Detection of high-latitude ionospheric plasma conditions leading to GPS scintillations using a novel Poker Flat Incoherent Scatter Radar mode

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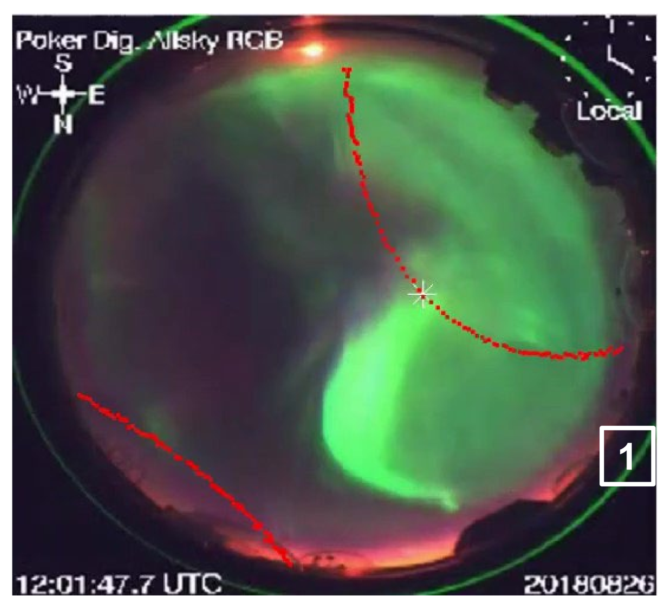
Problem Statement

Overarching Science Question: What are the underlying physical mechanisms causing observed unencrypted navigation signal scintillation in the auroral oval?

Research Question: How to quantify the spatial and temporal displacement of ionospheric plasma using a novel PFISR mode.

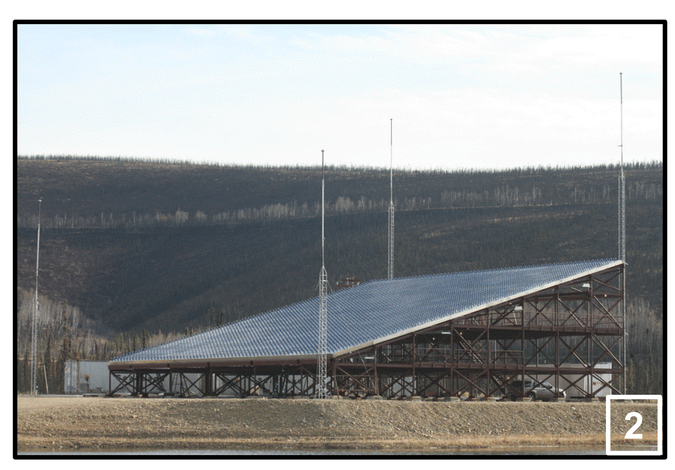
Background

A CME led to a geomagnetic storm on 26 August 2018. Ionospheric conditions were detected for this storm by PFISR using a novel five-beam GPS mode. The storm was unusually strong due to temporal proximity to the solar minimum with a recorded Dst of -171 nT. [1]

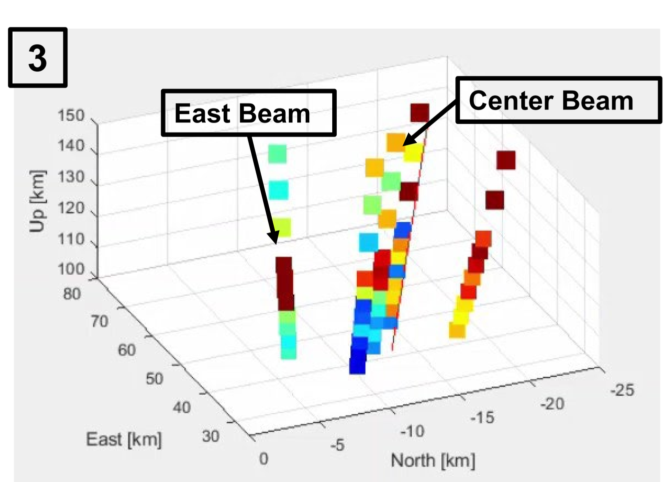


Poker Flat Incoherent Scatter Radar (PFISR)

PFISR is an electronically steered array radar with configurable multi-beam modes using its array of over 480 1.5° × 1° beams. It operates on multiple channels that target the E-region ionosphere (100-150km altitude). [2]

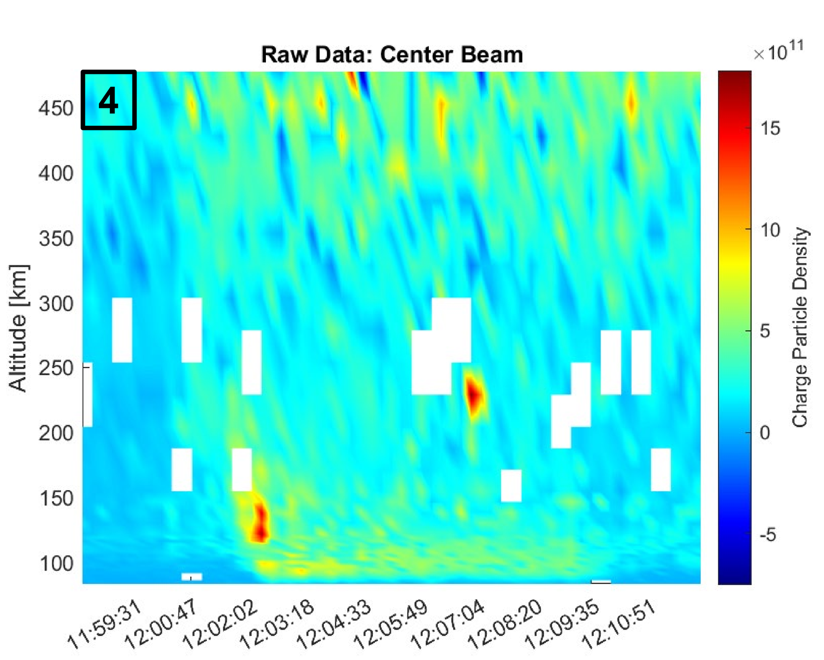


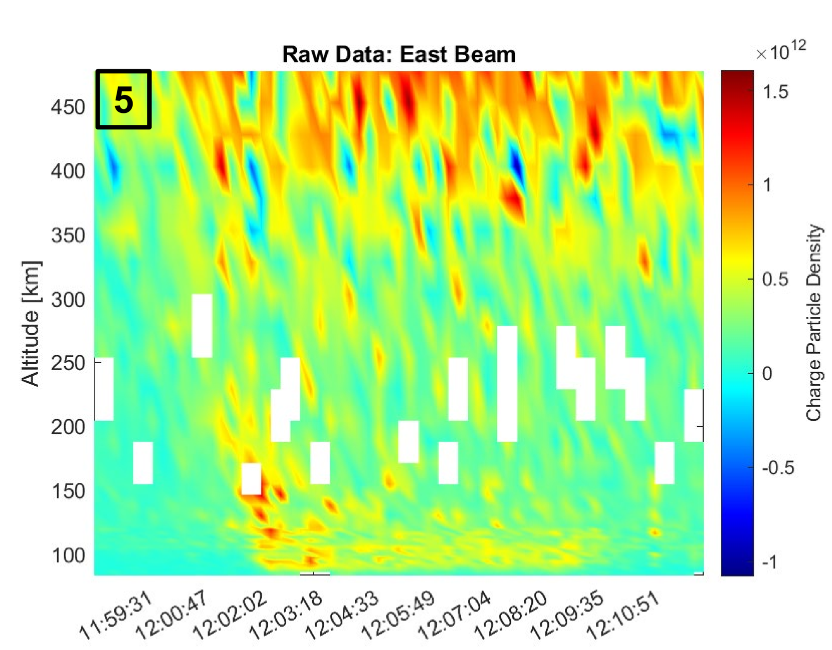
Final electron density were provided after being processed and fitted by SRI at 15 s cadences. [2]



Data

Data analyzed will be focused on the East and Center beams, depicted in figure 3. Data present is over a 13-minute time period in the E and F regions.





Theory

Wiener-Khintchine theorem: $\mathrm{Crr}(\tau)=\int_{-\infty}^{\infty} f(t+\tau)f^{*}(t)\,dt$

- Assume: Function of finite energy [3]

MATLAB xcorr: $xCorr(x,y) = \sum_{n=0}^{N-1} x[n]y[n]$

- Discrete application of Wiener's theorem
- Normalized in code to account for fluctuations in signal energy

This theorem allows for the determination of the similarity of two signals by way of autocorrelation. Normalizing the autocorrelation provides means to quantify how correlated two signals are by an R-squared value.

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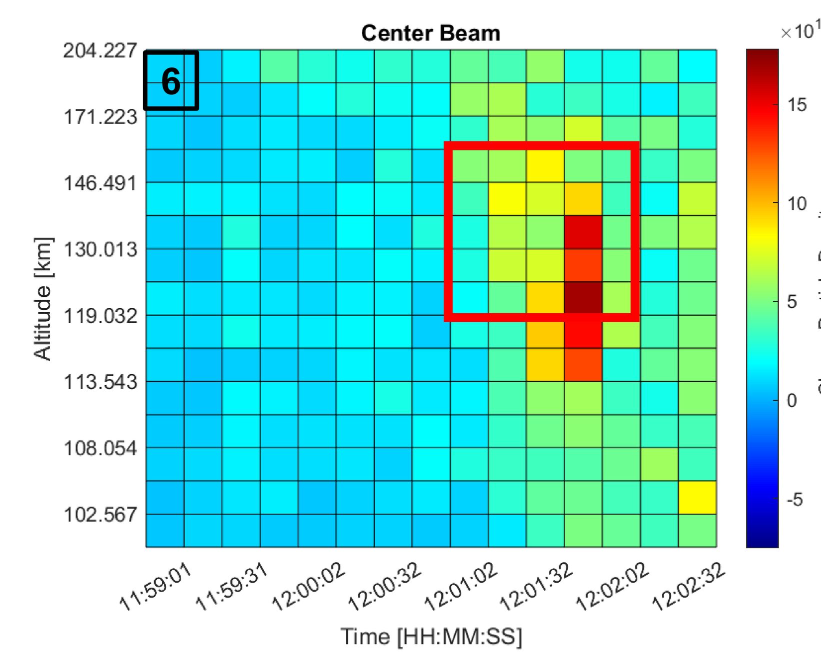
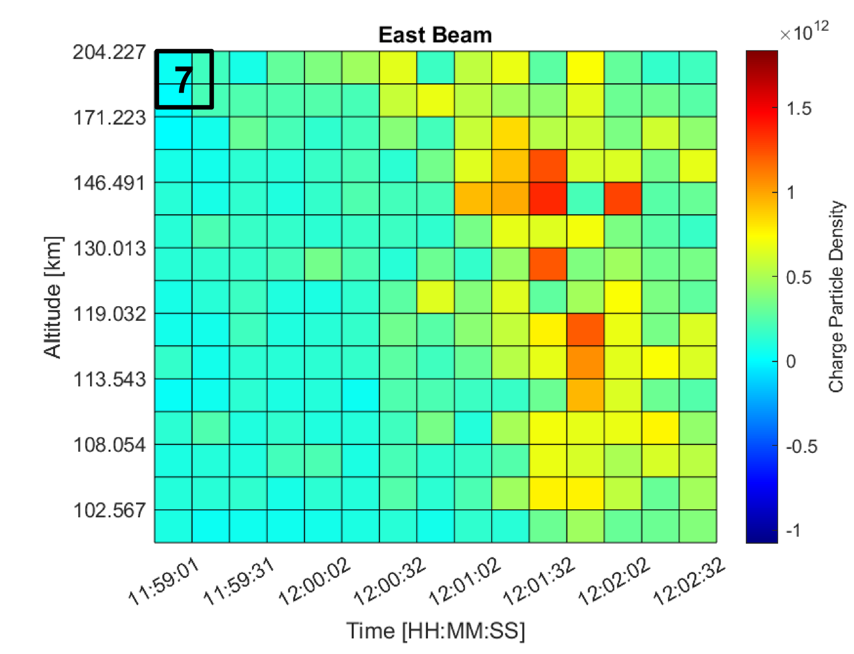
Methods

Correlation Study Concept: Compare a section of the center beam to the entirety of an outer beam to find where the center section appears in the outer beam. Iteratively repeat this process for all possible sections of the center beam.





Where does the section of the center beam (red box) appear in the East Beam?

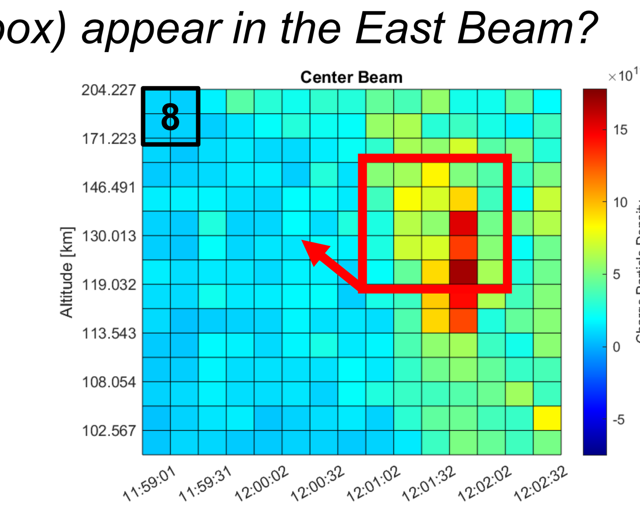
Shown in the figures are:

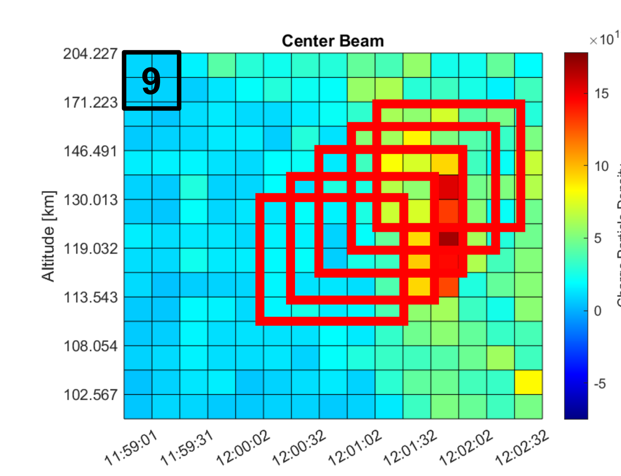
6,7. MATLAB xcorr2 compares center section and outer beam.

8. Displacement of section is represented by a quiver vector at the left corner of the section

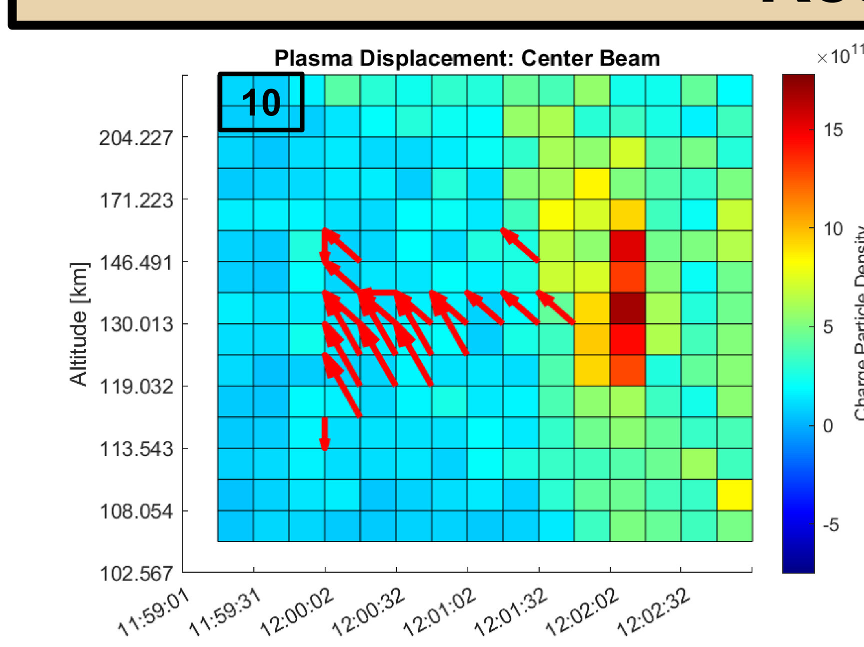
9. Process is repeated iteratively for every possible section of center beam.

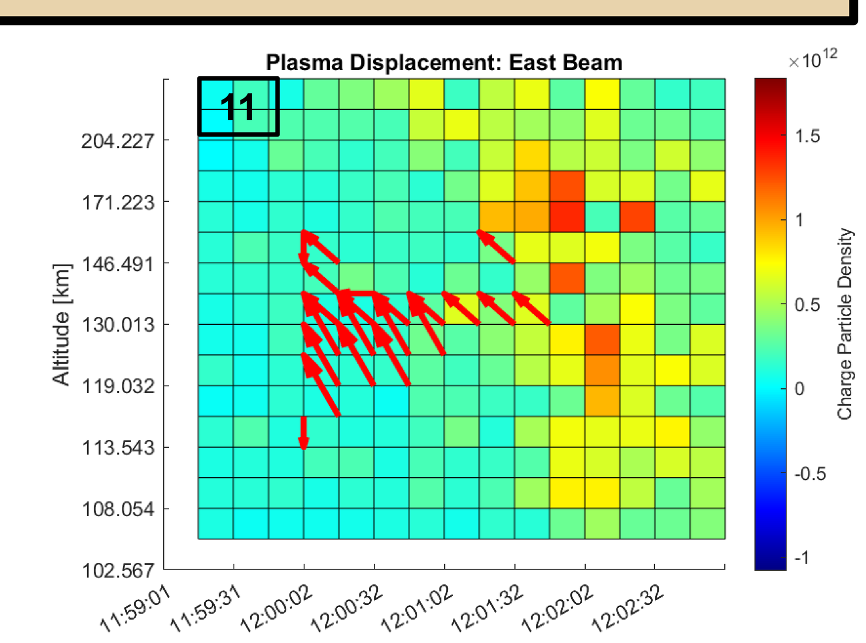
- Boxes are omitted in the final correlation to reduce clutter.
- R-squared cutoff to omit weak correlations ($R^2 < 0.4$).





Results





- Detection of plasma structures increasing in altitude from center to East beam
- Structure occurs in East beam first
- Number and accuracy of displacement vectors depend highly on center beam section size and R-squared cutoff criteria
- Section size must be large enough to capture structures but small enough that internal chaos does not reduce the R value

Conclusions

This correlation study shows evidence of tracking the displacement of plasma structures across PFISR beams. Future studies will expand the correlation study to include structures within the F region of the ionosphere

Abbreviated References* & Acknowledgements

[1] Oyedokun, O.J. (2021) "Solar Origins of August 26,2018 Geomagnetic Storm." *Space Weather.*

[2] Loucks, D. (2017). "Impact of High-latitude Ionospheric E Region Enhancements on GPS Scintillation in the Alaskan Sector. *Aerospace Engineering Sciences Graduate Theses & Dissertations.*

[3] Hetch, E. (2017) *Optics 5ed.* Pearson Education.

*Full reference table available upon request

PFISR is operated by SRI International under NSF Cooperative Agreement AGS-1133009. Processed PFISR data is available via amisr.com/database, and raw data is available upon request to roger.varney@sri.com.