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Atmospheric Measurement Techniques Discussions

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Interactive comment on "On the information content in linear horizontal delay gradients estimated from space geodesy observations" *by* Gunnar Elgered et al.

Anonymous Referee #2

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General comments

As expressed in the title, the manuscript deals with the information content in linear horizontal tropospheric delay gradients estimated from space geodesy observations, namely GPS and VLBI. The topic of the manuscript is highly actual. In past, the tropospheric delay gradients were estimated mainly for improving horizontal positioning (coordinate repeatability), although it was not always clear that it improved the troposphere modelling as the gradient parameters are highly sensitive to other error sources affecting the data analyses. So far, the gradients were also rarely estimated within an operational troposphere monitoring because the information content was often either

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Discussion paper

too noisy or too much smoothed by low temporal resolution or constraints. The situation is going to change in future when providing advanced tropospheric products on troposphere asymmetry monitoring, in particular with upcoming availability of more satellites from multi-GNSS constellations. Tropospheric delay gradients are also pre-requisite for delivering other products from GNSS such as retrieving slant delays, the reconstruction of three-dimensional refractivity field or generating severe weather event indicators. Attempts for developing assimilation techniques for GNSS-based tropospheric gradients emerged recently when it seems preferred way, compared the utilization of slant delays, due to the better production quality in (near) real-time. In this context, the manuscript contributes to a better understanding of how linear tropospheric delay gradients are able to characterize wet and hydrostatic effects of the neutral atmosphere on space geodetic observation analyses; both in actual situation or in a long-term trends and useable in geodetic, meteorological or climatology applications.

Generally, the manuscript is written carefully and results discussed in details. However, several suggestions are given below for completing the manuscript before its publishing.

1. Adding brief introduction of the model of calculating gradients from the NWM would be helpful for discussion of results, e.g. gradient mapping function, distribution of ray-tracing points, elevation angle cut-off.

2. Although the manuscript study a comparison of gradients, there are no information about gradient mapping functions used in estimating procedures of different techniques. Kačmařík et al. 2018 (submitted for discussions in ANGEO) showed that gradient mapping function could introduce systematic effects into estimated gradients. Similarly, no information about elevation-dependent weighting (if applied) was given neither for GPS nor VLBI. Please, add these information in corresponding tables or text paragraphs, and whenever useful, consider their impact in discussions as these might be more critical than the other processing settings.

3. The differences in size of estimated gradients estimated from different techniques are not discussed. These are visible in Figure 9 between GPS and Numerical Weather Model (NWM) and in Figures 11 and 12 for GPS compared to WVR. These could be attributed to various aspects such as used gradient mapping functions, limited resolution of numerical weather model data (ECMWF), observation sampling over the sky or others. Were similar characteristics common to the other stations?

For easier reading, I would also suggest to consider splitting sections 4.2 and, optionally 5.1, into two parts with more specific subtitles for more better clarity of different comparisons, see bellow in specific comments.

Specific comments

P1L11: 15-day long continuous

P2L4: VLBI, GPS and WVR (remove closing bracket).

P2L12: a 4-year period

P2L13: a 15-day long VLBI campaign

P2L20: over long-time scales

P6Tab2: add gradient mapping function and reference frame and PCV values applied (IGS08 or IGS14?)

P6L6: (consider modified wording) . . . estimated gradients are independent in adjacent epochs. . ..

P9L15: . . . as piece-wise linear offsets . . . Do you mean representation with a piece-wise linear function when represented with the interval end-point offsets? Or do you mean just constant offsets for individual intervals? Please, reword or clarify.

P11L5: the overall mean negative north gradients is also partly attributed to the flattening of the earth atmosphere, see Meindl et al. 2004, I suggest to add in the discussion in this paragraph.

P12 Figure 9: discuss the different ranges of gradient sizes,

P13L6: by long-term averaging . . .

P13L18: . . . at this low humidity level . . .

P13L19: I suggest to add here new sub-sections for discussing long-term trends in gradients. I found it confusing when mixed in a single section.

P13L21: a possibility . . .

P13L22: trends in the total amplitude value of the gradients (I don't understand what is meant exactly by the trend in the total amplitude value of gradients. It would be helpful to clarify it here)

P13L22: A positive trend in the amplitude will occur if there is an increase in the variability at the side which can happen even if there are no trend. . . (confused again how to understand the meaning of the sentence).

P15Sec5: Consider modifying Sect 5.1 title by adding WVR so it is easier to distinguish which paragraphs compare GPS to WVR, and GPS to VLBI (5.2). Optionally, split 5.1 into sub-sections dealing with original and averaged comparisons.

P15L5: . . . sites share several error sources . . . (suggest to specify them more)

P16Fig11: I suggest also discussing more ranges of estimated gradients, which seem different for GPS and WVR. GPS gradients are generally smaller. E.g. it could be due to constraining in GPS solution, mapping function, elevation angle cut-off, elevation-dependent weighting or other effects. Similarly, it seems for GPS vs VLBI, where VLBI gradients seem to be more smoothed than GPS, most likely due to the 6-hour temporal resolution.

P16L7: wet gradients from both GPS stations, ONSA and ONS1, . . . (suggesting for a better clarity)

P17Fig12: it seems that giving correlation coefficients in the text is enough, without further need to show both plots which characteristics are the same as in Figure 11.

P18Fig13: Consider merging four plots into a single one with the x-axis ranging in 2013 to 2016

P22L6: we find the wet component of the gradients cause most of the variability. (removed 'to')

P22L15: if small gradient trends . . . (remove plural)

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