Developing Sky Plots of Rocket Launches from GPS Scintillation Data

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Abstract

Sky plots displaying GPS satellite and rocket launch trajectories are developed to determine the spatial correlation between satellites that display ionospheric scintillations and heavy thrust-producing rockets. The trajectories of prior major Falcon Heavy and Artemis 1 rocket launches are considered. The 11/1/2022 Falcon Heavy launch is used within this study. Python code is utilized to compute and plot Ionospheric Pierce Point (IPP) coordinates which are then used to produce satellite trajectories from the receiver's point of view. Rocket latitude, longitude, and altitude data is integrated within the code to provide extensive detail into the location of the rocket in relation to GPS satellites that displayed scintillations from prior high-rate data collected during launch time. The corresponding plots show scintillation-displaying GPS satellites to be in close latitudinal and longitudinal proximity to the rocket trajectory. The spatial proximity of such satellites indicates that major rocket launches can incur disruptions in the signals of local satellites.

Introduction

- Rapid phase and amplitude radio wave fluctuations, known as ionospheric scintillations, result in Global Positioning System (GPS) signal disruption.
- An emerging area of study is the correlation between heavy-thrust producing rocket launches and ionospheric scintillations.
- While receiver data indicates the presence of ionospheric scintillations after rocket launches, there is a lack of spatial correlation between the rocket at time of scintillation and the GPS satellite.

Objective/Motivation

- Through generating Ionospheric Pierce Point (IPP) plots of scintillation-producing GPS satellites and rocket launch trajectory from the time of launch to scintillation, spatial correlation between scintillations and rocket launches can be developed.
  - The ionospheric pierce point serves as an intersection between the linear receiver line-of-sight and satellite ephemeris, assuming the ionosphere to be a thin shell at a fixed altitude.
  - This point is then projected down to a 2D map that can display a collection of IPP points over time to show satellite trajectory as well as rocket trajectory.

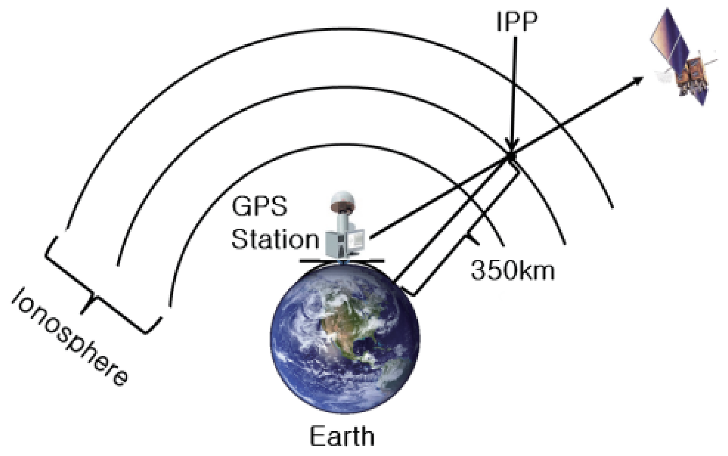

Figure 1: Illustration of Ionospheric Pierce Point [3]

Methodology

Part 1: Analysis of ionospheric scintillation during major prior rocket launches

I. Parsed and processed Novatel receiver data to produce ADR and Power vs. time plots for GPS satellites during the hour of rocket launch.
II. Analyzed plots for peaks after time of rocket launch.
III. Verified that the spikes are ionospheric scintillations through checking plots prior and after the day of launch to eliminate multi-path interferences.

Part 2: Production of IPP plots for GPS satellites showing ionospheric scintillations

I. Obtained sp3 orbital data from the UCSD Garner FTP Server and computed IPP latitude and longitudes in Python.
II. Extracted the respective rocket latitude and longitude data from FlightClub.io and interpolated the data from the start of launch to time of scintillation.
III. Plotted both GPS, IPP and rocket latitudes/longitudes together, setting the IPP altitude to the height of the rocket at the scintillation instant.

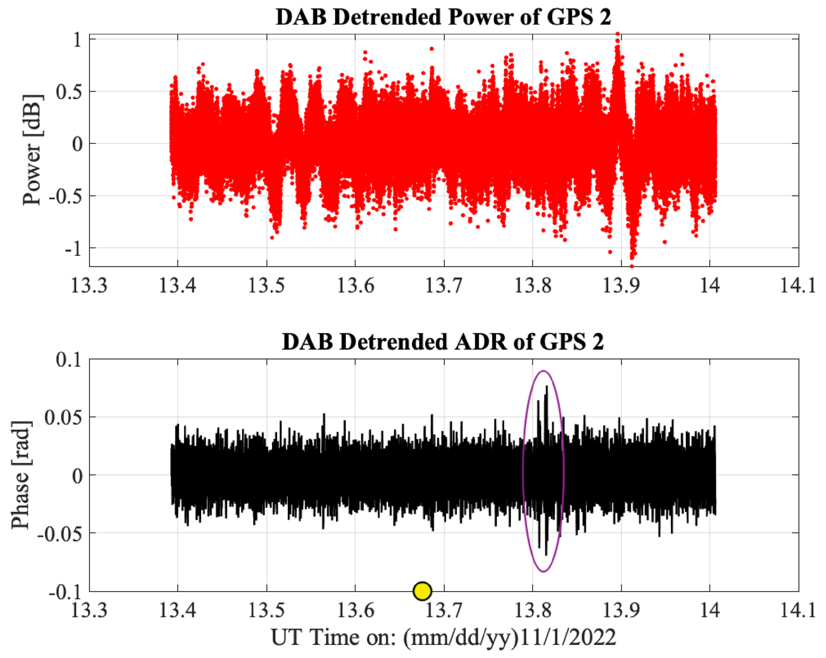

Figure 2: Novatel receiver data for GPS 2. The purple highlights the scintillation instant (~8 mins after launch) and the yellow marks the start of the 11/1/2022 Falcon Heavy Rocket Launch.

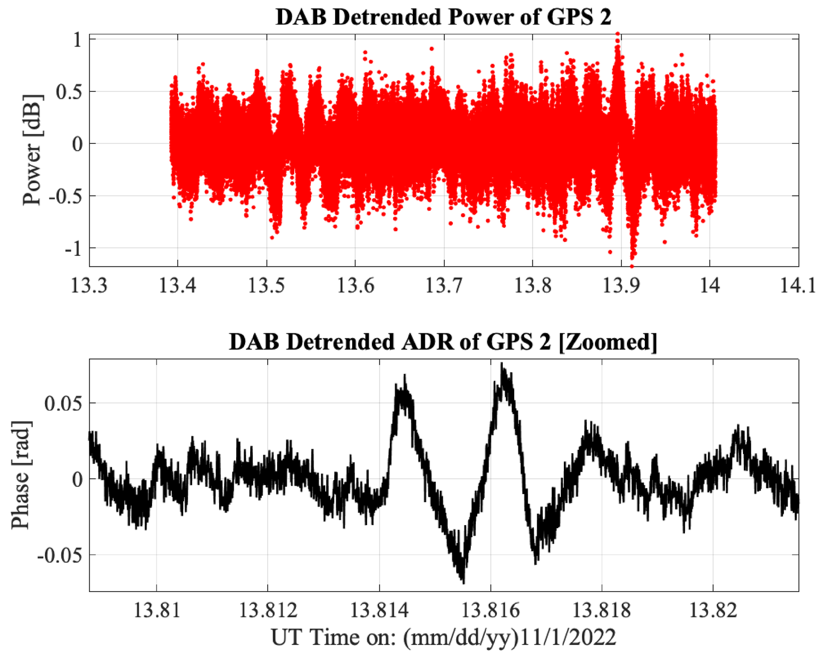

Figure 3: Novatel receiver data for GPS 2. Plot is zoomed to show potential scintillation as seen by the phase fluctuations.

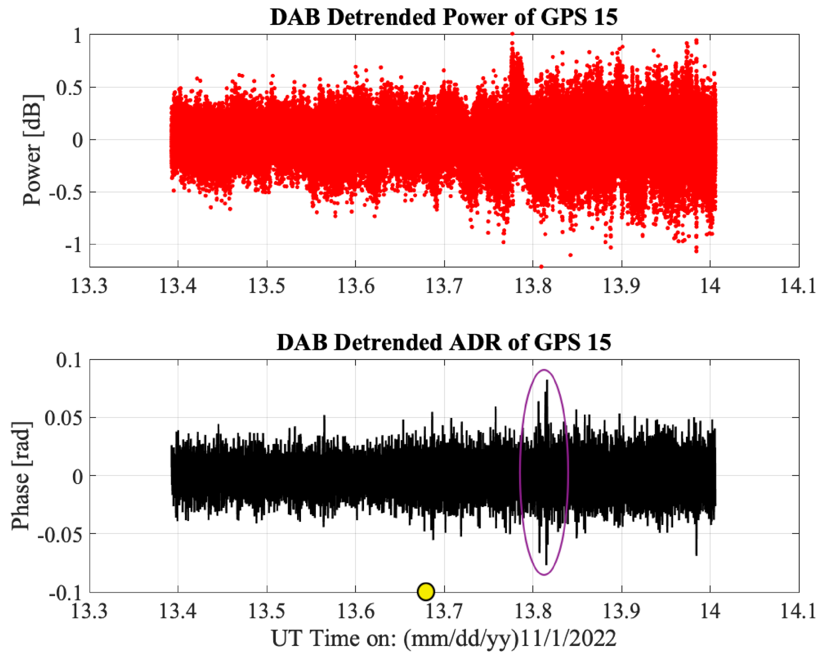

Figure 4: Novatel receiver data for GPS 2. The purple highlights the scintillation instant (~8 mins after launch) and the yellow marks the start of the 11/1/2022 Falcon Heavy Rocket Launch.

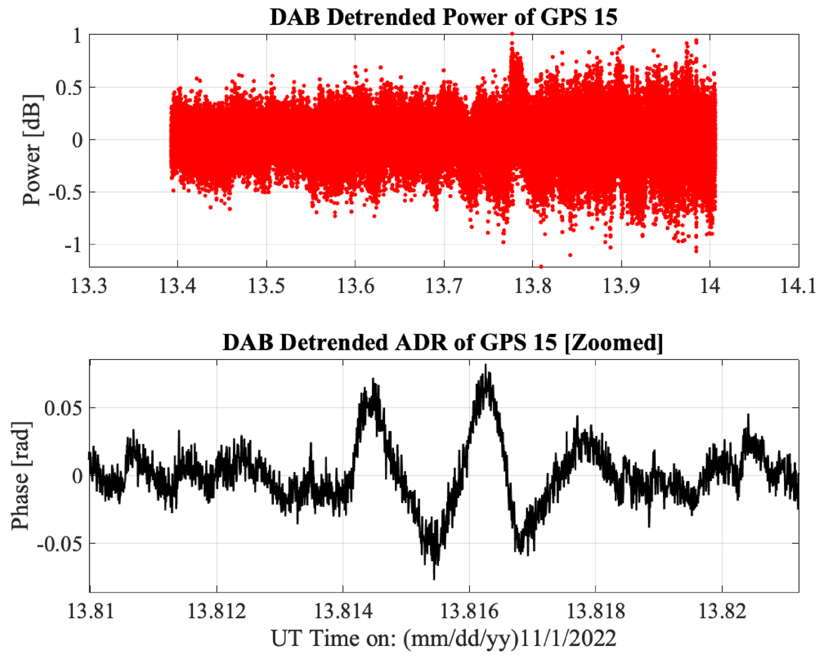

Figure 5: Novatel receiver data for GPS 15. Plot is zoomed to show potential scintillation as seen by the phase fluctuations.

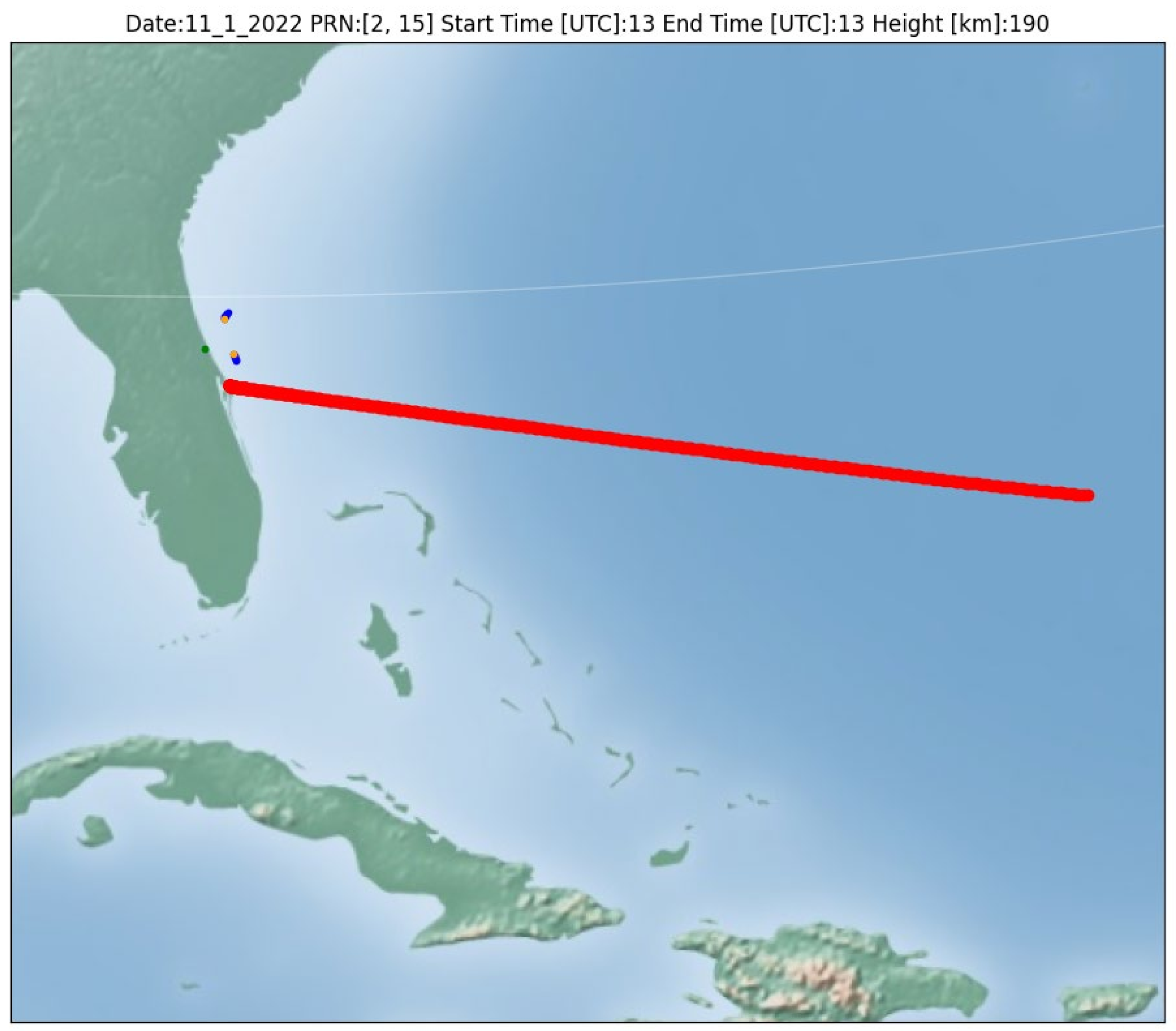

Figure 6: IPP Plot for GPS 2 and 15 during the 11/1/2022 Falcon Heavy Launch over an 8-minute interval from 13:41-13:49 UTC. The red represents the rocket trajectory and the blue marks the satellite trajectories. The orange dot represents the starting satellite position at time of launch.

Results

- The 11/1/2022 Falcon Heavy Launch occurred at ~13.68 or 13:41 UTC
- The rapid fluctuations in phase start at ~13.814 according to **Figures 2, 3, 4, and 5.** This translates to approximately 13:49, correlated to the end point of the rocket and satellite trajectories as seen in **Figure 6.**
- The rapid fluctuations hint at the potential of scintillation structures that occur approximately 8 minutes after the launch of the 11/1/2022 Falcon Heavy rocket.
- Both GPS satellites that showed evidence of scintillations were proximally located to the rocket launch site.

Conclusion/Future Work

- Rocket launches have the potential to cause scintillations among in-sight GPS satellites that are within close IPP latitude and longitude to the rocket trajectory.
- These scintillations cause disruptions in GPS signals and can prevent GPS receivers from locking onto satellites.
- Future research efforts can be put towards investigating the direct effects of rocket launches on the atmosphere and its relation to disrupting GPS signals.
- While the two other Artemis 1 and 1/15/2023 Falcon Heavy launches were also analyzed, their results are currently being evaluated for potential errors and interferences.

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References

[1] El-Gizawy, Mahmoud Lotfy. "Development of an Ionosphere Monitoring Technique Using GPS Measurements for High Latitude GPS Users." National Library of Canada = Bibliothèque Nationale Du Canada, 2004, pp. 157–159.

[2] Kintner, P. M., et al. "GPS and Ionospheric Scintillations." *Space Weather*, vol. 5, no. 9, 2007, https://doi.org/10.1029/2006sw000260.

[3] Lee, Chang-Moon, and Kwan-Dong Park. "Generation of klobuchar ionospheric error model coefficients using Fourier series and accuracy analysis." *Journal of Astronomy and Space Sciences*, vol. 28, no. 1, 2011, pp. 71–77, https://doi.org/10.5140/jass.2011.28.1.071.

[4] Murphy, Declan. *Flight Club*, flightclub.io/. Accessed 6 Oct. 2023.