Investigating the Correlation between GNSS Signal Scintillation and Thunderstorms

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Objective

- Study how **lightning** produced by a thunderstorms can **affect the ionosphere** in mid-latitudes.
- Investigate if lightning can create strong enough **ionospheric structures** to generate **scintillation in GNSS signals.**

Introduction

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

- There are 31 satellites used for the Global Positioning System (GPS), which is one of the various networks of satellites, or PRNs, that makes up the GNSS.
- Rapid modification of radio waves, otherwise known as scintillation, impacts and disrupts GPS signals.

THUNDERSTORMS

- Tropospheric disturbances (i.e. thunderstorms and lightning) can cause disturbances in the ionosphere.
- Variations in Total Electron Content (TEC) have correlated with notable thunderstorm activities in the area.
- Some thunderstorms can reach over 10 km into the stratosphere as seen in Figure 1.

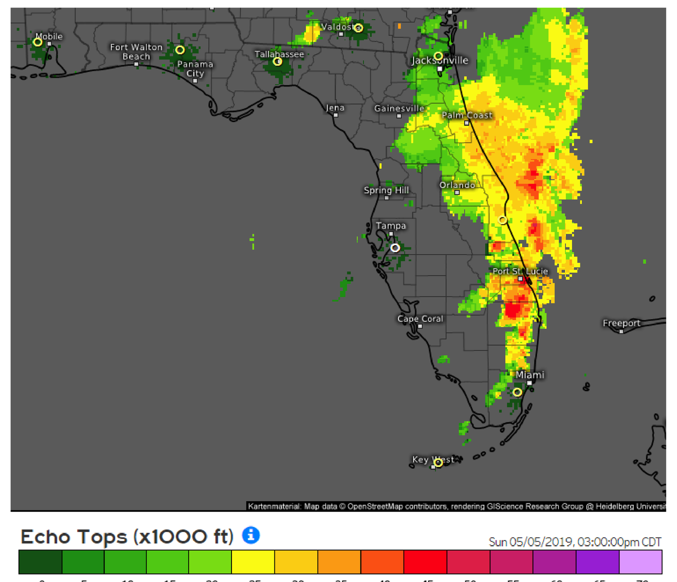


Figure 1: Radar analysis of the approximate max. elevation of precipitation (echo tops) of thunderstorms on May 5, 2019. The actual cloud top of the storm usually reaches beyond the echo top. The storm shown is over 45,000 ft (14 km). The times shown for these days correlate with scintillation observed on these days (Courtesy: weather.us).

- Lightning is currently the only tropospheric event known to affect the upper atmosphere.
- It has been observed lightning can shoot from the tops of thunderstorms and reach the ionosphere as seen in Figure 2.

Figure 2: Image taken by Hung-Hsi Chang during a flight over India. The gigantic jet seems to be coming from the plane wing but is much further away originating from the thunder cloud. The red branching structures at the top are sprites. These structures are huge and extend into the ionosphere at heights of almost 300,000 ft (90 km).

- ***Currently, no studies have been conducted to understand how scintillation caused by thunderstorms might affect GPS signals.***

Method

PLOTTING HIGH RATE DATA AND SKY PLOTS

- Converted GPS data from binary to more accessible data.
- Developed a Python code to filter data and produce sky plots for plotting a satellite's location (Figure 7) and a MATLAB code to graph high rate data for scintillation analysis (Figures 3 and 5).

DETERMINING CANDIDATES

- Found date of thunderstorms and matching high rate GPS data.
- Studied corresponding graphs to find matching thunderstorm times.

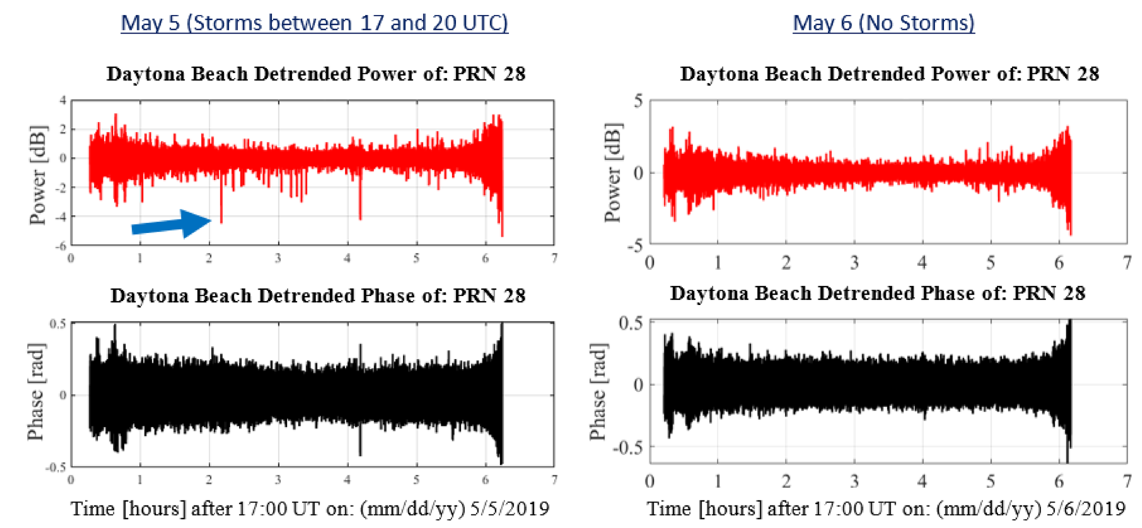


Figure 3: Plots from GPS satellite PRN 28 on May 5-6. A blue arrow points at possible scintillation on May 5. May 6 was a quiet day and multipath was ruled out as the May 5 dip is not seen on May 6.

- Looked for peaks and dips in the graphs which are commonly attributed to scintillation as seen in Figure 2.
  1. Ruled out multipath for cause of scintillation by comparing a nearby day without storms to a possible scintillation day.
- Lightning location and time data, as seen in Figure 4, is then analyzed within a few minutes before the time of scintillation.

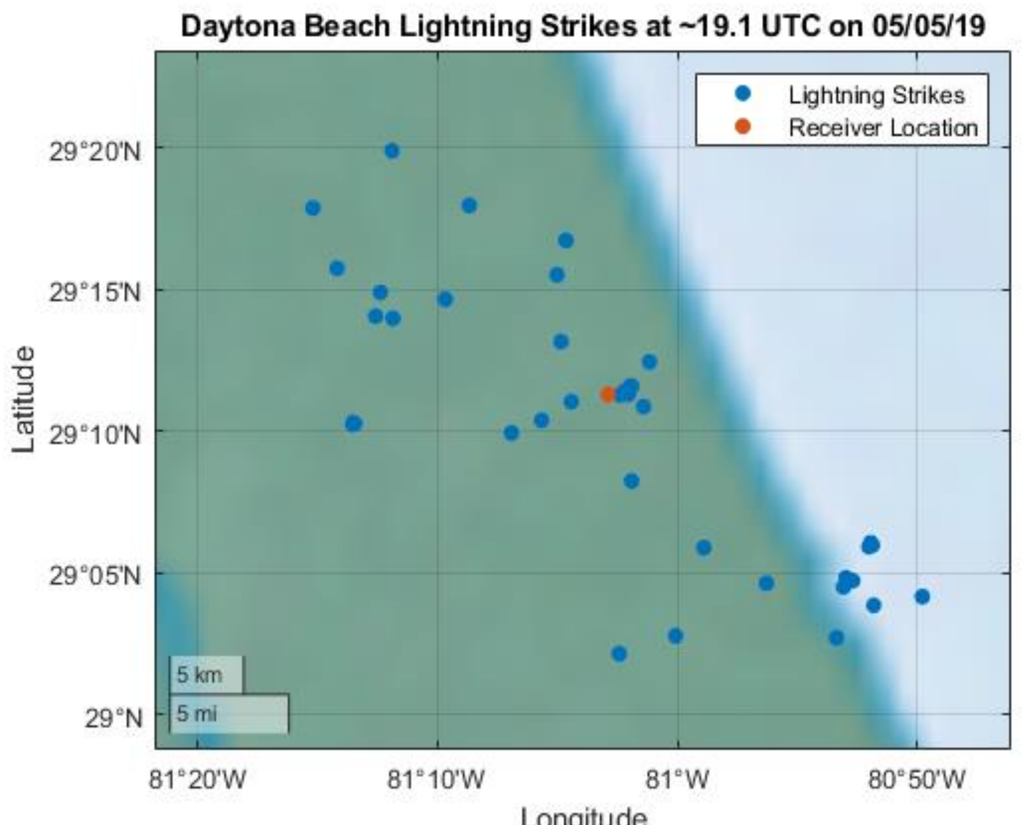


Figure 4: Map of lightning strikes on May 5 at around 19.1 UTC, which corresponds to the time of the dip seen in Figure 2.

- The proximity of lightning strikes with respect to the receiver helps show a possible correlation between thunderstorms and scintillation.

Discussion and Future Work

- Scintillation was observed on May 5, 2019 in the mid-latitudes during the time of a thunderstorm directly over the Daytona Beach area. Collected data, as seen in Figures 4 and 8, strongly suggests **the lightning that happened during these times caused the observed scintillation**.
- As seen in Figures 3 and 5, five different satellites showed the same dip (scintillation) at the same time.

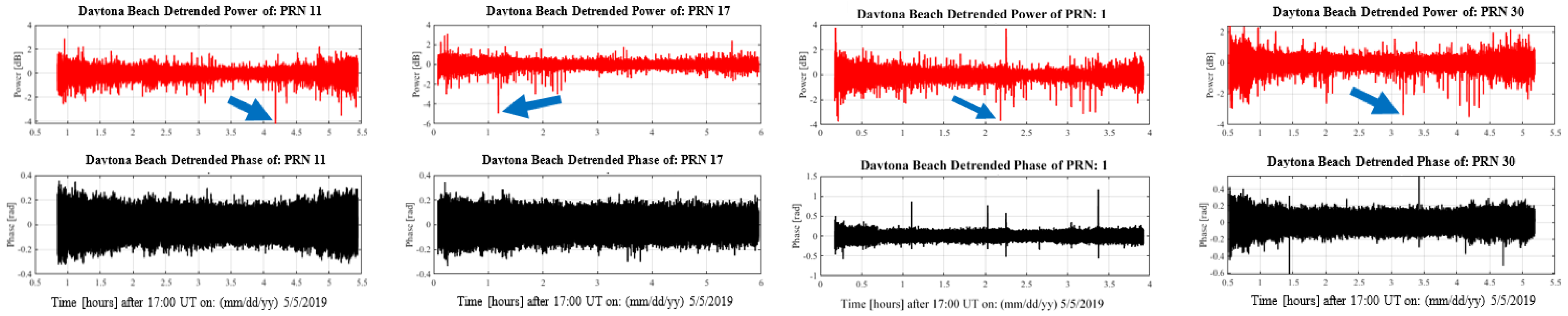


Figure 5: High rate data plots for PRNs 11, 17, 28, and 30 on May 5, 2019 at the time of the thunderstorm. All PRNs show the same scintillation signature at the same time, shown with the blue arrow.

- Other possibilities that cause scintillation were eliminated (i.e. multipath, geomagnetic storms).
  1. No significant correlation found between the change in the Disturbance Storm Time (DST) index, as shown in Figure 6, and the scintillation found on May 5.

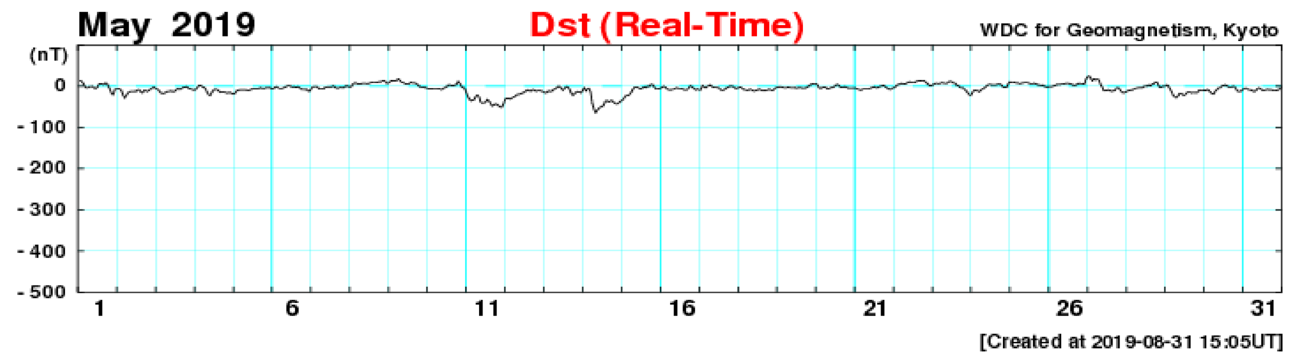


Figure 6: DST Index for May 2019 showing no significant behavior on May 5 (Courtesy: Kyoto GIN).

  2. Solar activity was very low and geomagnetic field activity remained in quiet levels on May 5.
- Cloud tops of this case reach into the stratosphere and potentially produce lightning that affects the ionosphere.

Figure 7: Sky Plot of the location of PRNs 1, 11, 17, 28, and 30 on May 5, 2019. The degrees on the outer circle represent the azimuth angle, and the inner circles represent the elevation of the satellites with respect to the receiver's location. All PRN trajectories are limited by a 50° elevation mask to help eliminate any multipath.

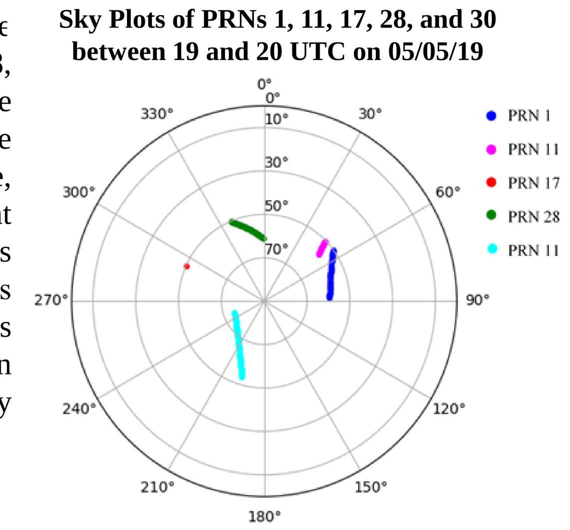
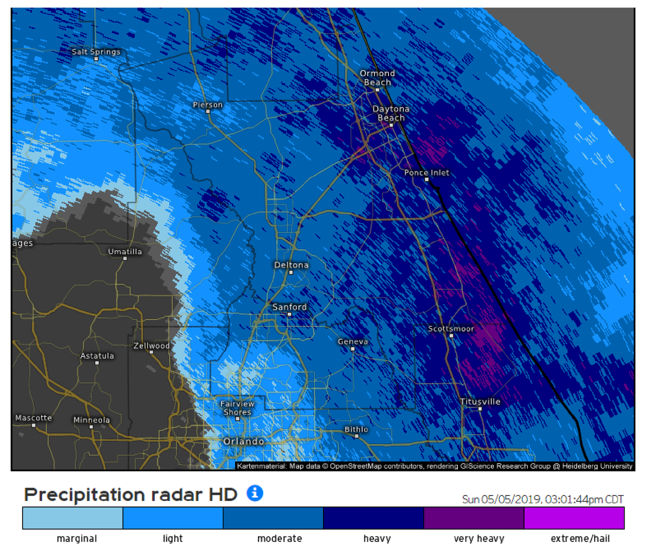


Figure 8: Radar image of a thunderstorm around Daytona Beach on May 5, 2019. Precipitation and wind speed is usually used to determine the severity of a thunderstorm. The times shown for this day correlate with scintillation observed (Courtesy: weather.us).



- For May 5, Figures 7 and 8 reveal that the satellites' signals were traveling through the thunderstorm region.
- The above-mentioned factors lead to the conclusion that **lightning strikes caused in the thunderstorm of May 5, 2019 had a correlation to the observed scintillation of the obtained GPS signal.**
- Further analysis is needed to determine whether this is the only case or if this is a consistent phenomenon. Whether individual lightning strikes or an entire thunderstorm is required to cause significant scintillation will also be studied more, as well as if this type of scintillation usually happens before, during, or after the storm.

Acknowledgements

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