On the solar radio burst event that occurred on August 28, 2022, and its impact on GNSS signals measured by distributed scintillation monitors in the American sector

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1. KEY POINTS

- We report on **a Solar Radio Burst (SRB)** that occurred on August 28, 2022, between approximately 17:45 UT and 18:20 UT.
- The SRB was detected from simultaneous S_4 increases measured by a network of low-cost Global Navigation and Satellite Systems (GNSS) based ionospheric TEC and scintillation monitors.
- **Sudden C/No fadings were measured of up to 8 dB-Hz on L1** (~ 1.6 GHz) and **12 dB-Hz on L2** (~ 1.2 GHz).
- **Calculations estimate maximum fadings of 9 dB-Hz for L1 and of 13 dB-Hz for L2** for GNSS receivers located under the sub-solar point.

2. BACKGROUND

- An SRB is an intense radio emission from the Sun usually associated with solar flares (Bastian et al. 1998).
- Early theoretical work predicted that SRBs having sufficiently **large strength at L-band frequencies** and with **Right Hand Circular Polarization** (RHCP) **could impact GNSS** by increasing the background noise (Klobuchar et al., 1999).
- Since then, only a few cases (<10) where an SRB has impacted GNSS signals have been reported.
- Most notably, we point out the SRB of December 6, 2006, with 1,000,000 SFU at 1415 MHz associated with an X6.5 flare which was responsible for significant GNSS failures (Carrano et al., 2009).

3. EXPERIMENTAL SETUP

- We maintain a volunteer network of low-cost GNSS-based ionospheric TEC and scintillation monitors (ScintPi).

Figure 1: ScintPi 3.0

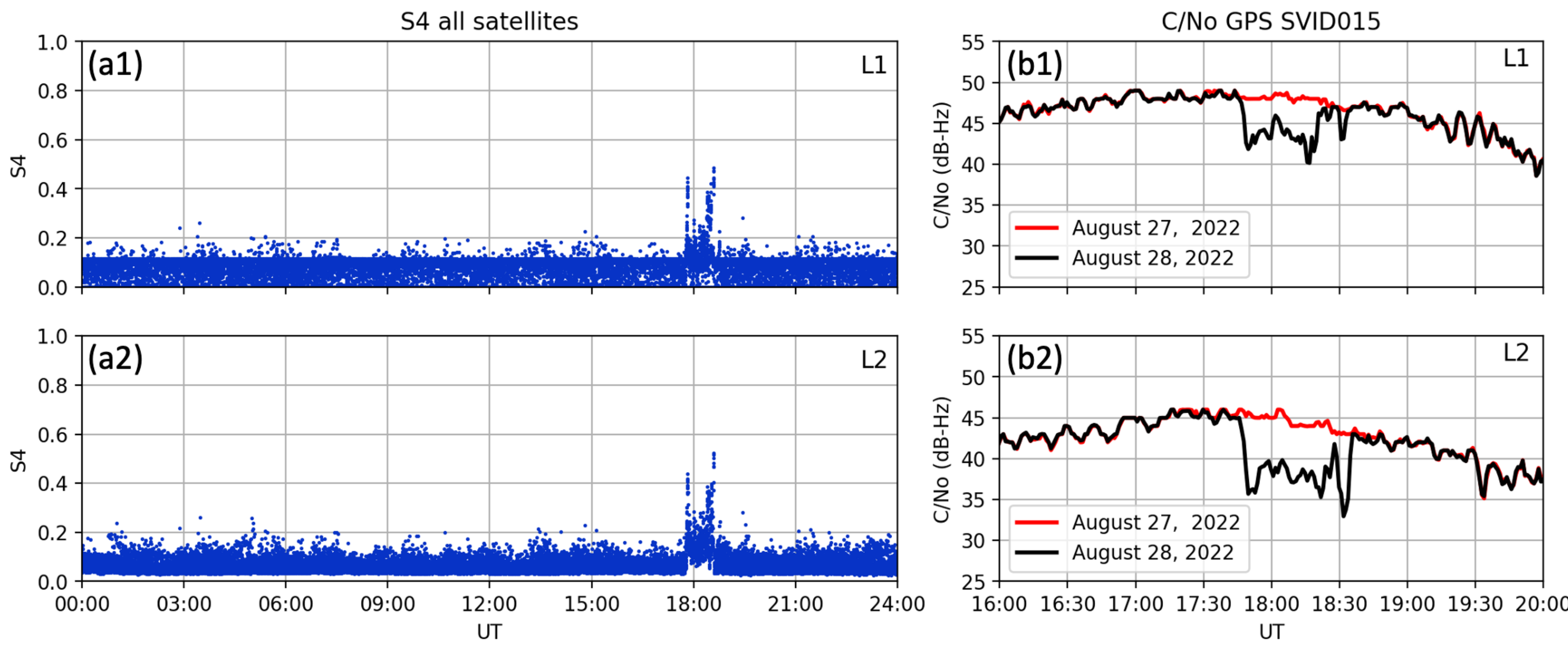
$$S_4 = \sqrt{\frac{\langle I^2\rangle - \langle I\rangle^2}{\langle I\rangle^2}}$$

Equation 1: S_4 index as a function of signal intensity *I*. Brackets indicate ensemble averaging.

- The monitors are based on commercial off-the-shelf components and are used by our lab in research and educational efforts (Sócola and Rodrigues, 2022).
- Multi-constellation and high-rate measurements (up to 20 Hz) enable ScintPi to calculate S_4 indices which are used to identify scintillation. ScintPi 3.0 can also provide total electron content (TEC).

4. INITIAL OBSERVATIONS IN DALLAS

- **Sudden increase in S_4 between 17:45 and 18:20 UT** associated with a rapid decrease in the carrier to noise ratio (C/No) lasting ~40 minutes on L1 and L2 frequencies
  - L1 ΔC/No up to 8dB (b1)
  - L2 ΔC/No up to 12dB (b2)
- TEC perturbations were not observed in the vicinity of the event.



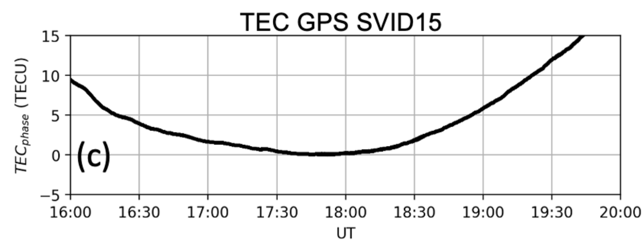


Figure 2: Measurements of GPS SVID 15 from the ScintPi in Dallas. S_4 and C/N0 for L1 (a1, b1) and L2 signals (a2, b2). Phase TEC estimated from L1 and L2 phase measurements (c).

5. DISTRIBUTED OBSERVATIONS

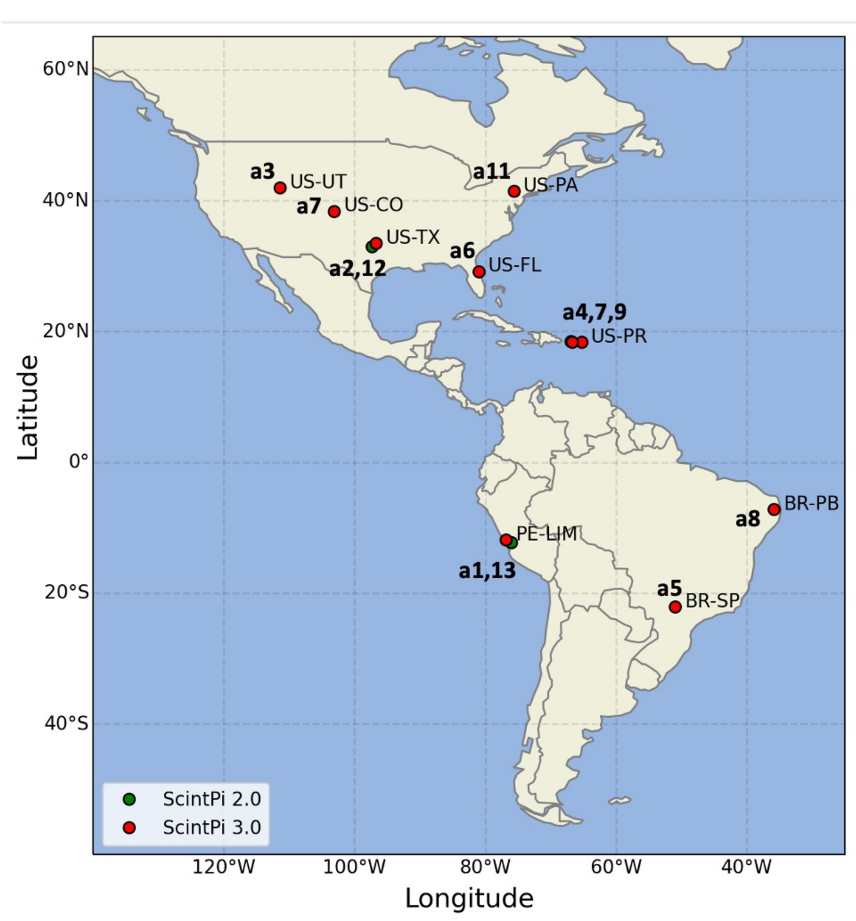
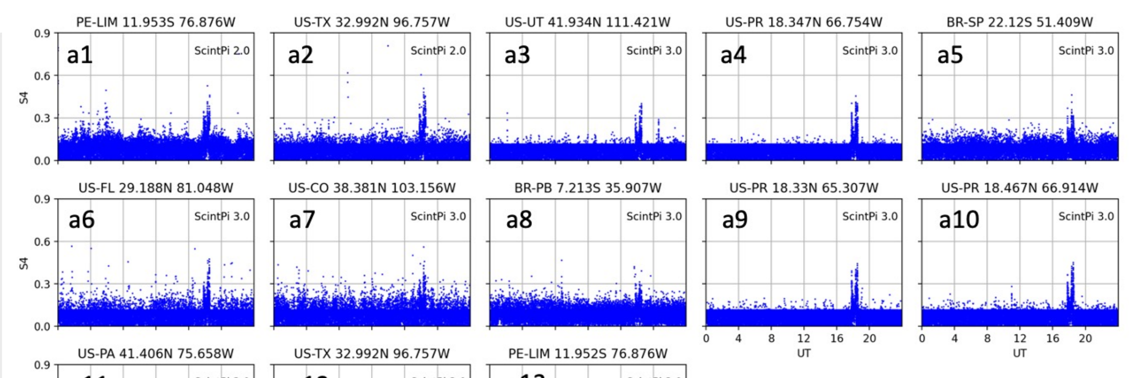


Figure 3: Locations of ScintPi monitors on August 28, 2022, and labels corresponding to subplots on the right.



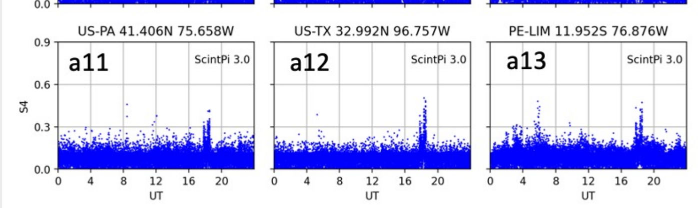
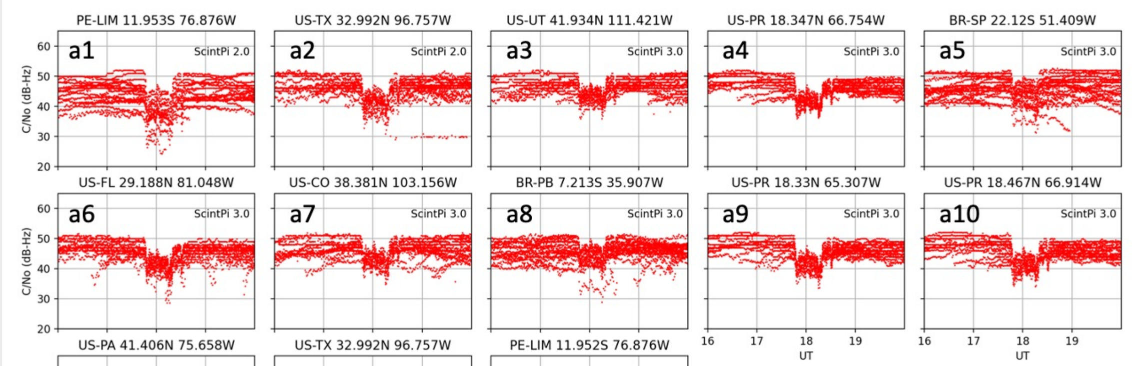


Figure 4: L1 S_4 for each station in the network (a1-13)



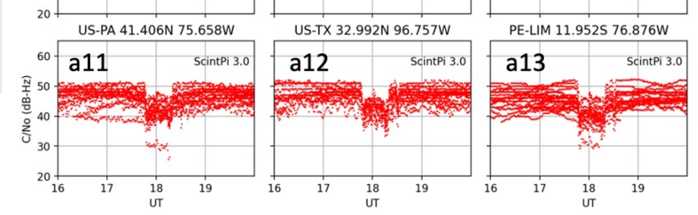


Figure 5: All visible L1 C/No measurements for each station in network (a1-13)

- Concurrent enhancement in S_4 to ~0.5 between 17:45 and 18:20 UT for all stations rules out typical ionospheric sources of scintillation. Further investigation showed that the **S_4 enhancement was due to a sudden decrease (>5dB) in the C/No in all visible satellites.**

6. STRONG SOLAR ACTIVITY FROM AR 3088

- Since the perturbation in C/No was observed in every satellite and in multiple stations, **we investigated reported solar events** as a possible explanation of activity.

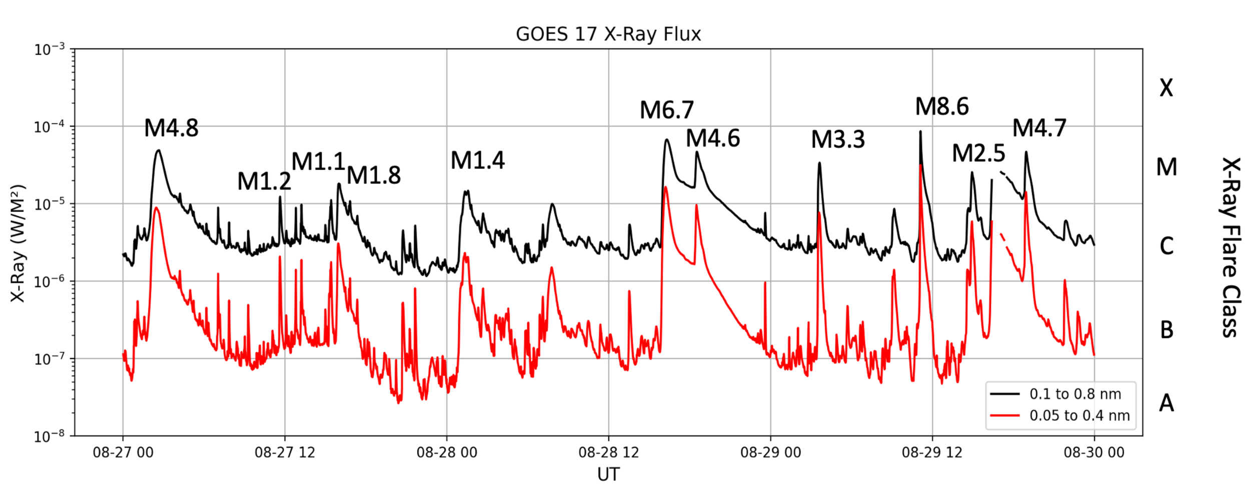


Figure 6: GOES-17 X-Ray flux from August 27 to 29, 2022

- M6.7 flare at 16:19 UT and a M4.6 flare at 18:32 UT
- **SRB at 1415 MHz of 230,000 Solar Flux Units (SFU)** from 17:13 - 19:59 UT
- Halo CME with linear speed of 1232 km/s at 16:12 UT

7. CONFIRMING SOLAR SOURCE OF NOISE

- If the source of the C/No decrease were an SRB, **the depth of the decrease would necessarily depend on local solar zenith angle** due to the anisotropy of the antenna gain.
- A vertical equivalent C/No, C/No^Z, can be determined as a function of zenith angle, θ, and gain, g (Carrano et al., 2009).

$$(C/No)^Z(\theta) = (C/No)^0 \left\{1 + \frac{g(0)}{g(\theta)}\left[\frac{(C/No)^0}{(C/No)} - 1\right]\right\}^{-1}$$

Equation 2: $C/No, C/No^0$ represent the C/No during the SRB and on a quiet day, respectively.

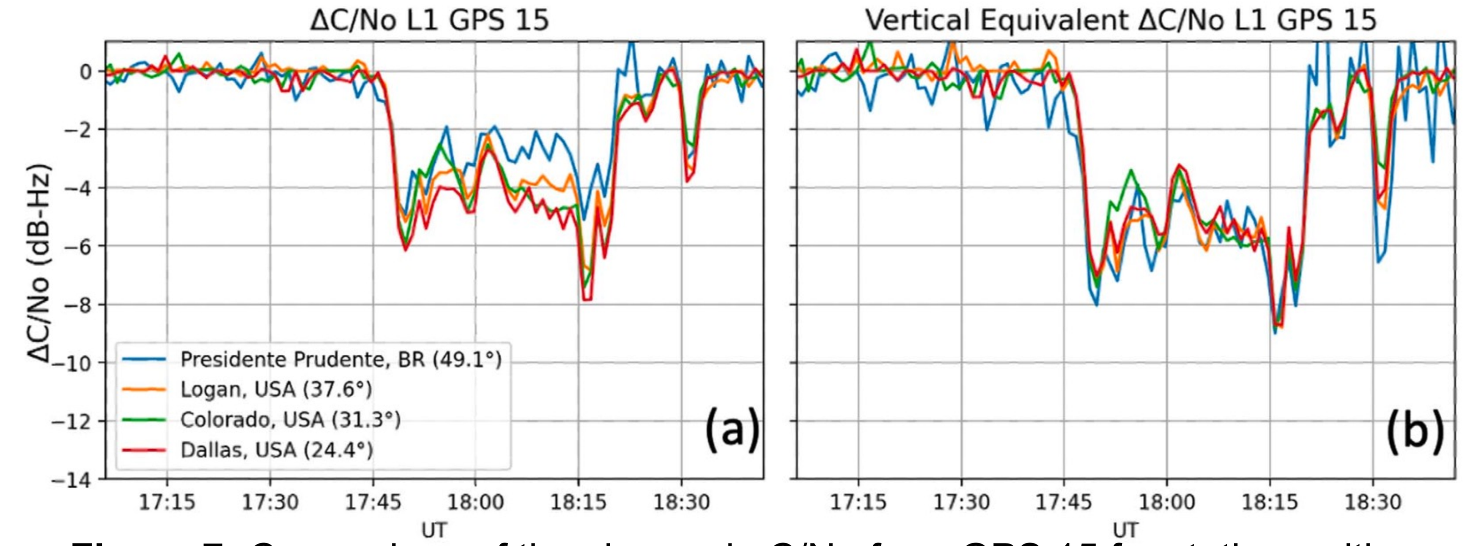


Figure 7: Comparison of the change in C/No from GPS 15 for stations with varying solar zenith angles at time of event (a). Calculated vertical equivalent fade in C/No for the same stations (b).

- The calculations show that the depth of **C/No fade is consistent with the local solar zenith angle**.
- We estimate **maximum fadings of 9 dB-Hz for L1 and of 13 dB-Hz for L2** for a receiver located under the subsolar point.

8. MAIN FINDINGS

- An SRB was detected on August 28, 2022, from its impact on the measurements of a low-cost network of ionospheric scintillation and TEC sensors.
  - C/No fadings were measured of up to 8 dB-Hz on L1 and 12 dB-Hz on L2.
  - Maximal C/No fadings were estimated at 9 dB-Hz for L1 and 13 dB-Hz for L2.
- **This finding exemplifies the usefulness of the low-cost monitors for studies beyond those typically associated with ionospheric irregularities and scintillation**
  - This event was identified because of the monitoring of S_4 which requires high-rate measurements and is not provided by many other midlatitude GNSS networks.
  - These observations occurred when many other instruments that are typically used to study this event were not making measurements (e.g., EOVSA, RSTN).

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