Interactive comment on "EPN Repro2: A reference GNSS tropospheric dataset over Europe" by Rosa Pacione et al.

Response to Review #1.

Overview

As the GNSS tropospheric products are getting longer, it becomes more and more important to create homogenized products, especially for climate applications. From this perspective, the manuscript is timely and important. I think that the manuscript still needs major revision before it is ready for publication. My main comments are two folds. First, I would like to see some more explanation on the differences (esp biases) presented from the comparisons with radiosonde and ERA-Int. There are a few specific comments listed below. Second, it would be great to show how the processed data improve the detection of PW trends, even with just a few examples.

Authors' Response

The authors would like to thank Reviewer #1 for his/her constructive comments. We have considered them in the revised version to improve the quality of the paper.

We have reviewed section 4.1 'Evaluation versus Radiosonde', section 4.2 'Evaluation versus ERA-Interim' and section 5 'Conclusion' as reported below in 'Detailed Comments'.

<u>Detailed Comments</u>

Reviewer # 1

Fig. 10: add a horizontal zero line, so that it would be easy to see the sign of the differences. This applies to other plots too. Any explanation to the statistically significant large biases? How does this compare with prior studies? It would be better to express the biases in percentage.

Authors' Response

We have changed Figure 10 expressing the bias and standard deviation in percentage and adding the zero line as suggested. In Figure 10, we have modified the x-axis adding to the GPS site name the code of the Radiosonde used for the comparison. Moreover, we have compared the obtained results with prior studies available in literature and we have discussed mainly about the bias.

Below the revised version of section 4.1. 'Evaluation versus Radiosonde'. **Lines 286-297 changed:**

> "Figure 9 shows an example for the EPN site CAGL (Cagliari, Sardinia Island, Italy). For all the 183 EPN collocated sites, and using all the data available in the considered period, we computed an overall bias and standard deviation (Figure 1). The sites are sorted according to the increasing distances from the nearest Radiosonde launch site. MALL (Palma de Mallorca, Spain) is the closest (0.5 km to Radiosonde code 8301) while GRAZ (Graz, Austria) is the most distant (133 km to Radiosonde code 14015). The amount of data available for the comparisons varies between sites depending on the availability of the GPS and Radiosonde ZTD estimates in the considered epoch and it ranges from 121 for VIS6 (Visby, Sweden, integrated in the EPN since 22-06-2014) up to 21226 for GOPE (Ondrejov, Czech Republic, integrated in the EPN since 31-12-1995).

The bias ranges from -0,87%, which corresponds to -21,2 mm, (at EVPA, Ukraine, and distance from the Radiosonde launch site 96.5 km, Radiosonde code 33946) to 0,68%, which corresponds to 15,4 mm, (at OBER, Germany, and distance from the Radiosonde launch site 90.8 km, Radiosonde code 11120). The mean bias for all sites is -0,6 mm with standard deviation of 4.9 mm. For the more than 75% (178 pairs), the agreement is below 5 mm and only 5.5% (13 pairs) have bias higher than 10 mm. The higher biases concern mostly the pairs over 50 km away from each other, like GPS stations OBER, OBE2 and OBET located in Oberpfaffenhofen (Germany) and collocated with Radiosonde (VRS90L code 11120) launched from Innsbruck Airport in Austria on the opposite side of North Chain in the Karwendel Alps. Our results are at odds with Wang et al. (2007), where authors compared PW from GPS and global Radiosonde. In contrast to them, we received small negative bias -1.19 mm for Vaisala Radiosondes, which is the most common type used in Europe (81% of all used in this study). For MRZ, GRAW and M2K2 Radiosonde type, which represent 4.6%, 3.4% and 3.0% of compared Radiosondes respectively, we received systematic positive bias. However, Wang et al. (2007) used global Radiosonde data from 2003 and 2004, while we used all available data over Europe from 1994 to 2015. This can partly explain the disagreement even though more analysis deserves to be done. Further investigation is also needed for several near or moved GPS stations. For example in Brussels (Belgium) BRUS station, included in the EPN network since 1996, was replaced by BRUX in 2012. Their bias w.r.t. the same Radiosonde (VRS80L code 6447) has opposite sign (-1.2 mm and 3.4 mm respectively). A possible explanation is the different time span over which the bias has been computed (1996-2012 for BRUS, 2012-2015 for BRUX).

In agreement with Ning et al. 2012, the standard deviation generally increases with the distance from the Radiosonde launch site. It is in the range of [0,16; 0,76] % ,which corresponds to [3; 18] mm, till 15 km (first band in Figure 10); [0,29;0,78] % ,which corresponds to [7; 19] mm, till 70 km (second band in Figure 10) and [10; 33] mm till 133 km (third band in Figure 10). The evaluation of the standard deviation is comparable with previous studies. Haase et al. (2001) showed very good agreement with biases less than 5 mm and the standard deviation of 12 mm for most of analysed sites in Mediterranean. Similar results (6.0 mm ± 11.7 m) were obtained also by Vedel et al. (2001). Both of them based on non-collocated pairs distant less than 50 km. Pacione et al (2011), considering 1-year of GPS ZTD and Radiosonde data over the E-GVAP super sites network, obtained a standard deviation of 5-14 mm. Dousa et al. 2012 evaluated ZTD and Radiosonde on a global scale over 10-month period and reported a standard deviation of 5–16 mm.

The assessment of the EPN Repro1 ZTD product with respect to Radiosonde using the same period, i.e. 1996-2014 when completed with the EUREF operational product after GPS week 1407 (December 30, 2006), and EPN Repro2 with respect to the Radiosonde data has an improvement of approximately 3-4% in the overall standard deviation."

Dousa J. and G.V. Bennett: Estimation and Evaluation of Hourly Updated Global GPS Zenith Total Delays over ten Months, GPS Solutions, Online publication date: 12-Oct-2012, doi:10.1007/s10291-012-0291-7, 2012

Haase J.S., H. Vedel, M. Ge, and E. Calais: GPS zenith troposphteric delay (ZTD) variability in the Mediterranean, Phys Chem Earth (A) 26(6–8):439–443, 2001

Ning, T., R. Haas, G. Elgered, and. Willén U: Multi-technique comparisons of 10 years of wet delay estimates on the west coast of Sweden, J Geod 86: 565. doi: 10.1007/s00190-011-0527-2, 2012

Wang, J., Zhang, L., Dai. A.,Van Hove, T.,Van Baelen, J.: A near-global, 2-hourly data set of atmospheric precipitable water dataset from ground-based GPS measurements, J Geophys Res 112(D11107). doi:10.1029/2006JD007529, 2007

Vedel, H., K. S. Mogensen, and X.-Y. Huang: Calculation of zenith delays from meteorological data comparison of NWP model, radiosonde and GPS delays, Phys. Chem. Earth Pt. A, 26, 497–502, doi: 10.1016/S1464-1895(01)00091-6, 2001.

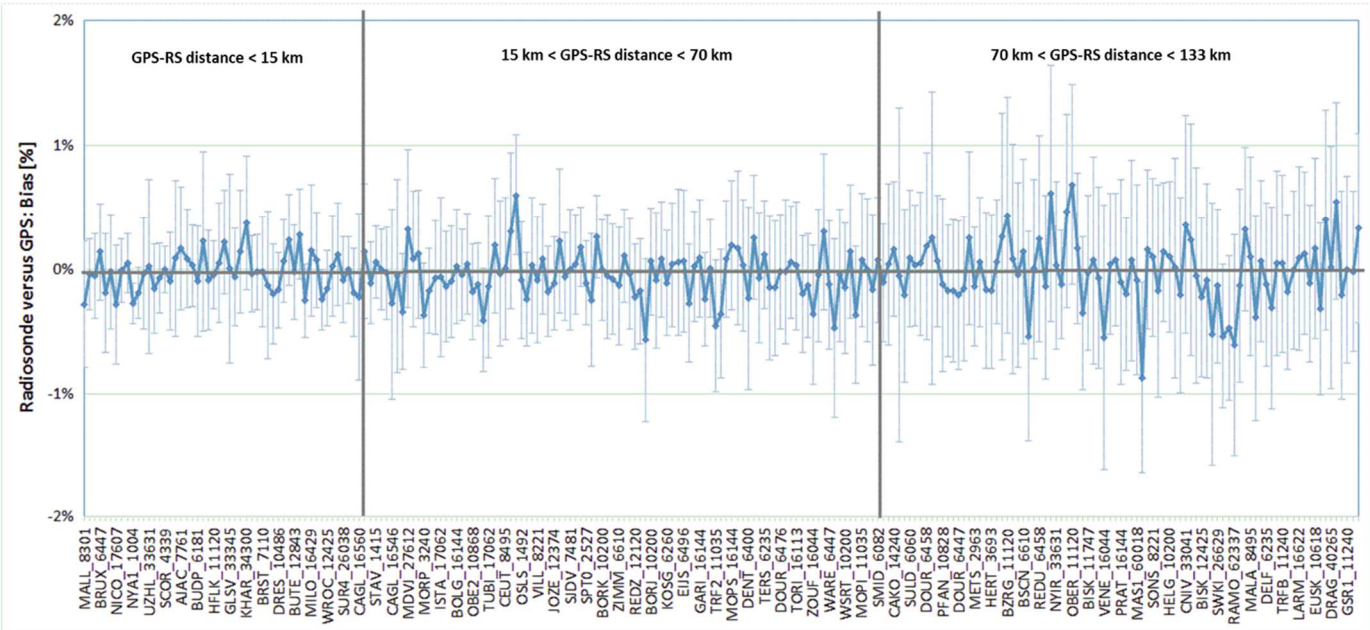


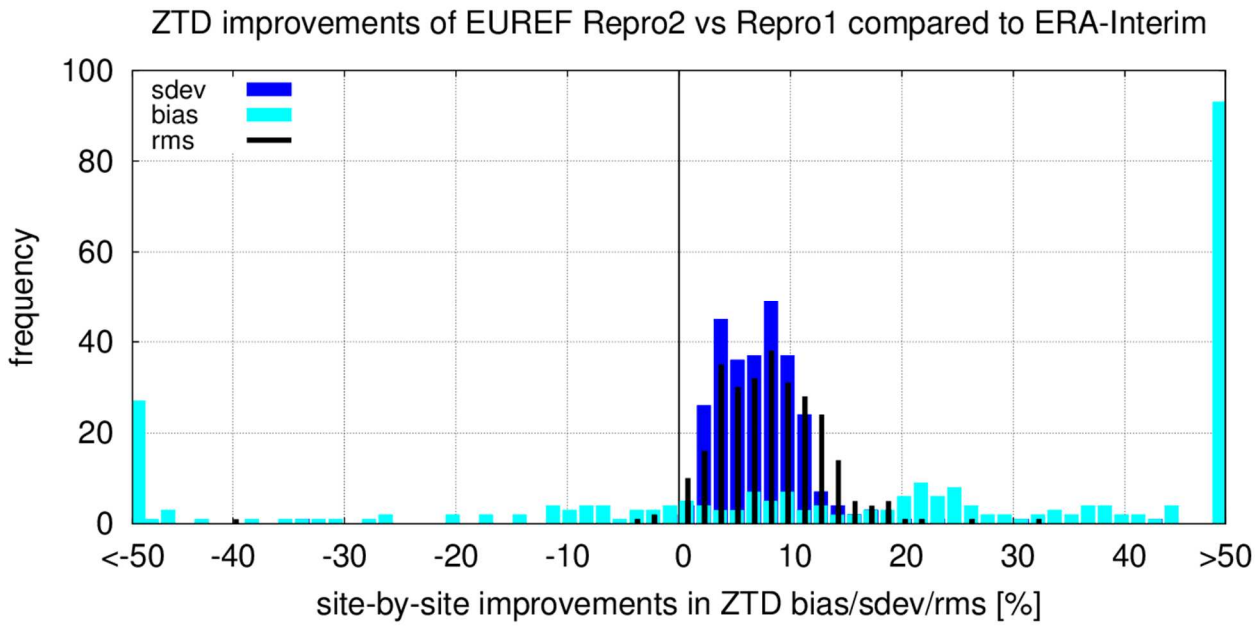
Figure 1 GPS versus Radiosonde Bias. The error bar is the standard deviation. Sites are sorted according to the increasing distances from the nearest Radiosonde launch site. The x-axis reports the GPS station and the Radiosonde code.

Reviewer # 1

Fig. 11: I would recommend to add some quantitative numbers, such as the reduction of biases and SDs, in the text (or Fig.) and the discussion. Based on visual examination, it looks like that it is mainly a shift 3.

Authors' Response

The quantitative number for overall improvement from EUREF Repro1 to Repro2 was enumerated as 8-9 % for ZTD when considering total statistics in Table 4 while Figure 11 shows distributions of ZTD bias, standard deviation over all stations. Using data from Figure 11 we expressed site-by-site improvements of all statistics. Calculated median improvements for bias, standard deviation and RMS reached 21.1 %, 6.8 % and 8.0 %, respectively, which correspond with the value of 8-9 % for an overall improvement. An additional figure (not included in the revised text) shows the distribution of statistics of ZTD improvements over all stations. Degradation of standard deviation was found for three stations only, SKE8 (Skellefteaa, Sweden, integrated in the EPN since 28-09-2014), GARI (Porto Garibaldi, Italy, integrated in the EPN since 08-11-2009) and SNEC (Snezka, Czech Republic, former EPN station since 14-06-2009) all of them providing much less data compared to others, 1%, 30% and 3%, respectively. All other 290 stations showed improvements. We found 72 with increased absolute systematic errors in EUREF Repro1 compared to Repro2 while for all others (221 stations, 75%) systematic errors were reduced.



Below the revised version of section 4.2. 'Evaluation versus ERA-Interim'**. Lines 346-352 changed:**

> "For completeness, we evaluated also EPN Repro1 ZTD product with respect to the ERA-Interim using the same period, i.e. 1996-2014 when completed with the EUREF operational product after GPS week 1407 (December 30, 2006). Comparing Repro1 and Repro2 with the numerical weather re-analysis showed the 8-9% improvement of the latter in both overall standard deviation and systematic error. Figure 11 shows distributions of station means and standard deviations of EPN Repro1 and Repro2 ZTDs compared to NWM ZTDs using the whole period 1996-2014. Common reductions of both statistical characteristics are clearly

visible for the majority of all stations. From data of the figure, we also expressed site-by-site improvements in terms of ZTD bias, standard deviation and RMS. Calculated medians reached 21.1 %, 6.8 % and 8.0 %, respectively, which corresponds to the abovementioned improvement of 8-9 %. The degradation of standard deviation was found at three stations: SKE8 (Skellefteaa, Sweden, integrated in the EPN since 28-09-2014), GARI (Porto Garibaldi, Italy, integrated in the EPN since 08-11-2009) and SNEC (Pod Snezkou, Czech Republic, former EPN station since 14-06-2009) all of them providing much less data compared to others, 1%, 30% and 3%, respectively. All other stations (290) showed improvements. We also found 72 stations with increased absolute bias in EUREF Repro1 compared to Repro2 while all others, 221 stations (75%), resulted in reduced systematic error."

Reviewer # 1

Fig.12, L357-358: It is not clear to me how "the limited temporal and horizontal NWM resolution as well as corresponding deficiencies in NWM orography" cause the negative differences in ZTD-NWM. Why does it vary with time (generally reduced magnitudes with time)?

Authors' Response

The corresponding sentence was finally removed. We have checked more individual stations at low altitude and the bias of -1 to 2 mm dominated even for those sites. Thus the dependence of an overall mean bias does not seem to be related to the limited spatial resolution or deficiencies in NWM orography as there was no observed significant difference in the Alps and within flat areas. The mean bias remains unknown and the uncertainty is still large and varying depending on a common set of stations.

Reviewer # 1

It would be great to show how the processed data improve the detection of PW trends, even just with a few examples.

Authors' Response

We have reviewed section 5 'Conclusion' and have added examples available in the literature. As an example of application of EPN Repro2 data, we cited, in addition to the assimilation trial ongoing at UK Met Office, comparisons with regional climate model simulations ongoing at Sofia University and Hungarian Meteorologic Service. **Lines 392-395 changed**:

"According to Wang et al. (2007) IGS ZTD products are valuable source of water vapor data for climate and weather studies. The GPS PW is useful also for monitoring the quality of the radiosonde data. However, a better spatial coverage of the GNSS PW data is needed to investigate and reduce systematic biases in comparison with the global radiosonde humidity data (Wang and Zhang, 2009). On the other hand extending the observation period and complement of temporal coverage is necessary to calculate more reliable mean values and trends. As it was pointed by Baldysz et al. (2015, 2016) additional two years of ZTD data can change estimated trends up to 10%. Therefore, data after 2010 and with a better coverage over

Europe are required for improving the knowledge of climatic trends of atmospheric water vapour in Europe. In this scenario, EPN-Repro2 can be used as a reference data set with a high potential for monitoring trend and variability in atmospheric water vapour. Comparisons with regional climate model simulations is one of the application of EPN-Repro2. Ongoing at Sofia University is comparison between GNSS IWV, computed from EPN-Repro2 ZTD data for SOFI (Sofia, Bulgaria), and ALADIN-Climate IWV simulations conducted by the Hungarian Meteorological Service, for the period 2003-2008. The preliminary results show a tendency of the model to underestimate IWV. Clearly, larger number of model grid points need to be investigated in different regions in Europe and the EPN-Repro2 data is well suited for this."

Baldysz, Z., Nykiel, G., Figurski, M., Szafranek, K., and Kroszczynski, K.: Investigation of the 16-year and 18-year ZTD Time Series Derived from GPS Data Processing. Acta Geophys. 63, 1103-1125, DOI: 10.1515/acgeo-2015-0033, 2015

Baldysz Z., Nykiel G., Araszkiewicz A., Figurski M. and Szafranek K.: Comparison of GPS tropospheric delays derived from two consecutive EPN reprocessing campaigns from the point of view of climate monitoring. Atmos. Meas. Tech., 9, 4861-4877, DOI: 10.5194/amt-9-4861-2016, 2016