ScintPi: Scintillation and Total Electron Content (TEC) monitors for distributed observations, education and citizen science initiative

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Abstract

- We have dedicated efforts towards the development of low-cost, easy-to-deploy, and easy-to-operate ionospheric sensors. Here, we provide information about one of our sensors, ScintPi 3.0, a GNSS-based ionospheric scintillation and total electron content (TEC) monitor. We describe the system, deployments and examples of observations including comparisons with measurements provided by commercial monitors. We currently seek collaborators willing to host our sensors for distributed observations of ionospheric scintillation and irregularities over the US.

Background Information

- Irregularities in the ionospheric electron density can cause the diffraction of radio waves such as those transmitted by global navigation satellite systems (GNSS). Interference of the diffracted wavefronts cause fluctuations in the phase and/or amplitude of radio signal as observed by receivers on the ground. This phenomenon is referred to as ionospheric scintillation. The severity of amplitude scintillation can be estimated from the signal intensity (I) and quantified by the S4 index (Kintner et al., 2007):

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

- Ionospheric perturbations can be monitored using measurements of the Total Electron Content (TEC) which is the integral of the electron density between satellite and receiver. TEC can be estimated from pseudo-ranges (ρ) and phases (ϕ) of signals trabsmitted by GNSS.

$$TEC_\phi = \frac{1}{40.3} \frac{f_1^2 f_2^2}{(f_1^2 - f_2^2)} \Delta\phi$$

$$TEC_\rho = \frac{1}{40.3} \frac{f_1^2 f_2^2}{(f_1^2 - f_2^2)} \Delta\rho$$

- Ionospheric density fluctuations can be also estimated using TEC measurements and the rate of TEC index – ROTI (Pi et al., 1997):

$$ROT = \frac{TEC_{k+1} - TEC_k}{\Delta t_k}$$

$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

ScintPi 2.0 and ScintPi 3.0

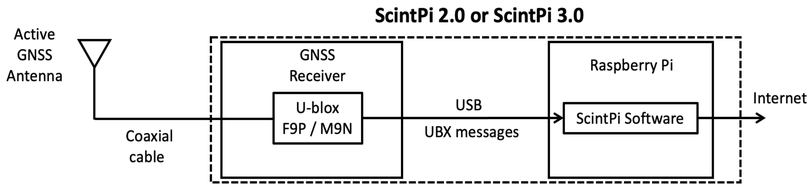

Figure 1 – Main components of our ScintPi 2.0 or ScintPi 3.0 monitors.

- Figure 1 shows the main components of ScintPi versions 2.0 and 3.0. ScintPi 2.0 uses a single-frequency GNSS receiver. ScintPi 3.0 uses a dual-frequency GNSS receiver.
- We have also developed software responsible for data acquisition, transfer of data to a server at UT Dallas (via internet) and post-processing.
- The server contains routines that read the measurements, estimate S_4, TEC_ρ, TEC_ϕ and $ROTI$. The routines also create daily summary plots and files (HDF5) that are used in our analyses and shared with collaborators.

Deployments, Field Tests & Results

- After carrying out tests at UT Dallas, we deployed ScintPi3.0 monitors at low latitudes. More recently, we started to deploy ScintPi 3.0 sensors over the United States as part of a project to collect information about the occurrence of ionospheric irregularities and scintillations at mid latitudes. Figure 2 shows the locations of our deployments.

The ScintPi Network

1. University of Texas at Dallas
2. University of Illinois Urbana Champaign
3. Embry-Riddle Aeronautical University
4. Scranton University
5. Puerto Rico (3 sites)
6. Jicamarca Radio Observatory
7. University of Sao Paulo State
8. Federal University of Campina Grande
9. Schenectady, NY(Citizen scientist)

Figure 2 shows the globe with ScintPi deployments.

- **Figure 3** shows example of TEC measurements made at UT Dallas. Code and phase TEC measurements are shown. Measurements made by a collocated commercial monitor (Septentrio PolaRx5S) are also shown. The examples in Figure 3 serve to show the excellent agreement between ScintPi 3.0 and PolaRx5S TEC measurements. Figure 3 also shows small amplitude (< 1 TECU) fluctuations in TEC that might be associated with TIDs.

- **Figure 4** shows results of measurements made at the Jicamarca Radio Observatory (JRO). JRO is located near the magnetic equator where scintillation and TEC perturbations occur frequently. At JRO, we compared TEC and S4 measured by ScintPi 3.0 using an inexpensive GNSS antenna against similar measurements made by a PolaRX5S monitor using a Choke Ring antenna. The receivers were spaced by about 50 m in the zonal direction.
- The JRO example serves to show additional evidence of the excellent agreement between ScintPi 3.0 and Septentrio scintillation and TEC measurements.
- The measurements at JRO also show the interesting occurrence of large amplitude TEC perturbations without the presence of amplitude scintillations. See, for instance, measurements on March 14 between 03:00 and 06:00 UT (22:00 and 01:00 LT).

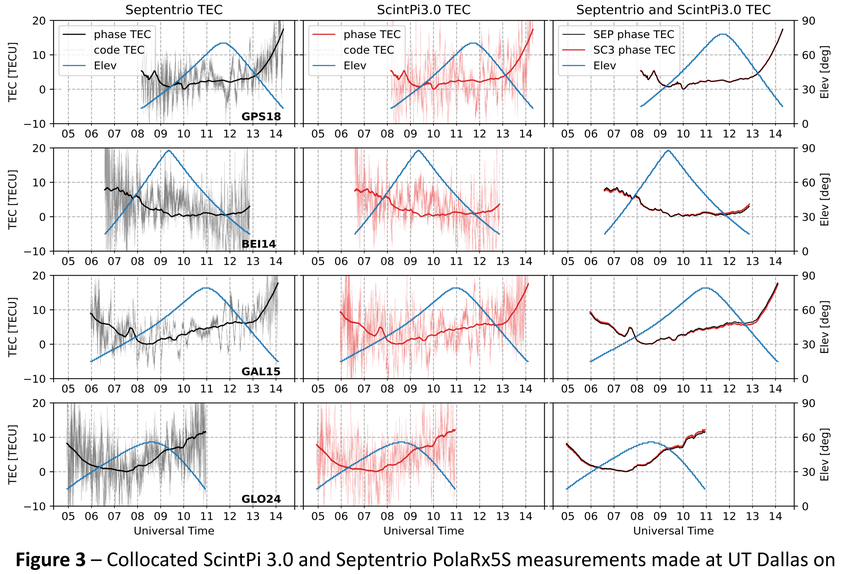

Figure 3 – Collocated ScintPi 3.0 and Septentrio PolaRx5S measurements made at UT Dallas on January 10, 2021.

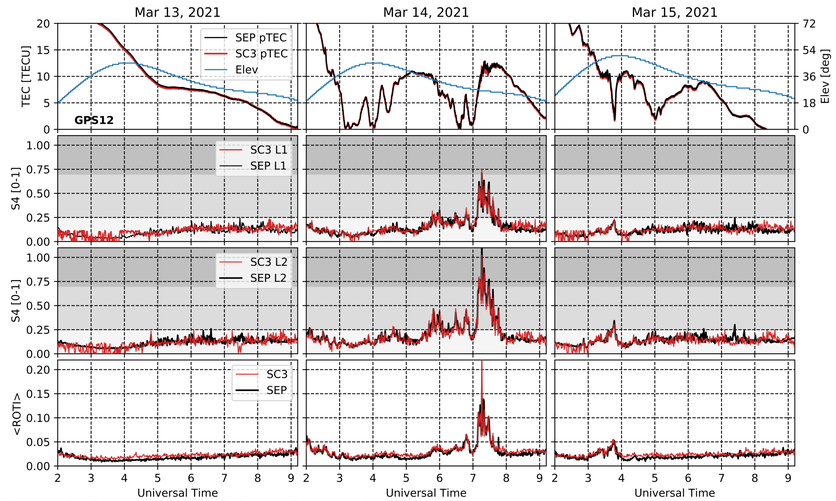

Figure 4 –Spaced ScintPi 3.0 and Septentrio PolaRx5S measurements made at the Jicamarca Radio Observatory between March 13 and 15, 2021.

Final Remarks

- We provided information about ScintPi 3.0, a GNSS-based ionospheric scintillation and total electron content (TEC) monitor.
- We described the system and showed examples of TEC and scintillation measurements it can provide. The measurements are in excellent agreement with those provided by a commercial monitor.
- The system can aid studies requiring distributed observations of ionospheric irregularities and scintillations Spaced system can also be used to study TIDs.

ScintPi Network

- We are seeking scientific and educational partners willing to host ScintPi 3.0 over the US and collaborate on studies. If interested, please contact Dr. Fabiano Rodrigues (fabiano@utdallas.edu).

Build your own ScintPi

- Isaac Wright (UT Dallas) created a online tutorial for those interested in building their own scintillation monitor based on ScintPi 1.0 (Rodrigues and Moraes, 2019). A description of the hardware and assembly as well as software for data acquisition are provided. Scan QR code to be directed to the tutorial.

Acknowledgements

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References

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