Total Electron Content and Ionospheric Scintillation Measurements during the Total Solar Eclipse of July 2, 2019

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Objectives

- Explore the relationship between the Sun, the Moon and the ionosphere through the effects of total solar eclipses on Global Navigational Satellite Systems (GNSS)
- Observe rapid changes in signal properties through the collection of high-rate signal phase and power data.
- Evaluate if such a celestial phenomenon can induce or enhance localized ionospheric disturbances

Introduction

What is GNSS?

- Constellations of satellites in specific orbits that provide a continuous and reliable source of data in the form of radio wave signals
- In the ionosphere, free-electron and ion concentrations are known to induce amplitude and phase fluctuations in the received signal known as ionospheric scintillation

About the Ionosphere

- Composed of ionized layers in the Earth's upper atmosphere and ranges from about 60-1000km
- Solar radiation and its interaction with Earth's magnetic field are its principal sources of ions and free electrons
- Fluctuations in solar radiation such as increased solar winds, solar flares, day to night transitions and solar eclipses are known to generate irregularities

On Solar Eclipses

- A solar eclipse is a celestial phenomenon where the sun is obscured by the moon casting a shadow on the Earth
- Provides a temporary obscuration period which locally affects incident solar radiation and surface temperature

Experimental Setup

- Two GNSS receivers and antennas were installed along the path of totality 63km from each other. One in La Serena, Chile and the other in Cerro Pachón, Chile

Figure 1: Novatel GPStation6 receiver (left) and GPS-703-GGG antenna (right)

Methodology and Results

- On site receiver installation and TEC calibration
- Both receivers were set to continuously collect GNSS data three days before and after the eclipse
- Parsing and detrending of binary files to convert to readable CSV files
- Plot and compare 60 second TEC and scintillation measurements for all available PRNs during the eclipse passage and for quiet days
- Enforce a conservative 45° elevation threshold for high-rate phase and amplitude data ($50Hz$) to avoid multipath interference

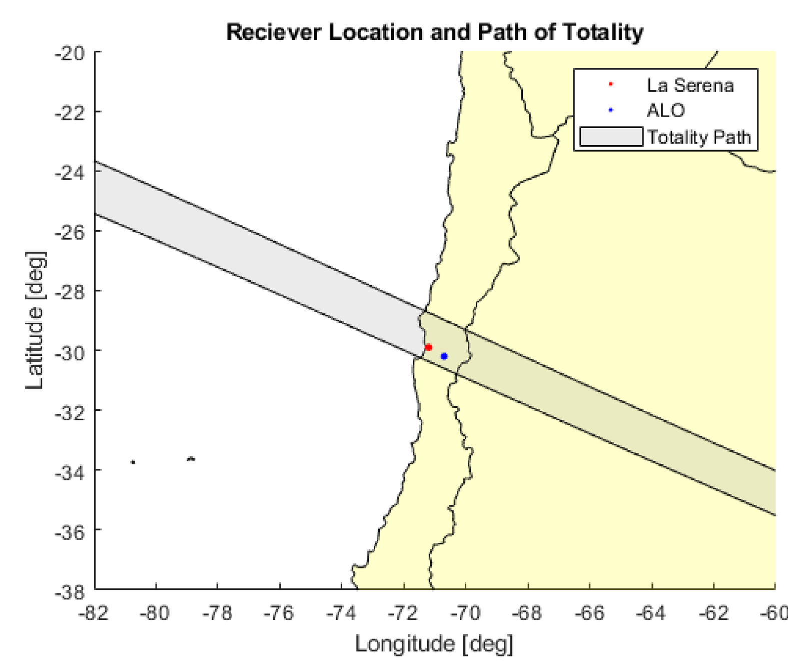

Figure 2: Receiver location and path of totality over Chile. Partial eclipse began at 19:22 UTC, totality at 20:39 UTC and ended at 21:46 UTC.

Total Electron Content Measurements

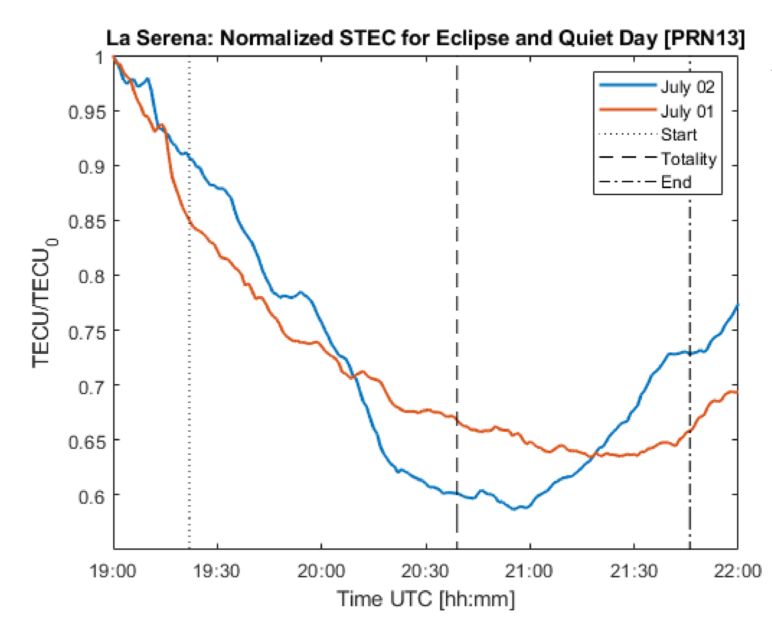

Figure 3: Slant TEC comparison between eclipse day and quiet day in La Serena. The values presented have been normalized in order to compare both days without accounting for TEC receiver bias.

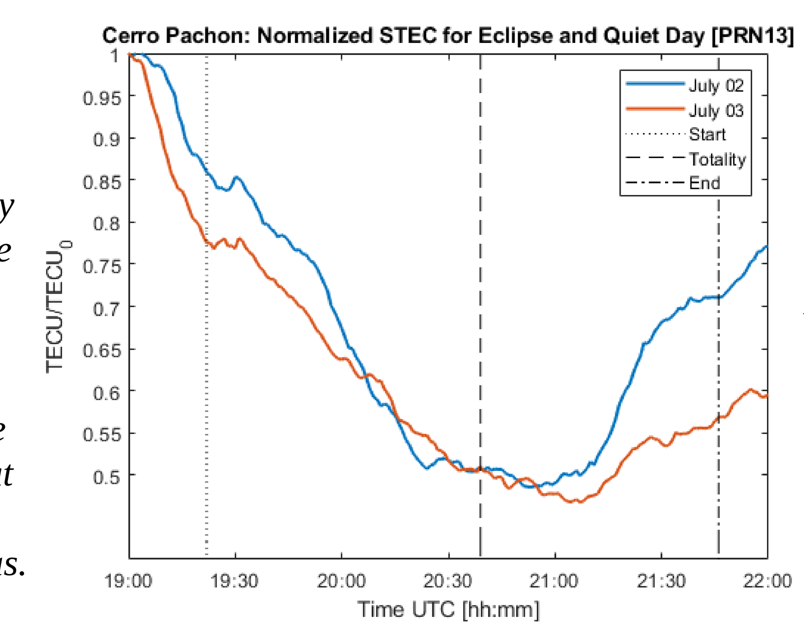

Figure 4: Slant TEC comparison between eclipse day and quiet day in Cerro Pachón. A pronounced drop in measured TEC is evident in both stations for July 2nd when compared to a quiet day.

High-rate Phase and Power Measurements

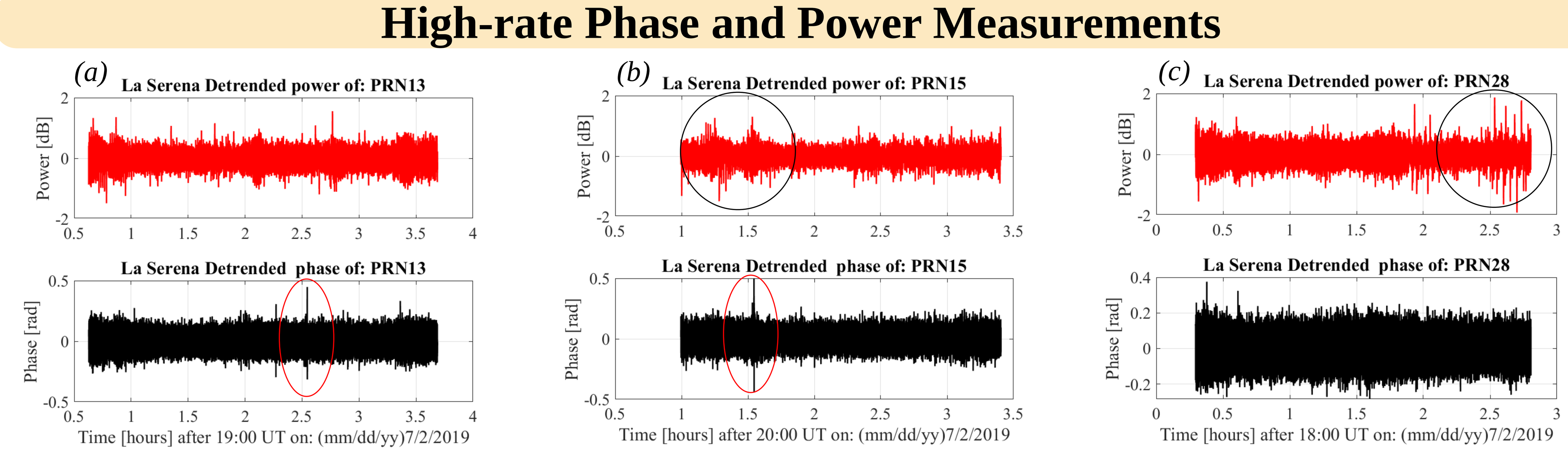

Figure 5: Two candidate phase scintillation events over La Serena occur at 21:34 UTC and are seen in (a) PRN13 and (b) PRN15 circled in red above. Two possible amplitude scintillations were also found in (b) PRN15 and (c) PRN28 and are circled in black. The disturbance observed in phase was also seen in PRNs 12, 17, 19 and 28 with no intrinsic differences or delays. Amplitude events are not evident but coincide with the end of the eclipse's passage at 21:45 UTC.

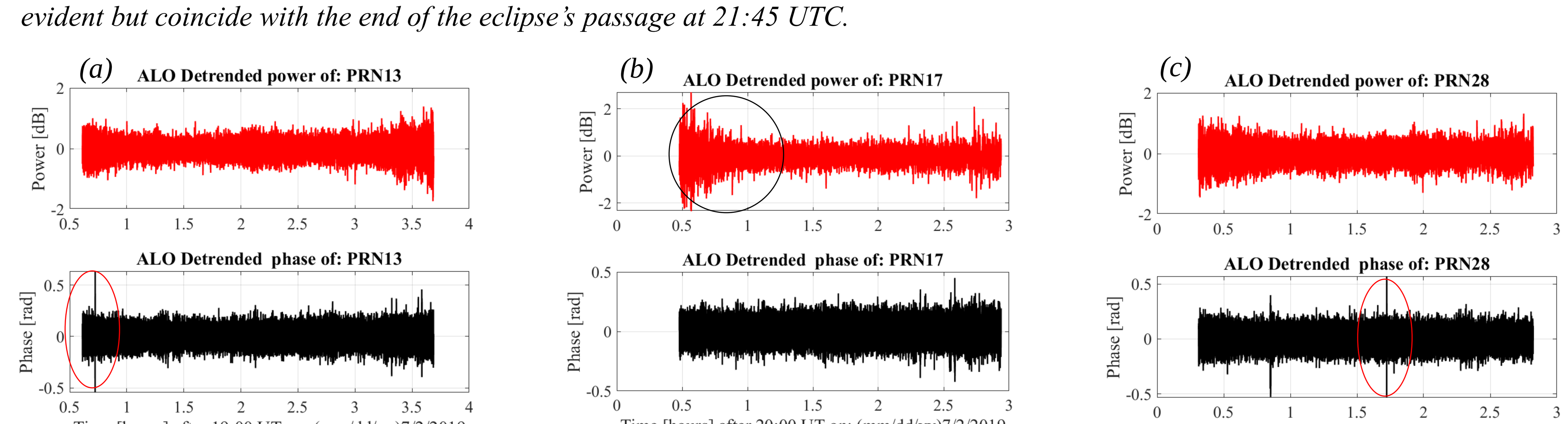

Figure 6: Over Cerro Pachón, two possible phase scintillations occurring at 19:40 UTC are circled in red and are seen in (a) PRN13 and (b) PRN28. Decreasing the elevation threshold to 35° reveals in (b) PRN17 a candidate amplitude scintillation is observed and circled in black. Such event also coincides in time with those observed over La Serena in figures 5.b and 5.c. Similar phase signatures are observed throughout the day of the eclipse and during quiet days as well.

Conclusions

- Total Electron Content observations are consistent with our initial hypothesis and results are a good indication that both receivers where working optimally
- Visually distinguishable inflection points where the magnitude of the rate of change in TEC is higher are observed to match with the end of the eclipse
- The eclipse having occurred near sunset (21:56 UTC) is to be taken into consideration since day to night transition also halt ion production in the ionosphere
- Measured phase signatures did coincide with eclipse time however due to their frequency both in active and quiet days and their simultaneous nature we cannot regard them as eclipse induced scintillations
- The amplitude events, seen in Figure 5.c and Figure 6.b, agree the time of totality. Speculation based on ionospheric pierce point (IPP) plots leads us to believe that the event in 5.b is the same disturbance as seen in 5.c and 6.b. Nonetheless a more in-depth analysis is needed to attribute this as an eclipse induced disturbance

Future Research

- Improve experimental methods by performing appropriate receiver calibration and removing receiver and satellite bias
- Complement the study with data from other sensors such as ionosondes or magnetometers to validate findings
- Organize a research cooperative with scientists in Chile to prepare for the next solar eclipse in Dec 2020

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