Review of *Determination of zenith hydrostatic delays and the development of new global long-term GNSS-derived precipitable water vapor* by Wand, Zhang, Wu, He, Cheng and Li, AMT-2016-264

Overview

To derive precipitable water (PW) from GNSS zenith total delay (ZTD) data, an estimate of the zenith hydrostatic delay (ZHD) is needed at the location of the GNSS receiver antenna in order to obtain the zenith wet delay (ZWD) from which PW can be deduced. ZHD is easily deduced given the location of the GNSS receiver antenna and the pressure at the same location.

This short, but interesting paper address the problem that often no pressure sensor data are available at GNSS sites and consider two alternative sources of pressure estimates. One is the empirical Global Pressure and Temperature 2 wet model (GPT2w), the other numerical weather prediction re-analysis data in the form of ERA-Interim data at 6 hourly time resolution, 80 km horizontal resolution and 60 vertical levels. Based on offset statistics for 108 GNSS sites at which pressure sensor data are available, it is concluded ERA data are best. This is not surprising, given GPT2w is derived from ERA data and neglects the daily variations, but here are numbers to detail it in various ways. Further it is concluded that of the two, only ERA data are of sufficient quality to provide PW estimates of the quality necessary for climate monitoring on global scale, whereas GPT2w might be used in the tropics. Obviously a more thorough analysis could have been made doing this type of analysis for all sites with available pressure sensor data of decent quality, without restriction to GNSS sites. However, the number and distribution of sites included in this analysis is high enough to merit the conclusions. Overall the paper is worthy of publication. A number of small issues which ought to be improved are listed in the detailed comments below.

Response: We are grateful for all the constructive comments from the Reviewer #1. In the revised version, we have tried our best to improve the manuscript by incorporating the comments into consideration.

Detailed comments

1. *There is a mismatch between use of numbers and symbols in equations, like 4 and 5 versus 14 and 15. I recommend use of symbols throughout. List in the text which values you used for the symbols when you cranked out numbers.*

Response: This comment is to do with the way how the numbers and symbols in our formulas are expressed. Since a new four-point computation method is adopted in our revised version of manuscript, formulae (4) and (5) have been deleted. We have made relevant changes whenever possible. However, some of the conventional formulae are kept in the original form because those constants in the formulae do not carry any specific physical explanation.

2. *Regarding equation 16 T_m is the inverse of the water vapour weighted inverse temperature. It does not read well, but it is not the same as the water vapour weigthed mean of temperature. You also need to specify the coordinate system (pressure levels or height levels; is Pv_i halfway between top and bottom of grid box in pressure space or height space?).*

Response: The definition of T_m has been changed from water-vapor-weighted mean temperature to water-vapor-weighted mean temperature of the atmosphere for consistency with previously published papers. (Bevis et al., 1992; Bevis et al., 1994; Wang et al., 2005). The meaning of P_{vi} has been clarified as "the partial pressure of water vapor between two pressure levels".

3. *An analysis is provided of the pressure offset statistics as function of the altitude of the sites. I recommend to show instead (or also) the offset statistics as function of the absolute offset between the model altitude (GPT2w or ERA) versus the GNSS antenna altitude. The higher such offsets, the more the short comings due to model resolution, and of the interpolation/extrapolation methods on page 3 and 4, can be expected to show up.*

Response: In the old version, we showed the mean pressure and annual/semi-annual variation of pressure at 371 stations with different heights since pressure values are closely related to height. As suggested by the reviewer, the error in model-derived pressure is probably related to the height difference between a GNSS station and its nearest pressure level (used to interpolate pressure for this GNSS station). A new paragraph for rectifying this problem has been added in this revised version: *"Since a pressure level closest to a GNSS station is used to compute the pressure at this station, the vertical distance between this pressure level and the GNSS station will probably affect the accuracy of the pressure derived from ERA-Interim due to its limited vertical resolution. We calculated the mean differences between a GNSS station and its nearest pressure level at 108 stations for the period of 2000–2013 for the study of the relationship between the errors in ERA-Interim-derived pressure and this mean height difference. Results indicate that the difference between a GNSS station and its nearest pressure level is between 26 m and 181 m at these 108 stations. And the error (bias and RMS error) in ERA-Interim-derived pressure does not show any obvious dependence on this height difference. For the height below 10 km, the height difference between two neighbouring pressure levels in ERA-Interim is about 500 m, which means we can always find a nearest pressure level to a GNSS station with a height difference less than 250 m. Therefore, the vertical resolution of ERA-Interim is sufficient for pressure interpolation for a GNSS station, and does not have an obvious impact on the accuracy of resultant pressure*".

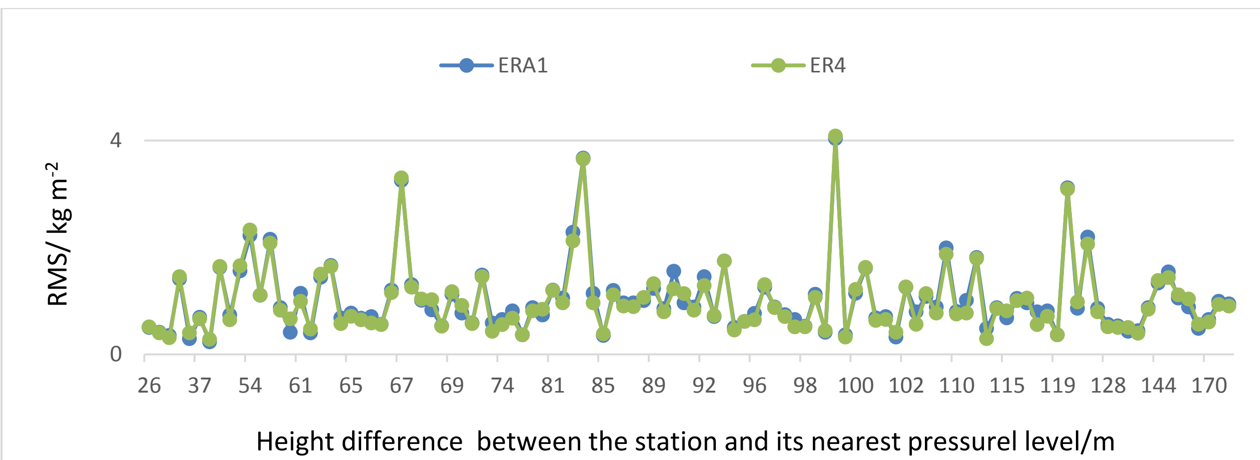

Figure 1. Relationship between RMS errors in pressure from ERA-Interim and the differences between station and its nearest pressure level

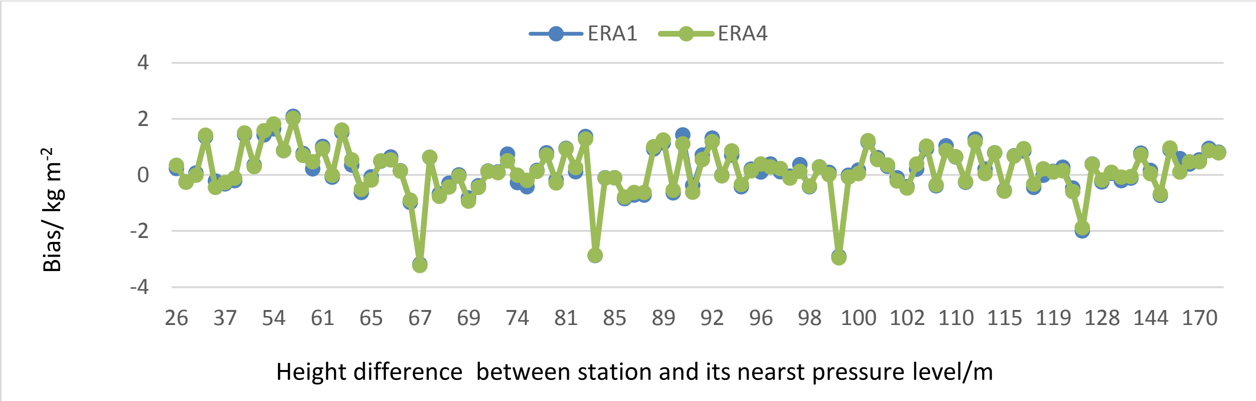

Figure 2. Relationship between biases in pressure from ERA-Interim and the differences between station and its nearest pressure level

4. *It is difficult to read the global maps properly. When zooming in on a computer screen, one realizes that a significant part of the sites appear in a few site dense regions, the overall color of which are dominated by the symbols plotted last, on top of the other ones. Some sites may even not be visible. When different symbols are used, fig 5 and 6, it becomes even more difficult. Consider turning most of the global maps into figures of the same type as figure 16, which is easy to read on an A4 printout. As an alternative consider to plot on the global maps the average for the sites for the regions in which the sites are not visible individually on the global maps at present.*

Response: As suggested by the reviewer, it is a bit difficult to read the global maps due to its size and the dense site distribution in some regions. In the revised version of the paper, we have enlarged the figure. In addition, we have provided two documents (in Excel format) containing all the results presented in this paper as supplementary materials. For those readers who are interested in the results in some specific regions, the provided supplementary can provide a more detailed information and can be used to produce a map for any region of interest.