RC1: 'Comment on angeo-2022-14', Anonymous Referee #1, 29 Jun 2022

Replies to Reviewer 1

Reviewer's report on the manuscript by Prykryl et al. titled "Multi-instrument observations of polar cap patches and traveling ionospheric disturbances generated by solar wind Alfvén waves coupling to the dayside magnetosphere" (manuscript #: angeo-2022-14)

In this manuscript, the authors try to show a close relationship between the solar wind Alfvén waves and the polar cap patches / traveling ionospheric disturbances, using multiple events based on the observation by the RISR IS radar, ground-based magnetometers, GNSS receivers, and SuperDARN radars. The topic itself is scientifically interesting, although several points should be improved. I consider that the following points should be addressed and revised before the manuscript is ready for publication in the Annales Geophysicae journal.

Reply: *We appreciate your comments and suggestions for improvements. We considered them all and revised the manuscript accordingly. Below we provide our replies (in italics) to individual points.*

Overall comments:

1. Interpretation of the data. The authors demonstrate that the TIDs are generated only by the Joule Heating due to the dayside ionospheric currents. These days it is not a generally accepted idea. The TIDs are highly correlated with the lower atmospheric disturbances (e.g., Frissell et al., 2016). I am also surprised to see that the manuscript includes minimal discussion. The authors should add the discussion section, cite the related papers such as those mentioned in this report, and discuss the differences between the current events and the previous studies.

Recent progress of the TID studies using the SuperDARN is summarized in the review paper by Nishitani et al. (2019). I recommend that the authors check this paper.

Reply 1: *Although some discussion was distributed in specific sections, we fully agree that the Discussion section is needed to summarize and compare our results with previous studies. It is now included in Section 4. This includes references to papers that provided various interpretations of TIDs and pointed to sources other than high-latitude ionospheric currents. Of course, the above papers, particularly the comprehensive 2019 paper, should not have been missed. It is now quoted several times throughout the manuscript. However, we believe that the presented case studies of equatorward propagating TIDs observed by SuperDARN and GNSS receivers clearly point to sources of gravity waves in the dayside high-latitude ionosphere, the ionospheric currents modulated by solar wind Alfvén waves. This is particularly evident in Fig. 9d and is consistent with previously published results (Prikryl et al., 2005).*

2. Definition of the LSTID / MSTID. The manuscript states that the LSTIDs have greater than 10000 km. I am not certain how the authors can distinguish between LSTIDs and MSTIDs in Figure 9. The authors need to add a more detailed description. In addition, I am not sure whether the LSTIDs observed by the SuperDARN radar and pointed out in the text are actually LSTIDs. Lines 261-262 state, "Figs. 9a-d show TIDs observed in the detrended vertical vTEC and the radar ground-scatter power focused and defocused by

TIDs moving equatorward." The LSTID wavelength greater than 1000 km cannot produce focusing / defocusing of the radar waves. LSTIDs are supposed to be observed in the Doppler velocities of the ground scatter data. For example, Hayashi et al. (2010) showed that the SuperDARN Doppler velocities changes in the ground scatter data are consistent with the GNSS TEC data in the framework of the propagation of atmospheric gravity waves.

Reply 2: *In the Introduction we referred to previous studies that provided definition of LSTIDs/MSTIDs: "Large-scale TIDs (LSTIDs) generally propagate at speeds between 400 and 1,000 ms−1, have wavelengths greater than 1000 km, and periods of 30 - 180 min, while medium-scale TIDs (MSTIDs) tend to propagate at speeds of 250 - 1,000 ms−1, and have wavelengths of several hundred kilometers and periods of 15 - 60 min (Francis, 1975; Hunsucker, 1982; Zhang et al., 2019)."*

We agree that it may not be possible to strictly distinguish between MSTIDs and LSTIDs, because of a continuum of sizes and periods. But we disagree with the statement that LSTIDs with wavelengths greater than 1000 km cannot focus HF radio waves. The electron enhancements, particularly when slanted as in TIDs, would certainly refract the radio waves, and focus them to produce enhanced ground scatter power. Of course, we agree that TIDs can also be observed in the variations of *Doppler velocities changes in the ground scatter data as shown and correlated with the GNSS TEC in the quoted paper by Hayashi et al. (2010, their Figs. 4 and 5). However, their equatorward propagating LSTIDs (Events 1 and 2) can also be clearly identified in the ground scatter power (https://cicr.isee.nagoya-u.ac.jp/web1/superdarn/sddata/hokql/gif/hok/2006/bm00/20061215_hok_bm00_ql.gif), although not shown or discussed by the authors. This is in contrast with their poleward propagating LSTID Event 3 that they observed both in TEC and Doppler velocity, but that does not seem to be observed in the ground scatter power.*

3. Lines 144-145 say, "Fig. 3 shows the ionospheric currents (EICs) mapped in geographic coordinates…." It is strange that later in the manuscript, Figures 16-18 are plotted in AACGM (geomagnetic coordinates). I do not understand why the authors plot the same (e.g., EIC) data in different coordinates in one manuscript. It will cause serious confusion among the readers. I strongly recommend plotting the data in the same coordinate system.

Reply 3: *Figures 16-18 that can be compared with Fig. 4 are shown in geomagnetic coordinates, which are also used in our previous study (Prikryl et al., 2016) that we are citing. Other figures in the present paper, particularly the RISR data (Fig. 2), PIFs (Figs. 6 and 7), EICs (Figs. 3, 5, etc.) and TEC maps (Figs. 11 to 14) are all using geographic coordinates. Unfortunately, we cannot provide all figures in AACGM coordinates, and we do not believe it is necessary to do that.*

Individual comments:

Lines 128-129 and Figure 2: Please describe the RISR-C and RISR-N field of views (beam positions). Otherwise, the readers cannot understand what the authors mean.

Reply: *Reference to Gillies et al., (2016; see, their Fig. 1) is provided. Also, geographic maps (Fig. 3, etc) show RISR velocity vectors.*

Lines 138-140: “The first few patches (enhancements in Ne) that were observed by RISR-N between 16:00 and 17:00 UT were not detected by RISR-C (Fig. 2a). This implies that the cusp was in the RISR-C FoV since polar patches are known to be produced by flow channels in the cusp.” I do not understand these sentences. Maybe something is wrong. Please check.

Reply*: The first sentence is modified: ”The first few patches (enhancements in N_e) started to be observed by RISR-N north of 75°N between 16:00 and 17:00 UT and were not detected by RISR-C (Fig. 2a).”*

Lines 146-147: “The GPS ionospheric pierce points (IPPs) at 110 km shown as circles scaled by the CHAIN GPS phase variation values, σΦ, are discussed in Section 3.3.3.” – I wonder why the authors set the pierce points at 110 km. Obviously, the electron density is higher in the F-region than in the E-region, and so is the amplitude of scintillations. By the way, I cannot find section 3.3.3.

Reply: *Both the EICs and IPPs are mapped at 110-km altitude to show that, in the auroral zone, IPPs of strong GPS phase scintillation are largely collocated with the electrojet currents (Prikryl et al., 2016; 2021). This is because, as discussed by the latter authors, there is a relation between vertical currents (Jz; not shown in the present paper) and strong GPS phase scintillation (variations) that map to upward or downward Jz, or near the reversal boundaries between downward and upward Jz, as would be expected for scintillation being caused by ionization due to precipitating electrons, which can maximize at lower than F-region altitudes. In section 3.3, the focus is on polar cap patches, so the occurrence maps of GPS variation occurrence are shown for 350-km altitude. The question of the actual altitude where the GPS scintillation originates has not been fully resolved.*

Line 185: “were” – is it “which were”?

Reply: *Agree. This is now corrected.*

Figure 9 and Lines 266-267 (as well as other corresponding lines): Are the ground scatter ranges plotted the same way as the ionospheric scatter? If so, it will cause a severe misunderstanding among the readers. If the ground scatter comes from a 1-hop propagation mode, then the focusing / defocusing point should be the mid-point between the radar and the backscatter region (for 2+ hops the geometry becomes more complicated). It is not appropriate to plot the SuperDARN echo data with the range set to the backscatter point, together with the GNSS TEC data with the same range.

Reply*: Agree. Fig. 9 is modified showing the ground scatter mapped range using mapping discussed by Bristow et al. (1994) and Frissell et al. (2014).*

Figure 4 caption: There is no description of the SuperDARN convection map.

Reply: *The missed description is now added.*

References:

Prikryl, P., et al. (2016), GPS phase scintillation at high latitudes during the geomagnetic storm of 17–18 March 2015, J. Geophys. Res. Space Physics, 121, doi:10.1002/2016JA023171.

Prikryl, P., J. M. Weygand, R. Ghoddousi-Fard, P. T. Jayachandran, D. R Themens, A. M. McCaffrey, B. S. R. Kunduri, L. Nikitina, Temporal and spatial variations of GPS TEC and phase during auroral substorms and breakups, Polar Science, Vol. 28, 2021, 100602. https://doi.org/10.1016/j.polar.2020.100602

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Frissell NA, Baker JBH, Ruohoniemi JM, Greenwald RA, Gerrard AJ, Miller ES, West ML (2016) Sources and characteristics of medium-scale traveling ionospheric disturbances observed by high-frequency radars in the North American sector. J Geophys Res Space Physics 121:3722–3739. https://doi.org/10.1002/2015JA022168

Hayashi H, Nishitani N, Ogawa T, Otsuka Y, Tsugawa T, Hosokawa K, Saito A (2010) Large-scale traveling ionospheric disturbance observed by SuperDARN Hokkaido HF radar and GPS networks on 15 December 2006. J Geophys Res 115:A06309. https://doi.org/10.1029/2009JA014297

Nishitani, N., Ruohoniemi, J.M., Lester, M. et al. Review of the accomplishments of mid-latitude Super Dual Auroral Radar Network (SuperDARN) HF radars. Prog Earth Planet Sci 6, 27 (2019). https://doi.org/10.1186/s40645-019-0270-5