Real-Time Scintillation Monitoring using Low-Cost GNSS-Based Monitors

Tarun L. Sankar, Isaac G. Wright, Josemaria Gomez Socola, and Fabiano S. Rodrigues
W. B. Hanson Center for Space Sciences, University of Texas at Dallas, Richardson, TX 75080

Contact:
TLS220003@utdallas.edu

1. INTRODUCTION AND MOTIVATION

- Ionospheric scintillation has been historically measured by relatively **expensive** and **specialized** receivers. This is due, in great part, to their ability to sample intensity and phase measurements from Global Navigation Satellite System (GNSS) signals at high sampling rates and fidelity.
- The high cost of these professional grade tools has **limited the deployment** of arrays scintillation monitors. As a result, scintillation monitoring coverage remains **sparse** over many regions of the world.
- ScintPi is a **low-cost multi-constellation, dual-frequency** scintillation and total electron content (TEC) monitor [1]. It is an easy to install and maintain alternative developed by UT Dallas UARS lab for **educational** and **research** initiatives.
- Previous studies demonstrated the potential of ScintPi monitors for use in **autonomous, solar-powered stations** [2]. Applications of the station, however, were limited by the high bandwidth requirement of the receivers (several GB/day).
- In this project we contribute with the efforts related to (1) deployment of scintillation monitors at locations with limited internet availability and (2) delivery of scintillation measurements in real time.

2. PROJECT OBJECTIVES

Presented here is a student-led project with the following main objectives:

Objective 1: Compute scintillation indices in **real-time** within the single-board computer (Raspberry Pi) used by the ScintPi monitors.

Objective 2: Create a real-time **visualization tool** to assist space weather monitoring and early detection of scintillation events.

3. INSTRUMENTATION

- We deployed a ScintPi 3.0 at **the University of Texas at Dallas (UTD)** as a test station. UTD coordinates: 32.99°N, 96.76°W, 43.2°N dip latitude. Figure 1 depicts an example of a unit.
- The receiver provides **high-rate measurements** of signal strength (carrier-to-noise ratio, C/N$_0$) at up to 20 Hz for all satellites in view.

Figure 1. ScintPi 3.0 scintillation monitor [1] used in this project. Cost of parts: ~600 USD.

4. METHODOLOGY

- To ensure that the scintillation index computation did not affect the normal datalogging software, **parallelization** was implemented via the **POSIX C library**.
- For each GNSS satellite, **the S_4 index is calculated over a moving 1-minute window** of signal intensity data as the standard deviation of the signal's power divided by its mean [3]:

$$S_4 = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle}$$

- The computed values are then moved to a comma separated value (CSV) file, along with elevation, azimuth, SVID, and number of samples.
- Onboard software **syncs** the CSV files **from the ScintPi to cloud-based Azure blob storage**, deleting older files to not over-accumulate.
- A **web visualization application** was created using the Python **plotly Dash framework** deployed on Azure web services.
- Figure 2 summarizes the overall workflow in a flow chart.

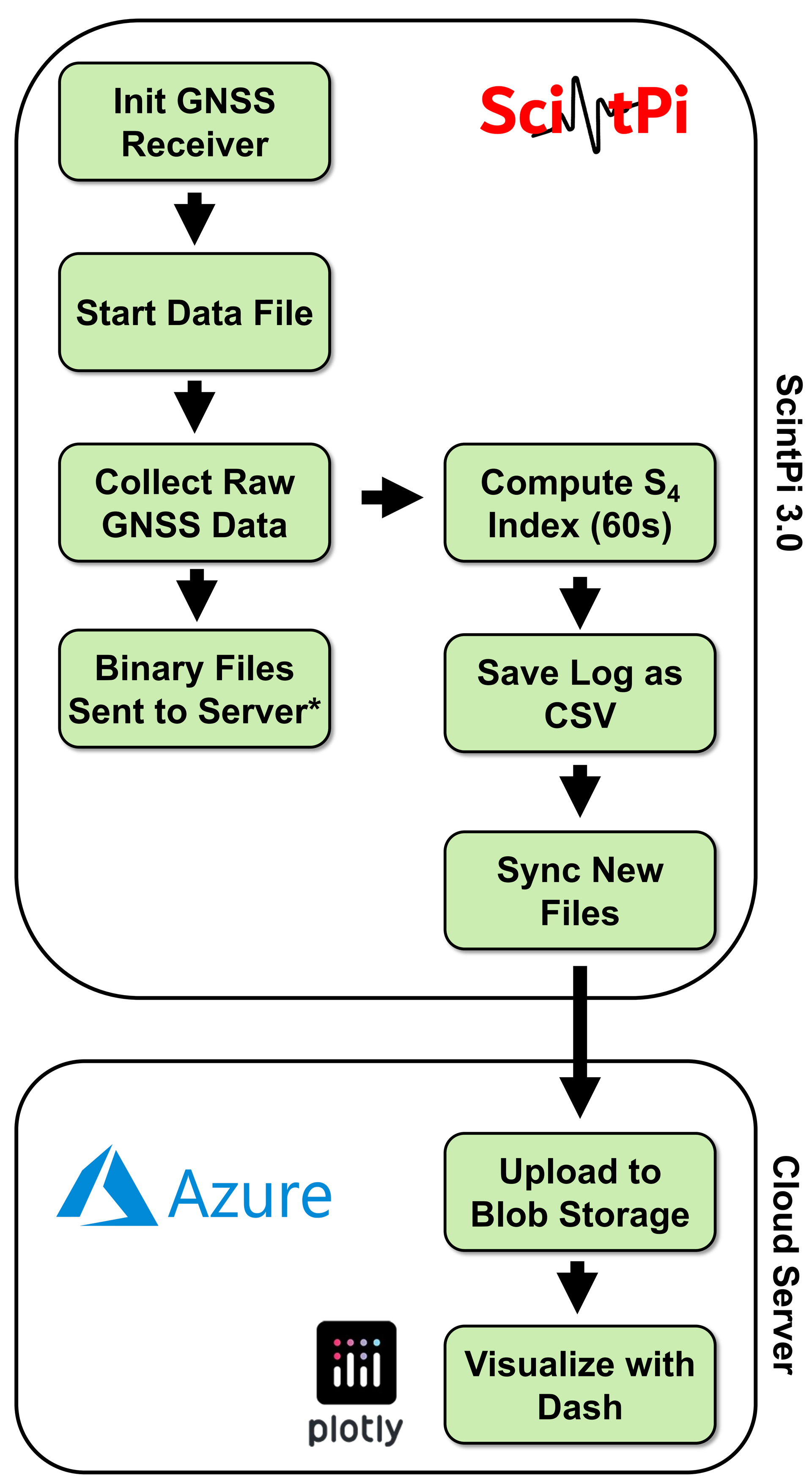

Figure 2. Flow chart of real-time scintillation monitoring and visualization pipeline.

**Assuming sufficient bandwidth*

5. RESULTS AND DEMO

- We created and deployed an **interactive, online dashboard** that provides visualization of scintillation indices.
- The dashboard **support real-time visualization**, showing the last 48 hours worth of data. The site **updates every minute**, allowing accurate tracking of ionospheric events as they are happening.
- The dashboard displays S_4 indices for all satellites in view either **aggregated over time** (Figure 3), **individual by query** (Figure 4), or in an overhead **"sky-plot" graph** (Figure 5).

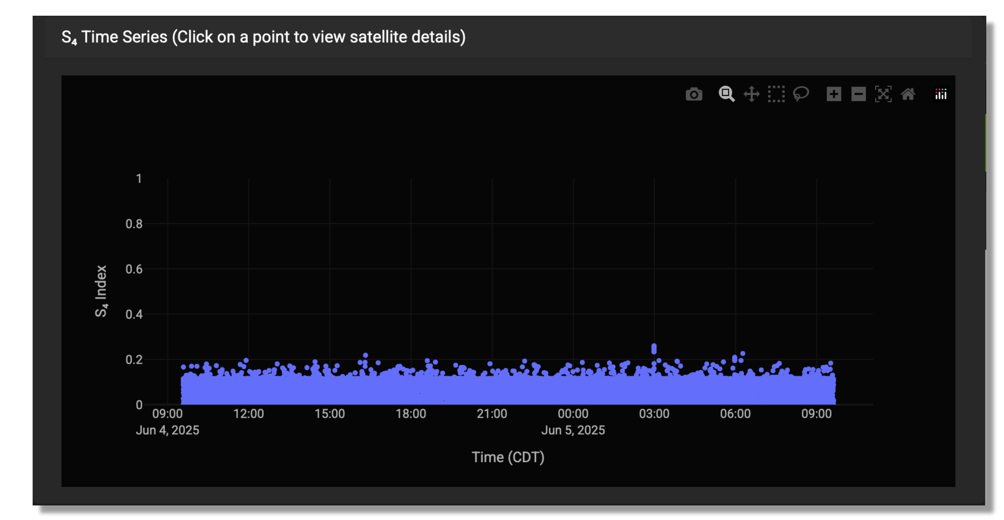

Figure 3. Plot of S_4 indices over the last 24 hours for the test station located at UTD.

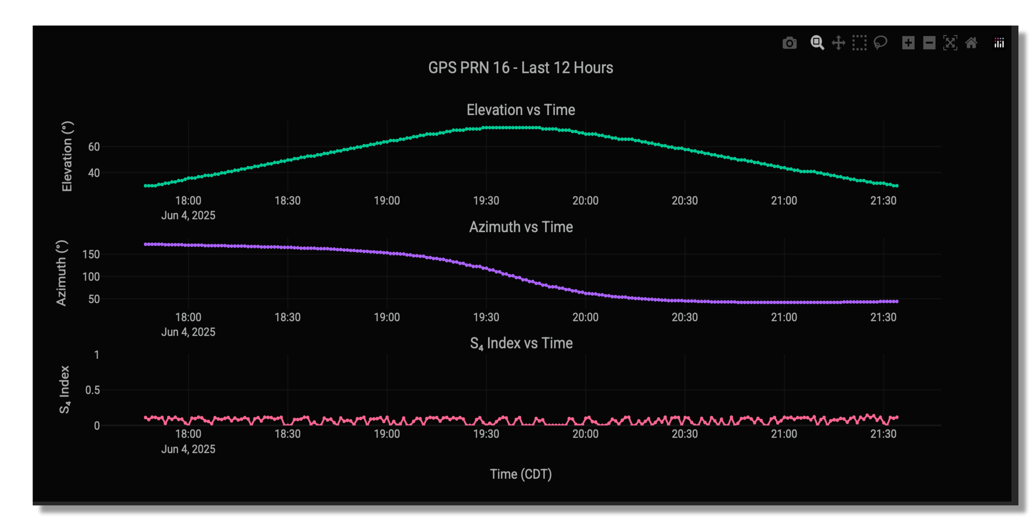

Figure 4. Plot of S_4 indices and locational data for a single satellite.

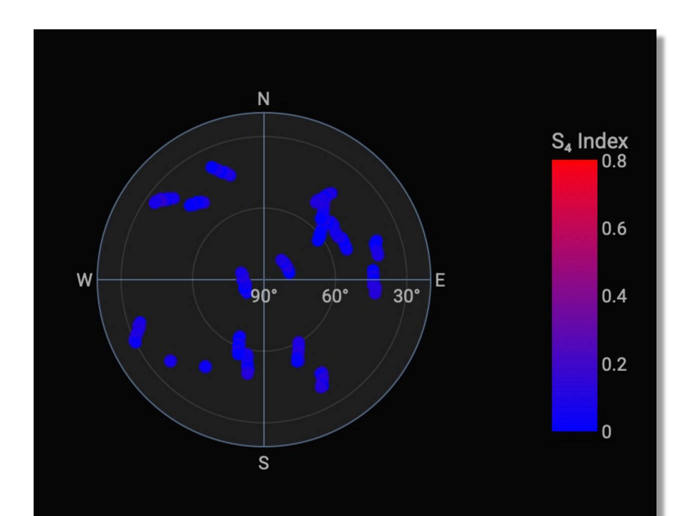

Figure 5. Sky plot of S_4 over last 15 minutes.

Scan for demonstration of the real-time dashboard

6. EMPHASIZED RESULT AND DISCUSSION

- The scintillation dashboard **provides a helpful display of system health** and can also be used as an educational tool.
- As shown in Table 1, onboard processing can **significantly reduce the bandwidth** required for scintillation monitoring by only transmitting the processed indices. In the case of Internet of Things (IoT) applications, the resulting files are small enough to be transmitted by most standard cellular plans.

Compressed Binary Raw Data	Real-Time Data
2.4 GB	4.5 MB

Table 1. Comparison of the average bandwidth per day needed to transmit full raw data versus only the real-time computed indices.

7. CONCLUSIONS

- **Objective 1:** Our results demonstrated that the Raspberry Pi is capable of processing real-time scintillation indices, reducing the bandwidth needed for scintillation monitoring from several GB per day to only a few MB.
- **Objective 2:** We have deployed a demonstration of a real-time scintillation monitoring dashboard for the test station in Dallas. The web-based application shows S_4 indices for all satellites in view and updates every minute.
- The results contribute (1) to advancing our ability to deploy ScintPi monitors in locations where **internet is limited** and (2) to **early assessments** of scintillation events**.**
- Future work seeks to **expand the real-time products** by incorporating real-time TEC observations, phase scintillation indices, and expanding the real-time service to other stations.

ACKNOWLEDGEMENTS

Work at UTD was supported by the NSF Awards AGS 2122639 and 2432609 (DASI Program) and by the NSF's GRFP Grant No. 2136516.

REFERENCES

[1] Gomez Socola J, Rodrigues FS. 2022. ScintPi 2.0 and 3.0: GNSS-based monitors of ionospheric scintillation. EPS, 74, 185.
[2] Wright, Isaac G., et al. "Student-led Design, Development and Tests of an Autonomous, Low-cost Platform for Distributed Space Weather Observations." *Journal of Space Weather and Space Climate*, vol. 13, 2023, article 12.
[3] Kung Chie Yeh and Chao-Han Liu, "Radio wave scintillations in the ionosphere," in Proceedings of the IEEE, vol. 70, no. 4, pp. 324-360, April 1982