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Reply on RC2

Vladimir B. Belakhovsky et al.

Author comment on "Influence of different types of ionospheric disturbances on GPS signals at polar latitudes" by Vladimir B. Belakhovsky et al., Ann. Geophys. Discuss., <https://doi.org/10.5194/angeo-2020-93-AC3>, 2021

We thank to the referee 2 for interest to our paper, careful reading and helpful comments and remarks. Below are our answers to the remarks.

Edition board asks us not to upload corrected manuscript with this answer. We will upload the corrected manuscript to the special link as I understand.

Reviewer:

«My main concern is about the meaning of the phase scintillation index...»

Answer:

We agree with the referee that the problem of the GNSS signal detrending for the high-latitude disturbances is actual, the fixed cut-off frequency is not always able to remove the refractive (deterministic) effects at high latitudes. At the same time the choice of the optimal cut-off frequency is still open problem.

There are a lot of papers and results since [Fremouw et al., 1978] where the standard cut-off frequency (0.1 Hz) was used. So the classic definition of the phase and amplitude scintillation indexes already is established in literature.

The best way in this situation in our opinion is to introduce new scintillations indexes. Therefore, there will be clarity through the researchers. For example [Mushini, 2012] introduced improved phase-scintillation index, σ_{chainr} [Forte, 2005] introduced $S\phi$ index.

We kept our events and we used the standard cut-off frequency (0.1 Hz) for the detrending. We mentioned in the paper about problem of the GPS signal detrending, we wrote that the term "phase scintillation index" used in our study means the phase fluctuations due to the presence of large-scale irregularities.

- Fremouw E.J., Leadabrand R.L., Livingston R.C., Cousins M.D., Rino C.L., Fair

B.C., Long R.A. Early results from the DNA wideband satellite experiment—complex-signal scintillation // Radio Sci. 13(1):167–187. doi:10.1029/RS013i001p0016, 1978.

- Mushini S.C., Jayachandran P.T., Langley R.B., MacDougall J.W., Pokhotelov D. Improved amplitude and phase-scintillation indices derived from wavelet detrended high-latitude GPS data // GPS Solutions, vol. 16, no. 3, pp. 363-373, <https://doi.org/10.1007/s10291-011-0238-4>, 2012.

- Forte B. Optimum detrending of raw GPS data for scintillation measurements at auroral latitudes // Journal of Atmospheric and Solar-Terrestrial Physics. 67. 1100–1109. 2005.

This text we pasted to the Introduction:

«In order to calculate scintillation indices a long-term trend caused by the satellite motion in relation to the receiver and ionosphere changes needs to be removed. A standard cutoff frequency (0.1 Hz) is commonly used for signal detrending since [Fremouw et al., 1978]. This cutoff frequency is adequate for the equatorial and midlatitude ionosphere. But the high-latitude ionosphere is characterized by the high and variable ionospheric drift velocity (~100 m/s–1 500 m/s). The value of the cutoff frequency affects on the phase scintillation index. So it often leads to the strong phase scintillations without amplitude scintillation. Some researchers to solve this problem introduce new scintillation indexes: [Mushini et al., 2012] introduced improved phase-scintillation index (σ_{chain}), [Forte, 2005] introduced S_{ϕ} index. The fast iterative filtering signal decomposition technique was used to find optimal cutoff frequency [Ghobadi et al., 2020; Spogli, 2021].

In our paper we use the standard detrending (0.1 Hz) in order to be able to compare our results with previous results obtained with using GPS receiver of Oslo University on Svalbard [Clausen et al., 2016; Jin et al., 2015, 2016, 2017, 2018]. So term “phase scintillation index” used in our study means the phase fluctuations due to the presence of large-scale irregularities (above the Fresnel radius)».

Reviewer:

«Are you applying an elevation mask to minimize the multipath?

Did you project the scintillation indices to the vertical to minimize the geometrical effects as suggested by Spogli et al. (2013)»

Answer:

We did not apply an elevation mask to minimize the multipath. We did not project the scintillation indices to the vertical to minimize the geometrical effects.

We use the data of the same GPS receiver on Svalbard that was used in other papers published in rating journals. So we apply the same data processing in order to be able to compare our results with results in other papers.

- Clausen L. B. N., Moen J. I., Hosokawa K., Holmes J. M.: GPS scintillations in the high latitudes during periods of dayside and nightside reconnection, *J. Geophys. Res.*, 121, 3293–3309, <https://doi.org/10.1002/2015JA022199>, 2016.

- Jin Y., Moen J. I., and Miloch W. J.: On the collocation of the cusp aurora and the GPS phase scintillation: A statistical study, *J. Geophys. Res.*, 120, 9176–9191, <https://doi.org/10.1002/2015JA021449>, 2015.

- Jin Y., Moen J. I., Miloch W. J., Clausen L. B. N., and Oksavik K.: Statistical study of the GNSS phase scintillation associated with two types of auroral blobs, *J. Geophys. Res.*, 121, 4679–4697, <https://doi.org/10.1002/2016JA022613>, 2016.

- Jin Yaqi, Zhou Xiaoyan, Moen Jøran I., Hairston Marc. The auroral ionosphere TEC response to an interplanetary shock // *Geophysical Research Letters*, Vol. 43, Issue 5, pp. 1810-1818. <https://doi.org/10.1002/2016GL067766>. 2016.

- Jin Y., Moen J. I., Oksavik K., Spicher A., Clausen L. B.N., Miloch W. J. GPS scintillations associated with cusp dynamics and polar cap patches: *J. Space Weather Space Clim.*, 7, A23. <https://doi.org/10.1051/swsc/2017022>, 2017.

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- Jin Y., Moen J.I., Spicher A., Oksavik K., Miloch W. J., Clausen L. B. N., et al. Simultaneous rocket and scintillation observations of plasma irregularities associated with a reversed flow event in the cusp ionosphere, *Journal of Geophysical Research*, 124, 7098–7111. <https://doi.org/10.1029/2019JA026942>. 2019.

- Chernyshov A.A., Miloch W.J., Jin Y., Zakharov V.I. Relationship between TEC jumps and auroral substorm in the high-latitude ionosphere, *Scientific Reports*. 10:6363. <https://doi.org/10.1038/s41598-020-63422-9>. 2020.

Reviewer:

«Minor comments: ...»

Answer: It is corrected.