of changepoints. It is a good dataset for such studies. For example, IGS stations have high standards and the logs are presumably complete and correct. So why should a changepoint be accepted that is not supported by a logged event?

Response: We appreciate all your valuable comments and suggestions. All the comments are responded point by point as shown below.

The changes that affect the homogeneity of the GPS data can fall into two categories: data-processing-related and site-related. The first type of changes is normally due to updates of the reference frame and applied models, different elevation cutoff angles, different mapping functions, and different processing strategies. In this study, the data-processing-related changes have been significantly reduced after a homogenous data reprocessing over the whole time series. The site-related changes comprise the replacements of hardware (antennas, receivers, cables, and radomes), the differences in the measurements (such as the number of visible GPS satellites and data rate), and the changes in the electromagnetic environment due to, for example, growing vegetation (Pierdicca et al., 2014) and/or different soil moisture (Larson et al., 2010). The changes in the electromagnetic environment can cause different multipath effects on the GPS data, and the resulting errors are normally not fixed in time but varying when reflective properties change and therefore harder to detect and document. The log file for each station only documents hardware changes, accounting for part of the changepoints, which has been reported in many previous literatures. For example, Ning et al. (2016) found that 70 % of the detected changepoints in the GPS-derived IWV time series cannot be related to any documented hardware change after examination 19 years of data at 101 TIGA stations.

Pierdicca, N., Guerriero, L., Giusto, R., Broioni, M., & Egido, A.: SAVERS: A simulator of GNSS reflections from bare and vegetated soils. IEEE Transactions on Geoscience and Remote Sensing, 52, 6542–6554. https://doi.org/10.1109/TGRS.2013.2297572, 2014.

Larson, K. M., Braun, J. J., Small, E. E., Zavorotny, V. U., Gutmann, E. D., & Bilich, A. L.: GPS multipath and its relation to near-surface soil moisture content. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens., 3, 91–99. https://doi.org/10.1109/ JSTARS.2009.2033612, 2010.

Ning T, Wickert J, Deng Z, Heise S, Dick G, Vey S, and Schöne T: Homogenized time series of the atmospheric water vapor content obtained from the GNSS reprocessed data. J Clim 29:2443–2456. https://doi.org/10.1175/JCLI-D-15-0158.1, 2016.

Specific comments

I agree with the 2nd reviewer that the short subsection on "station position analysis" is good to remove. The results do not add any new knowledge to what is already well known in the community, and the paper would have a better focus and in agreement with its title.

Response: In this work, we reprocessed the 44 IGS station data from 1995 to 2014 by using different strategies. The main purpose of this work is to access the impact of these strategies on GPS ZTD. Since ZTD and coordinate up component are strongly correlated, we decided to analyze the coordinate accuracy first, and want to illustrate that the same optimal mapping function and cut-off angle setting can be used for both the coordinate and ZTD solutions. In the latest review round, the 2nd reviewer has accepted our response and agreed us to remain this part.

In the previous review I wrote "When trends are estimated individual errors are averaged out, if no systematic errors are present". I missed to add: "Trends are not affected by different systematic errors at for different elevation cutoff angles, as long as they do not also show a time dependence that will alias with the estimated trends." In your response related to this issue you do not reflect upon this issue.

Response: We agree with your comment that the estimated trends would be the same if the systematic errors are time independent. However, differences of solutions by using different cut-off angle settings show time dependence. An example at station GODE is illustrated in the figure below, where we can find differences in both the vertical coordinate and ZTD by using 7° and 30° obviously change with time, which is largely caused by the time-related differences in the number of observations by using different cut-off angle settings.

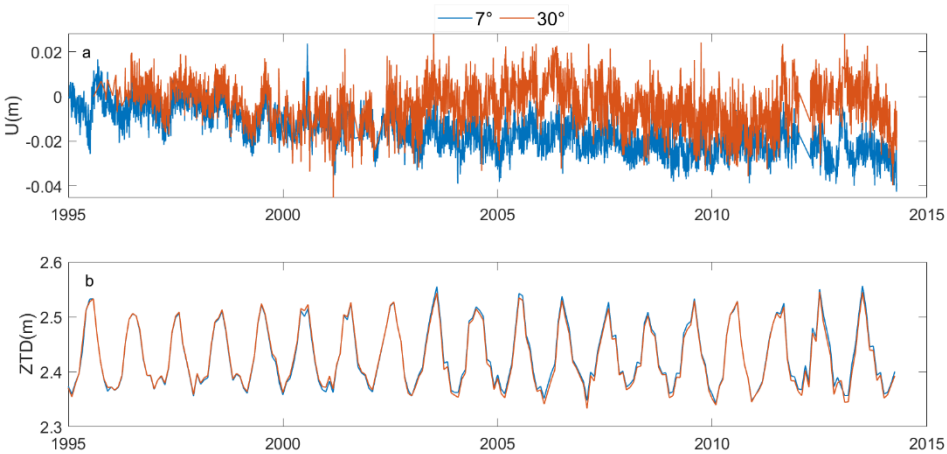

Figure. (a) The coordinate repeatability time series in up component applying 7° and 30° elevation cut-off angles; (b) The ZTD time series estimated from 7° and 30° solution at GODE station

I think you shall explain how the uncertainties (error bars) in Figure 4 are estimated.

Response: The uncertainty of the estimated trend is calculated as,

$$s^2 = \frac{\frac{1}{n-2}\sum_1^n (x_i - \hat{x})^2}{\sum_1^n (t_i - \bar{t})^2}$$

where n is a count of data points of the ZTD time series, x_i is a ZTD monthly anomaly at time t_i, and $\bar{t}$ is the average of all t_i. The $\hat{x}$ is estimated from the following equation,

$$\hat{x} = median(x_i) + trend * (t_i - median(t_i))$$

Following your suggestion, we have added the explanation. Please see L183-184.

L105+: Using different time periods for the raw (1995-2014) and homogenized (1995-2012) radiosonde data is not ideal when you at a later stage compare these results.

Response: Yes, you are right. In the revised manuscript, we have used the same time period (1995-2012) for different data sets (GPS, ERA5, Raw, and Dai) when estimating ZTD trends. We have added this information in the revised manuscript, please see L167-169. According to the new ZTD results, we modified all the figures and table in the section 4. The conclusions of our study remain the same.

L148: Regarding the relation between Bias, STD, and RMS, I think you shall describe how this is calculated in order to represent many stations. Is bias, STD, and RMS the mean values of those obtained for each station?

Response: Yes, bias, STD, and RMS are the mean values of those obtained for each station. The bias, STD, and RMS are calculated as,

$$\text{Bias}=\frac{\sum_{i=1}^{N}\left(\frac{\sum_{j=1}^{t}\left(\text{ZTD}_{\text{G}j}-\text{ZTD}_{\text{E}j}\right)}{t}\right)}{N}$$

$$\text{STD}=\frac{\sum_{i=1}^{N}\left(\sqrt{\frac{\sum_{j=1}^{t}(\text{dZTD}_j-\overline{\text{dZTD}})^2}{t-1}}\right)}{N}$$

$$\text{dZTD}_j=\text{ZTD}_{\text{G}j}-\text{ZTD}_{\text{E}j}$$

$$\overline{\text{dZTD}}=\frac{\sum_{j=1}^{t}(\text{ZTD}_{\text{G}j}-\text{ZTD}_{\text{E}j})}{t}$$

$$\text{RMS}=\frac{\sum_{i=1}^{N}\left(\sqrt{\frac{\sum_{j=1}^{t}(\text{ZTD}_{\text{G}j}-\text{ZTD}_{\text{E}j})^2}{t}}\right)}{N}$$

where N is the number of the stations. For each station, t is the number of ZTD observations in the time series. $\text{ZTD}_{\text{G}j}$ and $\text{ZTD}_{\text{E}j}$ represent the jth GPS and ERA5 ZTD products in the time series, respectively.

Following your comment, we have added the equations for calculating Bias, STD and RMS. Please see Equation (4)-(8).

L 222: I think you mean "smaller trend differences" not "smaller trend errors"?

Response: corrected. Please see L236.

L257-258: You write "The uncertainties are not greatly affected by processing strategies and homogenization method."

I find that surprising because for each additional changepoint introduced, the uncertainty of an estimated linear trend increases. This should be clarified as well as quantified, i.e. how many mm/year correspond to "not greatly"?

Response: We agree with this comment that the uncertainty of an estimated linear trend increases when additional changepoints introduced. We checked the results and found that the uncertainties are reduced after homogenization. We have added the information about uncertainties before and after homogenization in Table 10. Please see Table 10 and L182-183. Meanwhile, we changed “The uncertainties are not greatly affected by processing strategies and homogenization method.” to “The homogenization can reduce the uncertainties of the estimated trends.” Please see L270-271.

Technical Corrections

The unit for hour "h" in Table 3 is still in italic font.

Response: corrected.

L195-196: "... 1 stations have negative trends, ..." --> "... 1 station has a negative trend, ..."

Response: corrected. Please see L208.

L251: "... cut-off angle, with the maximum difference reducing from 1.96 to 0.61 mm/year ..." --> "... cut-off angle. The maximum difference was reduced from 1.96 to 0.61 mm/year ..."

Response: corrected. Please see L263-264.

2. Referee 2:

I would like to thank the Authors for all their responses to my questions/suggestions. In the present form, the manuscript is much better readable. In the reviewed manuscript, I would also like to correct and clarify several things:

Response: Thank you very much for the recognition of our work and we appreciate all your valuable comments and suggestions. All the comments are responded point by point as shown below.

Page 2, line 46 – should be 'performed'

Response: corrected. Please see L46.

Page 3, line 86 – I suggest "The E5 solution" change to the "The E5 (experiment 5) solution" to show that the shortcuts E* refers to the different experiments

Response: Following your comment, we have modified the sentence. Please see L87.

In Figure 4, we can clearly see that very often, the ERA5 ZTD and Radiosonde ZTD trends are quite different. Therefore it would be necessary to strongly underline the consistency of GPS solutions.

Response: Following the comment, we have underlined the consistency of GPS solutions in the revised manuscript. Please see L211-212.

A short discussion about GUAM station should be given here since this is the only example when we do have opposite trends from different homogenizations. Although in this case, it is worth underlining that ABS solution follows Radiosonde ones. As in the case of all small islands, considering the size of the land and the model grid box, we can expect some differences. Nevertheless, it should be somehow mentioned.

Response: Following your suggestion, we have added a discussion about GUAM station. Please see L210-211.

Page 8, Line 156-157 – now it is clear which stations are analysed and why (thank you for clarifying this). I suggest changing Figure 1 – mark 17 stations that are used for trend analysis with some different colour/sign than stations that are used for position analysis. Or something similar – to distinguish set that is used for trend analysis.;

Response: Following your suggestion, we have modified the Figure 1 in the revised manuscript. 17 stations that are used for trend analysis are marked with green colour in Figure 1.

I also want to clarify one thing because it is still unclear to me. The GNSS ZTD are from 1995 – 2014 (according to the accessibility of the IGS repro2 products). The Radiosonde (homogenized) products are from 1995 – 2012. Does it mean that comparison to ERA5 is for years 1995-2014 (both set), and the comparison to Radiosonde is for years 1995-2012 (both set) or for years 1995-2014 (GNSS) and 1995-2012 (Radiosonde)? Because in the second case the time span between GNSS and Radiosonde is not exactly same, which may cause differences in the trend estimation (according to Baldysz et al. 2016 in AMT, who also analyse the impact of 2 years differences in GNSS time series on the trend estimation).

Response: Yes, you are right. We also read the reference of Baldysz et al. (2016) and found the ZTD time period may affect the trend estimation. Therefore, in the revised manuscript, we have used the same time period (1995-2012) for different data sets (GPS, ERA5, Raw, and Dai) when estimating ZTD trends. We have added this information in the revised manuscript, please see L167-169. According to the new ZTD results, we modified all the figures and table in the section 4. The conclusions of our study remain the same.