On distributed observations of ionospheric irregularities and L-Band scintillation from Puerto Rico

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Abstract

Recently, we installed three ScintPi 3.0 in Puerto Rico to study ionospheric irregularities and scintillation in a region that can be considered to be a boundary between low and mid geomagnetic latitudes. ScintPi 3.0 is a GNSS-based, multi-constellation, dual-frequency ionospheric scintillation and total electron content (TEC) monitor developed at UT Dallas. Analyses have been carried out for measurements collected since December 2021. In this initial analysis, only geomagnetically quiet days were taken into consideration based on the time histories of the Kp index. In this poster, we will present the occurrence rate of L-Band scintillation, their properties, and the spatial distribution of ionospheric irregularities causing scintillation. We will also present evidence of the source of ionospheric irregularities causing scintillation.

Objectives

L-Band scintillations in Puerto Rico have been reported in the past but, in general, the observations have been limited in duration. Here we setup an observation campaign with the following goals:

- **Goal #1:** To create a database of routine, distributed L-Band ionospheric scintillation and TEC measurements at a site located in the boundary between mid and low geomagnetic latitudes.
- **Goal #2:** To determine the properties and sources of the observed scintillations.

More specifically: How often do we observe L-Band scintillation in Puerto Rico? How intense can observed scintillation be? Where do the irregularities causing scintillation in Puerto Rico come from?

Methodology

- In order to obtain measurements of irregularities and L-band scintillation in a location that is the boundary between mid and low geomagnetic latitudes, we deployed 3 ScintPi 3.0 receivers distributed over Puerto Rico. Those receivers are located in Arecibo (66.75°W, 18.34°N), Quebradillas (66.91°W, 18.46°N) and Culebra (65.30°W, 18.33°N). **Figure 1** shows the locations of our receivers.
- For this study, we analyzed measurements made from December solstice (~Dec 21th,2021) to March equinox (~Mar 20th, 2022). The average of decimetric solar flux (F10.7cm) was 102 SFU. See **Figure 2**.
- During the observation campaign (90 days) we found that 43 nights were geomagnetically quiet, that is, Kp index was lower than 3.0 during the entire night and the previous 24 hours. **Figure 3** highlights the nights where these conditions were met.

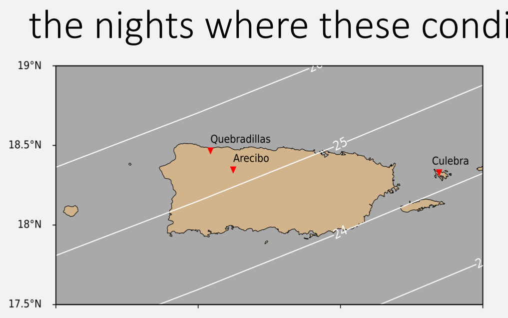

Figure 1. ScintPi 3.0 deployments

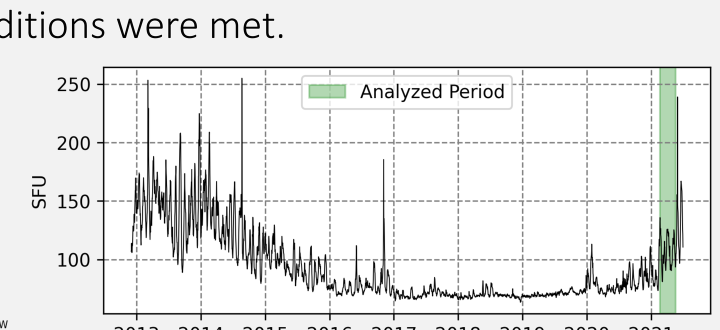

Figure 2. F10.7 solar flux for the analyzed period

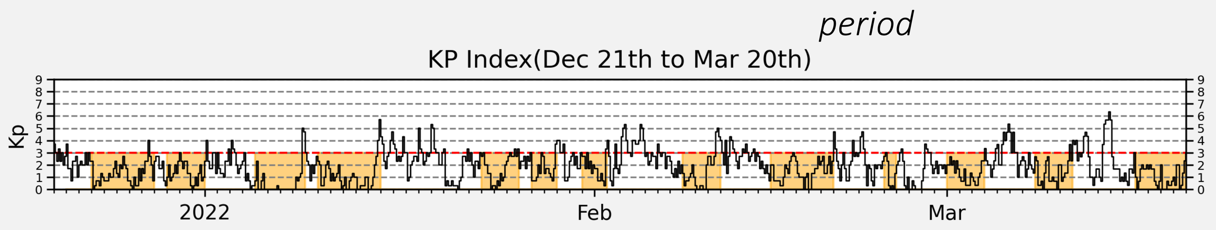

Figure 3. Nights under quiet Geomagnetic conditions

- **Measurements of irregularities/scintillation:** ScintPi 3.0 is capable of making measurements of ionospheric TEC and scintillation (at two frequencies). A previous version of ScintPi showed that estimations of S_4 agreed with S_4 values provided by commercial receivers (Rodrigues and Morales, 2019). **Figure 4** shows an example of irregularities in TEC and scintillation associated with them.
- In order to determine the occurrence of scintillation, we computed the S_4 index from the signal intensity (I) for each tracked satellite (Kintner et al., 2007):

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}} \quad (1)$$

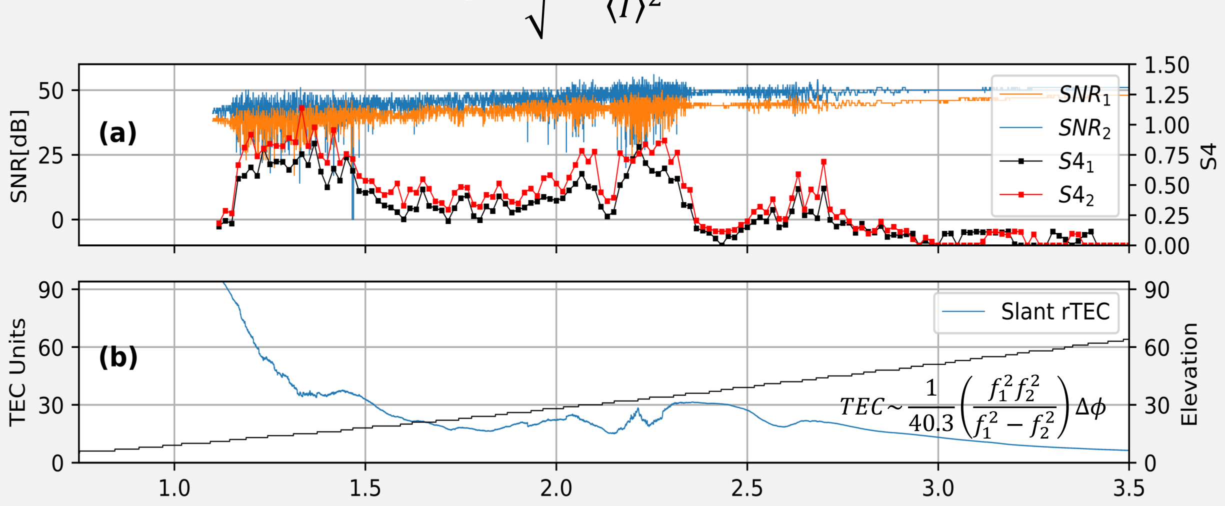

*Figure 4. Example of scintillation on GPS 14: **(a)** Signal to Noise Ratio (SNR) and S_4 for each frequency. **(b)** Slant relative TEC and satellite elevation.*

- **Figure 5** shows a summary of the scintillation measurements made in Arecibo during the 43 quiet days. **Figure 6** shows the percentage occurrence rate and the S_4 distribution of those measurements.
- **Location of scintillation-producing irregularities:** In order to determine the spatial distribution of the irregularities causing scintillation, we computed the ionospheric pierce points (IPPs) of all measured signals for the period in question as done in Prol et al. (2017). See **Figure 7**.

Results

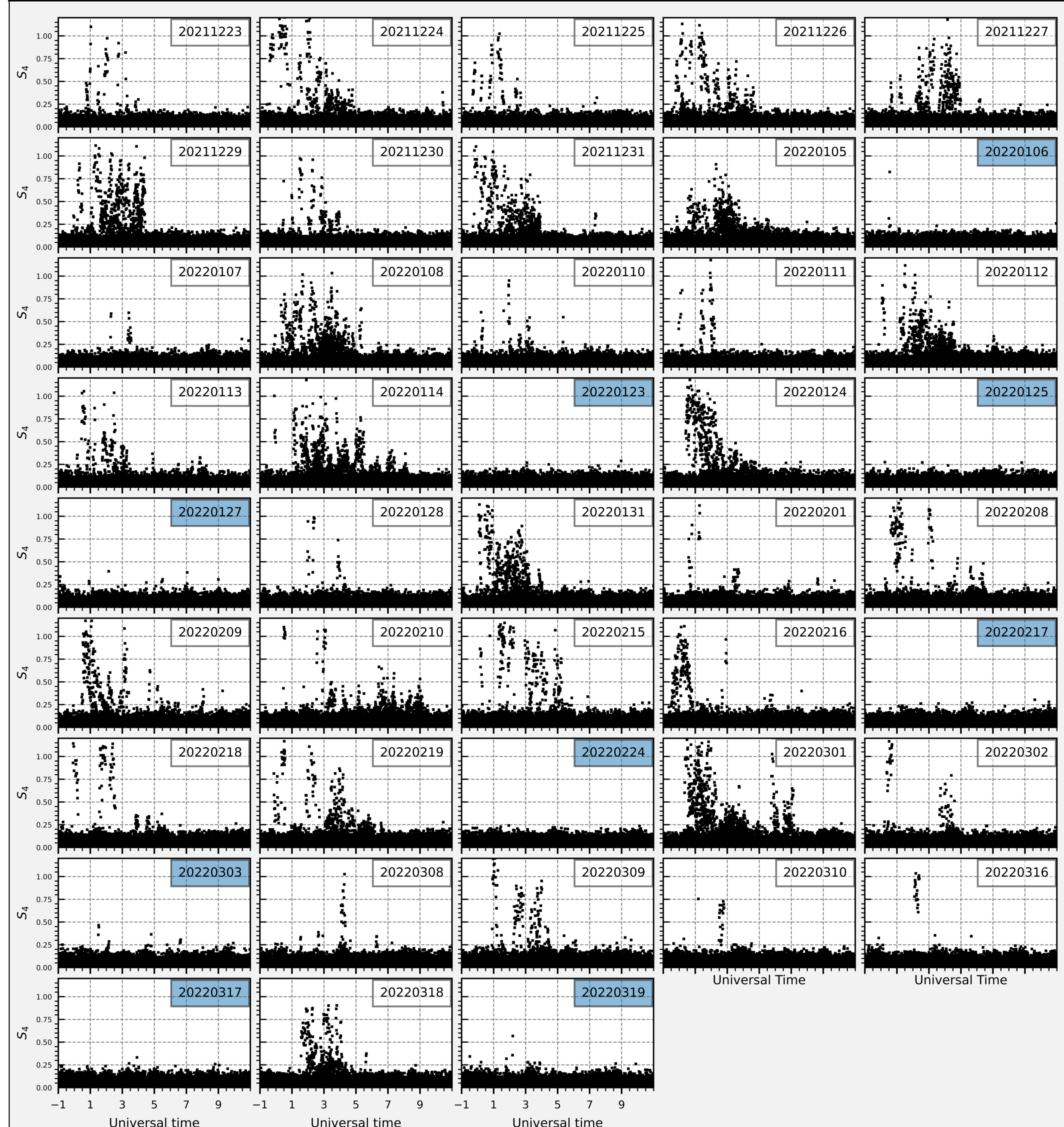

***Figure 5** – Summary of L1 (~1.6 GHz) S_4 measurements made by ScintPi 3.0 in Arecibo, PR during geomagnetic quiet nights. Highlighted dates indicate nights without scintillations. These new measurements show that, for the conditions of the campaign, L-Band scintillation could be observed nearly every day on a site located in PR. More importantly, the measurements show cases of severe amplitude scintillation.*

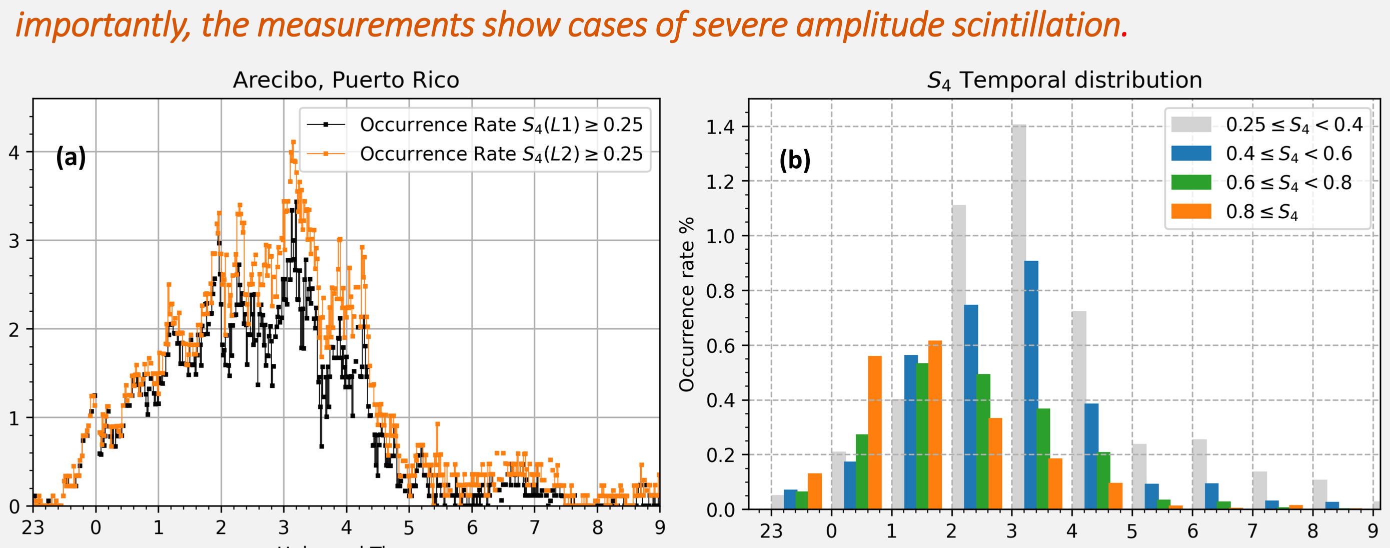

***Figure 6** – **(a)** The occurrence rate of $S_4 \geq 0.25$. **(b)** S_4 distribution of the measurements. Scintillation occurs predominantly in the post-sunset to post-midnight sector. A significant number of intense scintillation ($S_4 \geq 0.8$) cases are observed.*

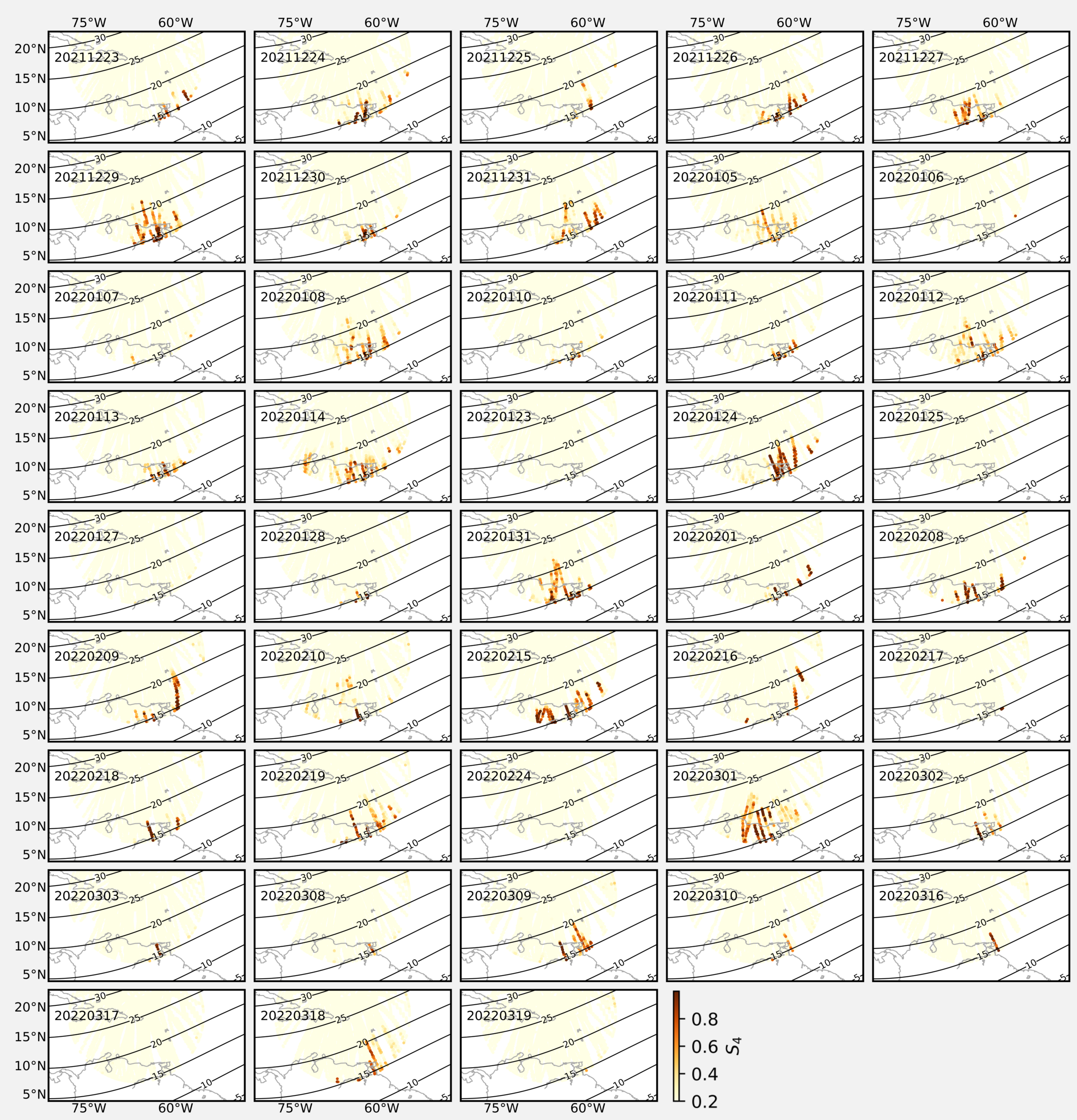

***Figure 7** – Spatial distribution of S4 values for each geomagnetic quiet night. The analysis serves to show that scintillations occur predominantly to the south of the observation site (Arecibo) indicating a link with low latitude ionospheric perturbations, that is, equatorial plasma bubbles (EPBs).*

The presence of EPBs can be identified by analyzing TEC measurements and looking for plasma depletions at the same time that scintillation occurs. See **Figure 8**.

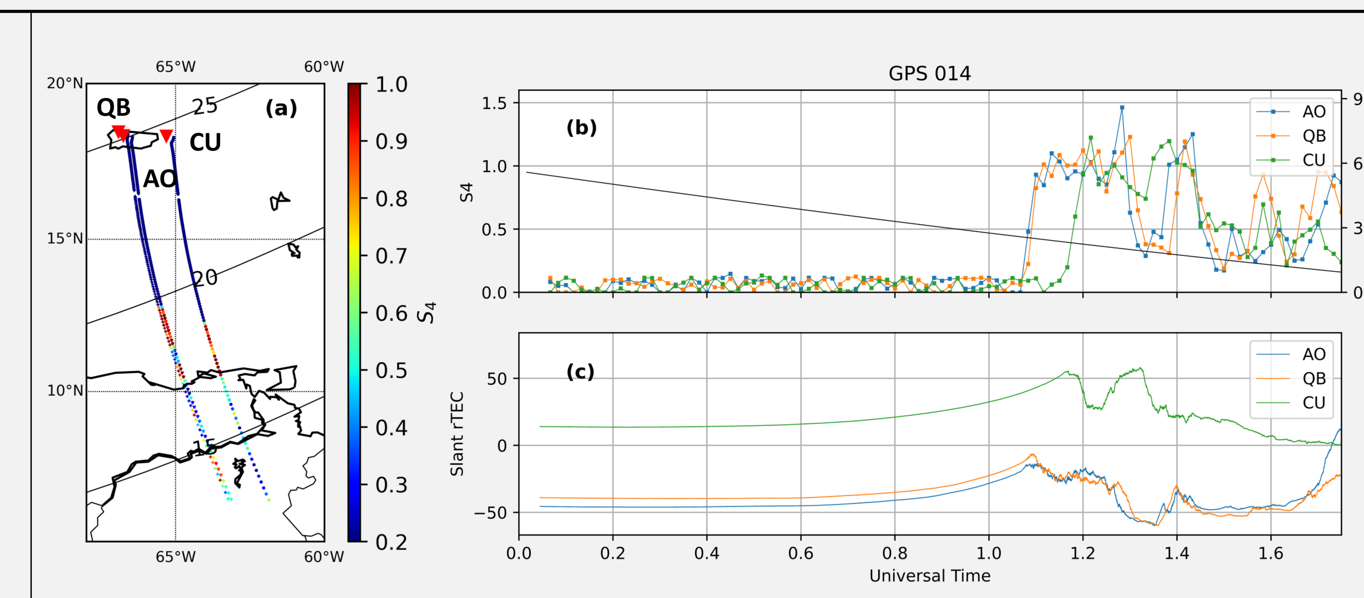

***Figure 8** – Example of scintillations measured using GPS 14. Panel **(a)** shows the IPPs for the three receivers in Puerto Rico color-coded according to the values of S_4 index on L1. Panel **(b)** shows the S_4 index values versus time. Panel (c), in particular, shows that strong scintillation is occurring due to small scale density fluctuations (shown by rTEC) embedded in large plasma depletions observed at low latitudes.*

At least for the quiet conditions scintillations were mostly contained between 15 and 20 magnetic latitude. (See **Figure 9**)

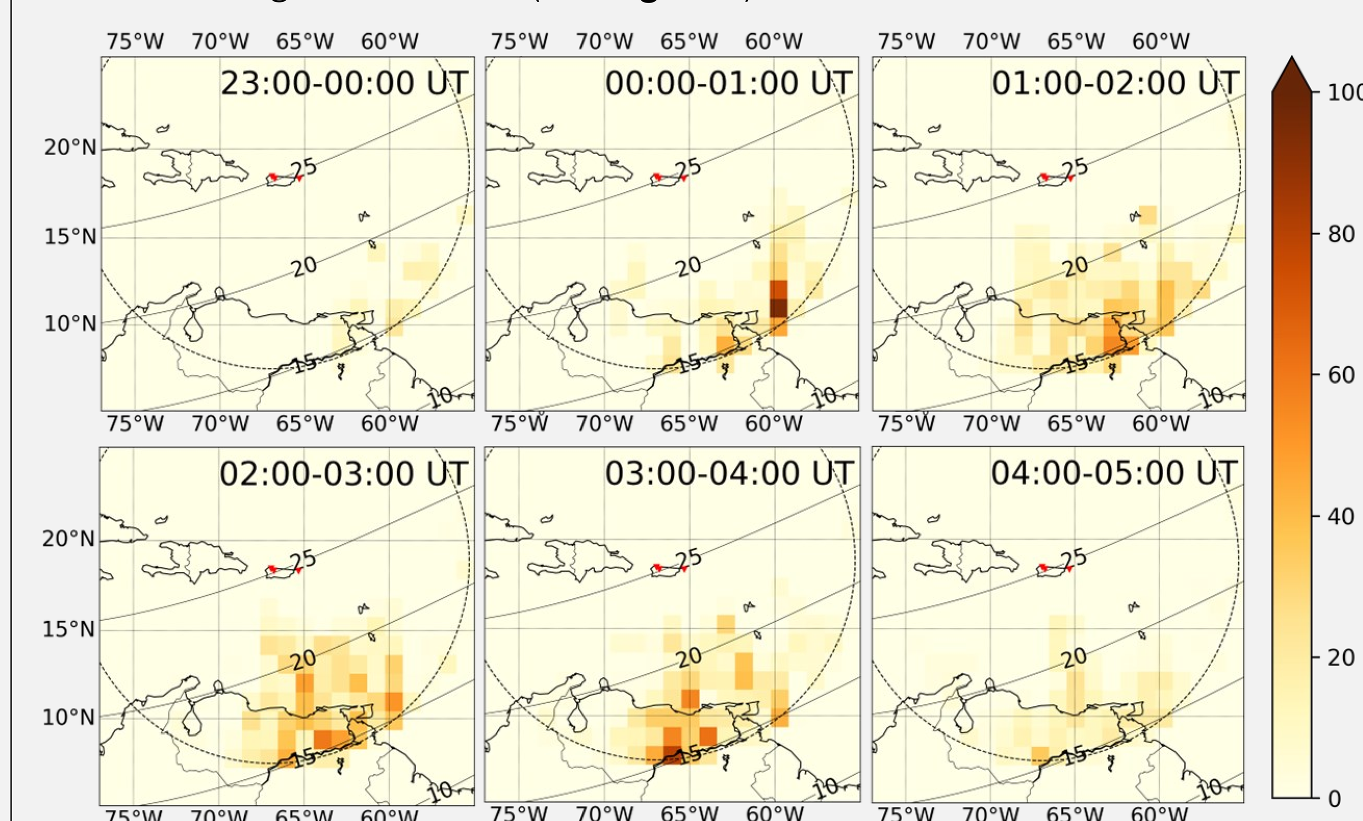

***Figure 9** – Spatial and temporal variations of L-band scintillations ($S_4 \geq 0.25$) observations made during the campaign period. The snapshots serve to show that scintillation occurs, predominantly, to the south of the sites and between 01:00 UT and 04:00 UT (~ 21:00 and 00:00 LT). The location and timing reinforce the association of observed scintillation with equatorial plasma bubbles.*

Conclusions and Future Work

- A new ground-based observational setup is now in place for distributed measurements of ionospheric irregularities and scintillation from Puerto Rico. The setup allows ionospheric irregularity studies at the boundary between low and mid geomagnetic latitudes.
- The most striking finding is that, at least for the period of the campaign (Dec. 21, 2021 – Mar. 20, 2022), quiet-time scintillation was observed almost every night from Puerto Rico.
- Intense scintillation ($S_4 \geq 0.8$) activity dominates at the beginning of the night, 20:00 to 23:00 LT (23:00 to 01:00 UT), and moderate to weak scintillation is found to occur near mid-night and in the post-midnight sector.
- The temporal evolution and spatial distribution of scintillation and TEC perturbations indicate that the observed irregularities are associated with EPBs.
- In the future, we will investigate the occurrence of scintillation activity as the solar cycle reaches its maximum under the different seasons.
- The ScintPis in Puerto Rico will help us better understand the occurrence of mid-latitude ionospheric scintillation and irregularities. The measurements will complement observations made by other ScintPi monitors being deployed by our collaborators across the US.

Acknowledgements

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