Estimation of low-latitude irregularity drifts using closely spaced low-cost scintillation monitors (ScintPi) and multi-constellation GNSS signals

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ABSTRACT
Previously (CEDAR 2022), we presented results of low-latitude ionospheric irregularity zonal drift measurements using closely spaced low-cost scintillation monitors (ScintPi) and signals from a geostationary satellite. The use of signals from a geostationary satellite greatly simplifies the estimation of the drifts since the ionospheric pierce point (IPP) velocity and geomagnetic field varying configurations with respect to the geomagnetic field do not have to be considered. ScintPi, however, can measure signals from multiple GNSS constellations. The use of GNSS signals allows a broader coverage of the sky than GPS-only receivers, which have been used in previous works. In this poster, we present and discuss results of the scintillation spaced receiver technique to estimate zonal irregularity drifts using multiple GNSS signals.

EXPERIMENTAL SETUP
In Figure 1, we show the experimental setup located at Universidade Federal de Campina Grande (UFCG), Brazil (7.213'S, 35.907'W, dip latitude -14°). UFCG is located at ~14° dip latitude where L Band scintillations occur frequently as a result of small-scale irregularities within plasma bubbles.

DATA PROCESSING WORKFLOW
The estimation of scintillation pattern velocity requires one to: (1) calculate satellite velocities using information from Precise Ephemeris (SP3) file and the magnetic components at the IPP from IGRF-13, (2) estimate the apparent velocity from the closely spaced scintillation monitors, (3) correct for any decorrelation-generated by turbulence of the medium, and, finally, (4) calculate geometrical corrections for any non-ideal position in the setup of the receivers (See Figure 3).

MULTI-SATELLITE MEASUREMENTS
The analysis illustrated in Figure 4 is performed for any satellite that experience scintillation. For instance, all the GNSS satellites for each constellation in the night of March 22-23, 2023, are shown as an example of the process (Figure 5a-e). The average velocity is shown in Figure 5f.

Fig. 5 - Scintillation pattern velocities for a full night from March 22 to 23, 2023. Measurements are separated by constellations (a) GPS, (b) Galileo, (c) GLONASS, (d) Beidou and (e) SBAS. Black dots in panel (f) correspond to 3-min average measurements whenever at least two satellites were available. The red bars represent a 1 standard deviation.

The goal of using multiple constellations is to gain temporal and spatial coverage. In the literature, at least a couple of approaches are used to derive irregularity drift curves. One approach averages all the measurements from a same time interval, minimizing the factor (Eq. 1) that controls the contribution of the vertical drifts in Equation 1 (Ledvina et al., 2004). Another approach is to use only measurements where u<q<0.5, which also minimizes the contribution from the vertical component of the drifts (Cerri, et al., 2006). Here, we take the first approach, averaging all the drifts in 3-minute time windows, as done in Figure 5f.

Fig. 5f also shows the existence of moderate variance in the irregularity drifts. The variance is more pronounced at the beginning of the night. These variations can represent either the random behavior of the horizontal and vertical plasma motion or different longitudinal contributions of vertical drifts within the field of view.

RELEVANCE & GOALS
This effort is well aligned with CEDAR Strategic Thrust 64: "Develop observational and instrumentation strategies for near-space systems." We contribute with an assessment of the use of low-cost commercial off-the-shelf (COTS) GNSS receivers for observations of ionospheric irregularities. The specific goals of this work are: (A) to produce new ionospheric irregular drift measurements and (B) assess the impact of irregularity drifts to underlying geospace conditions such as the different seasons.

THEORY
Data processing was done using the methodology described in the work by Ledvina et al. (2004). The geometry of the geomagnetic field is defined as g = (Bx, By, Bz, Bm) where Bm is the magnetic field at the IPP.

Ionospheric irregularities causing low-latitude scintillation are associated with equatorial plasma bubbles and are assumed to be aligned with the magnetic field (B). See Figure 2 for an illustration of the geometry.

Fig. 2 - (a) Estimated zonal velocity from the SP3 file (b) Carrier-to-Noise ratios (C/N0) in dB-Hz from L1 (c) Scintillations, i.e., S index and the normalized cross correlation coefficient (NCC) (d) Apparent velocity and True satellite compensated velocity after turbulence correction (e) Geometric correction factor (f) Geometrically corrected true scintillation pattern velocity (V_{scint}) representing zonal and vertical irregularity drifts.

Eq. 1 shows that V_{scint} has contribution from two components: the zonal drift and the vertical ionospheric drift. The meridional drift (V_{merid}) does not have to be considered since irregualrities are assumed to be elongated along the magnetic field lines.

Fig. 6 - Panel (a) shows 5-min averaged irregularity drift. (b) Standard deviations for each 3-min average drift. Different seasons determined at +/- 45 days around equinox and solstice days are also indicated.

VALIDATION BY CROSS-OBSERVATIONS
While the standard deviation of the averaged drifts exceeds 25 m/s at times (Figure 6b), the difference between independent measurements within the same angle of arrival (i.e., within 3° elevation) are less than 20 m/s for 90% of the observations. See Figure 7 below.

CONCLUDING REMARKS
• In this study, we presented new measurements of low-latitude irregularity drifts using GNSS signals (Figures 4 and 5) measured by alternative, low-cost scattering monitors (Goal A).
• We used the scintillation spaced-receiver technique introduced by Briggs et al. (1950) and improved by Ledvina et al. (2004).
• The averaged zonal irregularity drifts show significant variance (> 25 m/s) at times (see Figure 6b) which can be attributed to spatial variations in the drifts within the FOV of the monitor. Even measurements from the nearly same ionospheric region but using different GNSS signals show differences (> 20 m/s for 90% of cases) in drift estimates.
• Seasonal trends can be observed from the drifts with the ESF season (Figure 6a) which are attributed to seasonal variations in the thermospheric neutral winds (Goal B).

REFERENCES
• Gomez Socola, J., Rodrigues, F. S. (2022), ScintPi 2.0 and 3.0: low-cost GNSS-based technique for ionospheric scintillation and total electron content. Earth Planets Space 74, 185.

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Fig. 7 – The highlighted in green are examples of measurements within the same angle of arrival. Panel (b) statistics for the differences between the crossed observations. Around 1,200 crossings were detected during the campaign.

The small difference between the measurements indicates that our velocities agree very well between independent measurements, which means that the spaced-receiver technique captures geophysical drifts variations in any sub-region within the field of view. Differences greater than 20 m/s represent only ~10% of the cross-paths, and those errors can be caused by the accentuated quantification errors (low C/N0 resolution (scintillation monitors) for high drift values or by strong turbulence in the region of observations.