Investigation into Geomagnetic Storms and Ionospheric Scintillation

D. Mekonnen, C.Thakrar, J. Herrera, M. Priore, L. Tijerina, J. Gachancipa, D. Nigro, P. Vaggu, D. Patel, Dr.Deshpande
Space Physics Research Laboratory (SPRL)

Introduction

Identifying the relationship between solar activities, ionospheric irregularities and consequently ionospheric scintillation has inspired numerous research efforts due to the insight it provides on impacts of space weather on daily life. Solar activities such as geomagnetic storms cause ionospheric irregularities. When radio waves travel through these irregularities, they experience rapid fluctuations in the signal phase and amplitude. Such fluctuations, known as ionospheric scintillation, have great consequences in radio wave based technology such as the Global Position system as it can cause loss of lock. As such, industries that are dependent on the accuracy of radio wave based technology such as aviation, agriculture and mining are especially sensitive to the impacts of space weather events that directly affect the ionosphere.

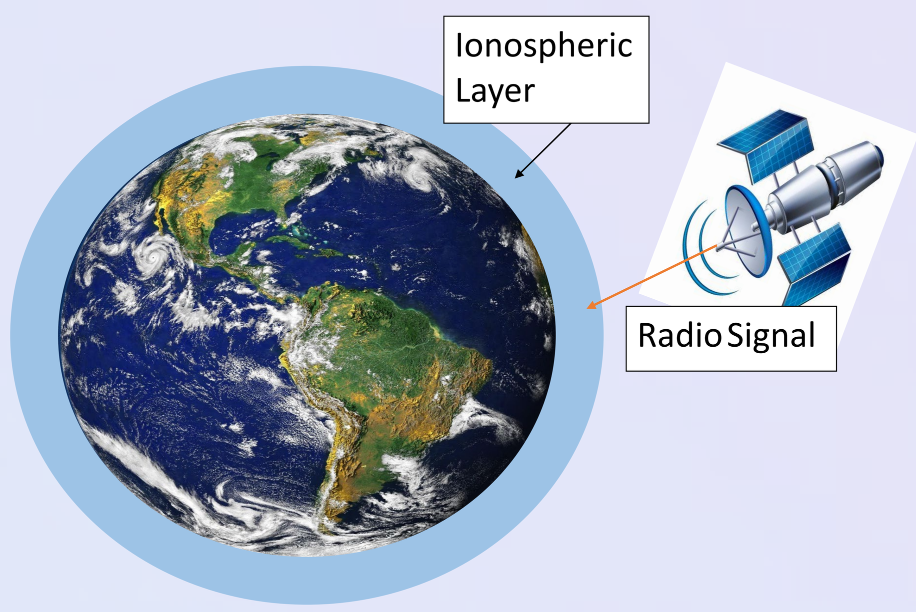


Figure 2: Illustration radio signal going through earth's ionospheric layer.

Therefore, radio signal data from the Global Navigation Satellite Systems(GNSS) is proceed to identify scintillation signatures that occurred during geomantic storms. A case study was conducted on January 31st, 2019, where scintillation signatures that correlated to a G1 minor geomagnetic storm were successfully identified. The method of analysis and identification of scintillation is adapted from the aforementioned case study to look into past years of data in hopes of identifying a similar trend. Through this study, it is hoped that a strong correlation between geomagnetic storms and ionospheric scintillation in the mid-latitude region will be highlighted.

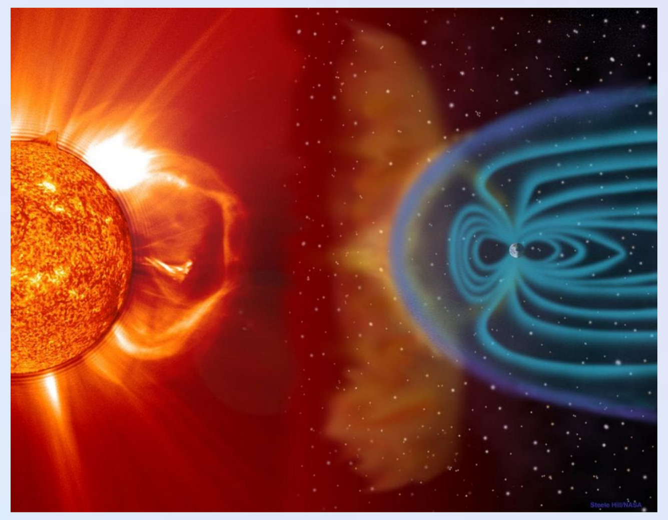


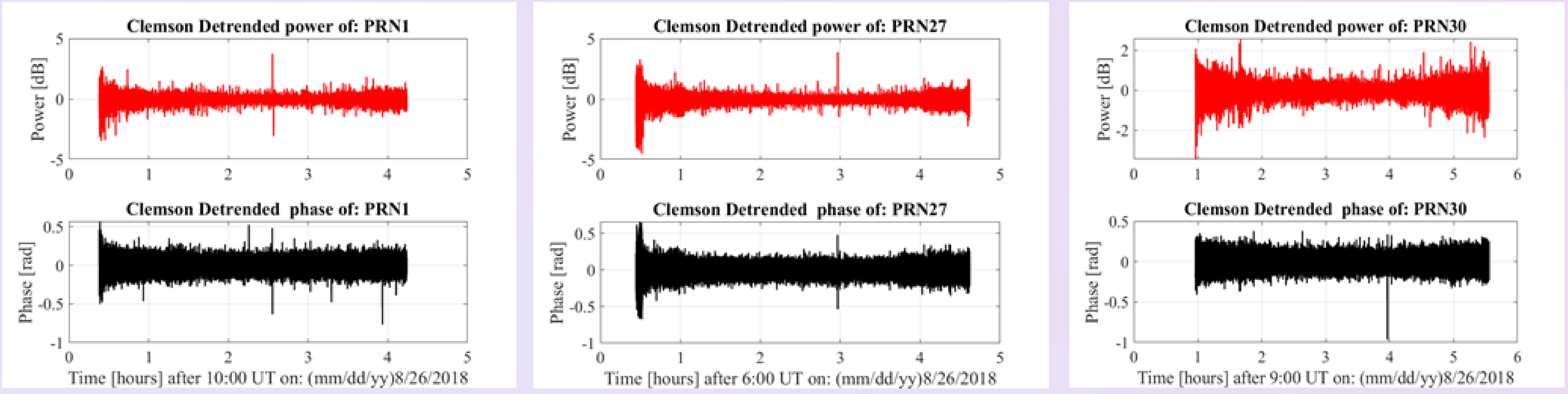
Figure 1: Illustration of interaction between a solar wind and Earth's magnetic field Curtesy of NASA.

Methodology

- Two GPS Receivers were implemented in the Space Physics Research Lab (SPRL) at Embry Riddle Aeronautical University. The receivers obtained the following data :
  - Index of Amplitude(S4) , phase and power of radio signals from GNSS.
  - Total Electron Content (TEC) of the ionosphere.
- MATLAB and Python codes are used to parse and graph the collected data. This produces three types of graphs showing measurements of S4 , power and phase as well as TEC in specific time intervals measured in universal time (UT).
  - An elevation mask from 0 to 50 degrees is applied in order to remove multipath caused by geophysical structures.
- Real time geomagnetic data is collected from World Data Center at Kyoto University, NASA's DSCOVR Spacecraft and NOAA

Results

- The month of August 2018 was selected as an initial point since intense geomagnetic activities were observed during this time period. The power, phase and amplitude of radio signals throughout each day of the month, as well as the recorded total electron content were plotted.
- Analysis of the plots showed signal perturbation between 6 and 12 UT on August 26th 2019.
  - Sudden spikes in Power and Phase on PRNs 1,27 and 30 are observed at 12 UT, 9UT and 13 UT respectively as seen in Figure 3.



Figures 3: Simultaneous, high rate (50Hz) plots of Power(dB) and Phase(rad) of radio signals vs. Time.

- The TEC plots from Galileo showed a gradual drop from 30 TECU to 24 TECU between 8 and 12 UT while GPS 8 showed a similar trend dropping from –6 TECU to -20 TECU. Both Galileo 12 and GPS 8 confirm a significant decrease in the total electron content as seen in Figure 4 .

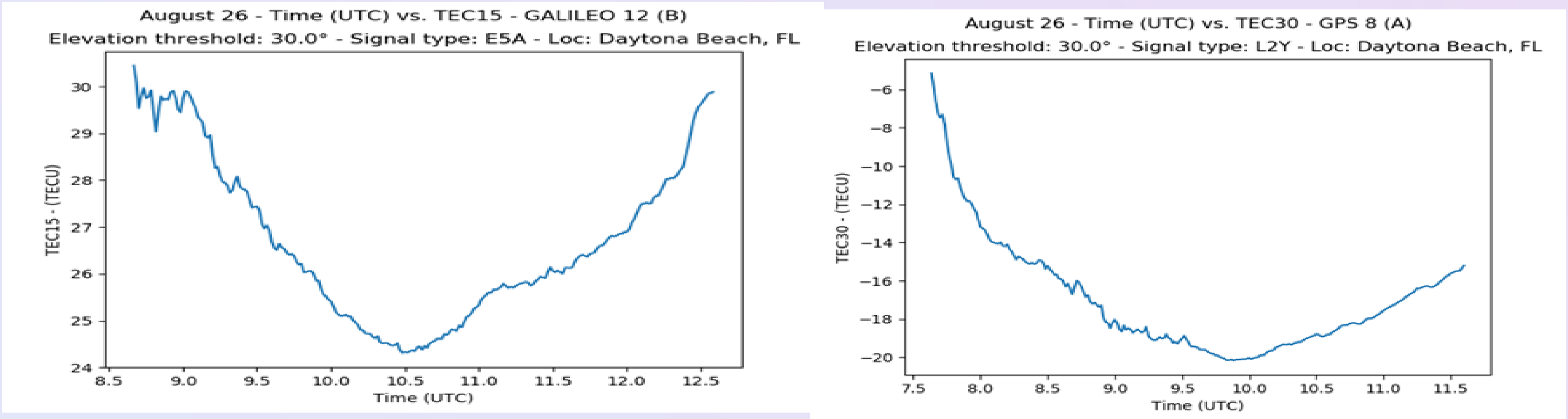


Figure 4: Total electron content (TEC) vs. Time

- The geomagnetic activity measurements showed that a Kp index of 9 was recorded between 6UT and 9UT. Further more the Auroral Electroject (AE) graph shows significant activity through out the day ranging from 500 nT to -2000nT.
- Finally the z component of the interplanetary magnetic field (IMF Bz) increases from 0 nT to 15nT between 6 and 12 UT. A negative Bz is observed at 6 UT and then again from approximately 16UT to 24 UT.

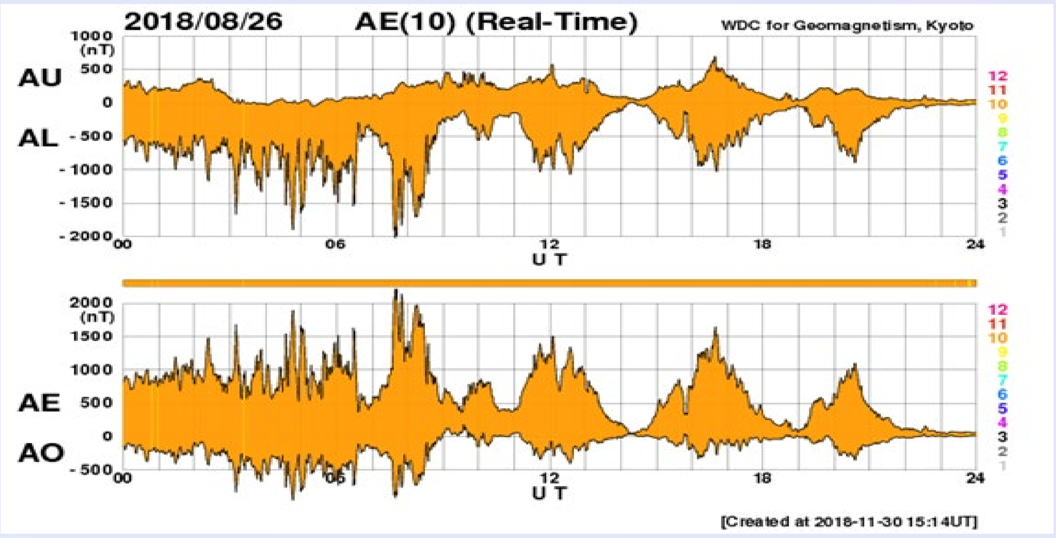


Figure 5a : Real time AE plot of the August 26th, 2018 Geomagnetic Storm obtained from World Data Center at Kyoto University.

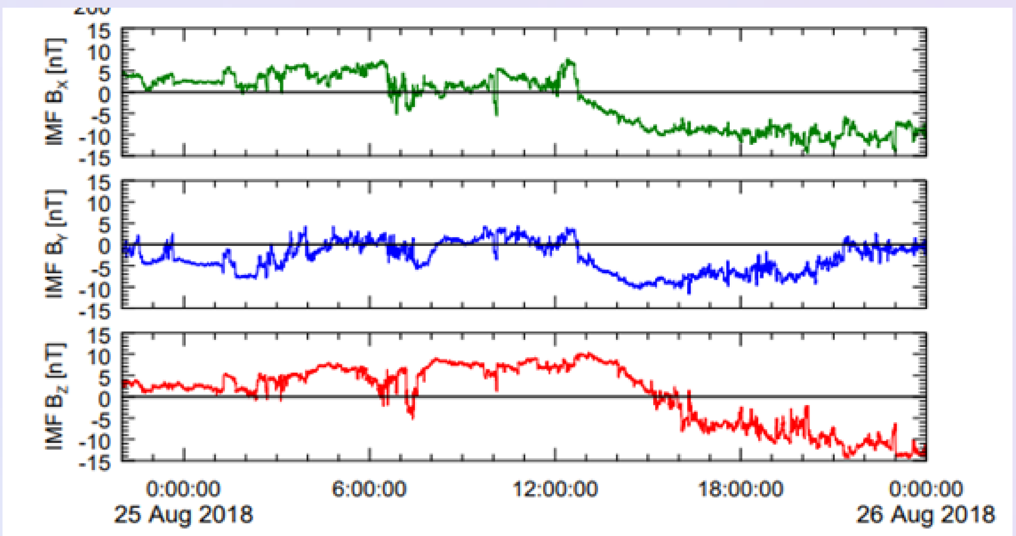


Figure 5b : Real Time IMF Bz data and plot obtained from NASA's DSCOVR Spacecraft located at about a million miles from earth.

Conclusion

- As seen in Figure 3, there is an interruption in the radio signal that causes it to fluctuate between 5dB and – 5 dB as observed in 3 different PRNs on August 26th, 2018. These fluctuations seem to occur between 6UT and 12 UT. Rapid fluctuations in radio waves tend to take place when there are irregularities in the ionosphere. To confirm whether the radio signal was passing through an irregularity in the ionosphere, the Total Electron Content plots were analyzed. On the same day, between approximately 6 UT and 12 UT, significant decrease in the TEC is observed.
- In addition, abrupt changes in IMF Bz's polarity from northward to southward can cause solar wind's magnetic field and earth's magnetic field to merge. This merging leads to a discharge of magnetic energy which causes the geomagnetic storms observed. The IMF Bz Plot shows a significant shift from positive Bz,, indicating northward polarity at approximately 5 UT to negative Bz at 6 UT, indicating a southward polarity. This leads one to conclude that a geomagnetic storm developed during this time.
- Furthermore, geomagnetic activity measurements were consulted . KP index ranges from 0 to 9, 0 indicating quiet activity while 9 indicates extreme geomagnetic storm. The highest value of KP index of 9 was recorder during the times radio signal fluctuations were observed. The AE plot also confirms intense geomagnetic activity throughout the day

Future Work

- The methodology adapted from the case study of January 31st, 2019 has proved effective. The method will continue to be applied in analyzing all geomagnetic storms between August 2018 and August 2019.
- After further analysis is complete with multiple days highlighting the relationship between geomagnetic storms and ionospheric scintillation in mid latitude, a manuscript with complied data analysis can be created.
- Continue analyzing GNSS scintillations in mid latitude region.

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