Estimation of low-latitude ionospheric irregularity drifts using spaced low-cost GNSS-based scintillation monitors (ScintPi)

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ABSTRACT

Previous efforts have estimated irregularity drifts using closely-spaced GNSS-based receivers. The relative high cost of commercial monitors, however, limits new spaced-receiver deployments and observations. At Universal Texas at Dallas (UTD), we have dedicated efforts to the development of alternative, low-cost GNSS-based scintillation and Total Electron Content (TEC) monitors. The latest version of this monitor is referred to as ScintPi3.0. A description of ScintPi3.0 and application on studies of ionospheric irregularities and scintillation were presented elsewhere (Gomez Socola and Rodrigues, 2022). Here we describe results related to the use of this monitor to derive ionospheric irregularity drifts. More specifically, we present results of an experiment that investigated zonal drift measurements of low-latitude ionospheric irregularities. We highlight that the experiment uses L-Band signals transmitted by geostationary (SBAS) satellites which greatly simplify drift estimation and interpretation of the results.

RELEVANCE

This study targets the advancement of instrumentation and observations that are relevant to fundamental and applied geospace studies. More specifically, we investigate the ability of low-cost sensors to provide ionospheric irregularity drift information. We envision that irregularity drifts can serve as indicators of both background plasma drifts and neutral wind conditions. Ionospheric drifts are also useful in applied studies of space weather at low latitudes.

SPECIFIC QUESTIONS (SQ)

We set up an experiment to address the following questions:

- ❑ **SQ1:** Can ScintPi monitors provide estimates of irregularity zonal drifts?
- ❑ **SQ2:** Provided ScintPi measurements, how do irregularity zonal drifts vary from day-to-day and with season?

EXPERIMENTAL SETUP

In order to address the SQs, we performed an experiment in Campina Grande, Brazil (7.21°S, 35.91°W, dip latitude ~14°S). This low-latitude site is well within the southern Equatorial Ionization Anomaly (EIA), which provides favorable conditions for the development of L-band scintillations. The severity of scintillation can be measured using the S_4 index, which is the standard deviation of the signal intensity normalized by its mean.

For this experiment, the monitors sampled GNSS signals at the rate of 20 samples per second. The magnetic zonal distance between receivers was 140 meters. See **Figures 1a** and **1b**.

The closely spaced-receiver technique determines drifts from the cross-correlation of signals measured by the receivers. Estimation of the drifts, however, is complicated for signals transmitted by GNSS satellites. For instance, for GNSS signals, both the ionospheric pierce point (IPP) velocity and changes in magnetic field direction need to be taken into account. Measurements can be simplified if signals from geostationary satellites can be tracked. For Campina Grande, ScintPi3.0 provides adequate measurements of the L1 (~1.6 GHz) signal transmitted by SBAS136 (azimuth 84°, elevation 42°).

Given the predominant magnetic zonal drift of low-latitude irregularities, receivers have been placed in the magnetic east-west direction. See **Figure 1c**.

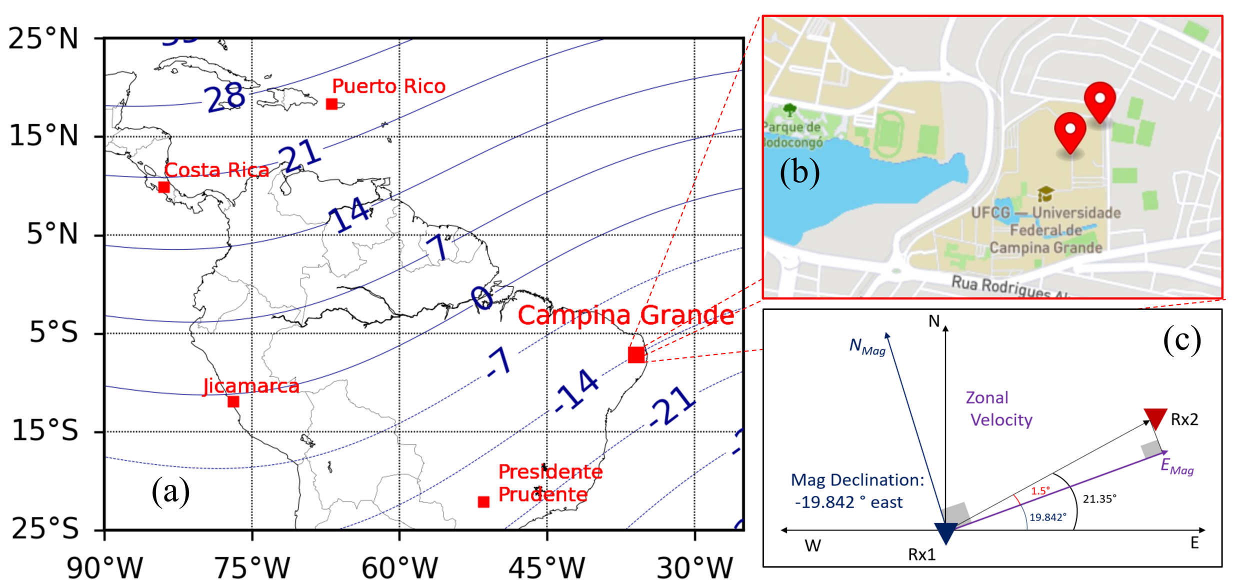

Figure 1 - Location of the spaced-receiver experiment in Brazil. (a) Map of South and Central America locations where ScintPi receivers have been deployed. (b) Closely-spaced receivers installed in Campina Grande. (c) Sketch of the position of the receivers relative to the magnetic zonal direction.

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MEASUREMENTS

As an example of the analyses performed to estimate irregularity zonal drifts, we present **Figure 2**, which is a single measurement performed with ScintPi3.0 monitors in Campina Grande. **Figure 2a** shows SNR curves for both receivers. It also shows that both receivers detect similar SNR variations. **Figure 2b** shows examples of strong L-Band scintillation occurring between 20:30 and 21:30 LT and moderate to weak scintillation between 22:30 and 00:30 LT. **Figure 2c** indicates high cross-correlation coefficients during scintillation activity. Zonal drifts are estimated when the coefficients exceed 0.75. **Figure 2d** shows estimated irregularity zonal drifts. We highlight the following main points:

1. Even when scintillations are weak, the cross-correlation coefficient exceeds 0.75, allowing estimation of the irregularity zonal drifts.
2. The irregularity zonal drifts follow the expected behavior of low-latitude ionospheric irregularity zonal drifts, that is, strong eastward zonal drifts in the evening weakening towards midnight.

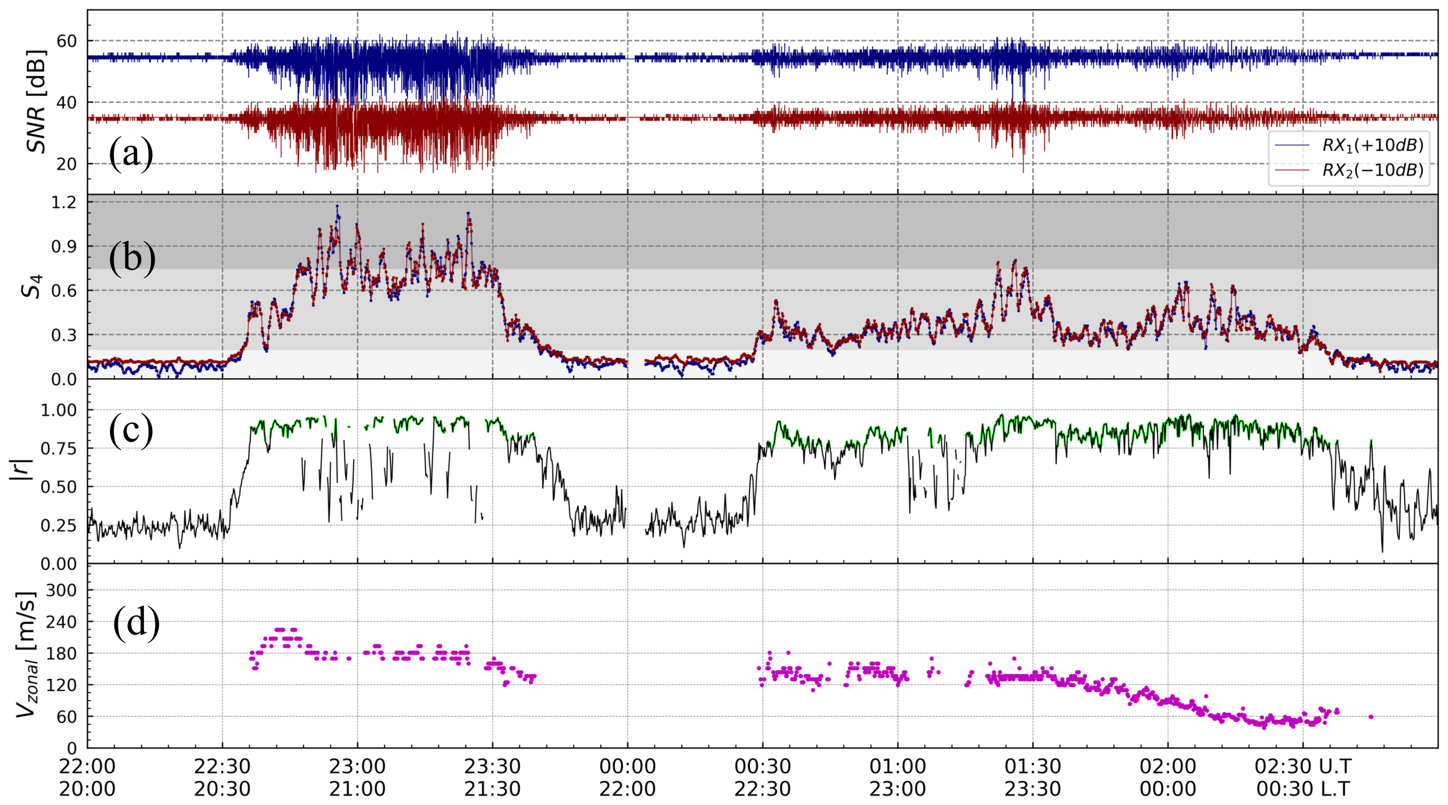

Figure 2 - Example of measurements and analyses made with closely-spaced ScintPi3.0 monitors in Campina Grande on October 05th, 2022. **(a)** Signal-to-Noise ratio (SNR in dB) for L1 from **SBAS136**. **(b)** Severity of scintillation, i.e., S_4 index. **(c)** Normalized cross correlation coefficient |r|. **(d)** Zonal irregularity drifts (positive eastward).

RESULTS AND DISCUSSION

The analysis illustrated in Figure 2 was applied to data from 237 nights between Sep. 2022 and Apr. 2023. This period corresponds to the equatorial spread F (ESF) season in Brazil. The results are gathered in **Figure 3.**

Figure 3a shows how L-Band scintillation varied with local time for each day between September 2022 and April 2023. The results in **Figure 3b** summarize the day-to-day variability of irregularity zonal drifts as a function of local time. Figure 3b also shows the variation of the zonal drifts with season.

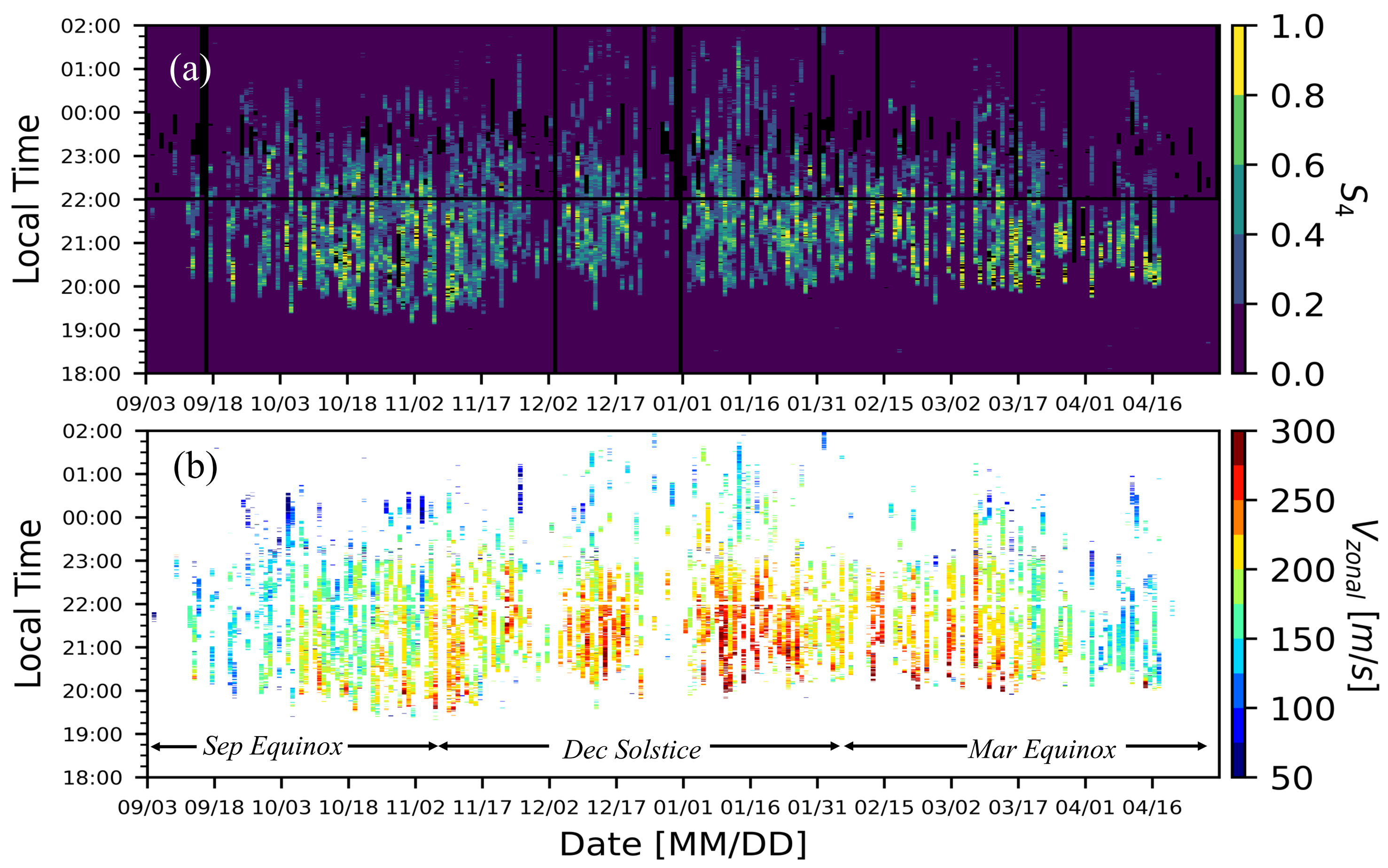

Figure 3 - S_4 and zonal irregularity drift measurements for 237 nights between September 2022 and April 2023. Panel **(a)** summarizes the averaged S_4 index measurements as a function of local time (LT = UT – 2 hours) and day. The average is between the two receivers. Panel **(b)** summarizes irregularity zonal drift results. Different seasons determined as +/- 45 days around equinox and solstice days are indicated.

High cross-correlation values, as in the example of Figure 2, consistency of consecutive drift estimates, and behavior of estimated drifts that agree with theoretical expectations confirm that ScintPis can be used to estimate irregularity drifts (SQ1).

In Figure 4 we summarize the results related to day-to-day and seasonal variations of the zonal irregularity drifts (SQ2). The day-to-day variability of the zonal drifts during equinoxes (combined drifts measurements from March and September equinoxes) and December solstice are quantified through standard deviations computed for 30-minute local time bins. For equinoxes, the variability has an average of 32 m/s. For December solstice, the variability has an average of 34 m/s.

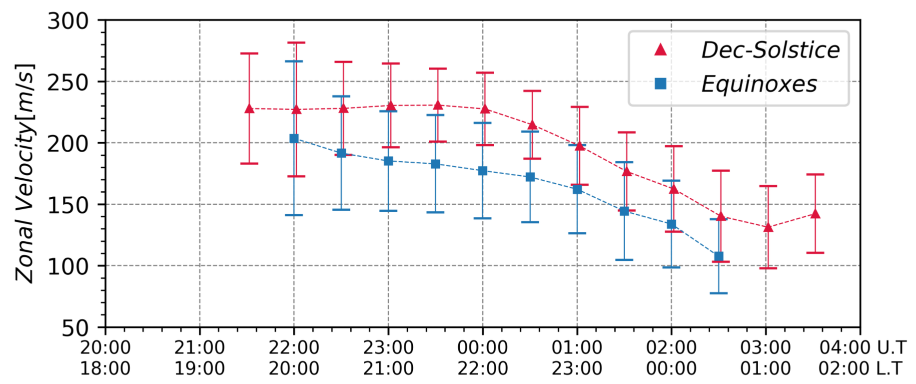

Figure 4 - Mean irregularity drifts for December solstice and equinoxes. Only geomagnetic quiet days have been considered (Kp at the time of the measurement and previous 24 hours cannot exceed 3). Vertical bars represent the standard deviation of the mean.

The seasonal variation of the zonal drifts is quantified through mean curves. The mean zonal drifts during equinoxes are weaker than the mean drifts observed during December solstice. Maximum mean zonal drifts during equinox are around ~200 m/s while maximum mean zonal drifts during solstice are around ~230 m/s.

We point out that the seasonal variability of the zonal plasma drifts follows the seasonal variability of the zonal neutral winds. Zonal ionospheric drifts (V_z) are related to zonal neutral winds (U_z) through the Pedersen conductivity weighted integral (Haerendel et al., 1992; Rodrigues et al., 2012):

$$V_z \sim \frac{1}{\Sigma_P} \int \sigma_P U_z ds$$

In **Figure 5** we show the irregularity zonal drifts superimposed on HWM14 model estimations of the magnetic zonal winds at 350 km altitude for the location of the SBAS 136 IPP. While differences in the magnitudes of the zonal drifts and winds exist, the comparison confirms that the winds are weaker during equinox compared to December solstice. The strong similarity between the mean behaviors of the winds and the irregularity drifts shows that irregularity drifts can be useful tracers of neutral wind dynamics.

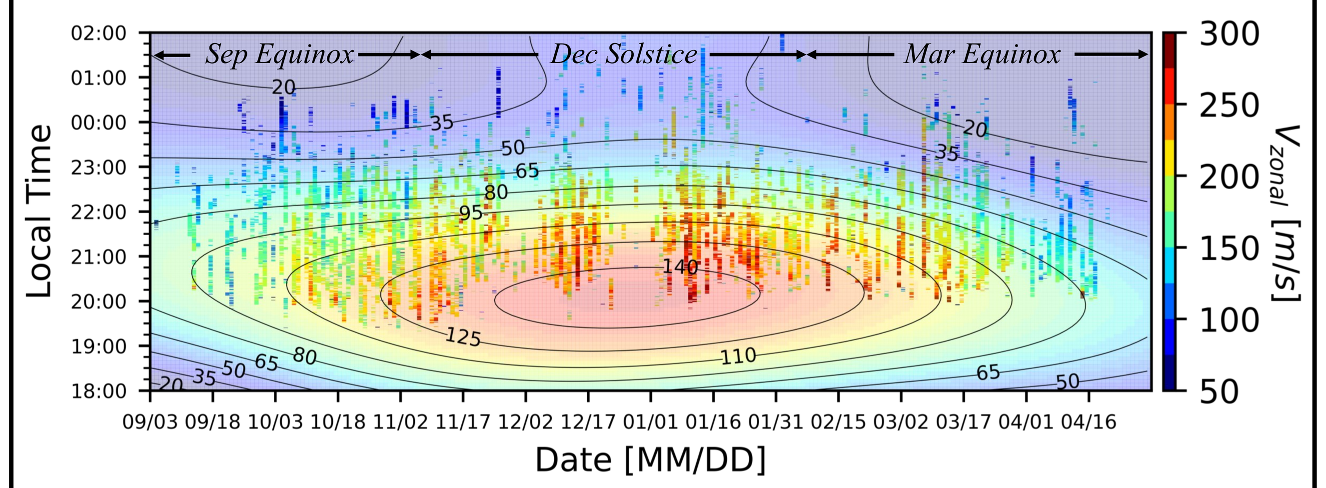

Figure 5 - Zonal wind velocities (U_z) from the Horizontal Wind Model 14 (HWM14) for the same period of the irregularity drifts shown in Figure 3. HWM14 U_z values are indicated by labels on the contour lines.

CONCLUDING REMARKS

- ❑ In this study, we presented (i) the proposal of an experiment, (ii) the deployment of instruments, and (iii) measurements and analyses for an alternative, low-cost approach to measure low-latitude ionospheric irregularity drifts.
- ❑ Results indicate the ability of the experiment to derive information about the day-to-day and seasonal variability of the drifts. The results also indicate that the drifts reflect the underlying neutral wind conditions.

ACKNOWLEDGEMENTS

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