Interactive comment on "The use of GNSS zenith total delays in operational AROME/Hungary 3D-Var over a Central European domain" by Máté Mile et al.

We would like to thank referee #1 for his/her valuable suggestions. In the following, you will find our responses, separately for each comment/concern. We are confident, that we can provide a revised version of the manuscript, which is trying to address all of your points.

In black: referee observations
In blue: our response

Anonymous Referee #1
Received and published: 14 January 2019
This paper presents results on the impact in terms of forecast scores of assimilating GNSS ZTD in a convective scale numerical weather prediction model within an experimental framework compatible with operational applications. Many papers have already been published on this subject during the last 15 years. An original aspect of the present study is the application over Central Europe with a specific network of surface stations. This study also examine the interest of using a variational bias correction scheme on the observations which has only been recently assessed by Sanchez-Ariola et al. (2016) and Lindskog et al. (2017). The presentation is clear and the forecast impacts on low level parameters and surface precipitation are consistent with previous published studies. My recommendation is to accept the publication once minor modifications suggested below are taken into account.

P1L12-13: replace "At the end of this article, the conclusion is drawn" by "Finally, conclusion are drawn"
Corrected.
P1L16: replace "System" by "Systems"
Replaced.
P2L2: replace "rely on more the remote" by " rely significantly on remote"
Replaced.
P2L4: replace "taken up" by "included"
Replaced.
P2L15: replace "employing" by "using"
Changed.
P2L17-18: replace "Recently new European" by "Recently a new European"
Replaced.
P2L21: replace "All of these" by "All these"
Replaced.
P2L23: replace "error" by "errors"
Replaced.
P2L24: replace "assay of ZTD bias were examined" by "assessment of ZTD were proposed"
Changed.
P2L25: replace "demonstrated the" by "demonstrated that the"
Replaced.
P2L29: replace "utilized" by " used"
Replaced.
P2L34: replace "the conclusion is drawn" by "conclusions are drawn"
Replaced.
P3L1: replace "Applied" by "Description of"
Replaced.

P3L3: replace "consortia" by "consortium"

Replaced.

P3L6: replace "Meso-NH(?)" by "Meso-NH (Lac et al., 2018)"

Lac, C., Chaboureau, J.-P., Masson, V., Pinty, J.-P., Tulet, P., Escobar, J., Leriche, M., Barthe, C., Aouizerats, B., Augros, C., Aumond, P., Auguste, F., Bechtold, P., Berthet, S., Bielli, S., Bosseur, F., Caumont, O., Cohard, J.-M., Colin, J., Couvreux, F., Cuxart, J., Delautier, G., Dauhut, T., Ducrocq, V., Filippi, J.-B., Gazen, D., Geoffroy, O., Gheusi, F., Honnert, R., Lafore, J.-P., Lebeaupin Brossier, C., Libois, Q., Lunet, T., Mari, C., Maric, T., Mascart, P., Mogé, M., Molinié, G., Nuissier, O., Pantillon, F., Peyrillé, P., Pergaud, J., Perraud, E., Pianezze, J., Redelsperger, J.-L., Ricard, D., Richard, E., Riette, S., Rodier, Q., Schoetter, R., Seyfried, L., Stein, J., Suhre, K., Taufour, M., Thouron, O., Turner, S., Verrelle, A., Vié, B., Visentin, F., Vionnet, V., and Wautelet, P.: Overview of the Meso-NH model version 5.4 and its applications, Geosci. Model Dev., 11, 1929-1969, https://doi.org/10.5194/gmd-11-1929-2018, 2018.

New reference (Lac et al. (2018)) was added. The previous (Lafore et al. (1997)) was also kept and corrected its appearance in the manuscript.

Lafore, J.-P., Stein, J., Asencio, N., Bougeault, P., Ducrocq, V., Duron, J., Fischer, C., Héreil, P., Mascart, P., Masson, V., Pinty, J. P., Redelsperger, J. L., Richard, E., Vilà-Guerau de Arellano, J.: The Meso-NH atmospheric simulation system. Part I: Adiabatic formulation and control simulations. Ann. Geophys., 16, 90–109., 1997.

P3L10: replace "Later major upgrades consisting direct" by "Later, major upgrades consisting of a direct"

Replaced.

P3L12: replace "improvement" by "improvements"

Replaced.

P3L15: replace "(Mahfouf, 1991)" by "(Mahfouf, 1991; Masson et al. 2013)"

Masson, V., Le Moigne, P., Martin, E., Faroux, S., Alias, A., Alkama, R., Belamari, S., Barbu, A., Boone, A., Bouyssel, F., Brousseau, P., Brun, E., Calvet, J.-C., Carrer, D., Decharme, B., Delire, C., Donier, S., Essaouini, K., Gibelin, A.-L., Giordani, H., Ha-bets, F., Jidane, M., Kerdraon, G., Kourzeneva, E., Lafaysse, M., Lafont, S., Lebeaupin Brossier, C., Lemonsu, A., Mahfouf, J.-F., Marguinaud, P., Mokhtari, M., Morin, S., Pigeon, G., Salgado, R., Seity, Y., Taillefer, F., Tanguy, G., Tulet, P., Vincendon, B., Vionnet, V., and Voldoire, A.: The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes, Geosci. Model Dev., 6, 929-960, https://doi.org/10.5194/gmd-6-929-2013, 2013.
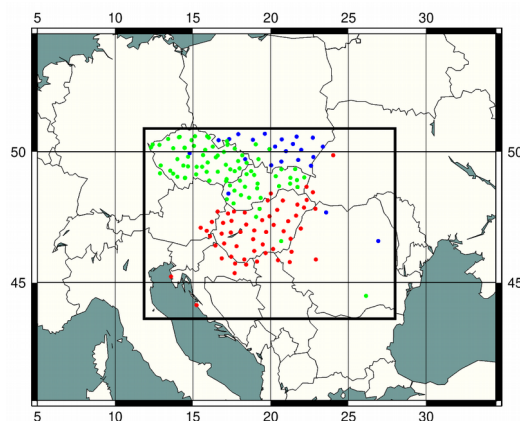
Added.

P3L15-16: remove "called OI_main"

Removed.

P3L17: I suggest to provide the location of the ground based GNSS receivers on this map, instead of the model orography (that is not commented and not necessary)

New figure is added to the manuscript.

P3L18: replace "employs" by "considers"

Replaced.

P4L1 : replace "appiled" by "applied"

Corrected.

P4L4 : It is not clear what are the instruments that are used from NOAA-19 (AMSU-A only or AMSU-A and MHS ?)

Both AMSU-A and MHS from NOAA-19 were used, the related sentence is corrected.

P4L9: replace "(Girard, 1987)" by "(Girard, 1987; Chapnik et al., 2006)"

Chapnik, B., G. Desroziers, F. Rabier and O. Talagrand, 2006 : Diagnosis and tuning of observational error in a quasi-operational data assimilation setting. Quart. Jour. Roy. Meteor. Soc., n ◦ 615, Part B, volume 132, pp 543-565.

New reference is added.

P4L11-12: replace the sentence by "where HK is the product of the linearized observation operator by the Kalman gain, and the DFS scores can be approximated by its trace as (1). The y and y' are the unperturbed and perturbed observations sets"

Replaced.

P4L13: replace "states at the observation space" by "states in the observation space"

Replaced.

P4L19: replace "dates back" by "started in"

Replaced.

P4L20: replace "experiences" by "results"

Replaced.

P4L27: replace "provides the most of ZTD estimated" by "provides most of the ZTD estimates"

Replaced.

P4L30: remove "estimation for"

Removed.

P5L1-2: Explain what is a relative DFS (division by the number of observations). A 2-D pie chart would be more readable

Explained. "The relative DFS is a normalized value by the amount of observations for each observation subset providing the diagnostic information regardless the actual amount and geographical coverage in the assimilation system."

If it's not a big concern, we would prefer to keep the 3D pie.

P5L3-4: As mentioned above (comment about Figure 1). A map showing the GNSS stations would be very useful

Done.

P5L7: replace "with increased observation error" by "with very large observation errors"

Replaced.

P5L8: put "passive" with quotes

Done.

P5L9: replace "without its influence on the analysis" by "without influencing the analysis"

Replaced.

P5L10-13: I propose to reformulate this sentence that is not clear enough: "background check(which is dedicated to reject observations far from model background state) one also needs to ensure that only observations with Gaussian, zero mean and uncorrelated errors are selected in the assimilation (i.e. reliable stations). For that purpose, a specific pre-selection procedure has to be performed by checking passive observation minus first-guess (OMF) departures on a training period. Due to the increased"

It is accepted and reformulated.

P5L13: "Due to the increased" : one can wonder with respect to what ? It would be better just to state "Due to the high"

Replaced.

P5L15: remove "examined"

Removed.

P6L1-2: There is a need to clarify what you mean by "station multiplication". My understanding is that one specific station can be processed by several analysis centre and you have to select the best duple (station/analysis centre)

The sentence is changed according to this remark. "Considering that particular stations can be processed by several analysis centre (we can call it station multiplication) that station/processing centre pair is selected which has the smallest standard deviation of OMF."

P6L2: replace "is also a part" by "is also part"

Replaced.

P6L3: replace "are written in" by "are given in"

Replaced.

P6L6-7: I propose to rewrite as follows: "The actual training period led to the availability of 197 GNSS stations inside the NWP domain (from three different networks). The pre-selection procedure excluded more than 30 % of them, resulting in 122 trusted GNSS stations for active assimilation experiments"

Rewritten.

P6L6-7: Again a map with the location of the stations (all + selected ones) would be useful

Another new figure is added as well. See the figure of all GNSS stations above and another of the selected ones below. The high quality figures are going to be inserted into the manuscript.
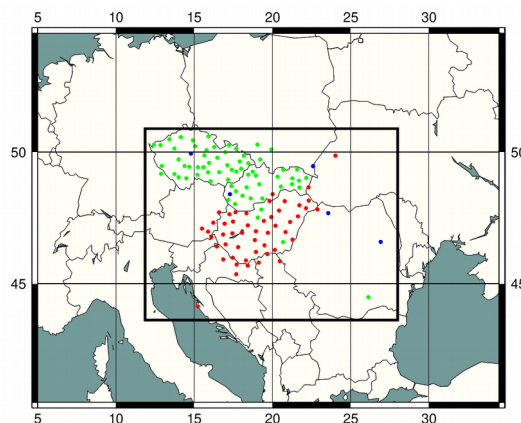
P6L8: replace "coverage issues" by "coverage"

Replaced.

P6L9: replace "than the pre-defined limits" by "than pre-defined limits"

Replaced.

P6L11: replace "station multiplication" by "multiple (station/analysis centre)" See similar comment above

Replaced.

P6L12: "observation error correlations" by "horizontal observation error correlations"

Added.

P6L17: replace "having" by "considering"

Replaced.

P6L19: replace "cheap approach" by " efficient approach"

Replaced.

P6L19: replace "another whitelist is originally" by "a revised whitelist is" You should explain above what you mean by "whitelist" since it has not been defined before.

Replaced and whitelist is explained above. " The selected GNSS stations are written into a specific whitelist which ensures the active assimilation of ZTDs."

P6L22: replace "on Figure 3 20 km" by "in Figure 3, a 20 km" Why not using a curve fitting of the correlation function for an objective estimation of the thinning distance ?

Replaced and the local polynomial regression method (LOESS) was used for fitting a smooth curve. It is now mentioned in the caption of the figure (in the manuscript).
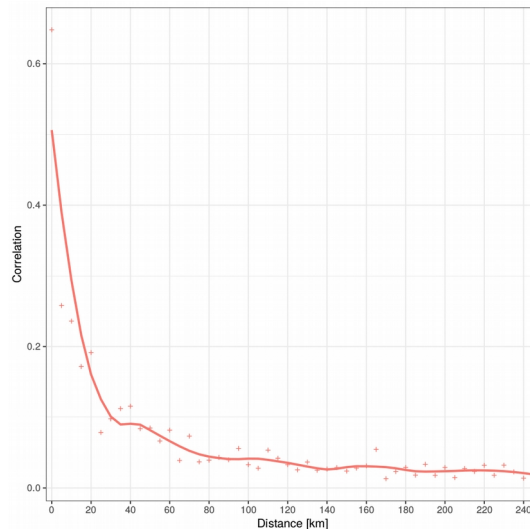
P7L1 : The figure should be improved (horizontal axis unreadable) and the legend should be completed (provide information on the period and on the domain)

The quality of figure is improved (see above).

P7L5: replace "it presumes the" by "it assumes that the"

Replaced.

P7L7: replace "are plotted on Figure 4" by "is plotted in Figure 4"

Corrected.

P7L8: replace "on Figure 5 and 6 that observed" by "in Figure 5 and 6 that the observed"

Replaced.

P7L9: replace "Therefore bias correction" by "Therefore the bias correction"

Replaced.

P7L14: replace "experiments in the Section 5" by "experiments presented in Section 5"

Replaced.

P8L1: Enhance the legend (specify that it is ZTD, provide the period and the domain)

Done.

P8L2: Enhance the legend (specify that it is ZTD). The information given on the horizontal axis is totally unreadable.

Enhanced, the names of GNSS stations are enlarged, and the size of the figure is increased as well.

P8L5: Provide a reference defining the stiffness parameter in terms of VARBC formulation (e.g. a paper by Dick Dee or the ECMWF documentation on data assimilation)

The following reference was added.

"Dee, D. P., 2004: Variational bias correction of radiance data in the ECMWF system. Proceedings of the ECMWF workshop on assimilation of high spectral resolution sounders in NWP, Reading, UK, Vol. 28, 97–112."

P8L7: replace "information in every new analysis" by "information at every analysis"

Replaced.

P9L1: The horizontal axis of the Figure is not readable. Specify that the quantity is

ZTD. replace "purpule" by "purple"

Replaced, the names of GNSS stations are enlarged, and the size of the figure is increased as well.

P9L2: replace "prepare warmstart" by "prepare a warm start"

Replaced.

P9L9: replace "operational setup" by "operational setup (without ZTD observations". It is not clear to me if satellite observations are included in this "operational setup". The confusion comes from P3L18-19 defining the operational configuration. Have the satellite observations only been introduced for the DFS or also for this reference experiment ?

Replaced. Configurations are explained with more details in the manuscript.

"The non-conventional satellite and RADAR observations were added to AROME experimental analyses solely for diagnostic study and they were not considered in the GNSS ZTD observing system experiments."

P9L10: replace "of operational observation set an static bias correction is compared with the reference" by "of the operational observation set an a static bias correction is compared to the reference".

Replaced.

P9L11: replace "employs variational" by "employs a variational"

Replaced.

P9L14: replace "traning" by "training"

Corrected.

P9L15: replace "till" by "until"

Replaced.

P9L18: replace "expected to seen in" by "expected to reflect more on"

Replaced.

P10L1: replace "Outline" by "Summary"

Replaced.

P10L1: specify in the text is EEGPS2 includes or not satellite data

Explained.

P10L2: replace "on Figure 8" by "in Figure 8"

Replaced.

P10L5: replace "error reduction" by "error reduction with respect to the reference"

Replaced.

P10L5-6: "Furthermore, similar results are obtained with the static bias correction, but they are not statistically significant (not shown)"

Corrected.

P10L7: replace "on Figure 9" by "in Figure 9"

Replaced.

P10L7: replace "where the Equitable Threat Score (ETS) and the Symmetric" by "in terms of Equitable Threat Score (ETS) and Symmetric". Please provide a suitable reference for the definition of the SEDI.

Replaced and a reference is added.

"Ferro, C., A., T., and Stephenson, D., B.: Extremal Dependence Indices: Improved Verification Measures for Deterministic Forecasts of Rare Binary Events. Weather and Forecasting, pp 699-713, https://doi.org/10.1175/WAF-D-10-05030.1, 2011."

P10L8: replace "+12 hours precipitation forecasts can be seen" by "+12 hour forecast range"

Replaced.

P10L10: replace "has clear added value" by "has a clear added value". Given the smaller size of the sample for large precipitation amounts this result is maybe not significant. Could you perform a statistical test of significance ?

Replaced.

We agree with this comment. The verification of larger precipitation thresholds might consist very few data which makes the corresponding results less reliable. The applied verification software (Harmonie monitor verification package) doesn't have a tool for test of statistical significance for skill scores and the raw data are also not easily accessible. Therefore, it would be difficult to perform such examination, however, when more thresholds are added to the SEDI verification, the scores are fluctuating for larger precipitation thresholds which is a clear signal of limited data amount (around 1-3 observation-forecast pairs). Therefore, we would like to propose to exclude larger precipitation thresholds (i.e. keep thresholds smaller than 10mm) from the verification of precipitation skill scores and mention this in the manuscript accordingly.
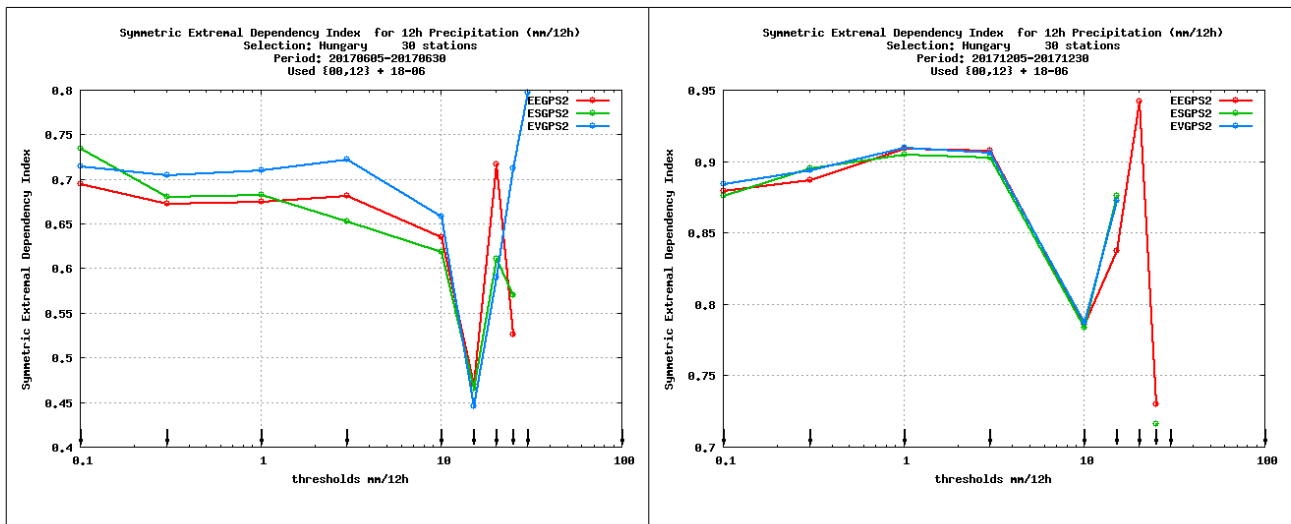

Figure: SEDI with additional 15, 20, 25mm thresholds for summer (left) and winter (right) impact studies.
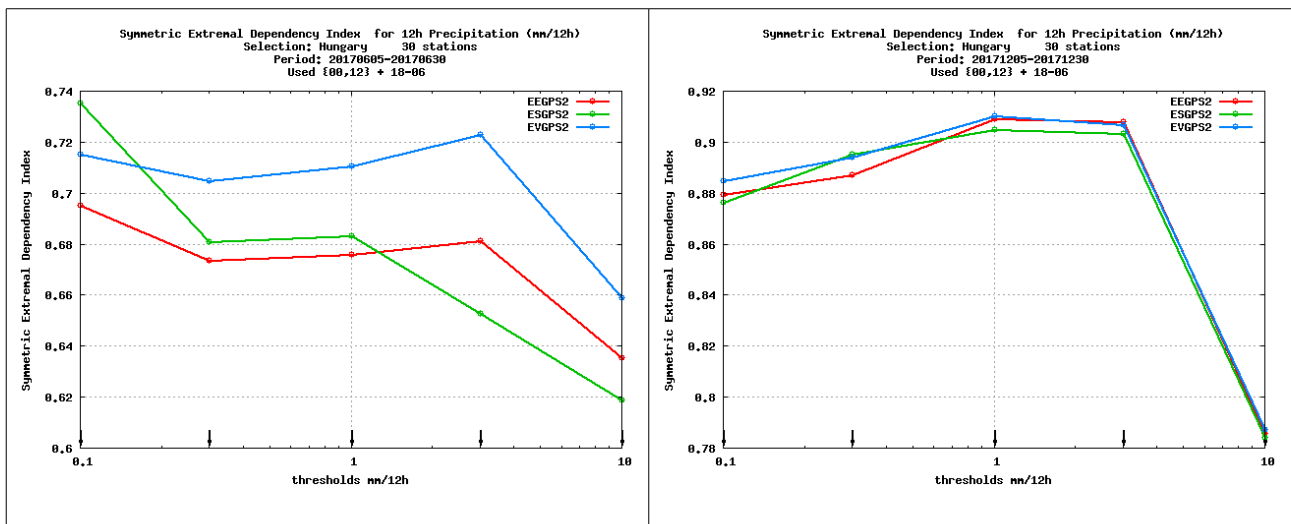

Figure (proposal): SEDI with restricted (below 10mm) thresholds for summer (left) and winter (right) impact studies.

Proposal for modification in manuscript's text.
Original:
"The AROME's precipitation forecasts are verified on Figure 9, where the Equitable Threat Score (ETS) and the Symmetric External Dependency Index (SEDI) (Ferro and Stephenson, 2011) for +12 hours precipitation forecasts can be seen. Overall, for the small precipitation thresholds both ESGPS2 and EVGPS2 can improve the precipitation forecasts, but for higher thresholds only the experiment EVGPS2 with ZTDs and VARBC has a clear added value."

"The AROME's precipitation forecasts are verified on Figure 9, where the Equitable Threat Score (ETS) and the Symmetric External Dependency Index (SEDI) (Ferro and Stephenson, 2011) for +12 hours precipitation forecasts can be seen. Overall, for small (less or equal than 1 mm) precipitation thresholds both ESGPS2 and EVGPS2 can improve the precipitation forecasts, but for 3 or 10 mm thresholds only the experiment with ZTD and VARBC (EVGPS2) has positive impact compared to the reference. Due to the limited number of high precipitation cases, the verification of larger precipitation thresholds (above 10 mm) is not taken into account."

P10L14: The information on the use of 30 stations has to be put in the legend of Figure 7.
The information is added.
P10L14: replace "This is due to taking into" by "Taking into"
Replaced.
P10L15: replace "smaller impact of the relatively" by " a smaller impact given the relatively"
Replaced.
P10L15: replace "employed" by "assimilated"
Replaced.
P10L16: replace "the cause" by "another reason"
Replaced.
P10L16-17: The sentence needs to be clarified since the writing is awkward.
Rewritten. "Furthermore, another reason might be that AROME/Hungary's background errors are derived from an AROME EDA (Ensemble Data Assimilation) which statistics provide more localized increments and sharp background error correlations."
P10L19: replace "chosen to run the second" by "selected to perform a second"
Replaced.
P10L20: replace "as the summer trial" by "as for the summer trial"
Replaced.
P10L21: replace "applied for the" by "applied to the"
Replaced.
P10L22: replace "but has the possibility to" by "but allows to"
Replaced.
P11L1-2: indicate the statistics are performed using 30 SYNOP stations.
Done.
P11L4: replace "to static bias correction. Examining" by "to the static bias correction. By examining"
Replaced.
P11L4: replace "on Figure 10" by "in Figure 10"
Replaced.
P11L5-6: replace "obtained in summer period is slightly remained for short-ranges" by "obtained for the summer period slightly remains at short-ranges"
Replaced.
P11L6: replace "slightly" by "slight"
Corrected.
P11L7: what do you mean by "for one or two forecast ranges" ?
Explicitly written. "...statistically significant for +3 hour T2m forecast and for +1, +2 hour Rh2m forecast ranges."
P11L8: what do you mean by "overfitting issues" ?
Overfitting of the observations in the assimilation by the inaccurate and most probably too small observation errors. Sentence was corrected to "observation overfitting".
P11L9: replace "were overestimated by the" by "are overestimated using the". If observation errors are too large, it should not lead to an "overfitting". Please clarify

The observation error is estimated (not overestimated) which means we computed ZTD observation errors (and the whitelist) on the spring training period and that might not be accurate for the winter period. We assume that observation error is probably smaller (than it should be), according to the verification results.

P11L9: replace "the impact of other forecast parameters was" by "the impact on other forecast parameters is"

Replaced.

P11L10: replace "to summer" by "to the summer"

Replaced.

P11L11: replace "include" bu "show". replace "This is positive" by "The impact is positive"

Replaced.

P11L12: replace "3mm" by "3 mm"

Replaced.

P11L12-13: "Similarly to the summer OSE, the value of an adaptive bias correction is confirmed by the results of the winter trial as well"

Corrected.

P11L14: replace "SYNOP stations, therefore overall results show neutral" by "SYNOP stations. Indeed, overall results show a neutral"

Replaced.

P12L5-6: reformulation of the sentence: "The potential and importance of this observation type was shown through DFS diagnostics. This is particularly relevant in data assimilation systems with a high frequency analysis cycle"

Replaced.

P12L7: replace "having potential" by "have the potential"

Replaced.

P12L8: remove "As ZTD observations are by default blacklisted"

Removed.

P12L8: replace "the pre-selection procedure of the trusted GNSS" by "A pre-selection of reliable GNSS"

Replaced.

P12L8-9: replace "has to be done" by "has been done"

Replaced.

P12L9: replace "sufficiently cover the wider area" by "cover sufficiently a wide area" (this has to be presented in a Figure plotting the stations)

Replaced. Figure is added (see above).

P12L12: replace "without risking" by "and to avoid"

Replaced.

P12L13: what do you mean by "separate correction" ? a specific correction for each (station/analysis centre) ?

Corrected.

P12L14: replace "debiasing" by "removing the bias of"

Replaced.

P12L15: replace "GNSS data has positive" by "GNSS data have a positive"

Replaced.

P12L16: please clarify what you mean by "if bias information is also up-to-date" ? This was not the case in winter

This part of the sentence was not appropriate and does not necessary. Removed.

P12L16: replace "The observation impact in the verification of" by "This positive impact on forecast scores during the"

Replaced.

P12L17: replace "using only" by "given the"

P13L1: replace "12 hours" by "12 hour". Replace "cummulation" by "accumulation"

P13L4: replace "when" by "using the". Remove "was employed"

P13L4: replace "but with" by "whereas with the"

P13L8: replace "concluded that" by "concluded that the"

P13L11: replace "smaller" by "small"

P13L13: "an improved stiffness parameter might be investigated in order to allow more flexibility to the system"

P16L1: replace "12 hours" by "12 hour". Replace "cummulation" by "accumulation"