Development of a Scintillation Monitoring System in Peru: Preliminary Results

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Abstract

This study presents the preliminary results and initial evaluation of a low-cost, ground-based ionospheric scintillation monitoring system utilized in Peru. The receiver is engineered to detect disturbances in satellite signals caused by ionospheric irregularities, with the aim of enhancing the spatial resolution of scintillation measurements. The pilot system has been tested in the northern and central regions of the country to measure rapid fluctuations in the amplitude of GNSS signals. Preliminary results indicate that the system is capable of detecting distinct scintillation events, which have been correlated with data from commercial high-precision, albeit more expensive, GNSS receivers. In addition, the measurements were compared with observations from the LISN instruments. These promising preliminary results highlight the potential of the system to enhance the monitoring of ionospheric disturbances and contribute to the improvement of satellite-based navigation and communications in low-latitude regions.

1. Introduction

Ionospheric scintillation is characterized by rapid fluctuations in the amplitude and phase of radio signals as they pass through the plasma-rich regions of the Earth's upper atmosphere. These fluctuations occur due to irregularities in the ionospheric electron density and can significantly disrupt critical satellite-based navigation and communication systems [1],[2]. These effects are particularly pronounced in low-latitude regions such as South America, where complex ionospheric dynamics lead to frequent and intense disturbances, especially during periods of high solar activity.

Although the study of these effects has typically relied on high-accuracy instruments, interest is rising in utilizing affordable, low-cost receivers to expand observational coverage across both space and time, particularly in areas where ionospheric behavior is especially complex [3],[4],[5],[6].
In this study, we investigate the use of low-cost GNSS receivers to measure and analyze preliminary measurements of ionospheric scintillation across selected sites at the central and northern regions of Peru (Jicamarca Radio Observatory, Piura, and Jaén) as shown in Figure 1.

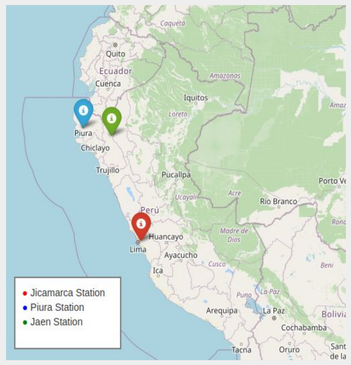

Figure 1. Receiver stations

2. Description

To measure the S4 index across Peruvian territory, two types of receivers were developed. The first is a GNSS signal receiver that uses a ZED-F9P module with a sampling rate of 1 Hz. Based on the acquired data, the S4 index is calculated every minute for the GNSS constellations. The second receiver is designed to capture signals from the COSMIC-2 satellites and uses an ADALM-PLUTO SDR for data acquisition. In this case, the S4 index is computed every second due to the limited number of minutes these satellites are visible from the receiver.

These measurements are conducted at three different stations; Jicamarca Radio Observatory (JRO), Piura, and Jaen, for the GNSS receiver, and at the JRO for the COSMIC-2 receiver. The measurements shown in Figures 2-9, were taken on the dates shown in Table N° 2.

Table N°1. Stations coordinates

Station	Latitude	Longitude
JRO	-11.952	-76.875
Piura	-5.170	-80.875
Jaen	-5.676	-78.779

Station	JRO (GNSS)	Piura (GNSS)	Jaen (GNSS)	JRO (COSMIC-2)
Date	2025-02-01	2024-12-03	2025-12-05	2025-06-16

Table N°2. Day of measurements

In addition, the solar activity and geomagnetic conditions during the measurement days are indicated in Table N° 3.

Index avg	JRO (2025-02-01)	Piura (2024-12-03)	Jaen (2025-12-05)
Kp	4	3	2
Dst (nT)	-10	-13	-12
F10.7	182	169	169

Table N°3. Solar flux and geomagnetic indices.

3. Measurements

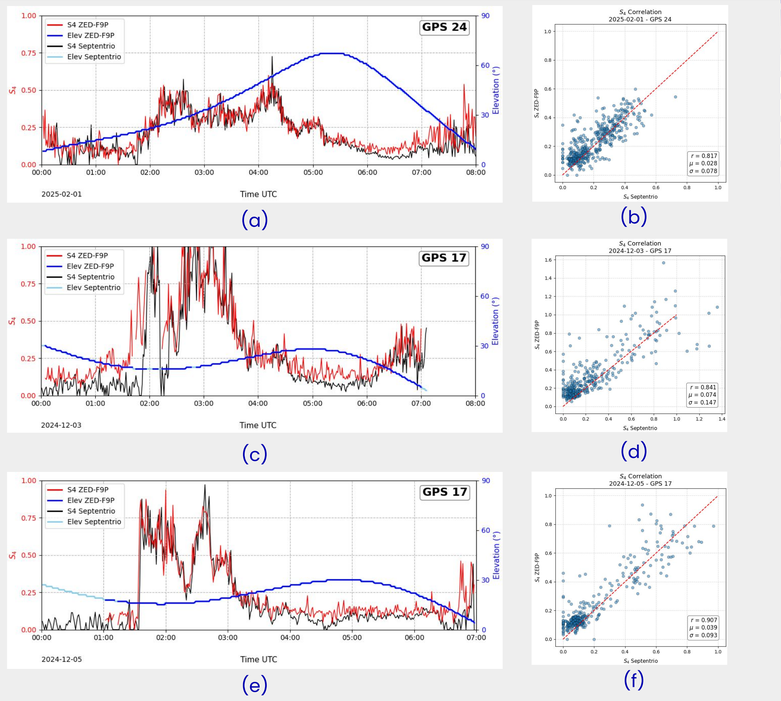

Figure 2. Comparison of S4 index between our receiver and the Septentrio PolaRx5S at JRO(a), Piura(c), and Jaén(e) and their corresponding correlation (b), (d), and (f).

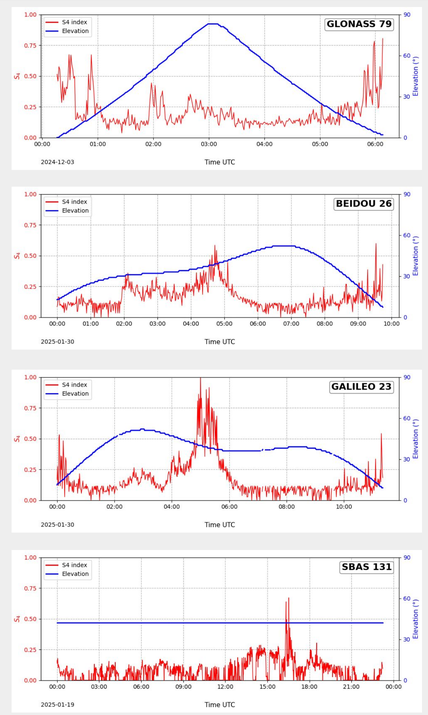

Figure 3. S4 index from GLONASS at Piura Station (2024-12-03)

Figure 4. S4 index from BEIDOU at JRO Station (2025-01-30)

Figure 5. S4 index from GALILEO at JRO Station (2025-01-30)

Figure 6. S4 index from SBAS satellite at JRO Station (2025-01-19)

COSMIC-2/FORMOSAT-7 S4 measurement

Figure 7. Tracking COSMIC-2

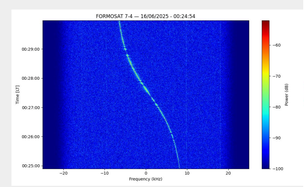

Figure 8. Doppler shift effect

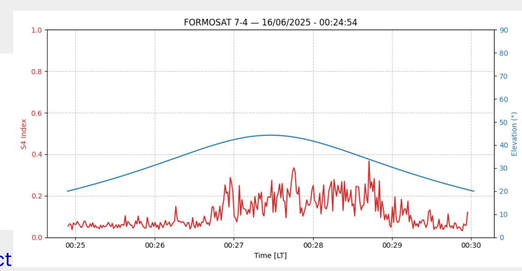

Figure 9. S4 index measurement using the N° 4-COSMIC-2/FORMOSAT-7 satellite signal at 400 MHz during its pass over the Jicamarca station.

4. Conclusions

- We have investigated the use of low-cost receivers in the central and northern regions of Peru (Jicamarca, Piura, and Jaén) to obtain ionospheric scintillation measurements.
- Preliminary scintillation measurements from Dec 2024 to Feb 2025 showed a very good agreement between the S4 index obtained from the developed low-cost receivers and the high-precision systems with a correlation of about 0.817 (Jicamarca), 0.841 (Piura) and 0.907 (Jaén).

5. Acknowledgments

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6. References

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