INVESTIGATION INTO THE G1 GEOMAGNETIC STORM OF JANUARY 31ST, 2019 THROUGH GNSS DATA PROCESSING

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OBJECTIVE

Highlight the relationship between geomagnetic storms and ionospheric scintillation through the analysis of processed GNSS data and proposes techniques for the identification and classification of scintillations in the mid-latitude region.

INTRODUCTION

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

- There are 31 satellites used for the Global Positioning System (GPS)
  - GPS has multi-industry and daily life applications.
- Rapid modification of radio waves, otherwise known as scintillation, cause loss of lock in GPS systems.

GEOMAGNETIC STORMS

- Solar events like solar flares and coronal mass ejections are known to cause fluctuations in the Earth's magnetic field and the ionosphere.

(a) (b)

Figure 1: Pictured are two different types of aurora. Figure 1.a is from Tromso, Norway during the coronal hole event in April 2018. These are lower and more powerful aurora. Figure 1.b is from Houston, Texas during the Halloween Storm in 2003. The aurora are red because they are weaker and higher in altitude.

- Storm classification ranges from G1, minor fluctuations in operations, to G5 yielding massive system failures.
- This projects highlights that mid-latitude scintillations are detectable and significant and thus should be studied in order to understand midlatitude ionosphere.

METHOD

- Two GPS receivers were installed in SPRL to collect data.
- Real-time space weather data is used to select days with geomagnetic activities.
- Multipath removal instructions, developed by the team, was used to confirm the signals were scintillations
  - An elevation mask applied between 0-50 degrees to ignore surrounding geographical features.
- MATLAB and Python are then used to process, and graph collected data. Then all data is analyzed for correlation.
- Unsupervised clustering algorithm is implemented to provide further insight on mid-latitude scintillations

RESULTS

The following graphs show the Ionospheric Amplitude Scintillation (S4) in Figure 2. The High Rate data retrieved by the SPRL from GPS satellites 14, 26, and 31, GALILEO 25, and GLONASS 5. The Total Electron Content (TEC) was also retrieved from GPS 14 and 26. The following graphs are analyzed and compared to Auroral Electrojet (AE), Disturbance Storm Time (DST)(not shown), and Kp indices of the Jan 31st G1 geomagnetic storm to find correlations and confirm that the observed event is an ionospheric scintillation.

SATELLITE SIGNAL MEASUREMENTS

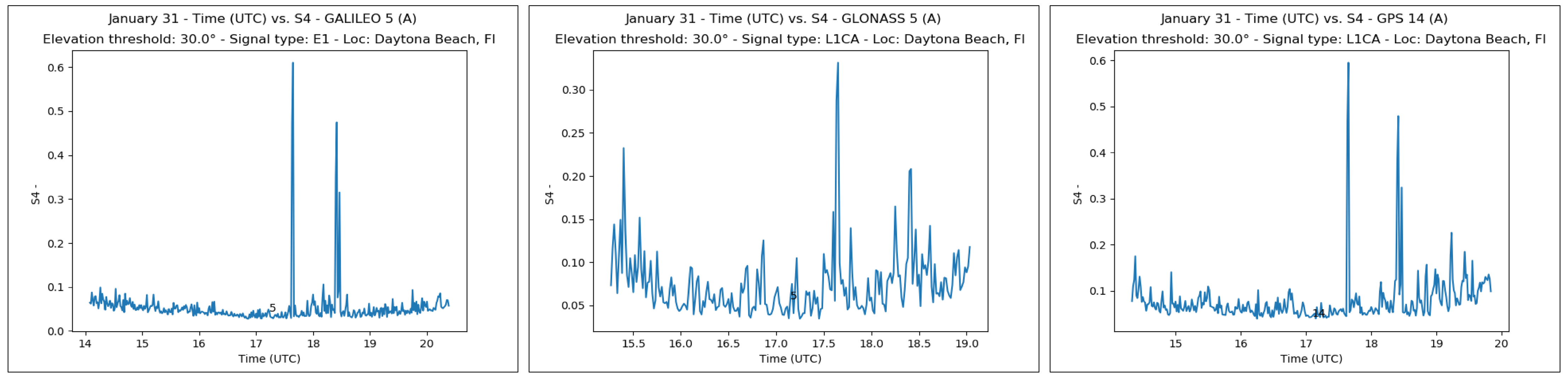


Figure 2: Ionospheric Amplitude Scintillation (S4): S4 vs Time plots from 3 distinct GNSS service providers, GALILEO (EU), GLONASS (Russia), GPS (USA). S4 unitless) is the known scintillation index defined as the standard deviation of the received signal power normalized by its mean value. All three GNSS providers show scintillation with coincident times.

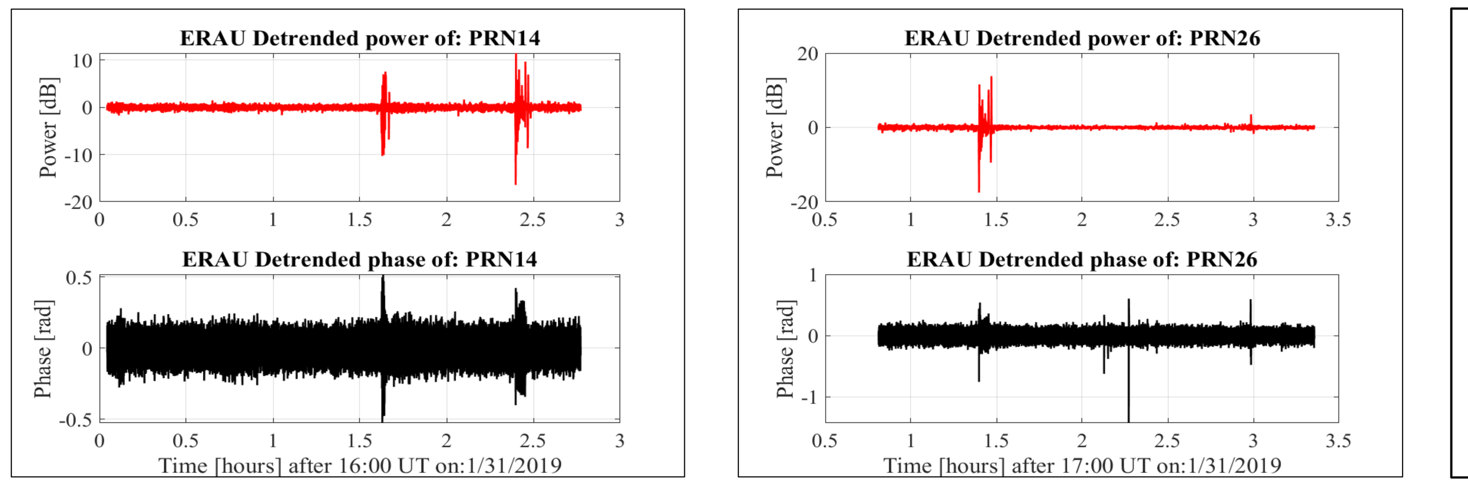


Figure 3: High Rate Plots: High-rate data (50Hz) of power (dB) and phase (rad) plotted simultaneously vs time. Two events are shown in these plots, the latter confirmed by all three satellites PRN 14, 26, and 31(shown in Figure 6) and showing both amplitude and phase activity. See Figure 6 for phase vs power correlation.

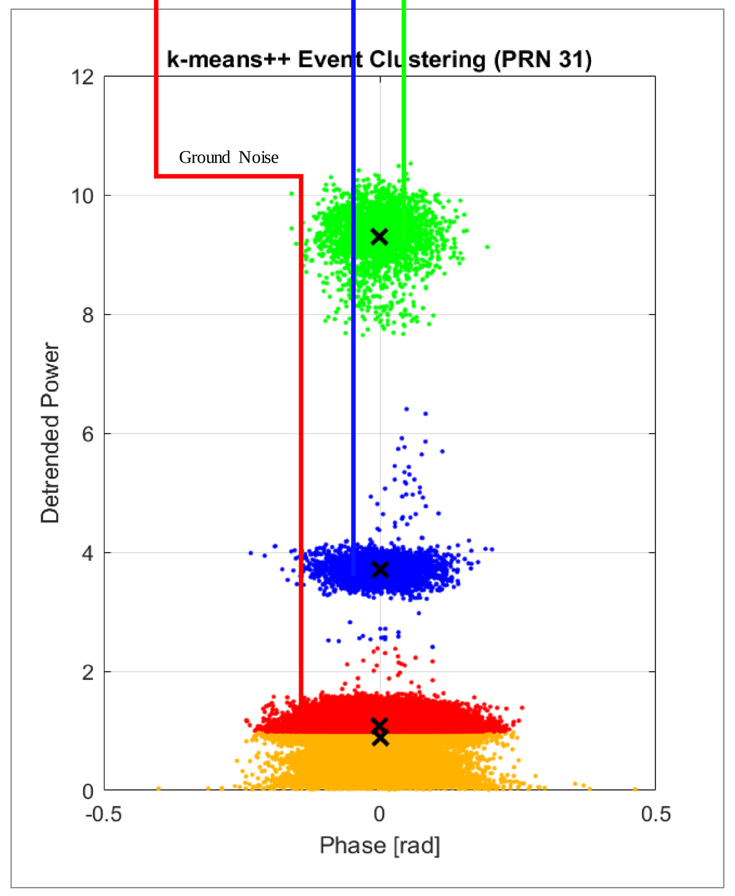


Figure 6: K-means Clustering: K-means++ clustering of the events detected on January 31st for PRN 31. Arrows point at corresponding events in the high rate plots. The red cluster denotes ground noise hence describes the data points not related to the event. The blue and green clusters correspond to the observed amplitude scintillations. The orange cluster below was found to be part of the observed scintillations and does not appear as part of the other clusters due to the processing strategies used. Nonetheless it provides powerful insight regarding the correlation of power drop to phase scintillation.

GEOMAGNETIC AND IONOSPHERIC MEASUREMENTS

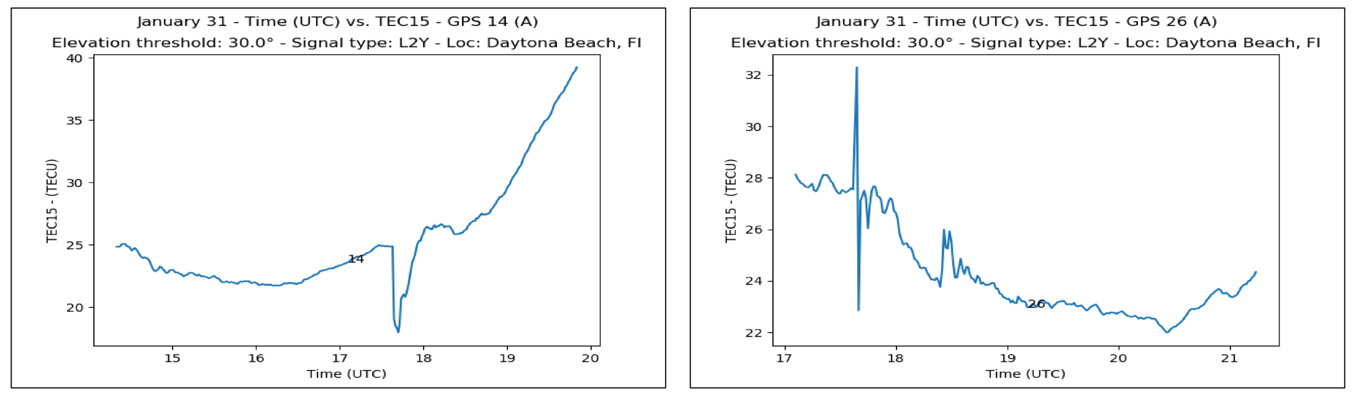
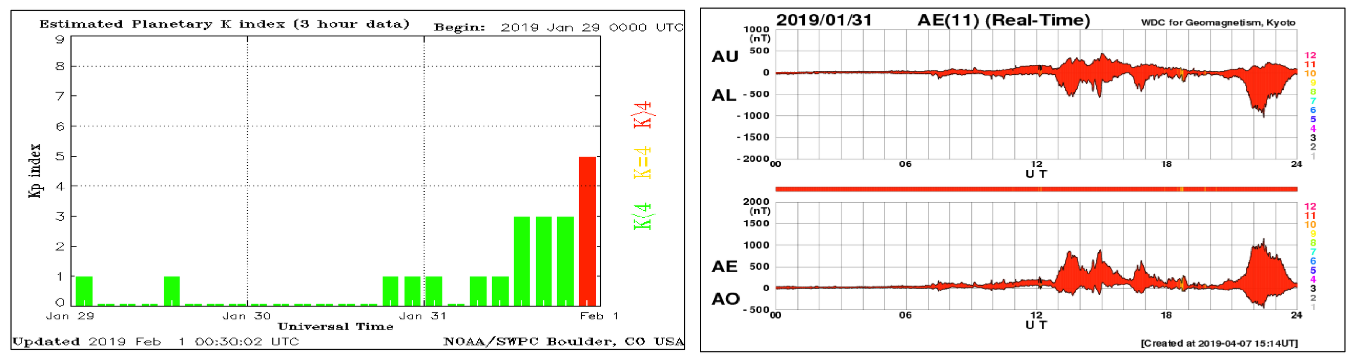


Figure 4: Total Electron Content (TEC): Total electron content vs time plots for PRN 14 and 26. Graphs show coincident irregularities in measured total electron content which also correspond to the same time as the ionospheric scintillations presented in S4 and high rate plots.



(a) (b)

Figure 5: Figure 5.a NOAA estimated Kp indices from January 29 to February 1. The Kp index is seen to be less than 4 towards the end of January 31 and more than 4 at the beginning of February 1. Figure 5.b Auroral electrojet indices for January 31st obtained from WDC for Geomagnetism, Kyoto. Indices suggest strong activity during 12-19 UTC where scintillation was observed. This suggests that a minor G1 geomagnetic storm was present during our observation period

Conclusion

- Between 17 and 19 UTC, significant peaks were observed in the S4 graph for GPS 14, GALILEO 5 and GLONASS 5 seen in Figure 2.
- High rate plots for PRNs, another term used for GPS satellites, 14, 26 and 31 also show the same activity with spikes noticed in both power and phase.
- TEC graphs exhibit similar behavior around 17 UTC on PRN 14 and PRN 26. Same results are echoed by the AE and DST Indices. The Kp max was 5 indicating that a minor geomagnetic storm was present.
- Jan 31st geomagnetic storm was during solar minimum according to sunspot data, yet notable scintillations were observed in mid-latitude.
  - The storm was not that powerful seen in Figure 5. The data suggests that there is a strong correlation between the weak geomagnetic storm and scintillations.
  - Since this was a weaker storm, the possibility of a stronger storm having a larger effect is likely.
  - Scintillations are expected to occur more often during high solar activity.

FUTURE WORK

- Analyze multiple geomagnetic storms besides the geomagnetic storm of January 31st that might correlate with collected scintillation data.
- Continue studying GNSS scintillations at mid-latitude through data collection and analysis to identify a stronger relationship between geomagnetic storms and scintillations in the mid-latitude region.
- Develop a scintillation detection method using a supervised decision trees algorithm and further explore their characteristics in mid-latitudes through clustering and different processing techniques.
- Explore how the Earth's ionosphere and magnetic field and solar phenomenon interact.

ACKNOWLEDGEMENTS

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