ScintPi: Advancing ground-based observational capabilities for space weather monitoring and studies

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Abstract

The relatively high cost of scintillation monitors to be used in education and research applications led us to create ScintPi. ScintPi is a series of GNSS-based ionospheric scintillation total electron content (TEC) monitors. While ScintPi is not designed to fully replace commercial systems, they have proven adequate for many application including space weather. In this presentation, we summarize the design of ScintPi monitors and highlight their benefits. We present the status of collaborative deployments at low, mid and high latitudes. We also showcase examples of measurements and results of studies that highlight the adequacy of ScintPi in different applications. These include, for instance, magnetic conjugate observations of low latitude scintillation, spaced-receiver measurements of ionospheric irregularity drifts, and detection of strong mid-latitude L-Band scintillations.

ScintPi 3.0: features and Performance

ScintPi monitors were designed for mass production, keeping costs low by utilizing commercial off-the-shelf (COTS) components. As illustrated in Figure 1, the total cost remains under $600 USD. This monitor is capable of collecting high-rate data, including carrier phase (φ), pseudo-range (ρ), and signal strength across multiple frequencies and codes (Gomez Socola and Rodrigues, 2022)

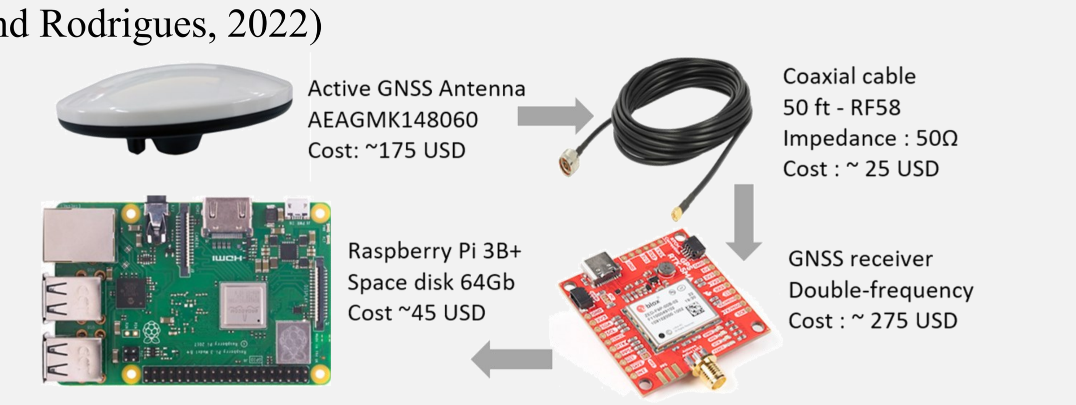


Fig. 1 – *COTS components used in the development of latest ScintPi (3.0).*

Features:

- ✓ All GNSS constellations (GPS, GLONASS, BeiDou, GALILEO)
- ✓ Multi-signals (L1A/C,L2C, E1B,E5B,L1OF,L2OF,B1i,B5i)
- ✓ Sampling rate resolution (20Hz @ 4constellations)
- ✓ Signal strength resolution = 1 dB/Hz
- ✓ Cost of parts : ~US$ 560 per unit w/ antenna and 50 ft cable.

Performance:

The results from ScintPi 3.0 closely match the outputs of the commercial Septentrio PolaRx5s receiver, as shown in Figure 2.

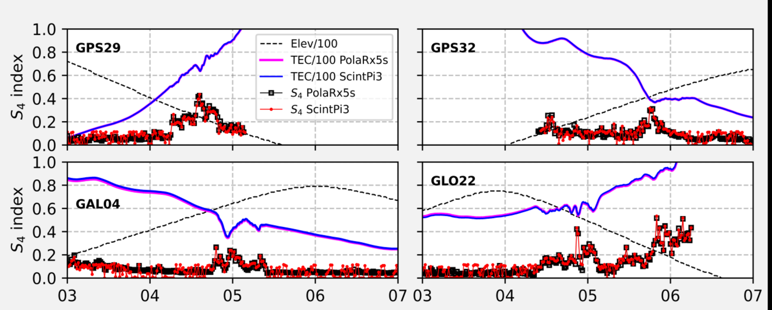


Fig. 2 – S_4 and TEC from *ScintPi 3.0 and PolaRx5s.*

Platform for data collection

We also developed an automatic system that allows ScintPi monitors to upload and back-up data. This system also allows collaborators to download products using SFTP.

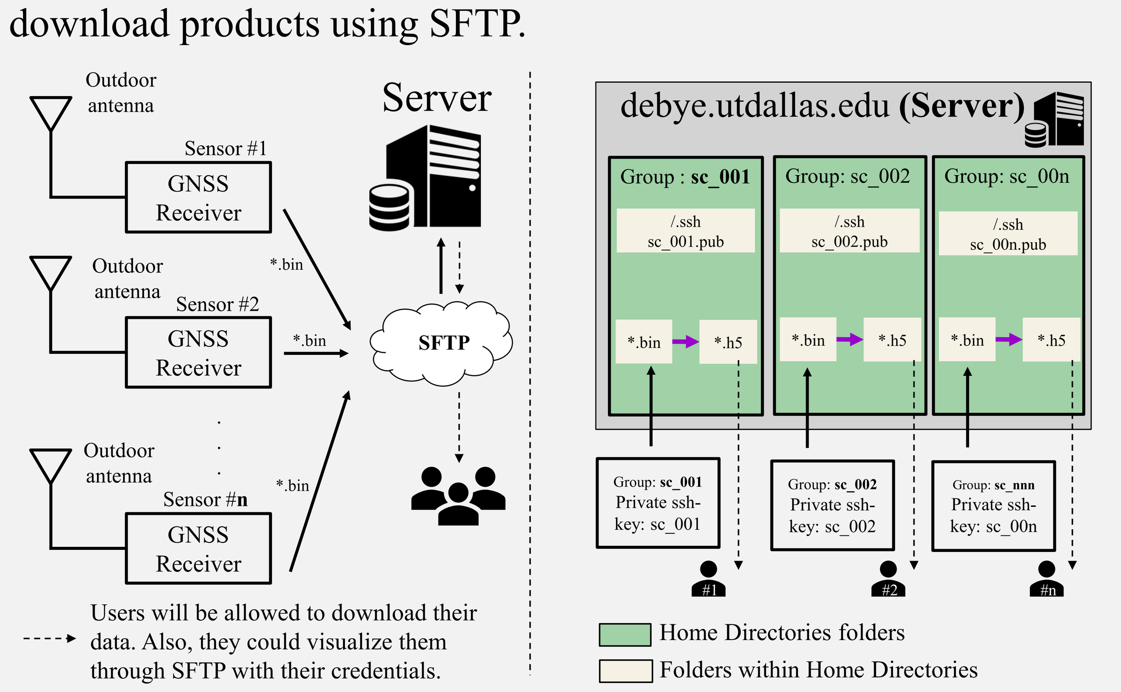


Fig. 3 – *Operational diagram of the internal server for ScintPi monitors.*

The ScintPi network: An international collaborative effort

The easy-to-install and easy-to-operate ScintPi 3.0 monitor has been deployed by collaborators, covering a significant portion of low- and mid-latitudes in the American sector (see Figure 4). These monitors are hosted by researchers and citizen scientists interested in space weather.

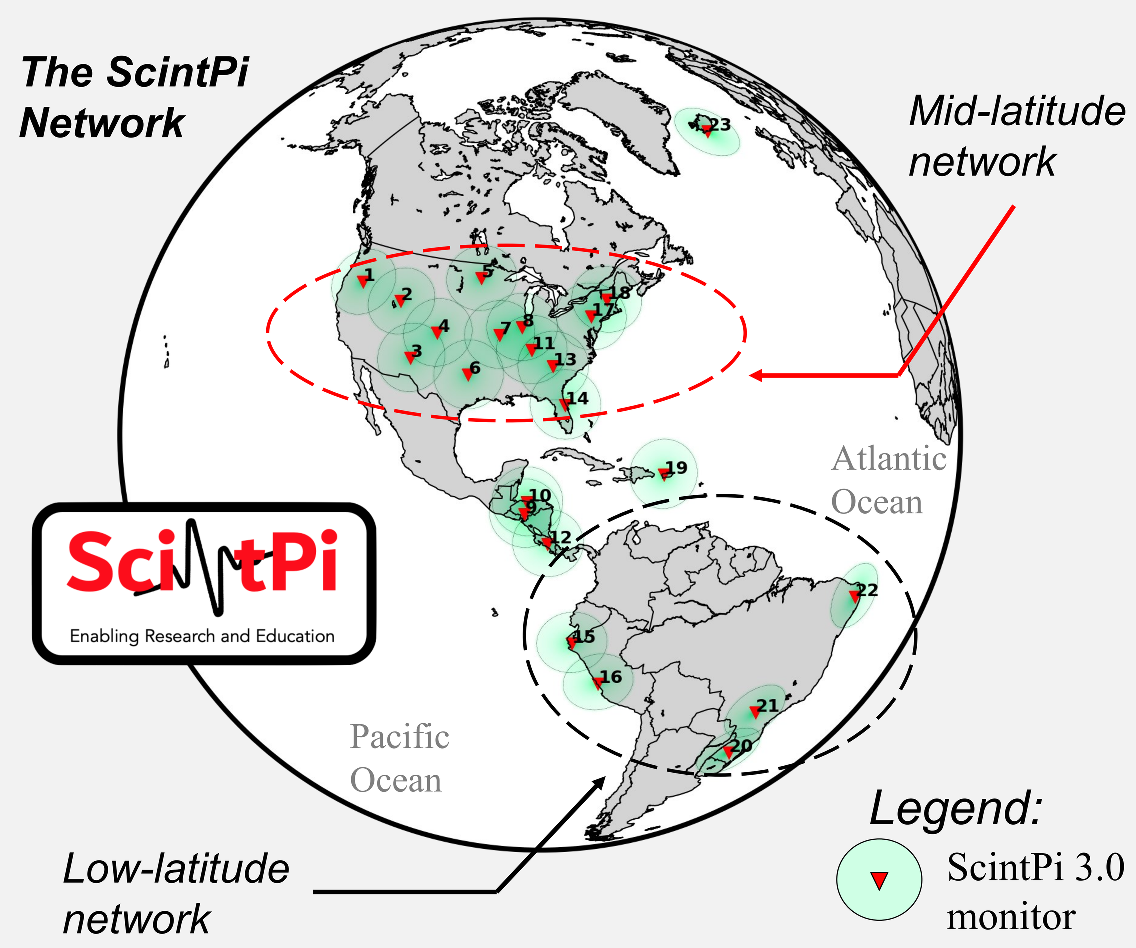


Fig. 4 - *The current (2025) ScintPi3.0 network, with receivers indicating their respective field of views for elevations greater than 30 degrees.*

Table 1 lists the institutions and collaborators hosting ScintPi monitors.

Rx#	Institution	Collaborator	Latitude	Longitude	Rx Status
1	Darthmouth College - Christmas Valley	Simond Shepperd	43.27 N	120.35 W	Operative
2	Utah State University - Bear Lake Observatory	Ludger Scherliess	41.93 N	111.42 W	Operative
3	New Mexico University	Greg Taylor	34.35 N	106.88 W	Operative
4	Deep Space Exploration Society	Dan Layne	38.38 N	103.15 W	Operative
5	North Dakota **(Citizen science)**	Michael James Hauan	46.91 N	96.79 W	Operative
6	University of Texas at Dallas	Josemaria Gomez*	32.99 N	96.75 W	Operative
7	Missouri **(Citizen science)**	Michael James Hauan	38.91 N	92.13 W	Operative
8	U. of Illinois Urbana Champaign	Jonathan Makela	40.17 N	88.16 W	Operative
9	U. Nacional Autónoma de Honduras	Yvelice Castillo Rosales	14.08 N	87.16 W	Operative
10	U. Nacional Autónoma de Honduras	Yvelice Castillo Rosales	14.09 N	87.16 W	Operative
11	Kentucky **(Citizen science)**	Nathaniel Butts	36.93 N	86.43 W	Operative
12	Instituto technologico de Costa Rica	Miguel Rojas Quesada	9.85 N	93.91 W	Operative
13	Clemson University	Stephen Roland Kaeppler	32.99 N	96.75 W	Stand By
14	Embry-Riddle Aeronautical U.	Kshitija B. Deshpande	29.18 N	81.04 W	Operative
15	Universidad de Piura - Peru (**Spaced-receivers**)	Rodolfo Arizmendi	5.17 S	80.62 W	Operative
16	Lima - Peru, Jicamarca Radio Observatory	Danny Scipion	11.95 S	76.87 W	Operative
17	Scraton - University of Scranton	Nathaniel A. Frissell	40.21 N	80.62 W	Operative
18	Darthmouth College - New Hamsphire	Simond Shepperd	43.70 N	72.29 W	Operative
19	Puerto Rico - Arecibo Observatory	Pedrina Terra	40.21 N	80.62 W	Operative
20	Bate-Papo Astronômico - Santa Maria - Brazil	F. Colvero	40.21 N	80.62 W	Operative
21	Presidente Prudente - Brazil	Alison de Oliveira Moraes	40.21 N	80.62 W	Operative
22	Federal U. of Campina Grande **(Spaced-receivers)**	Igo Paulino & Ricardo Buriti	40.21 N	80.62 W	Operative
23	Darthmouth College - Iceland	Simond Shepperd	63.77 N	20.54 W	Operative

***Table 1** – List of the institutions and collaborators hosting ScintPi monitors.*

- A mid-latitude network was deployed to study scintillation activity, focusing on properties such as severity, rapidity, and origin.
- The low-latitude monitors were initially deployed for testing purposes and later supported observations of equatorial density irregularities extending into mid-latitudes and ionospheric irregularity drifts.

Studies using distributed and collocated observations

Ionospheric monitors in Puerto Rico have been collecting scintillation measurements since December 2021. The location of these monitors allows study of occurrence rates, latitudinal extent, and scintillation severity at the boundary between low and middle magnetic latitudes. Continuous observations provided by ScintPi since December 2021 also allows us to investigate the latitudinal variability of scintillation as a function of both solar flux conditions during the ascending phase of Solar Cycle 25 and during geomagnetically quiet and disturbed periods.

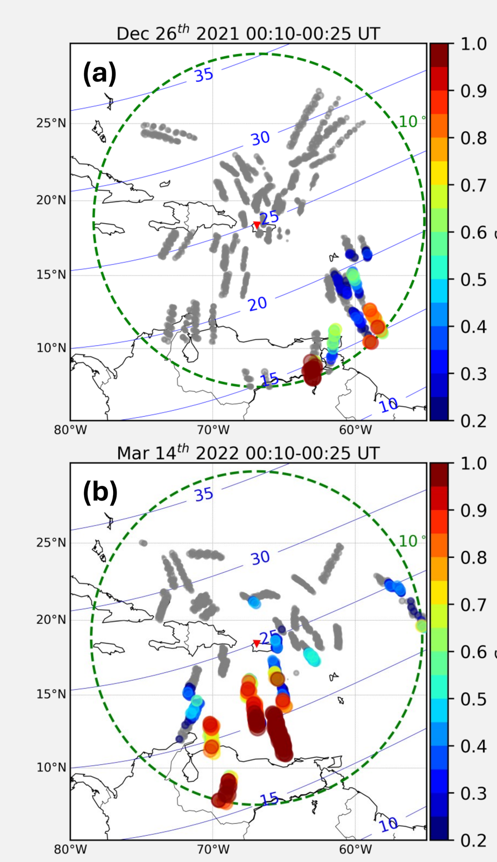


Fig. 5 – *Scintillation observations from Puerto Rico.*

Figure 5 illustrates the latitudinal extent of geolocated scintillation activity. Geolocation was performed using the Ionospheric Pierce Point (IPP) at 350 km. Figure 5(a) represents a geomagnetically quiet day. Statistically, geolocated scintillation activity does not exceed 22° magnetic dip latitude under quiet conditions and moderate solar flux (81–136 s.f.u) (Gomez Socola et al. 2023). However, during disturbed periods, scintillation can extend to higher magnetic latitudes (~28° dip latitude) (Sousasantos et al. 2022).

To illustrate typical sources of scintillation observed by Puerto Rico monitors, Figure 6 presents four consecutive days with clear signatures of equatorial plasma bubbles in collocated scans from the GOLD mission (Figure 6a). During these days, scintillation entered the field of view of our Puerto Rico receiver, as shown in Figure 6(b)

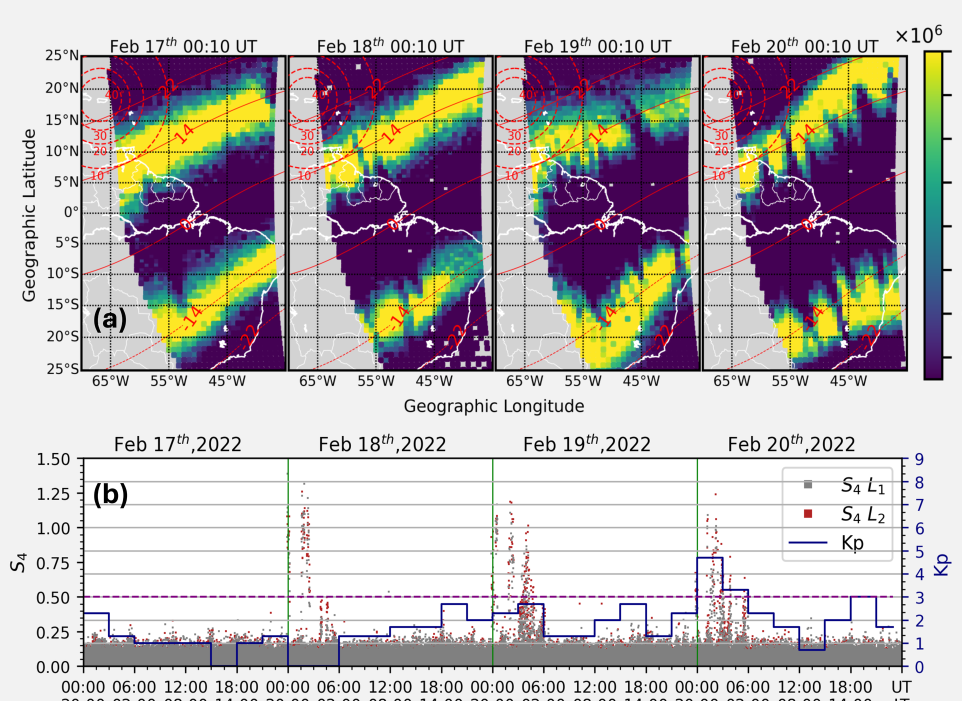


Fig. 6 – *Scintillations measurements around the Caribbean region (low-latitudes) collocated with scans from the GOLD mission (oxygen emission at 135.6 nm).*

Quiet-Time Extreme Equatorial Plasma Bubbles (EPBs)

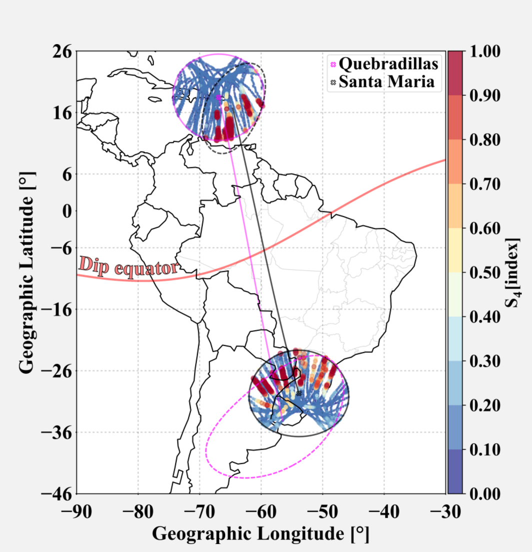


Fig. 7 – *Conjugated observations from Puerto Rico and Brazil.*

Observations presented in Figures 7 and 8 show that, unlike geomagnetically disturbed events reported in previous studies, extreme EPBs and severe scintillation can extend to dip latitudes above 26° even under geomagnetically quiet conditions. Continuous observations can contribute to a better understanding of how far, in terms of dip latitude or apex height, EPBs can extend under varying geomagnetic and solar activity conditions. These findings suggest that scintillation effects associated with EPBs may impact GNSS systems in the low-to-mid latitude region more frequently than previously anticipated (Sousasantos et al., 2024).

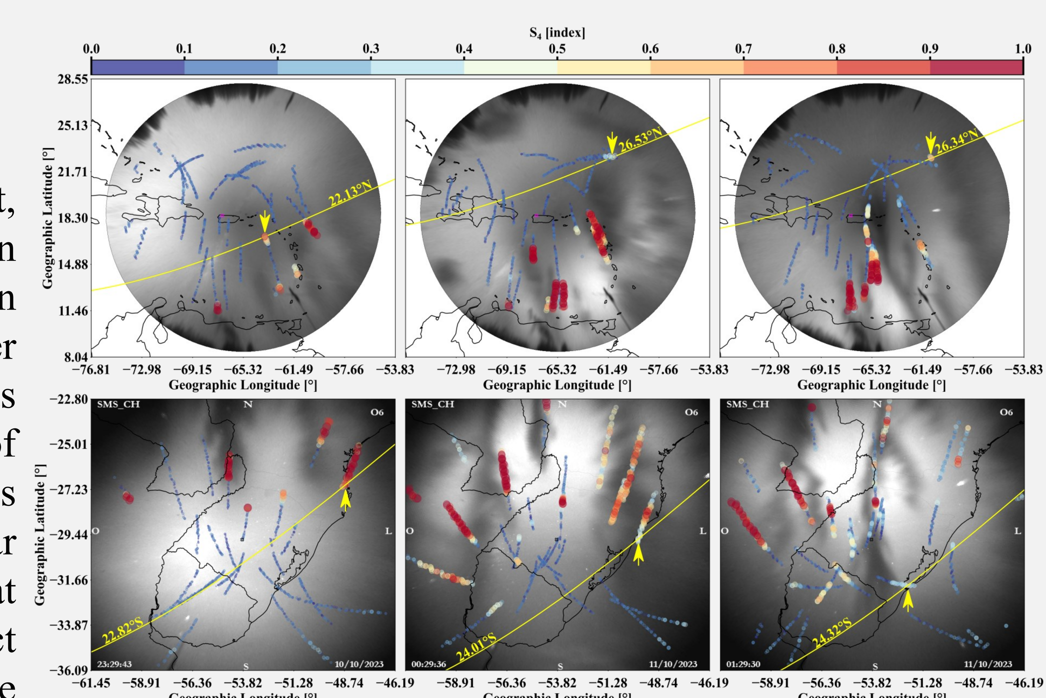
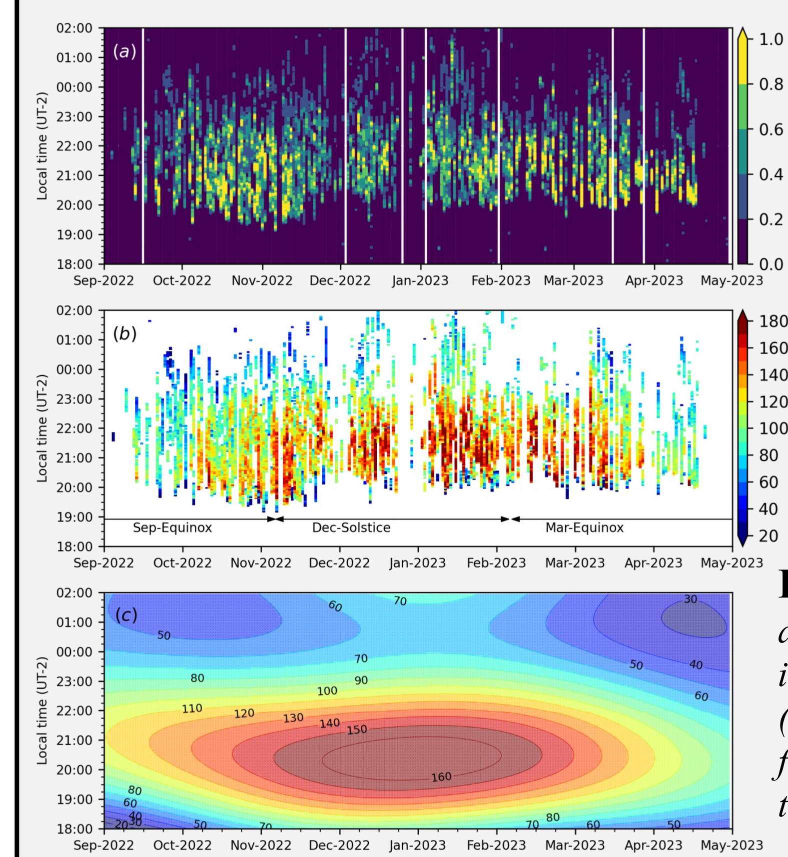


Fig. 8 – *Conjugated observations from all-sky imagers and scintillation monitors from Puerto Rico and Santa Maria, Brazil.*

Spaced-receiver observations: Irregularity drifts

We evaluate the use of ScintPi 3.0 to estimate ionospheric irregularity drifts through an experiment in Campina Grande, Brazil. The results show that the local time variation in the estimated irregularity zonal drifts is in good agreement with previous measurements and with the expected behavior of the background zonal plasma drifts.



Our results also reveal a seasonal trend in the irregularity zonal drifts. The trend follows the seasonal behavior of the zonal component of the thermospheric winds as predicted by the Horizontal Wind Model (HWM).

Fig. 9 – *Panel (a) shows amplitude scintillation, (b) irregularity drifts estimates, and (c) HWM zonal winds velocities for the same region at 450 km for the campaign in Campina Grande.*

Mid-latitude scintillation events

Distributed deployment of ScintPi monitors help us to better understand the occurrence of scintillation in the US. Figures 10 and 11 show an extraordinary scintillation event detected by the ScintPi monitors from the magnetic equator to mid latitudes. The scintillation event was caused by an extreme EPB-like perturbation that originated at low latitudes and extended to mid latitudes.. It exemplifies the coupling between low and mid latitudes.

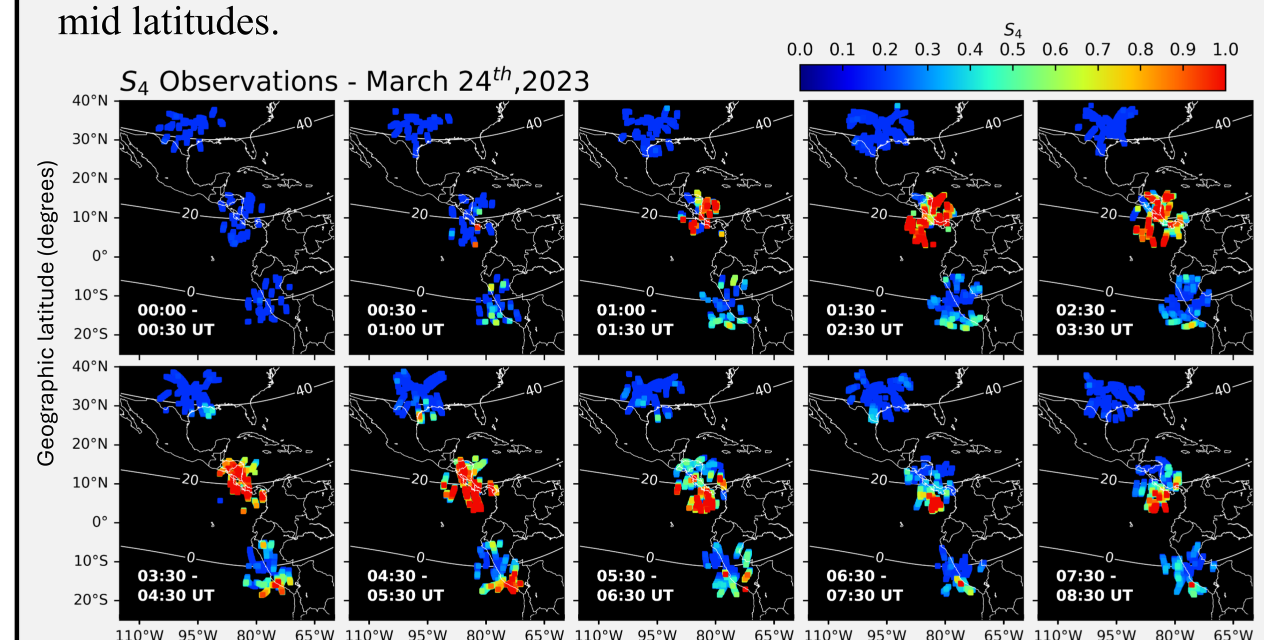


Fig. 10 – *Spatio-temporal evolution of S4 observations.*

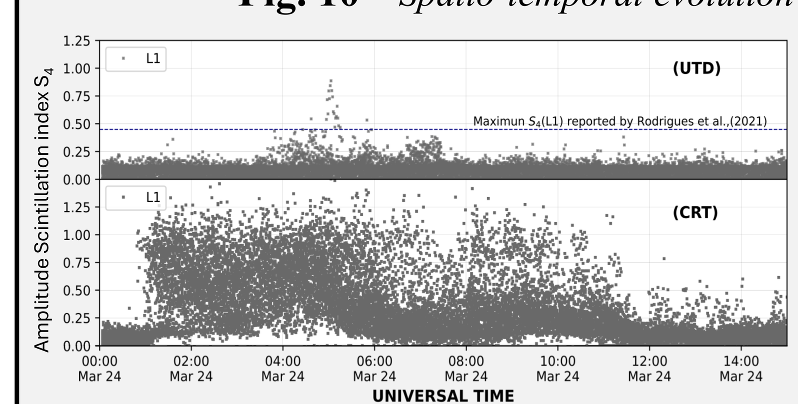


Fig. 11 – *The results also indicate extremely severe and long-lasting scintillation at low latitudes, as recorded by the monitor in Costa Rica (CRT).*

Acknowledgements

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