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Tropospheric Scintillation Signatures: Observations of the Possible Effect Thunderstorms Have on GPS Signals

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Objective

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

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 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.

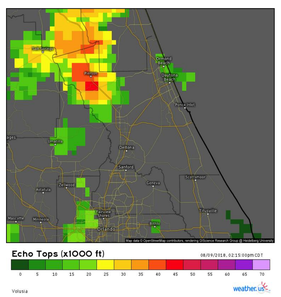


Figure 1: Radar analysis of the approximate max. elevation of precipitation (echo tops) of thunderstorms on August 9, 2018. The actual cloud top of the storm usually reaches beyond the echo top. The storm shown is over 45000 ft (14 km). The times shown for these days correlate with scintillation observed 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 the International Space Station (ISS) of a thunderstorm during an orbit over Southeast Asia. The bright flash is from lightning travelling down to Earth, but red sprites are produced seen above the flash and circled in red. Red sprites are a type of lightning that can reach the ionosphere and can cause radio noise.

- ***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 6) and a MATLAB code to graph high rate data for scintillation analysis (Figure 2).

DETERMINING CANDIDATES

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

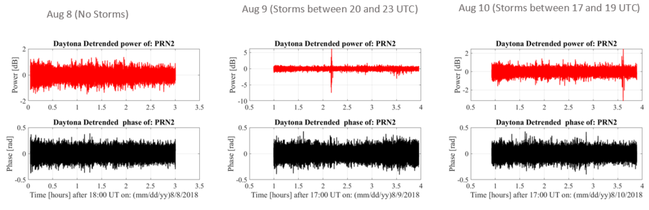
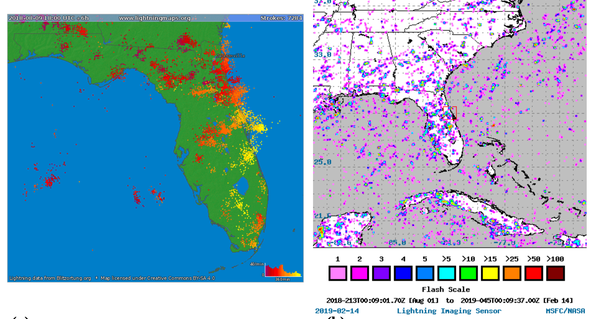


Figure 2: Plots from GPS satellite PRN 2 on August 8-10. Possible scintillation can be seen on August 9 two hours after 17:00 UTC and August 10 three and a half hours after 17:00 UTC. August 8 was a normal day used to rule out multipath.

- Looked for peaks in the graphs which are commonly attributed to scintillation as seen in Figure 2.
  1. Ruled out multipath for cause of scintillation by comparing "normal day" to a possible scintillation day.
  2. All scintillation graphs are accompanied by a "normal day" graph to show the extent of the scintillation.
- Lightning data, as seen in Figure 3, is then analyzed when scintillation is seen to happen during or near the time of a thunderstorm.



(a) (b)

Figure 3: Examples of two different methods used to locate lightning strikes. Figure 2.a is community sourced lightning map. It shows a six hour time lapse of August 9 starting from 18:00 UTC (Courtesy: blitzortung.org). Figure 2.b is the map of all lightning strikes from August 2018 to February 2019. This data is obtained from the International Space Station (ISS). The red square is one degree by one degree centered on the approximate longitude and latitude of Daytona Beach set at 29°N and 81°W (Courtesy: NASA's GHRC).

- Lightning data and weather maps, as seen in Figure 7, are used to compare the tropospheric event's location with the satellite's location, as seen in Figure 6.

Discussion and Future Work

- Significant scintillation was observed on August 9 and 10, 2018 in the mid-latitudes before the thunderstorm was directly overhead; the cause is currently undetermined, but data, as seen on Figures 2 and 4, may suggest **the lightning that happened during these times may have caused the observed scintillation**.

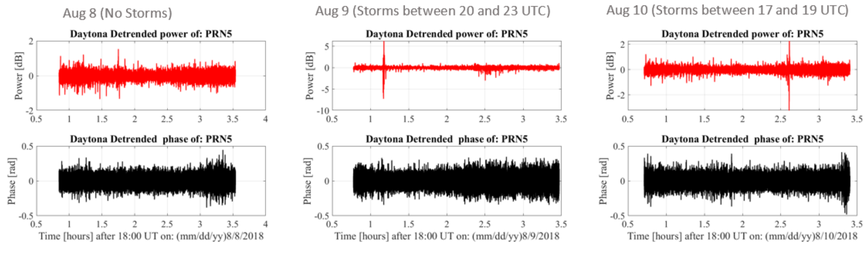


Figure 4: Plots from GPS satellite PRN 5 on August 8-10. August 8 and August 10 were used to compare and rule out multipath. Peaks, which are typically scintillation, are mainly seen in the power plot on August 9.

- 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 5, and the scintillation found on August 9 and 10.

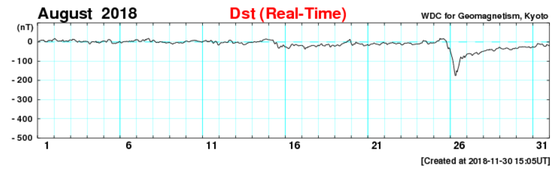


Figure 5: DST Index for August 2018 showing no significant behavior between August 8 and 10 (Courtesy: Kyoto GIN).

  2. Solar activity was very low and geomagnetic field activity remained in quiet levels from August 8-10.
- Cloud tops of this case reach into the stratosphere and potentially produce lightning that affects the ionosphere.

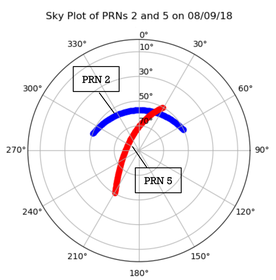


Figure 6: Sky Plot of the location of PRNs 2 (in blue) and 5 (in red) on August 9, 2018. The degrees on the outer circle represent the azimuth angle, and the inner circles represent the elevation of the satellites. Both PRN trajectories are limited by a 50° elevation mask to help eliminate possible multipath.

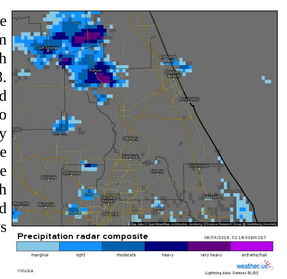


Figure 7: Radar image of a thunderstorm around Daytona Beach on August 9, 2018. Precipitation and wind speed is usually used to determine the severity of a thunderstorm. The times shown for these days correlate with scintillation observed on these days (Courtesy: weather.us).

- For August 9, Figures 6 and 7 reveal that the satellite was travelling near the thunderstorm region.
- The above-mentioned factors lead to the conclusion that **lightning strikes caused in the thunderstorm of August 9, 2018 had a likely 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 scintillation happens before, during, or after the storm.

Acknowledgements

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