Editorial Board and Referee #2
Atmospheric Measurement Techniques, EGU

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AMT-2022-57

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Dear Referee #2,

Thanks for your comments on AMT-2022-57 "Detection and Localization of F-layer Ionospheric Irregularities with Back Propagation Method Along Radio Occultation Ray Path". The authors have considered them, and this document contains our answers.

An updated manuscript with modifications based on the comments of both reviewers will be made available soon.

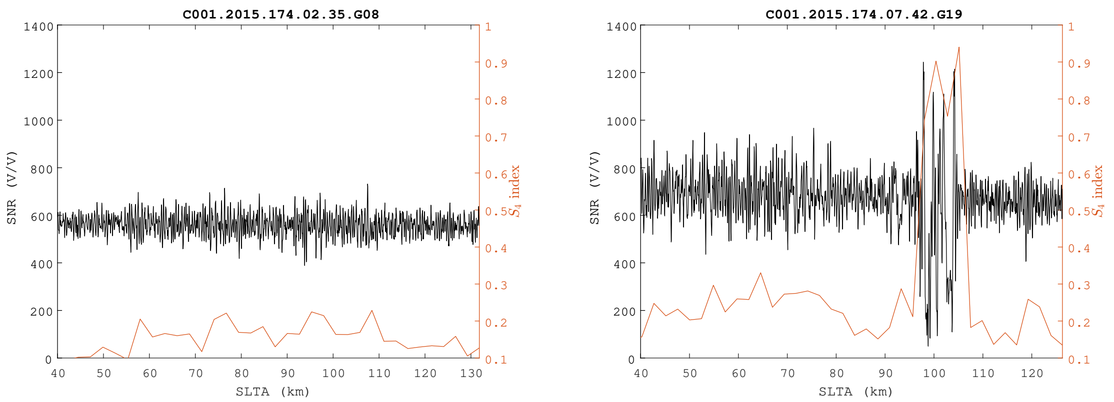
Best regards,
Authors

Referee's comment
This paper investigates the detection and localization of F-layer ionospheric irregularities with the back propagation (BP) method.

The most confusing me is that the authors listed the observations of the sporadic E layers from two COSMIC RO measurements in the 4.3 Analysis COSMIC occultations results, while Section 3 is the simulation of plasma bubbles in the F-region with the BP method. They even did not analyze the sensitivity level and estimation accuracy of sporadic E-layers since it is beyond the scope of this study (line 238). What is section 4.3 meant to explain? This may indicate that two or more irregularity regions occurred in the E region, but not the F-layer ionospheric irregularities.

I suggest the authors analyze the F-layer ionospheric irregularities from the COSMIC RO measurements and compare the simulations and observations to validate the detection and localization estimate with BP method along radio occultation ray path. Otherwise, conclusions made here are not very convincing through only simulations. That is my main comment.

Authors' reply:
Fig. R1 shows the SNR for the two COSMIC occultation events discussed in Section 4.3.



(a) (b)

Fig. R1: COSMIC occultation events in DOY 174, 2015 presented in Section 4.3: SNR (black) and S_4 index (red) in different tangent heights.

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The SNR in Fig. R1(a) does not give a clear indication of scintillation due to sporadic-Es, either by containing one or multiple u-shape fades as presented in the following reference:

- Yue, X., Schreiner, W. S., Zeng, Z., Kuo, Y.-H., Xue, X., "Case study on complex sporadic E layers observed by GPS radio occultations," *Atmospheric Measurement Techniques*, 8(1), 225–236, 2015. https://doi.org/10.5194/amt-8-225-2015.

The disturbance seems to have a stable variance and its overall pattern is similar to the cases reported in:

- Wickert, J., Pavelyev, A. G., Liou, Y. A., Schmidt, T., Reigber, C., Igarashi, K., Pavelyev, A. A., Matyugov, S. S., "Amplitude variations in GPS signals as a possible indicator of ionospheric structures," *Geophysical Research Letters*, 31(24), L24801, 2004. https://doi.org/10.1029/2004GL020607¡/div¿

However, the characteristics of a sporadic-E scintillation case are observed in Fig. R1(b). An u-shape fade is observed around 100 km SLTA. This altitude is within the common range for sporadic-E occurrences, increasing the likelihood that the disturbance layer is aligned with the propagation direction (Zeng et al., 2010). The S_4 index value is considerably stable outside the SLTA range affected by the u-shaped fade and, therefore, presumably unrelated to the sporadic-Es.

In Fig. 15, the detrended BP amplitude standard deviation (red curve) was computed outside the altitude range for sporadic Es. Therefore, we reduced the chances of having the estimation contaminated by sporadic-E irregularities. The same methodology was described by Cherniak et al. (2019). We will add this discussion to the revised manuscript.

The results of the BP method in simulations assuming two irregularity regions in the F-region (Fig. 11, 12, 14) show σ_u curves resembling the pattern observed in BP results of the two COSMIC occultation events. Thus, the hypothesis of disturbances observed outside the sporadic-E regions being caused by F-region irregularities is plausible in these measurements.

Nevertheless, we would like to stress the importance of collocating occultation events to other techniques in future studies. In this manuscript, we have used occultation events previously investigated in publications applying the BP method.

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Referee's comment
The descriptions about back propagation are too brief and incomplete in the text. Some recent similar work should also be referenced and mentioned. Figures 1 and 2 (but not limited to) are difficult for the reader to understand without detailed captions. Please add appropriate content and improve the diagram to make it easier for readers to read.

Authors' reply:
Following your recommendation, the section describing the BP method has been modified. We hope the changes are satisfactory and have made the text more comprehensive.

Next, a search was made to collect related publications in the platform Scopus using the following search string:

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ALL(("backpropagation" OR "back-propagation" OR "back
propagation") AND ( "radio occultation" ) AND (ionospher*))
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All references containing the theoretical definitions for the method are already cited in the manuscript. Newer publications focus on the method's application and not on the theoretical background. Among these, the following references will be added in the upcoming manuscript version:

- Carrano, C. S., Groves, K. M., Mcneil, W. J., Doherty, P. H. (2012). "Scintillation Characteristics across the GPS Frequency Band," *25th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS)*, 1972–1989, Nashville, TN, September 2012.
- Carrano, C. S., Groves, K. M., Delay, S. H., Doherty, P. H., "An inverse diffraction technique for scaling measurements of ionospheric scintillations on the GPS L1, L2, and L5 carriers to other frequencies," *Institute of Navigation International Technical Meeting (ITM)*, 709–719, San Diego, CA, January 2014.
- Sokolovskiy, S., Schreiner, W. S., Zeng, Z., Hunt, D. C., Kuo, Y.-H., Meehan, T. K., Stecheson, T. W., Mannucci, A. J., & Ao, C. O., "Use of the L2C signal for inversions of GPS radio occultation data in the neutral atmosphere," *GPS Solutions*, 18(3), 405–416, 2014. https://doi.org/10.1007/s10291-013-0340-x

Finally, we have made minor modifications to the diagrams shown in Fig. 1 and 2, and rewrote their captions.

Referee's comment
Please add appropriate text captions in Figures 6 and 7.

Authors' reply:
The text captions have been rephrased to describe better these figures and others introduced at a later point in the document.

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Referee's minor comments
`Lines 41-42`: Please reexamine carefully, it seems difficult to derive this description from the literature you cited.

We have added the following reference to complement the initial citation:

- Cherniak, I. and Zakharenkova, I., "High-latitude ionospheric irregularities: differences between ground- and space-based GPS measurements during the 2015 St. Patrick's Day storm," *Earth, Planets and Space*, 68(136), 2016. https://doi.org/10.1186/s40623-016-0506-1

`Figure 6`: The last number on the Y-axis, 0, is half missing. Other pictures have similar problems. Please check it.

We have updated all figures showing simulation results. The overall quality of the figures has been improved.

`Lines 222-223`: I don't know how did you arrive at this "$\sigma_{\Delta\rho/\rho} = 3.0\%$ represents $S_4 < 0.1$". In addition, please show the reference or basis for the low scintillation threshold ($S_4 = 0.2$).

The S_4 index value was calculated at the LEO orbit plane after the forward propagation assuming $\sigma_{\Delta\rho/\rho} = 3.0\%$. We will add the following references to the manuscript to motivate the threshold $S_4 \leq 0.2$:

- Béniguel, Y., Romano, V., Alfonsi, L., Aquino, M., Bourdillon, A., Cannon, P., Franceschi, G. de, Dubey, S., Forte, B., Gherm, V., Jakowski, N., Materassi, M., Noack, T., Pozoga, M., Rogers, N., Spalla, P., Strangeways, H. J., Warrington, E. M., Wernik, A. W., Zernov, N. (2009). Ionospheric scintillation monitoring and modelling. *Annals of Geophysics*, 391–416. https://doi.org/10.4401/ag-4595;

- Ma, G., Hocke, K., Li, J., Wan, Q., Lu, W., Fu, W. (2019). GNSS Ionosphere Sounding of Equatorial Plasma Bubbles. *Atmosphere*, 10(676), 1–11. https://doi.org/10.3390/atmos10110676.

Below such a threshold, disturbances produced by other sources can be similar to weak ionospheric scintillation.

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`Line 242`: by what threshold values are the irregularities still detectable?

We establish that irregularities are detectable as long as $\sigma_0 = 0.0456$, defined after the receiver noise level considered in our study, i.e., $\sigma_u > \sigma_0$. Nevertheless, the receiver noise of each system bounds this threshold. This statement will be made more explicit in the updated manuscript.

General comment:
Comments not listed in the document will be addressed in the revised manuscript.

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