Statistical and event analysis of phase and amplitude scintillations associated with polar cap patches

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Abstract

Global navigation satellite systems (GNSS) or satellite navigation is an important technological advancement; however, it is greatly impacted by the effects of space weather, such as ionosphere scintillation. Ionosphere scintillation is one of the causes of errors in the GNSS signals and also has the potential to cause a loss of access to GNSS. Ionosphere scintillation often impacts the polar region; however, the cause is not always known. One potential source of scintillation is polar cap patches. In Ren et al., [2018], a polar cap patch database was created based on the incoherent scatter radar measurements at Resolute Bay (RISR). Using data provided by the CHAIN Network of ionosphere scintillation detected near Resolute Bay in 2016, it can be determined how polar cap patches impact ionosphere scintillation. A statistical analysis as well as event analysis have been performed. Scintillation data from GNSS satellites with an elevation angle over 40 degrees were collected from each patch in the database and were compared to daily average. It was found that statistically there is no obvious phase scintillation or amplitude scintillation increase associated with patch in the polar cap. For the event analysis, three different patch events with and without enhanced scintillation were chosen for in-depth analysis and cross-comparison. Other datasets, including AMPERE FAC and RISR, are used to understand the plasma characteristics and geomagnetic activity conditions during these events.

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Abstract

- Ionospheric scintillation is one of the causes of errors in the GNSS signals and has the potential to cause a loss of access to GNSS.
- **Figure 1** shows a visual representation of the impacts of ionospheric scintillation
- One potential source of scintillation is polar cap patches.
- Using a polar cap patch database provided by Ren et al. [2018] and scintillation data from 2016 provided by CHAIN, it can be determined how polar cap patches impact ionospheric scintillation.
- It was found that statistically there is no obvious phase scintillation or amplitude scintillation increase associated with patch in the polar cap. For the event analysis, three different patch events with and without enhanced scintillation were chosen for in-depth analysis and cross-comparison.

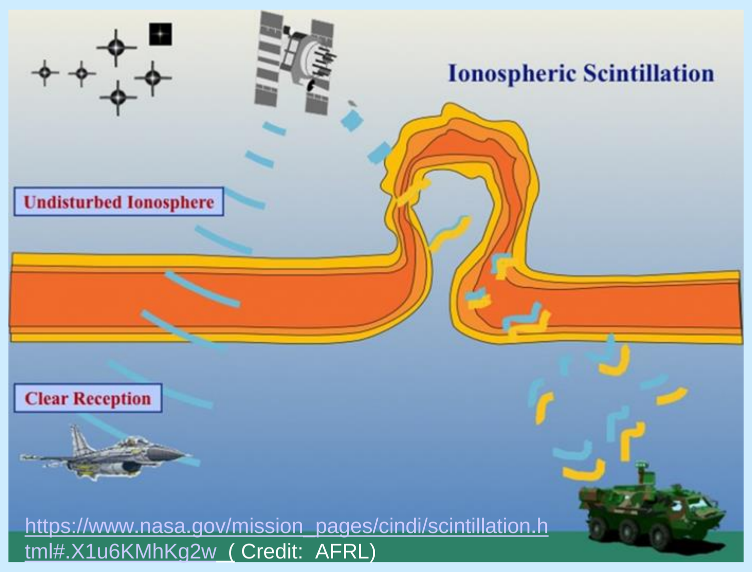

Figure 1: Representation of ionosphere scintillation, a signal passes cleanly through an undisturbed ionosphere, but is disrupted in a disturbed ionosphere causing loss of lock or noise (Credit: AFRL)

Statistical Analysis

Canadian High Arctic Ionospheric Network (CHAIN) GPS receiver collocated with RISR-N provided the phase and amplitude scintillation data for 408 patches in 2016. In order to exclude multi-path effects and identify scintillation close to the RISR-N beam that was used to detect patch, the ionospheric pierce points (IPPs) that corresponded to an elevation angle higher than 40 degrees were used. **Figure 2** shows the amplitude scintillation difference between the daily average and the 10-minute patch average. **Figure 2** illustrates that most differences are near or very close to zero. Based on this figure, in general the amplitude scintillation is not impacted by the patches.

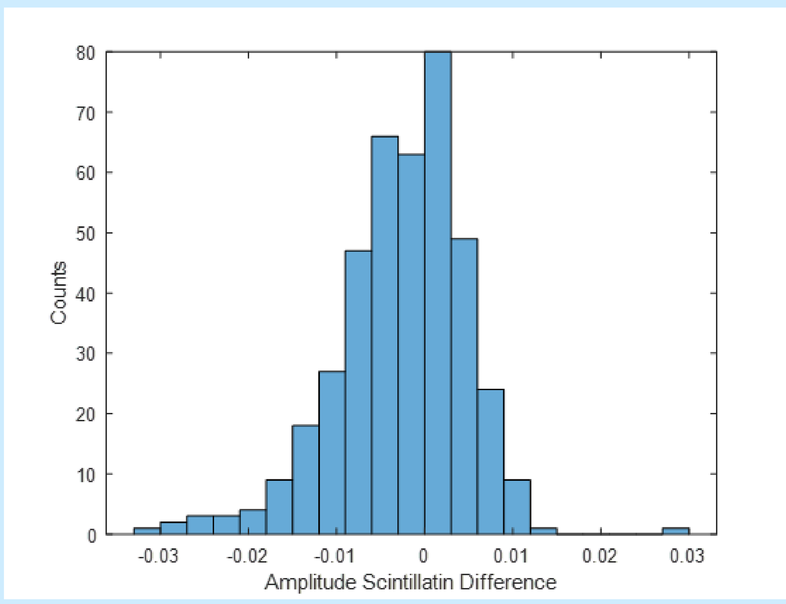

Figure 2: Histogram of the amplitude scintillation difference between the daily average and the 10-minute patch average.

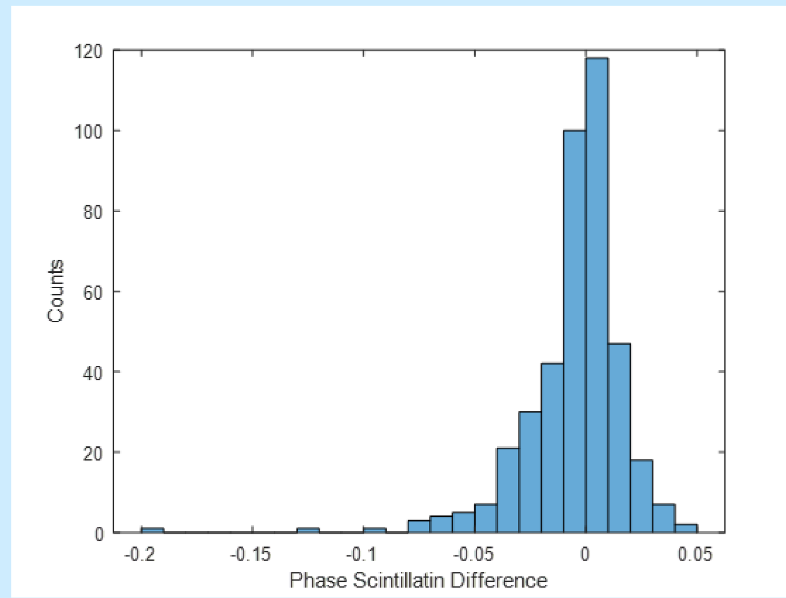

Figure 3: Histogram of the phase scintillation difference between the daily average and the 10-minute patch average.

Figure 3 shows the difference between the daily average and the 10-minute average for the phase scintillation, in the same format as **Figure 2**. The histogram is centered near zero, indicating that there is little to no difference between these values. The distribution is asymmetric with a longer tail on the negative value side, which indicates that the phase scintillation within patches indeed increased in 15 events. However, the overall trend does not show a significant difference, which implies that there is no obvious phase scintillation increase associated with patch in the polar cap.

Event Analysis

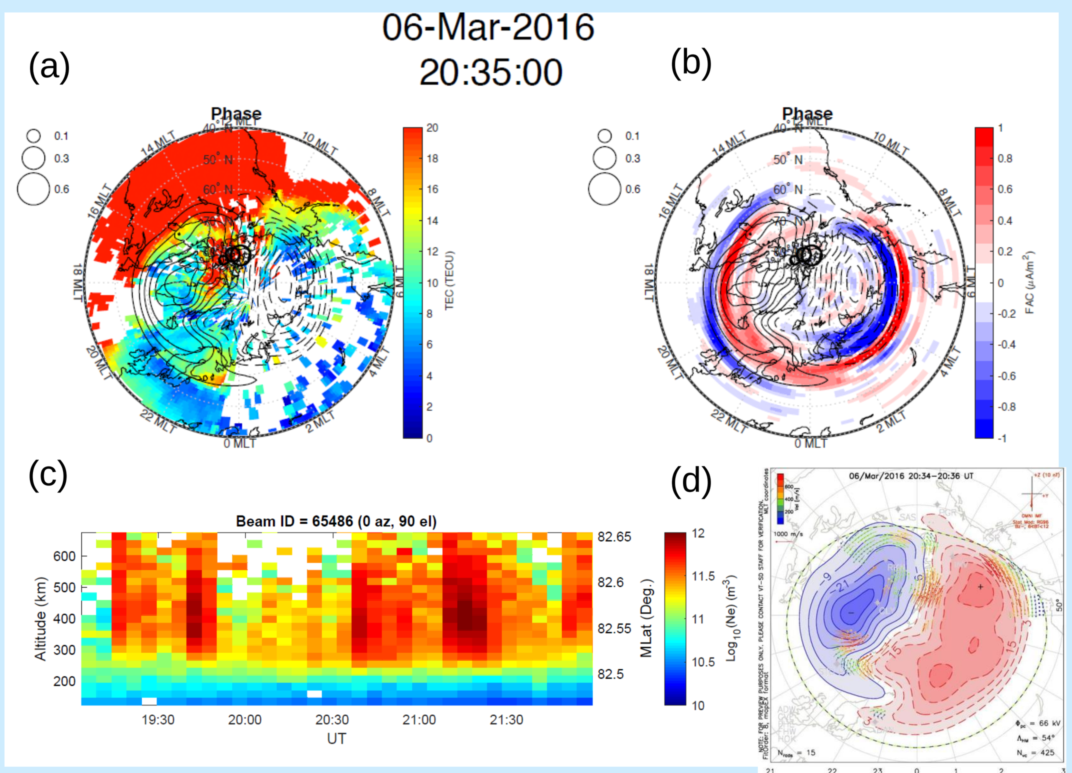

Figure 4: (a) Total Electron Content Map showing in units of TECU (b) Current density at March 6, 2016 at 20:35 UT. The phase scintillations observed are also plotted as black circles (c) The electron density from RISR on March 06, 2016 between 19 UT and 22 UT (d) Ionosphere convection map for March 6, 2016 between 20:34 and 20:36 UT. Figure from SuperDARN Virginia Tech.

Despite there being no obvious increases in scintillation associated with polar cap patches statistically, there are times when scintillation increases with patch presence. One example occurred on March 6, 2016 between 20:00 and 21:00 UT. In general the TEC increased on the dayside around 20:35 as shown by **Figure 4 (a)**, i.e., storm-enhanced density (SED) and the enhanced TEC extended poleward into the polar cap. Where Resolute Bay resides (near the black circles, which show the phase scintillation magnitude), there is a region of high TEC at ~20 TECU when compared to the surrounding regions at about 10 TECU. Interestingly, the Resolute Bay receiver was just poleward of the cusp near the noon MLT. The maximum phase scintillation occurred at 20:37 UT, which coincides with the density peak between 20:30 and 21:00 UT and the sharp density gradient there in **Figure 4 (c)**. **Figure 4 (d)** shows that the convection flow speed is very high (~800 m/s) in the region where the patch was observed. It is possible that polar cap patches that are severe enough with large electron density and sharp density gradient, as well as large convection flows to enhance scintillation significantly.

Conclusions

- Comparing the 10-minute averaged scintillation when a patch occurred to the scintillation averaged over one day, it was noted that there is not a significant difference between the two. This was seen for both the phase and the amplitude scintillations. Therefore, statistically there is no obvious phase scintillation or amplitude scintillation increase associated with patch in the polar cap.
- A patch itself is not a sufficient condition for the scintillation to increase. It may cause scintillation if paired with other effects, such as large density gradient and convection flow. This is consistent with earlier studies by Jenner et al. [2020]. More quantitative work is needed to find out the exact conditions for patch to enhance scintillation.

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