Editor comments on manuscript amt-2018-318-version 3 "On the information content in linear horizontal delay gradients estimated from space geodesy observations" by Gunnar Elgered and co-authors.

I think the authors addressed well the major questions and comments raised by the referees. Several new figures and Tables have been added which enhance the purpose and the discussion of the paper. However, due to these additions, the focus on the main questions is sometimes blurred and the reasons and objectives for the various intercomparisons are becoming unclear. I suggest some revisions to smooth the flow of the discussion and sharpen the message. Some points deserved also for further discussion.

General comments:

Goal of the study: it is stated in the Abstract and in the Introduction that the goal is to assess the quality of the GPS gradient estimates based on comparisons with independent data: ECMWF model, WVR and VLBI observations. State more clearly which scientific questions you are addressing and justify the study scenario (why you test several specific processing options) and the use of each of the data sources (how each of the data sources helps you to address part of the questions). The specific advantages/disadvantages and the complementarity of the reference data sources and their uncertainties should be introduced as well.

My feeling is that the study would be better presented as an inter-comparison/inter-validation rather than an assessment of GPS gradients because the gradients from the various reference data sources don't agree very well… I think understanding properly the uncertainties and limitations of all the data sources used in this study is the main point of the paper and it needs to be enhanced. In this respect, I suggest that you also compare the ECMWF wet gradients to the WVR data in Section 5.1. Probably this sub-section should be split in two (as also suggested by one of the reviewers) and the GPS processing tests and the other tests (GPS vs. WVR and ECMWF vs. WVR) might be addressed separately.

Section 4. Comparisons with ECMWF at seasonal scale: two features in the ECMWF gradients are highlighted at ONSA station: 1) the persistent NS hydrostatic gradient and its seasonal variation (with winter maxima); 2) the increased EW wet gradient in summer. The hydrostatic feature is attributed to the influence of the Icelandic low pressure. I think the Icelandic low is not the only pressure system influencing the surface pressure variations in the region and it is located quite a distance to the West from the study area, so its direct influence would rather be in the EW direction. If the main seasonal changes are in the NS gradient, there must be influence of other centres (e.g. Arctic Oscillation), unless the gradients are of a more local nature. Can you elaborate be a bit more on the processes involved and their impact on the regional pressure field (e.g. inspect mean sea level pressure maps from ECMWF analyses and time series of observed surface pressure in Iceland and Sweden, etc.). This would help to better understand the information content in the GPS gradients.

Regarding the 2nd feature, sea breeze circulation is hypothesized which is a rather local phenomenon driven by a temperature and pressure gradient between sea and land. Again, can you be a bit more descriptive and quantitative about the local pressure, temperature, and humidity gradients in the vicinity of the GPS stations to support this assumption? Note that all these variables are available from the ECWMF analyses.

You wrote that the results for the four other stations are identical (except KIR0, so rather write "for the three nearby stations MAR6, SPT0, and VIS0"). However, I would not expect that the changes in the wet gradients are identical because sea breeze is a local feature which depends on the

orientation of the coastline (and not all coastlines in your study area are identically oriented). Please reformulate and be more specific on which features are seen and explained at the other sites.

In Figure 10, the dispersion of the results for each month (which I interpret as internannual variability) is much larger in the GPS series than in the ECMWF series. Can you comment on this feature? Is GPS over-estimating the gradients and their variability or is ECMWF underestimating them?

Section 5 now includes a lot of new material but the objectives and methods become a bit blurred. Please add a short rationale at the beginning of each sub-section and/or before you comment the results. E.g. What is the purpose of including systematically the two collocated GPS stations ONS1 and ONSA in all graphs? Why do you compare both total gradients and wet gradients in this section? (wouldn't be better to separate hydrostatic and wet gradients? Or focus only on wet gradients?).

Water Vapour Radiometer results: the WVR gives much larger wet gradients. Your interpretation is that this is due to the absence of constraints between estimates. I don't understand how the increased variability would increase the amplitude of the mean gradients. Or in the opposite situation, why would adding constraints in the processing change the monthly means? I think it would only reduce the short-term variability. Probably the contamination from liquid water in the measurements is a better explanation (but I am not an expert in these measurements). Could they explain the spikes in Fig. 15 and 17? Did you check the results after a more severe editing of the WVR data?

P20L29: I think the uncertainty due to the mapping function is still critical. The 17% reported by Kacmarik 2018 which you mention would explain about half of the bias seen in Fig. 11. There might also be a similar uncertainty associated with the mapping function used in the estimation of the WVR gradients. Can you comment on this? (btw, the type of mapping function is not specified in Section 3.2).

You conclude that the results for a cutoff angle of 3° are the best, though the difference with a cutoff angle of 10° is very small. Is this difference statistically significant?

P21: "The solution giving the best agreement, when comparing gradients from ONSA and ONS1 data with each other, is the one with elevation dependent weighting, whereas the comparisons with the WVR, for both ONSA and ONS1 give the best agreement without weighting." This result merits further comments and interpretation.

Specific comments:

Please be consistent in the denomination of the gradients throughout the paper. In some places you write "linear horizontal gradients" (e.g. captions of Table4), or "linear gradients" (P18L10), and most of the time "gradients". I think the latter is fine.

Abstract: P1L4-5: "GPS gradients confirm known seasonal effects both in the hydrostatic and the wet components" this sentence suggests that GPS is used to confirm the seasonal feature, but maybe you rather want to write that "GPS is able to reproduce / detect / monitor" the known seasonal effects since the purpose here is to assess GPS… By the way, I have 2 more comments: 1) I am not sure the seasonal effects in delay gradients in this region is something well known (the fact that it is well represented in the ECMWF model doesn't mean that it is well known) and 2) GPS cannot confirm the hydrostatic and wet components because GPS is measuring the total gradients… So this sentence needs be reformulated.

Section 2: I think the basic definitions and modelling of gradients from the paper by Davis et al., 1993, don't need to be repeated here. If you need to refer to specific equations and variables you can cite them from Davis' paper, or alternatively move the equations in an Appendix. In this section, mainly Equation (6) and some text from paragraph P4L7-17 might be kept and moved to the beginning of the section. Additional references worth mentioning because they describe atmospheric processes that can be sensed by the GPS gradients are given below (Koulali Idrissi et al., 2011, and Nahmani et al., 2019).

Figure 1 is a very simplified version of the reality. I suggest that you remove it as also suggested by a reviewer. Furthermore, the numerics that are given in the caption are not used in the text.

Figure 2: add latitude and longitude ticks.

Table 2: add the information on elevation depending weighting

Section 3.2: how many observations are available in each estimation batch? What is the mapping functions used for the ZWD and gradient parameters?

P9L20: "adjacent" -> "successive"?

Section 3: it would be interesting to compare the formal errors for the estimated parameters (ZWD and gradients) from the 3 techniques (GPS, WVR, VLBI).

Figure 9: not easy to see something… Maybe plot just one year for the 6-hourly data. The monthly values are more or less shown in Fig. 10, and the SD values should be given in a table similar to Table 5 (see comment below).

Figure 10: I guess each symbol in the plots is for one year, but why are more than 11 symbols plotted for some of the months? Are the two stations ONSA and ONS1 superposed maybe?

Section 4.2: could focus on wet gradients only

Add a scatter plot of GPS and ECMWF wet gradients (similar to Fig. 13) to compare the range of values from the two data sources.

P18L8: "We assess the data quality…" If you mean the quality of GPS data, this assumes that ECMWF is of higher quality which is probably not the case (this point should be discussed).

P18L15-20: Regarding the positive impact of microwave absorbing material at ONSA and SPT0, statistical significance of the differences between correlation coefficients in Table 4 should be tested to have an objective basis for this statement as the differences are very small. Moreover, it would be good to include results for ONS1 here as it is claimed later (P24-25) that thanks to the different mechanical structure at station ONS1, there is no need for microwave absorber. This has an important practical implication.

P19: Long term trends: did you estimate linear trends directly from the gradient components or from their anomalies? I guess even if the seasonal cycle is small, it should be removed. You don't write if you analyse the GPS gradient trends only. How do they compare to the ECMWF trends? How do the trends for the hydrostatic and wet components differ?

P19L8: "Given that horizontal gradients in general are small and that the larger values typically occur for a short time" how short a time do you mean here? Give numbers and associated processes.

P19L9-10: "An estimated gradient has a direction and from a time series we estimate trends for the east and the north gradients. Combining these two trends … offers the possibility to also search for trends in the total amplitude value of the gradient at the station" => "From the time series of the NS and EW gradient components we can compute trends for the two components but also for the amplitude of the gradient vector (refer to an equation that can be given in section 2 or in the Appendix)".

P19L11-12: "total amplitude value of the gradient" and "total amplitude"… => Remove "total" (amplitude or magnitude involves both components by definition). Instead use "total" when you refer to the sum of the hydrostatic and wet components. But is it really useful to show the amplitude instead of the two components here as in all other sections the two components are shown?

P19L12-15: I don't understand how a trend in amplitude can happen if there is not a trend in the EW or NS components…

P19L15-: the discussion is not easy to follow. It would help if you could include the trend estimates in Table 5.

Table 5: "horizontal wet gradient" -> "wet gradient"

I suggest that you add a similar table but with the ECMWF results. This would help to further document the consistency/differences between the two data sources at regional scale and at different time scales.

Section 5.1: the title could be changed to "test of GPS processing variants" or something similar

P20L29-30: "The uncertainty of the estimated gradient amplitude, to which the assumption of a linear model for the atmosphere is also contributing, is significantly larger." I guess by "a linear model for the atmosphere" you mean a piece-wise linear function of time? However, I don't understand the general meaning of the sentence (what is larger than what? and why?).

P21 and Fig. 11: "wet total gradient" same comments as above => "amplitude of the wet gradient"

Fig. 11: here you could also plot the standard deviations of the 15 min data for each month for the 3 data sources. I am wondering how different the standard deviations are (I guess WVR SDs are much larger). Another option would be to plot the SDs for the 2 components (NS and EW) in a separate Figure in the same format as Fig. 14.

In the captions of Fig. 11: are all these correlation numbers really useful? Here we don't have other stations to compare with (like in Table 4) and other results (Table 5) are given for EW and NS components. I suggest that you remove the numbers. From the figure it is quite clear that the 2 GPS series are in better agreement with each other than with the WVR series.

Fig. 12 and 13 could be merged.

Fig. 13: use the same x and y limits in all plots.

P24, Fig. 14 shows the results for 4 years. Can you comment on the similarities/differences between years?

Could the month-to-month and year-to-year variability in the correlation coefficients shown in Fig. 14 be due to occasional spurious values in the WVR time series?

Fig. 14: here you could add the SDs for the 2 components (NS and EW) to support the idea that the variability in the wet refractivity is larger in summer (P24).

Section 5.2: The title doesn't include ECMWF.

Why do you compare total gradients in Fig. 15? I think it is sufficient to show the hydrostatic gradients in Fig. 16 (very small variability) and compare only wet gradients in Fig. 15. However, it is difficult to distinguish the different data sources in Fig. 15. Maybe consider using different colours, or removing one GPS series, or split in two figures.

P27L4-5: "The left plot in Figure 8 may explain why the north gradient has a larger uncertainty at this specific time". I am not sure I understand the explanation. Can you be more specific?

Table 8: total gradients? 6-hourly data? Please add VLBI-ECMWF.

P27L16: Figure 17 and 18: case study of day 135-136: can you describe briefly the meteorological situation?

P28L4 "Figure 5.2" => Figure 18.

Figure 17: maybe only wet gradients are necessary here. Don't connect the VLBI symbols (it gives the impression that the variation is mis-represented whereas it is just under-sampled).

Fig. 17 could be merged with Fig. 15.

Additional references:

Please see the paper by Koulali Idrissi et al. (2011) who analysed the seasonal variations of GPS gradients in a different region, and the paper by Nahmani et al., 2019, who shows the changes in GPS gradients during the passage of MCSs.

Koulali Idrissi, A., D. Ouazar, O. Bock and A. Fadil, Study of seasonal-scale atmospheric water cycle with ground-based GPS receivers, radiosondes and NWP models over Morocco (2012) Atmos. Res., 104–105, February 2012, Pages 273–291; https://doi.org/10.1016/j.atmosres.2011.11.002

Nahmani, S., Bock, O., and Guichard, F.: Sensitivity of GPS tropospheric estimates to mesoscale convective systems in West Africa, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018-1242, in review, 2019.