Correlation of Navigation Solution Parameters Affected by High-Latitude Ionospheric Scintillation Through Allsky Imagery

CDT Mason Bay, CDT Stephen Litterini, and CDT Natane Randall
Advisors: COL Diana Loucks, PhD, Dr. Carolann Koleci, and Dr. Jason Derr

Problem Statement

Overarching Science Question: Can a globally accepted metric be devised to represent the operational impact of observed unencrypted navigation signal scintillations in the auroral oval?
Research Question: At what point do we see an appreciable decrease in the GPS position solution's accuracy in the presence of dynamic aurora?

Background

Much of understanding the nature of how GPS signals are affected by our atmosphere is primarily based in areas where most of the GPS users live—below the Arctic. Therefore, much of the GPS issues that are solely specific to the Arctic go largely unmitigated [1].
To understand the ionospheric plasma, its relationship to position offset, and the observable phenomenon of discrete aurora, visible imagery is necessary to build a product that shows the aurora and the real-time effects of GPS signal scintillation.
The northern lights, or aurora borealis, is as much of a beautiful spectacle to us as it is a problem for low-grade GPS receivers, and with the upcoming solar maximum, an increase in the number of geomagnetic storms and substorms is expected.

Theory

Scintillation: defined as rapid fluctuations in the amplitude and/or phase of the GPS signal as measured by a receiver. In the high-latitudes, our primary focus is on phase scintillation which is measured by the phase scintillation index ($\boldsymbol{\sigma_\phi}$), as calculated by the equation below:

$$\sigma_\phi = \sqrt{\frac{1}{n}\sum(\bar{\phi} - \phi_i)^2}$$

Instrumentation

Illinois Institute of Technology's Space Weather Lab collected data using CASES receivers located in Poker Flat Research Range, Alaska (O'Hanlon).
Our research focuses on 26 August 2018 in which a notable geomagnetic storm occurred.
The CASES receiver (Figure 1, right) is a 100Hz sampling, multifrequency GPS receiver which produces phase and amplitude scintillation data [2].

The Digital All-Sky Camera (DASC) has a FOV that can observe the complete sky at all times. Red-Blue-Green (RGB) images are compiled around every 11-13 seconds, which can be compiled to create a timelapse video of an auroral event.

Acknowledgements

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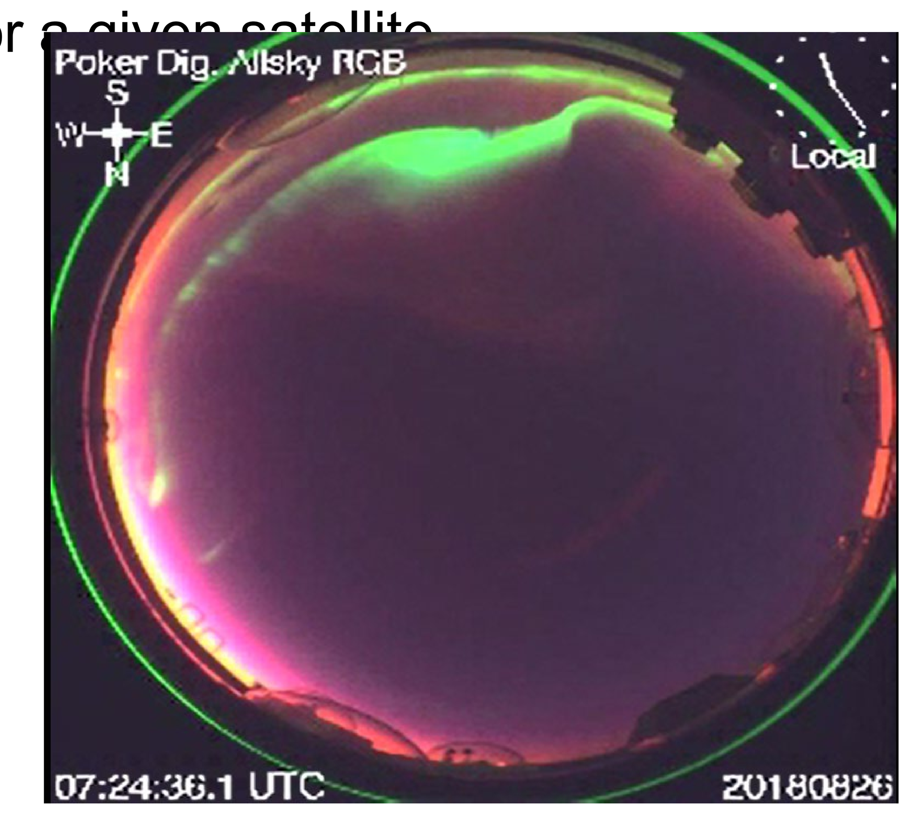
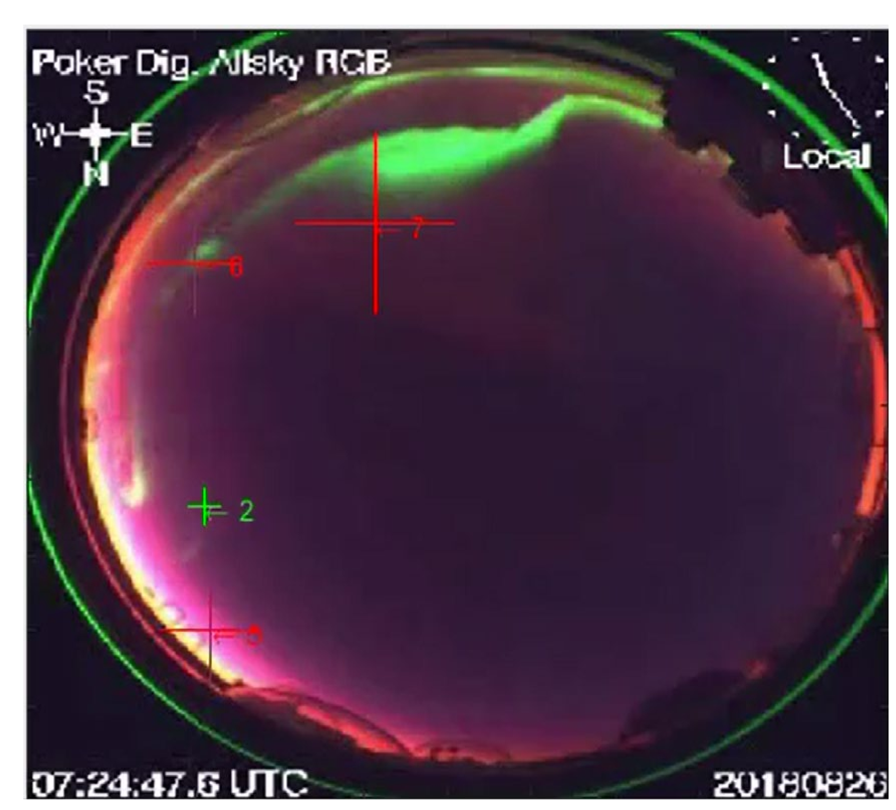
Methodology

For the timelapse video (figure 2, below), a crosshair that changes size and color can best demonstrate the amount of phase scintillation for a given satellite.



The CASES data provides Iq.log and scint.log files that were processed in MATLAB to calculate the $\boldsymbol{\sigma_\phi}$ of the L1 GPS signal of all active and visible satellites above PFRR. This $\boldsymbol{\sigma_\phi}$ data was then processed into a visualization program which takes the DASC RGB imagery video and plots the satellites as crosshairs with varying colors and sizes based on the magnitude of phase shift at that given time along the given satellite path.

Results



Using a MATLAB program, the DASC imagery was overlayed with the scintillation information (Figure 3, above).

Conclusion

The DASC imagery provides evidence that auroral motion creates a gradient in TEC. Thus, visible discrete aurora is directly correlated gradient in TEC causing a depreciable effect in a local low-grade GPS receiver.
Future research should focus on developing a more efficient methodology that incorporates other large-scale geomagnetic storms that have discrete aurora over the Arctic in order to quantify and build an index that would give the user a better understanding of space weather impacts on operations within the Arctic.

Abbreviated References

[1] McGranaghan, Ryan M., Anthony J. Mannucci, Brian Wilson, Chris A Mattmann, Richard Chadwick. "New Capabilities for Prediction of High-Latitude Ionospheric Scintillation: A Novel Approach With Machine Learning." 12 October 2018. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018SW002018.
[2] O'Hanlon, B., Psiaki, M., Bhatti, J., Crowley, G., & Bust, G. (2011). CASES: A Smart, Compact GPS Software Receiver for Space Weather Monitoring. *ION GNSS 2011*, 1–9. http://web.mae.cornell.edu/psiaki/Paper_F4_2_ION_GNSS_2011.pdf

POC: mason.bay@westpoint.edu