Interactive comment on "Benchmark campaign and case study episode in Central Europe for development and assessment of advanced GNSS tropospheric models and products" by J. Douša et al.

REVIEW NUMBER 2

Specifications and characteristics of the Benchmark campaign data set are described in detail. I believe the data set will contribute for both geodesy and meteorology in not only Europe but other countries and regions. However, there are not a few typos, insufficient explanations in body, tables, and figures. I would like authors to carefully polish the article. Followings are for reference.

About the chapter arrangement:

(1) It would be nice to move "3. Case study episode in 2013" to after "4. Benchmark data set" and before "5. Initial analysis and reference products"

Manuscript changed (order of the chapters has been changed).

(2) Effects of hydrometeor described in the latter half of the "6. Conclusion" and latter half of the "Appendix B" should be moved to "5. Initial analysis and reference products".

Manuscript changed (Appendix B has been removed). The effect of hydrometeors is now presented in Sect 5.5. Conclusion has been modified referring results about hydrometeors shown in Sect 5.5.

Abstract.

1 Introduction

2 GNSS4SWEC Benchmark campaign

2.1 Description of WG1 objectives

2.2 Data inventory and requirements for the Benchmark design

2.3 Selected spatial and temporal domain

P6L3: "in Sect. 0" might be "in Sect. 3.2"

Manuscript changed (Sect 3.2).

P6L4: "Additionally, seven clusters were set for an effective GNSS processing." It is unclear which areas in figure 1 are the "seven clusters", and what does "effective processing" mean. Please describe clearly.

Manuscript changed (the text was reformatted to better describe the situation). Additionally, the whole domain was geographically divided into nine clusters (five within the 'core' domain and four within the 'extended' domain, see different colors of individual station in Figure 1) to allow reasonable GNSS data handling.

P6L6: "covered areas hit by" -> "covered areas were hit by"

Manuscript changed.

2.4 Envisioned studies and activities

P6L13: "real-time (RT)" -> "RT". Firstly appeared in P3L3.

Manuscript changed.

P6L14:"evaluating new analytical centres" > Please explain what the "new analytical centres" are.

Manuscript changed (text was slightly reformatted). New analytical centers were established with support of the GNSS4SWEC COST project in Turkey, Bulgaria, Greece and Iceland. The Benchmark dataset could be used for evaluating own built solutions while comparing them with solutions from well-established centers.

P6L17: "real-time" -> "RT"

Manuscript changed.

P6L24:"IWV" -> "Integrated water vapor (IWV)"

Manuscript changed.

3 Case study episodes in 2013

3.1 Weather analysis, May 2013

P7L7: "daily accumulated precipitation (24-hour) from" -> "daily accumulated precipitation (24-hour) at Prague-Ruzyne (11518) synoptic station from"

Manuscript changed (correction accepted).

P7L11: "weak gradient at 500hPa" -> Of what "gradient"?

Manuscript changed (weak gradients of the geopotential). On May 5, the precipitation was associated with an upper level trough and weak gradients of the geopotential at 500 hPa.

P7L11-L24: Overall synoptic characteristics in May are described but no such description is seen for June.

We believe a sufficient description is given in Sect 4.2.

P7L21: "On May 31-31," -> Please check the exact date.

Manuscript changed (corrected: May 30 – 31).

P7L25: Figure 4 -> It would be nice if the area of the figure is more focusing on the area of the Benchmark campaign.

Manuscript changed (Figure 4 edited). For a good overview on the synoptic pattern it is better to look at the whole Europe region and see this big process over the Benchmark region. Nevertheless, both pictures where zoomed to show better central Europe.

3.2 Extreme precipitation events in the Czech Republic, June 2013

P8L7: Figure 5 -> It would be nice if the distance scale and topography of the area are shown. Also, locations of "Šumava mountains", "Bohemia", "Plague", "Vltava", "Elve" should be pointed in the figure.

Manuscript changed (Figure 5 edited). Geographic names were not included since it would deteriorate the legibility of the figure. Legends for x/y axes with geographic coordinates and a distance scales were added.

4 Benchmark data set

4.1 GNSS data

P8L27: Figure 6. -> Mark for WVR station is hard to distinguish from that of radiosonde station.

Manuscript changed (symbols for WVR and RS in Figure 6 were changed).

P9L3: "processing double-diference" -> It would be nice to add a reference on "double-difference", for example "Hoffmann-Wellenhof, et al, 2000: GPS theory and practice, 5th rev. ed., Springer-Verlag Wien New York."

Manuscript changed (reference added).

P9L5: Table 1 -> Does "Height" mean "Ellipsoidal height" or "Height above sea level (i.e. altitude)"?

Manuscript changed (ellipsoidal height is correct).

P9L6: "All GNSS" -> It would be nice to add brief summary regarding antenna type (Choke ring, ground plane, etc.), and elevation cut off angle.

It is almost impossible to provide such information since practically all types of receivers/antennas were used. Data from each country came from at least one stand-alone network and also within these networks different equipment is used at individual stations. So a real mixture of various devices exists there.

4.2 E-GVAP operational GNSS products

P9L21:"14 analysis centres (and 29 solutions)" -> It would be nice to show the names of 14 centres and 29 solutions in a table.

From our perspective this is out of scope of the paper while E-GVAP operational products are only supplementary to the whole dataset.

P9L23:"TOUGH (2004)" -> Is it appropriate to use a project name rather than specific author(s) name?

Manuscript changed (TOUGH Final report by H. Vedel referenced in Sect 3.2).

4.3 Synoptic data

4.4 NWM data and products

P10L10: "Table 3" -> There is no information about geopotential height at each vertical layer. How users get geopotential height at each 3D grid point?

Manuscript changed (added text in Sec 3.4). Geopotential heights are provided for the model surface only while the model levels are expressed using hybrid vertical coordinates. The atmospheric pressure between model levels is calculated with two pre-defined coefficients (a,b), reference pressure (101325Pa) and top level pressure, all provided in each file. Geopotential heights at any level could be additionally calculated using the hypsometric formula, atmospheric pressure and temperature at individual model levels.

P10L13: "Vertical resolution" -> "Vertical layers"

Manuscript changed.

4.5 Radiosonde data

4.6 Water Vapour Radiometer data

P10L28: "Water Vapor Radiometer (WVR)" -> WVR

Manuscript changed.

P11L4: "Integrated water vapor (IWV)" -> IWV

Manuscript changed.

P11L9: "GOPE and WTZR" -> Please describe the detail information about these two stations.

We don't think it would be useful to describe instruments at GOPE and WTZR since no data from them were available for the Benchmark dataset. We wanted to mention that although in the area there were two other WVRs in hope to be used, but were unfortunately, out of order during the Benchmark time period.

4.7 Meteorological Radar images

5 Initial analysis and reference products

5.1 Reference tropospheric products

5.2 NWM-derived tropospheric parameters

P13L11:"German Research Centre for Geosciences (GFZ)" -> "GFZ"

Manuscript changed.

P13L26: "compared in the GOP-TropDB" -> It would be nice to explain how to correct height differences between NWM surface and GNSS antenna. PWV and ZTD are highly dependent on height of antenna. It brings significant effect for the comparison.

Manuscript changed (added text in Sect 5.2). The same vertical parameter scaling is used in the GOP-TropDB if there is a need to compare parameters at two collocated stations with different heights, e.g. GNSS vs. other space geodetic techniques. This procedure is however not applied in case of our GNSS vs. NWM comparison since NWM parameters are calculated for the GNSS locations and heights.

P14L2: “a negative mean bias of about 5mm” -> It is important to describe possible reasons for the large negative biases.

Manuscript changed (an explanation added in the text). “A possible explanation for the systematic deviation between NCEP’s GFS and ECMWF's ERA-Interim ZTDs is the low vertical resolution of the NCEP GFS data (available on 26 pressure levels). In fact, the bias in the ZTD stems from a bias in ZWD. For a comparison between all NCEP GFS and ECMWF ERA-Interim tropospheric parameters, see Zus et al 2015 ('WG1 model sub-group summary', ES1206-GNSS4WEC COST Meeting, Wroclaw, Sept 28 – Oct 1, 2015).

Note that a comparable bias between NCEP and ECMWF ZWDs was reported by Urquhart et al. 2011 ('Generation and Assessment of VMF1-Type Grids using North-American Numerical Weather Models', presented at XXV IUGG General Assembly, Melbourne, Australia, June 28th – July 7th, 2011, available at http://unbvmf1.gge.unb.ca/Publications.html). We also note that the interpolation routine, that is used to compute the refractivity at arbitrary points, is the same for both NWMs. Therefore the low vertical resolution of the NCEP GFS data also implies larger interpolation errors.”

P14L4: Figure 8 -> Color scale should be identical for both GNSS and NWM.

Color scales are identical for all three comparisons of GNSS vs. NWM, just different scales are used for biases (left plots) and standard deviations (right plots) since the standard deviation can’t be negative.

P14L6: “As already seen in k in the local area model” -> What is “k”?

Manuscript changed (there was a typo, the reference should have pointed to Table 5).

P14L8: “good homogeneity” -> The expression is ambiguous. Please describe what it means by “homogeneity.”

Manuscript changed (we use the word agreement instead).

P14L12: “23 times better horizontal resolution” -> Please explain of which horizontal resolution is “23 times better” than of which resolution.

Manuscript changed (sentence reformatted). “This shows that a complex terrain such as in the Alps is much better captured by the meso-scale model ALADIN-CZ with up to 23 times better horizontal resolution than both used global models have.”

P14L15: “it has not been explained yet.” -> At least, I would like authors to compare reproduced atmospheric fields among GFS, ERA-interim, and ALADIN. Which element field (surface pressure, water vapor, or temperature) is different in GFS from other two models?

Manuscript changed (see P14L2 comment). The difference stems from ZWD, i.e. the water vapor and/or temperature field. We will certainly not start to compare atmospheric fields in this manuscript which is out of its scope.

5.3 GNSS and NWM tropospheric wet delay maps

P14L22: “in Section 0” -> There is no “section 0” in this article.

Manuscript changed (Sect 3.2 corrected).

5.4 Comparison of horizontal gradients from GNSS and NWM

P14L29: “zero a priori gradients” -> Please briefly explain this. I can’t understand why “zero a priori gradients” leads “all solutions are considered as independent”?

Manuscript changed (text reformatted). “No information about gradients was introduced in the GOP or GFZ reference GNSS analyses and thus they can be considered as fully independent from NWM derived gradients.”

P15L9: “Figure 10” -> The amount of estimated gradients in GNSS analysis seems larger than those in NWM. Is this happened by chance? Did authors statistically compare gradients between GNSS and NWMs?

No. Current thinking is that the low horizontal resolution of the NWMs (1 by 1 degree) is responsible for the underestimation of gradients. Therefore we added the following comment in the manuscript: "For example, Zus et al. 2016 ('Station specific NWM based tropo parameters for the Benchmark campaign', ES1206-GNSS4WEC COST Workshop, Iceland, March 8-10, 2016) show how an increased horizontal resolution of the NWM amplifies the gradient components under severe weather conditions."

6 Conclusion

P16L23-P17L2:"An initial study – GNSS4SWEC project." -> This paragraph seems to be a sudden. If authors want to discuss about the effects of hydrometeors, I want authors to discuss it in section 5 in association with difference in IWV (or ZWD) between GNSS analyses and NWMs.

Manuscript changed (the effect of hydrometeors is now presented in Sect 5.5). A discussion about the overestimation of ZWD and IWV from GNSS induced by such hydrometeors contribution is presented in this new section. Conclusion has been modified referring results about hydrometeors shown in Sect 5.5.

Appendix A: GNSS tropospheric model

A. 1 Mapping function coefficients – a, b, c

A. 2 Horizontal tropospheric gradients

Appendix B: Functional relation between NWM meteorological parameters and GNSS tropospheric model

P20L1-P20L16:"For the Benchmark campaign – (%0.4)." -> This paragraph seems to be better discussing in section 5.

Manuscript changed (the effect of hydrometeors is now presented in Sect 5.5).

P22L13: "TOUGH" -> Is it appropriate to use a project name rather than specific author(s) name?

Manuscript changed (changed to TOUGH Final report by H. Vedel referenced in Sect 3.2).

P24: Table 2. -> Available parameters of German stations are listed as "P, T, Td, RH". However,

"Td" can be calculated using "P, T, and RH". Is there any reason why "Td" is listed only for Germany sites?

Manuscript changed ("Td" was removed from the line for Germany).

P30: Figure 2. "June 4, 2013" -> "June 30, 2013"

Manuscript changed (Figure 2 edited). We added the name of the station on the text and we changed the x axis, putting on it more days for clarifying.

P32: Figure 4 -> It should be nice if the area of the figure is more focusing on the area of the Benchmark campaign.

Manuscript changed (Figure 4 edited).

P33: Figure 5 -> It should be nice if the distance scale and topography of the area are shown.

Manuscript changed (Figure 5 edited).

P34: Figure 6. -> Mark for WVR station is hard to distinguish from that of radiosonde station.

Manuscript changed (Figure 6 edited).

P36: Figure 8 -> Color scale should be identical for both GNSS and NWM.

Color scales are identical for all three comparisons of GNSS vs. NWM, just different scales are used for biases (left plots) and standard deviations (right plots) since the standard deviation can't become negative.

Figure caption: "two numerical weather models" -> "three numerical weather models"

Manuscript changed (Figure caption corrected, three models).