

New GOES Signal Application for Monitoring Ionospheric Irregularities: A HamSCI Collaboration Vision

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Overview

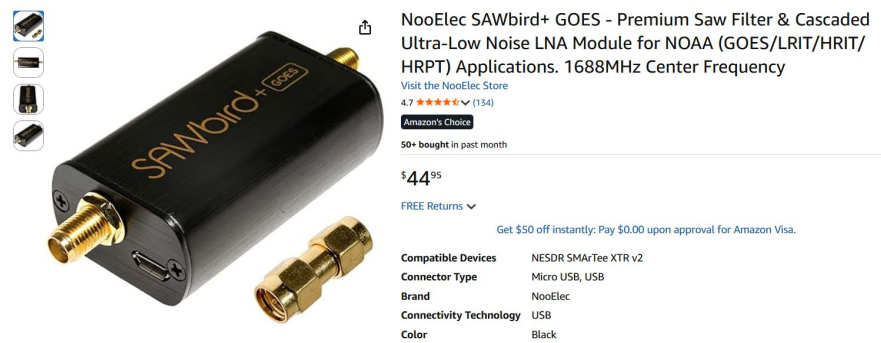
Exciting New Frontier for Ionospheric Monitoring with Low Entry Cost

- Opportunity to survey ionospheric turbulence routinely across entire western hemisphere using one or more L-band receivers
 - Byproduct of normal Geostationary Operational Environmental Satellite (GOES) transponder use
 - Monitors amplitude scintillation on ~30,000 Data Collection Platform (DCP) uplink transmissions
 - Similar relay system on European Meteosat (Qty 2) and Japanese Himawari (Qty 1) satellites
- BC ISR (with NOAA) has performed a feasibility demonstration of DCP signal technique
 - Demonstrated GOES bent-pipe analog transponder faithfully reproduces amplitude fluctuations
 - Manually identified some scintillation cases in Gannon Storm (May 2024) data
- Scintillation not always directly related to amateur radio interests, but “ham adjacent”
 - Direct impact on transionospheric VHF / UHF propagation—e.g., EME and AMSAT
 - Maps of scintillation should relate to ionospheric structures that impact HF propagation

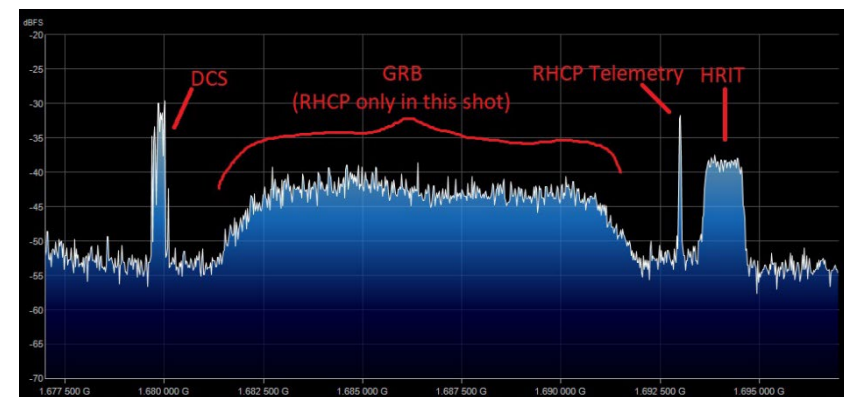


Goals of Talk

- Develop community interest in GOES DCP experimentation
- Gather pointers on developing as a HamSCI (or other citizen science) project
- Promote the project vision: open a frontier for scientific discovery by monitoring hemispheric scintillation patterns regularly



Preamp Image from [Nooelec Store at amazon.com](https://www.amazon.com/dp/B078888888)



HRIT
1694.1 MHz

DCS
1680 MHz

Annotated GOES Spectrum from <https://usradioguy.com/>

HRIT = High Rate Information Transmission

DCS = Data Collection System (DCP Relay Downlink)

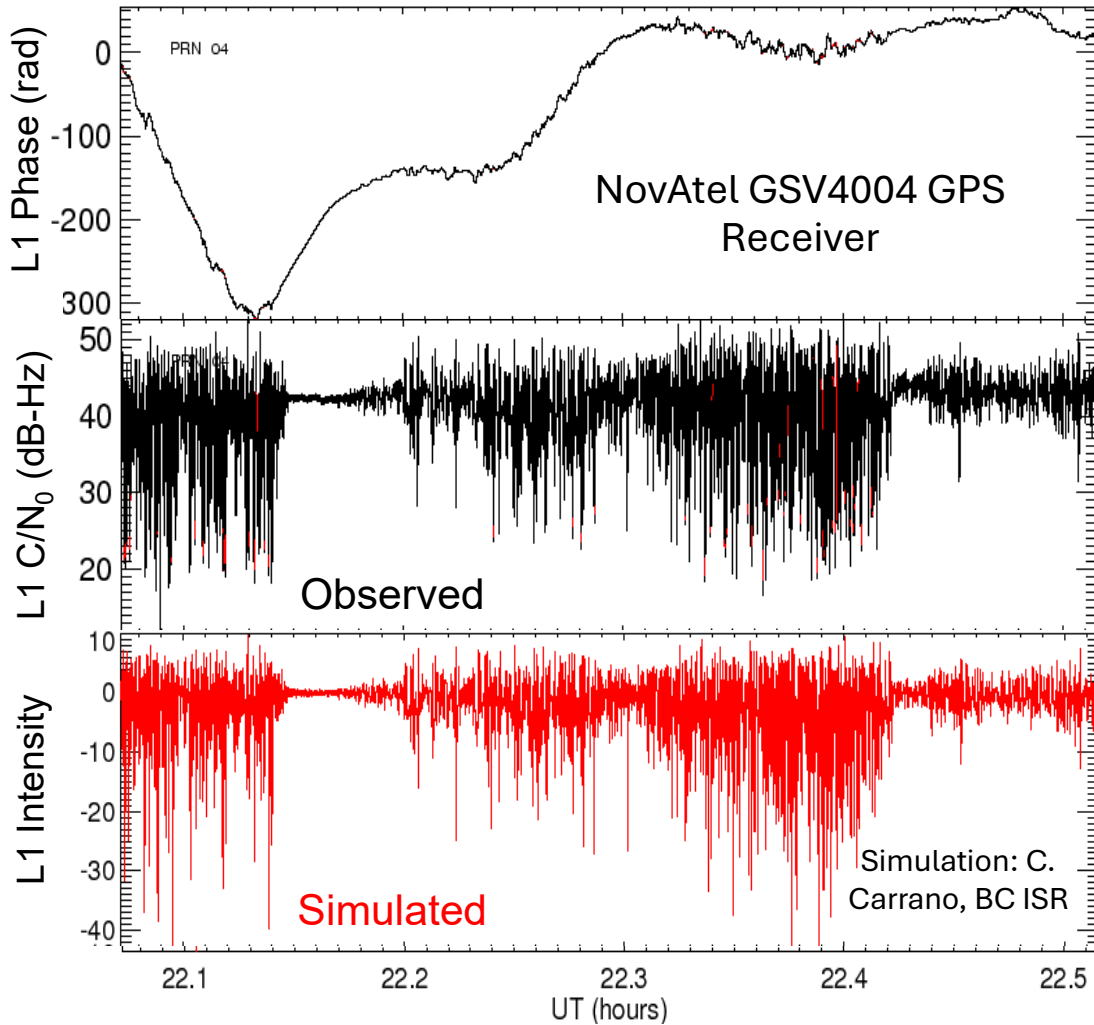
Inexpensive Hobbyist GOES Weather Image Hardware Can Potentially Receive DCP Downlink



Scintillation Background



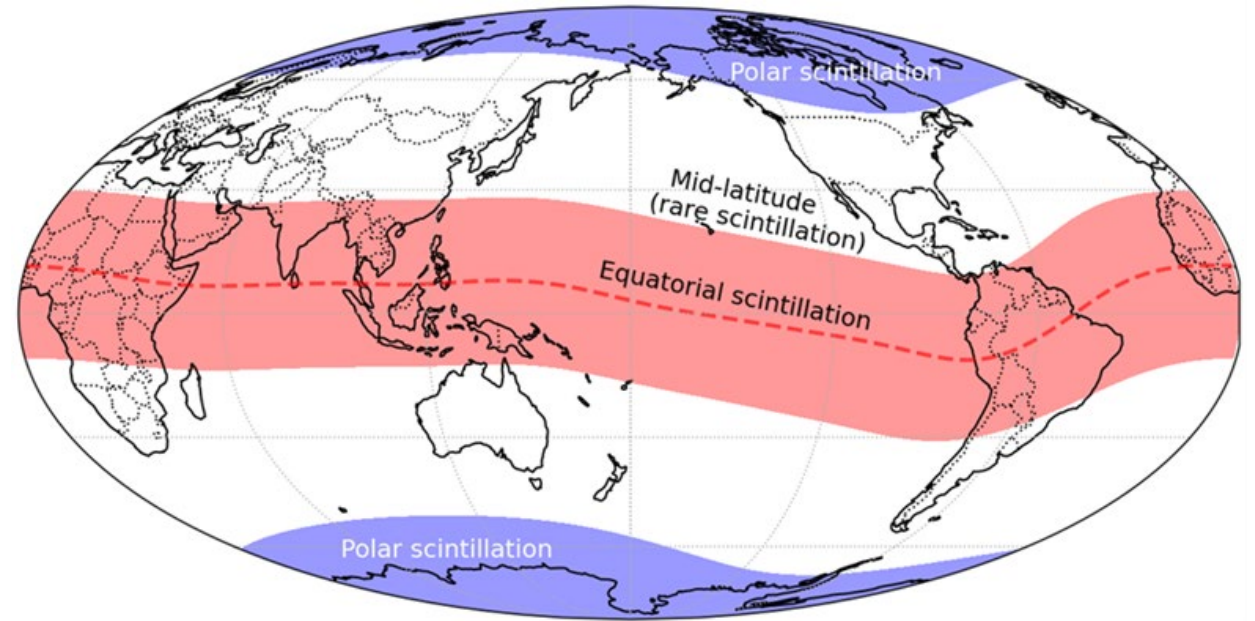
What Is Scintillation? Where Does It Occur?



Ascension Island (7.98°S, 14.4°W, 15°S dip latitude)

Scintillation = Phase and Amplitude Fluctuations from Propagation through Ionospheric Plasma Turbulence (Scintillation Strength ↓ as Radio Frequency ↑)

Worldwide Occurrence Wherever Turbulence Likely



Note: Mid-Latitude Scintillation Perhaps Not As Rare As Once Thought



Ionospheric Scintillation Radiophysics

Note: VHF / UHF
Approximations

Time Delay:

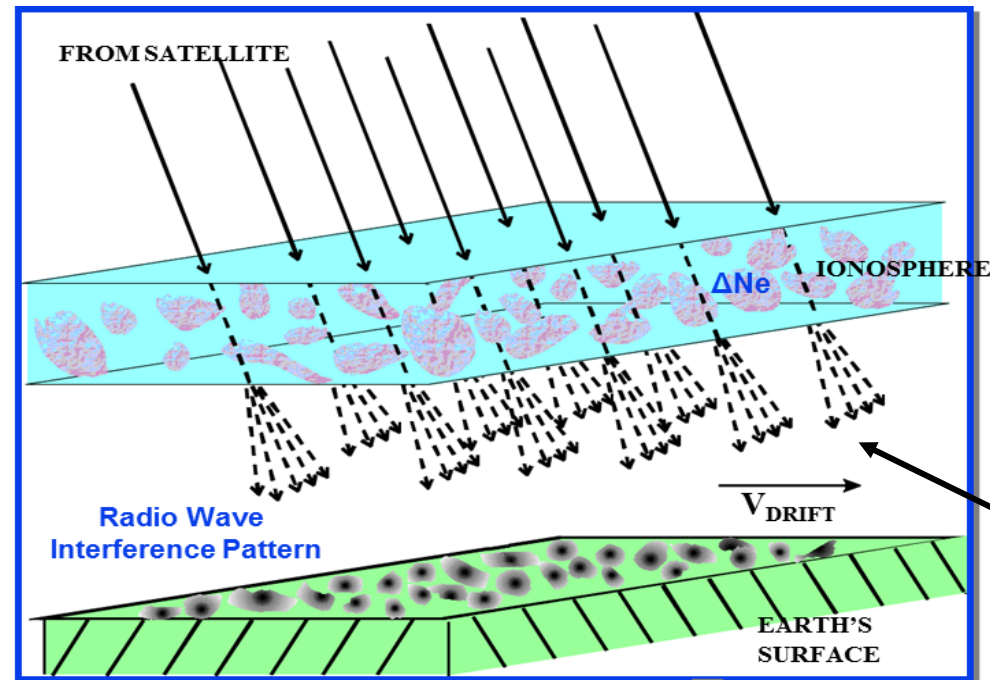
$$\tau_d = \frac{R}{c} + \frac{r_e c N_{tot}}{2\pi f^2}$$

Phase Perturbation:

$$\delta\phi = \frac{2\pi f R}{c} - r_e c \frac{N_{tot}}{f}$$

Both Depend on Total
Electron Content (TEC):

$$N_{tot} = \int N_e(x, y, z) dz$$



Refractive Index ROM

$$\epsilon_r(x, y, z) = 1 - \frac{80.6 N_e(x, y, z)}{f^2}$$

$$n(x, y, z) = \sqrt{\epsilon_r(x, y, z)}$$

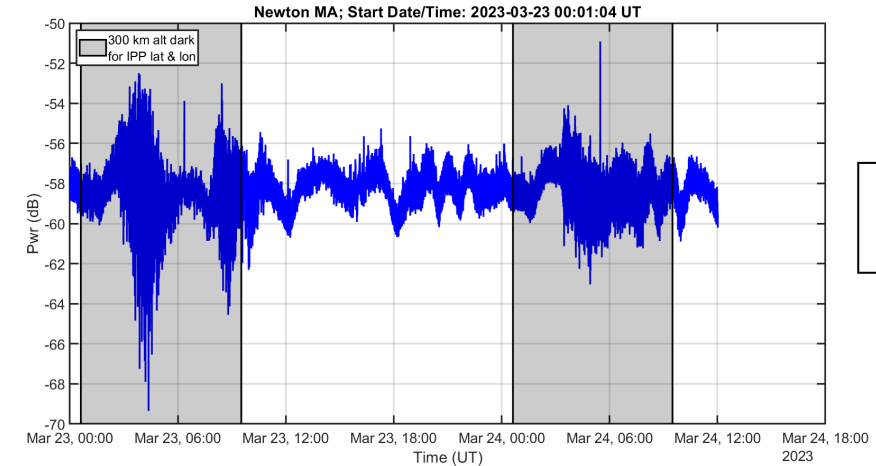
$$N_e = 10^{12} \text{ el/m}^3, f = 402 \text{ MHz} \\ \Rightarrow n = 0.99975$$

Huygens Principle
(Modern, Rigorous Form)
for Propagation below
the ionosphere

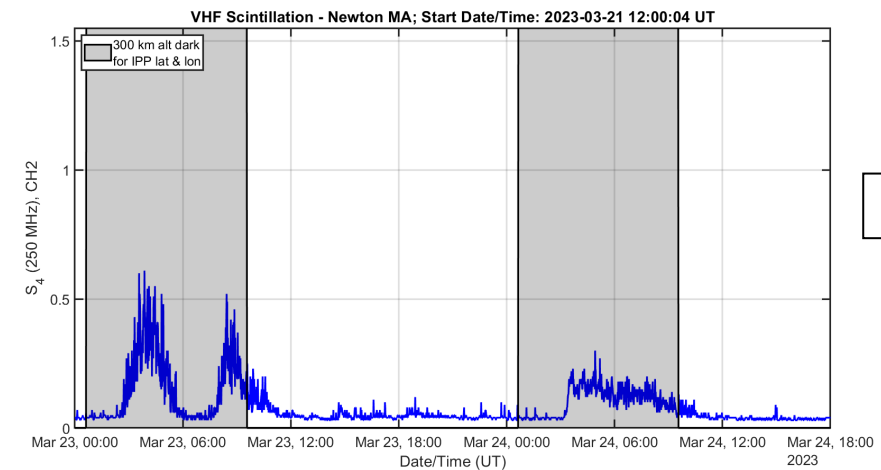
- Differences in phase between adjacent paths produce an interference pattern
 - Interference pattern + net motion \Rightarrow scintillation (time-varying signal fluctuations)
 - Smooth ionosphere \Rightarrow no scintillation
- Constructive & destructive interference yield amplitude scintillation below ionosphere

Amplitude Scintillation Index (S_4)

- A simple standard deviation can quantify amplitude fluctuations
 - $S_4^2 = \frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}$, where $\langle \dots \rangle$ denotes averaging
 - Note I is linear power, not dB
 - S_4 asymptotically approaches 1 at high turbulence strength
 - Can be related to $\int \Delta N_e^2(x, y, z) dz$, albeit through complicated scaling
 - The name “ S_4 ” sticking is a bit of an historical accident (name from Briggs and Parkin, 1963)
- Caution: S_4 can be influenced by fluctuations from other sources—noise / RFI, transmit power changes, multipath



Power Data
(50 Hz)



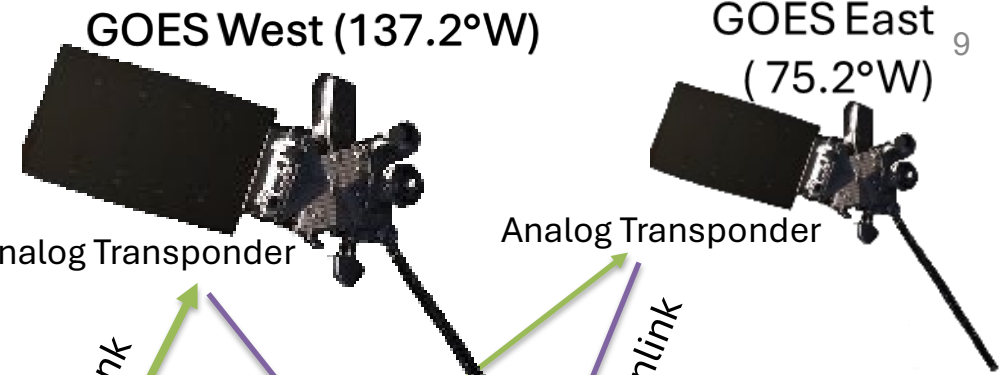
S_4 (1/min, typ.)



Data Collection System (DCS) and Scintillation



Data Collection System (DCS)

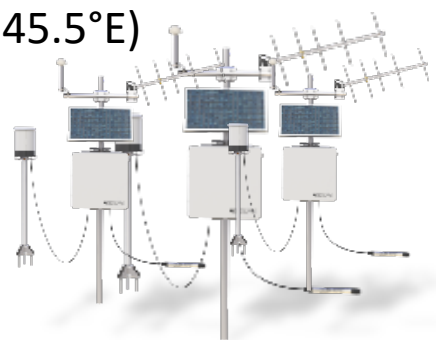


Satellites (US):	GOES East & West (Current) GeoXO East & West (Future?)
Data Collection Platforms (DCPs):	33,000+ active 43,000+ registered

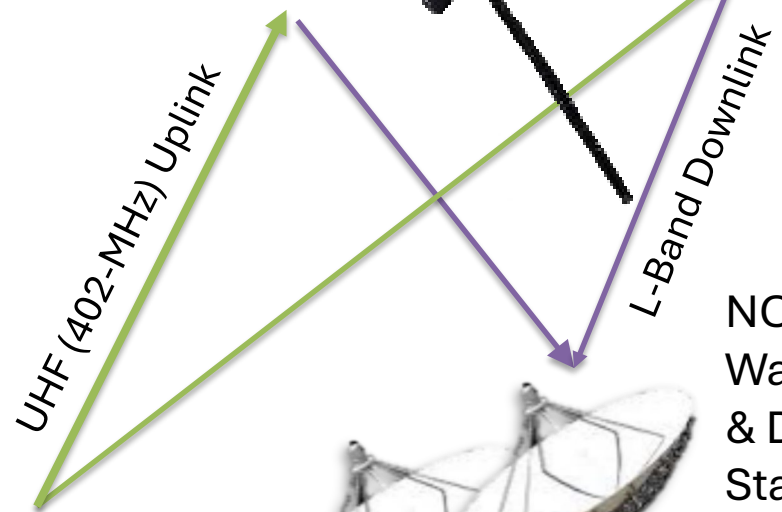
Function	Frequency (MHz)
DCP Uplink (Data)	401.7 – 402.4
Bent-Pipe Downlink	1679.7 – 1680.4

GOES DCS = Environmental data relay system for western hemisphere DCPs (carries ~1 million messages/day)

International
 Japan: Himawari-8/9 (140.7°E)
 Europe: Meteosat (0°E, 45.5°E)



Data Collection Platforms (DCPs)



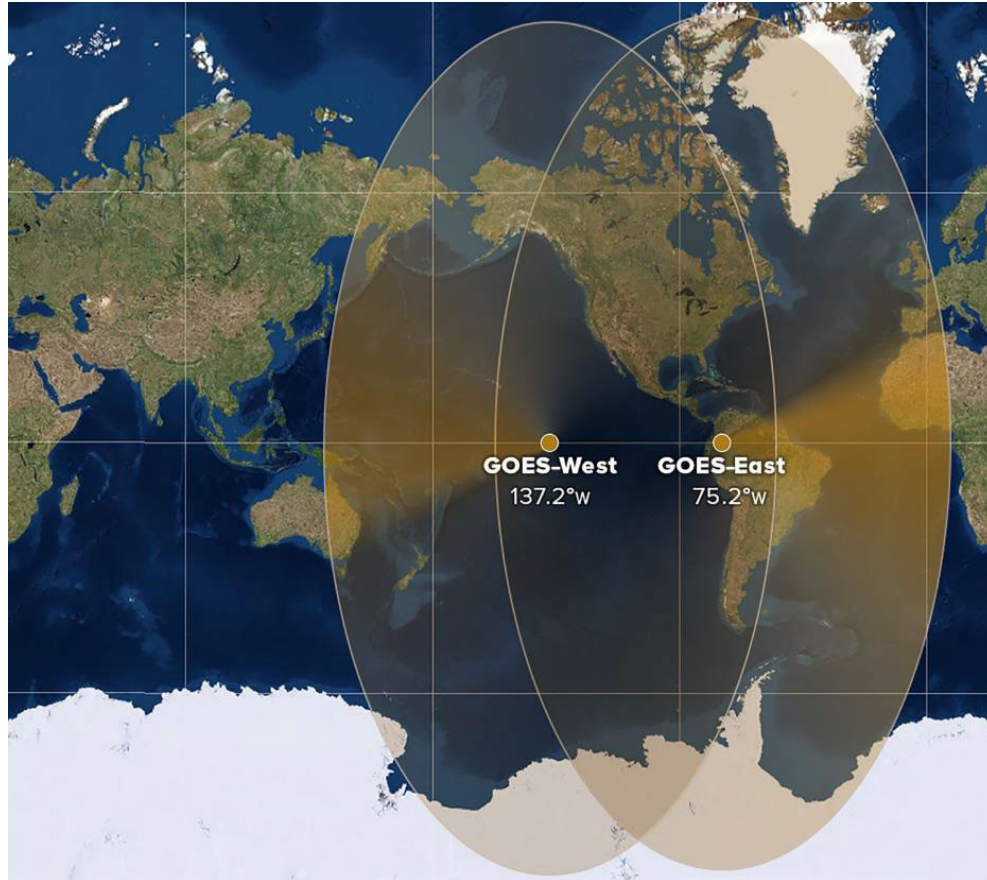
DCS Administration and Data Distribution System (DADDS)



NOAA/NESDIS
 Wallops Command & Data Acquisition Station (WCDAS)
 (Suitland MD Alt. Receive Site)

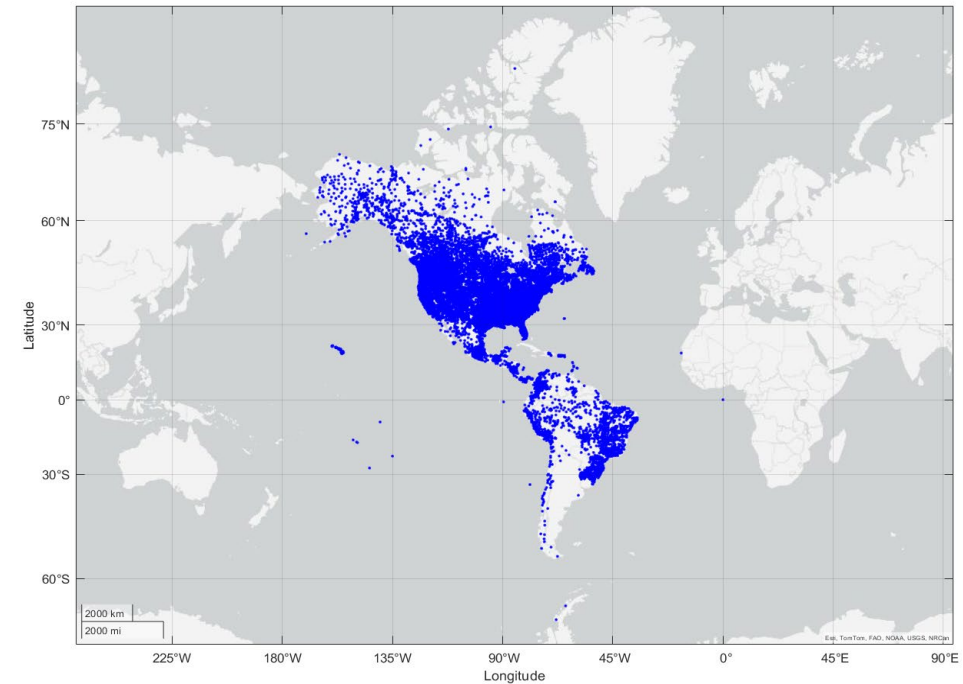


GOES Coverage, “Long” DCP Transmissions



GOES-E/W DCS Ground Coverage Areas

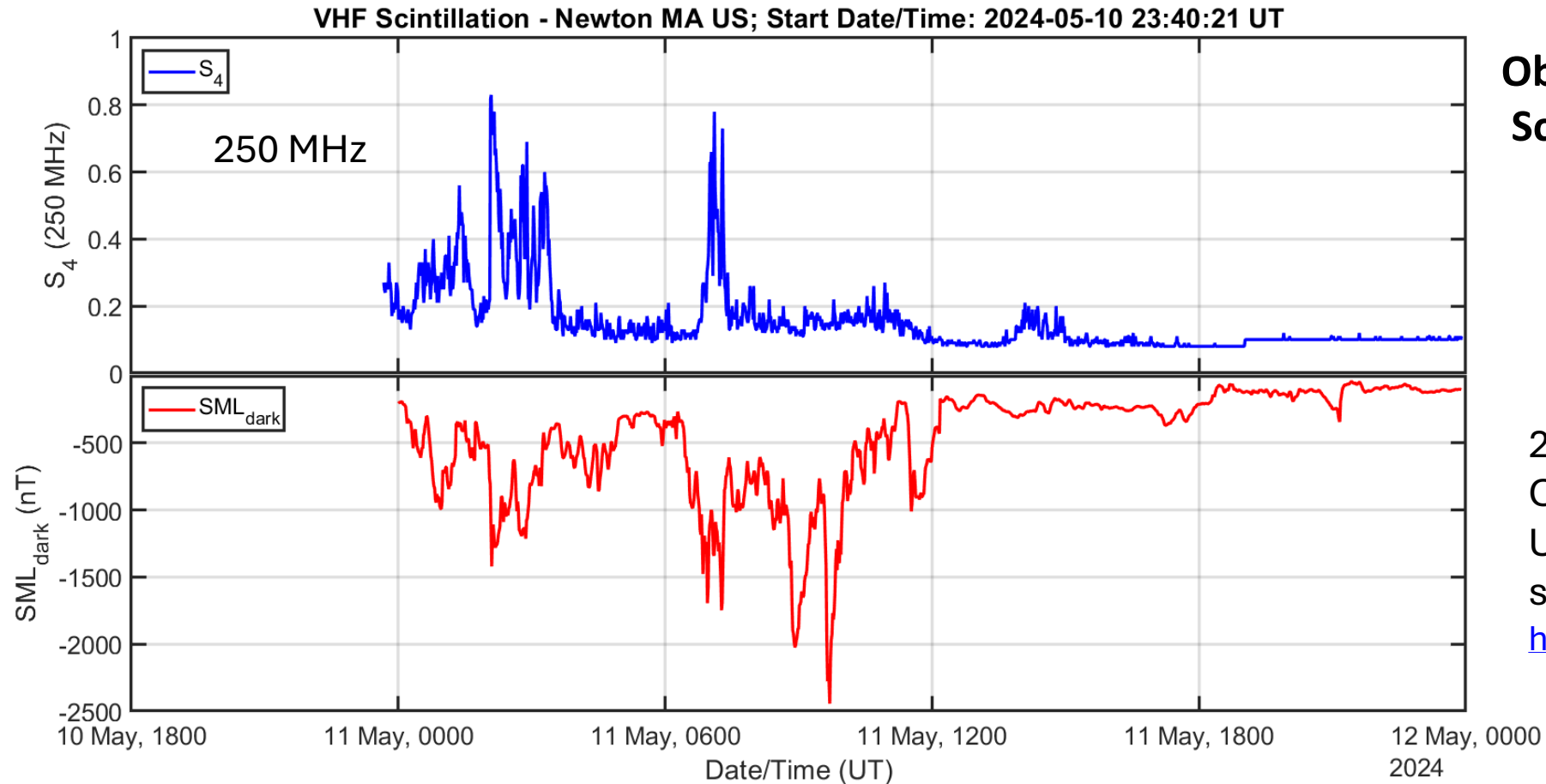
Extensive DCP Coverage May Compensate for Low Repetition (1/hr Typ.) from a Given Site



GOES DCP Transmitters (≥ 5 s Tx, $> 1 \times$ /day)
Geographic Distribution – 29704 Stations

Mid-Latitude VHF Scintillation – Gannon Storm

Confirmed 250-MHz Scintillation at BC – Associated with Substorms and Auroral Precipitation



Observed Mid-Latitude VHF Scintillation (11 May 2024)

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

250-MHz S_4 (Top)
Observed at Newton MA,
USA with SuperMAG dark
side SML (Bottom)

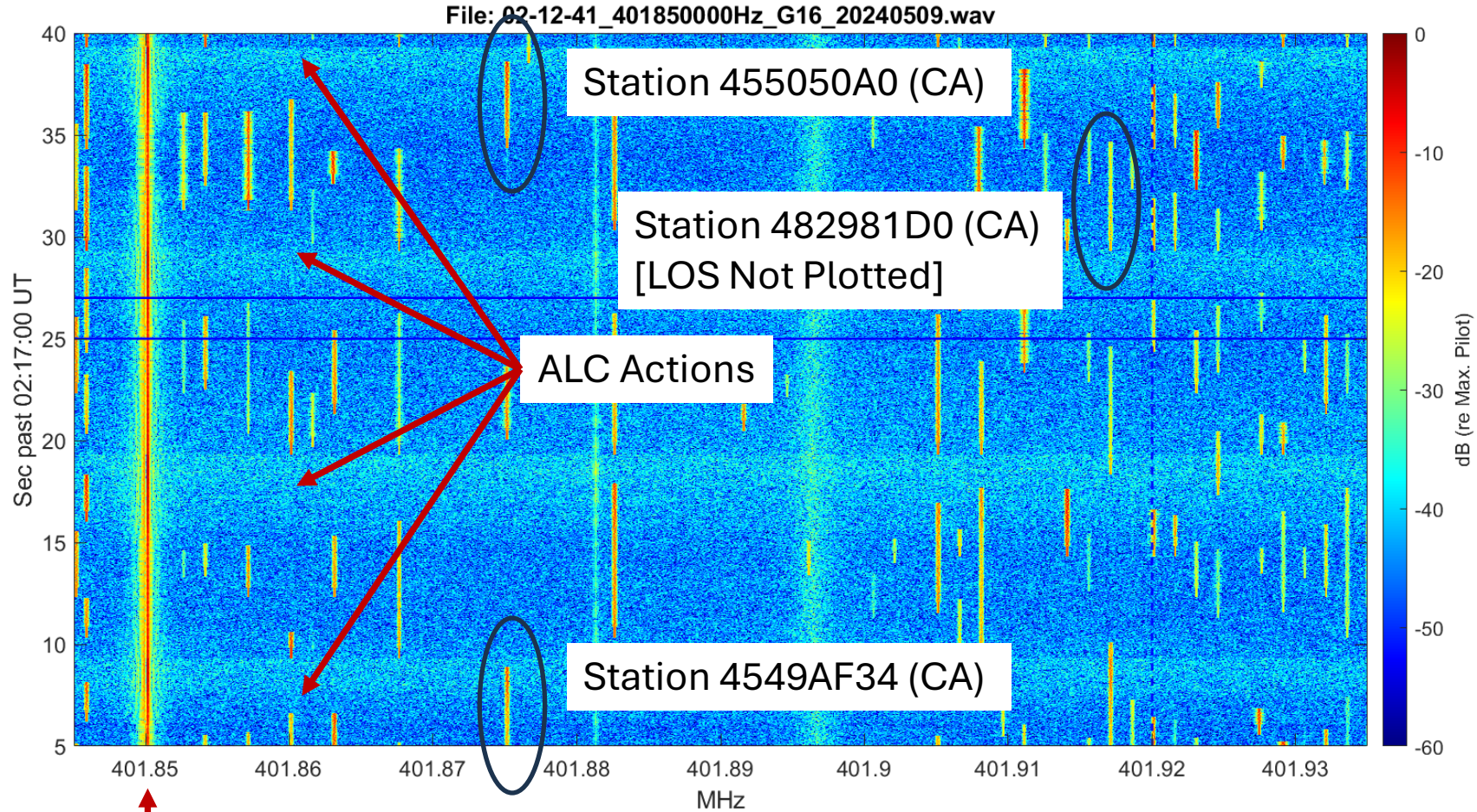
<https://supermag.jhuapl.edu/>



Pre-Storm Amplitude Monitoring (09 May 2024)

Pre-Storm “Quiet” – Will Show Peak Storm Timeframe 2 Days Later

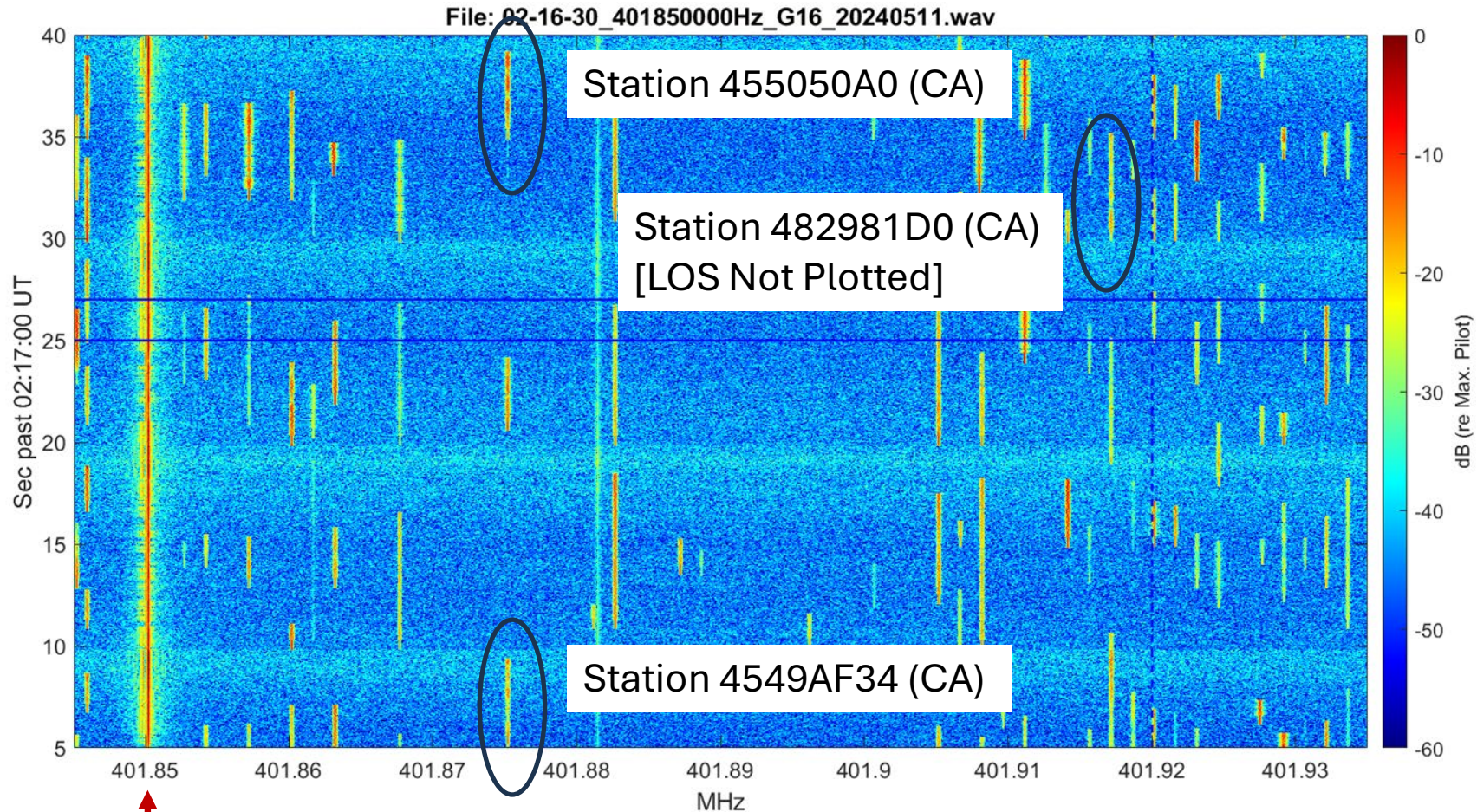
ALC = Automatic Level Control
LOS = Line of Sight



Storm-Time Amplitude Monitoring (11 May 2024)

Disturbed: Storm Timeframe – Likely Scintillation Cases

Note: there is a ± 0.5 s downlink logging time tag inaccuracy because of RTL-SDR timestamp resolution



Pilot Tone
(Primary)

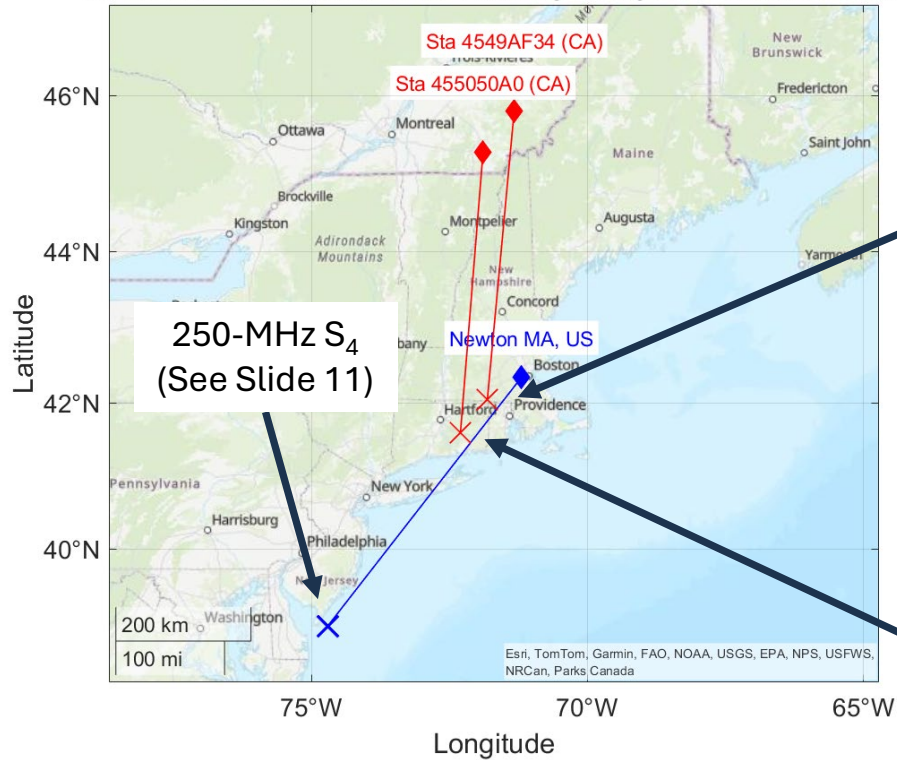


Sample DCP Signals Before and During the Storm

09 May 2024 (Quiet)

11 May 2024 (Storm)

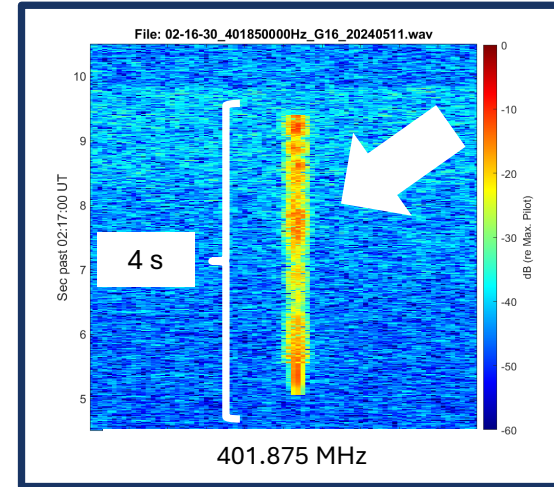
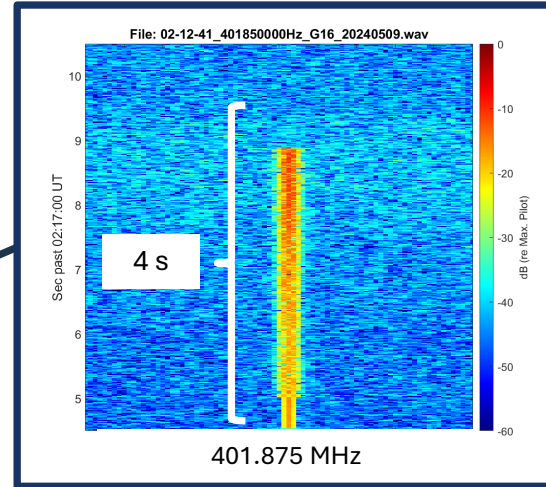
GOES-E IPP & Newton GEO Visibility Analysis - Gannon Storm



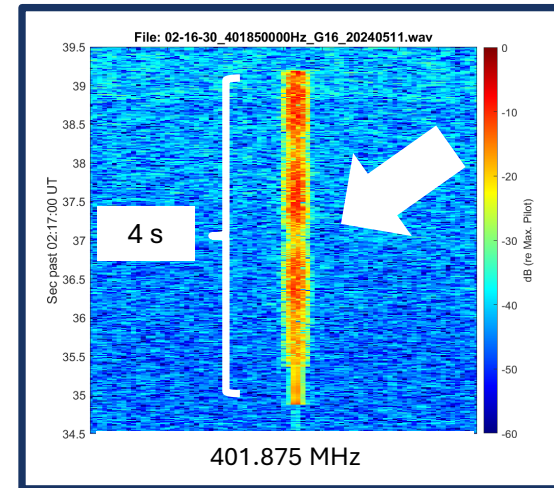
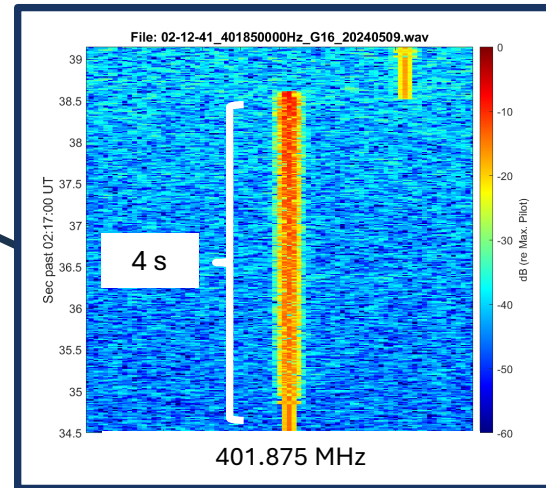
250-MHz S₄
(See Slide 11)

Longitude

350-km Altitude Ionospheric Pierce Points (IPPs):
 Blue X - Newton 250-MHz GEO Line of Sight
 Red X - GOES-East DCP 402-MHz Lines of Sight



Station 4549AF34



Station 455050A0



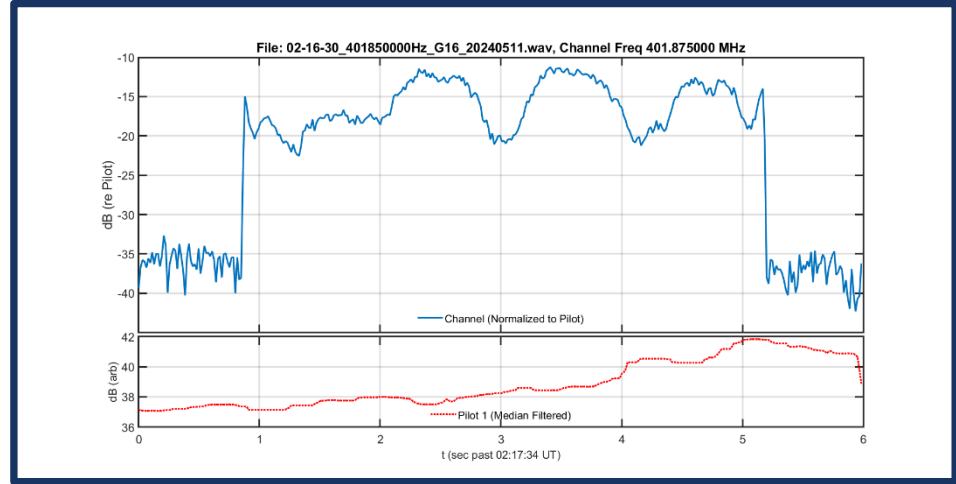
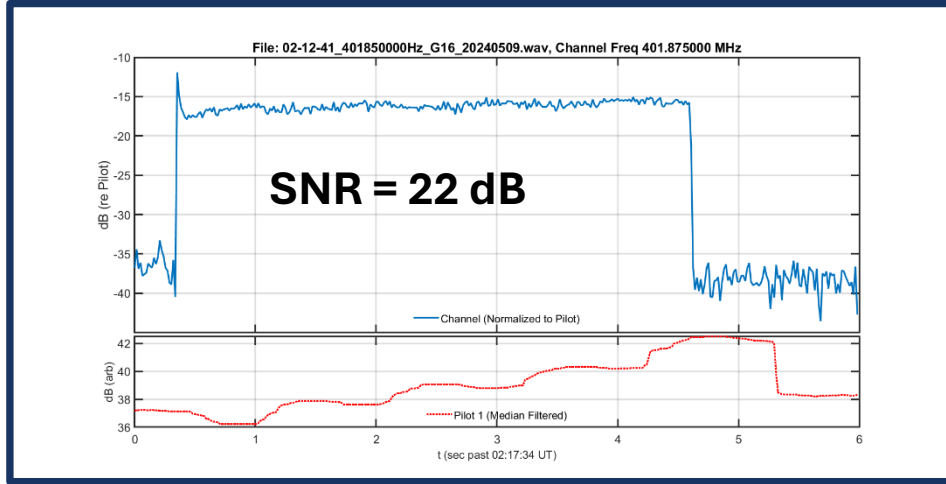
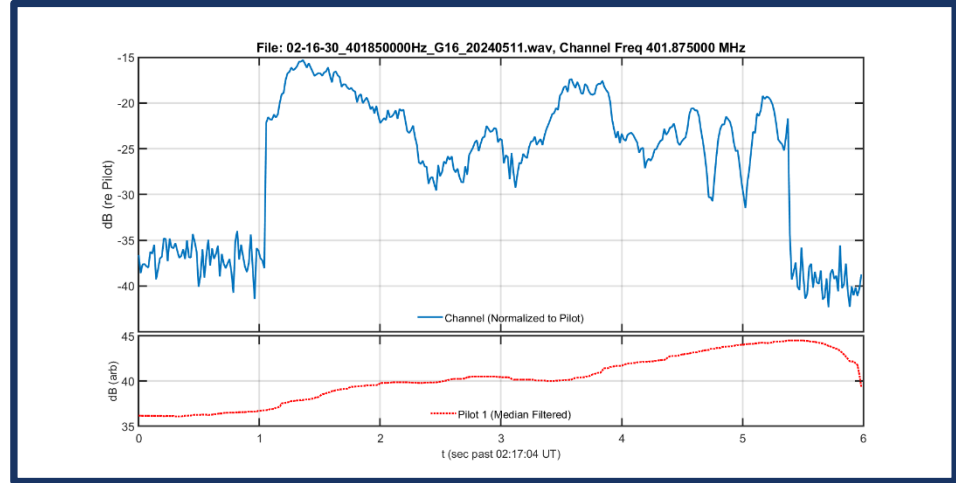
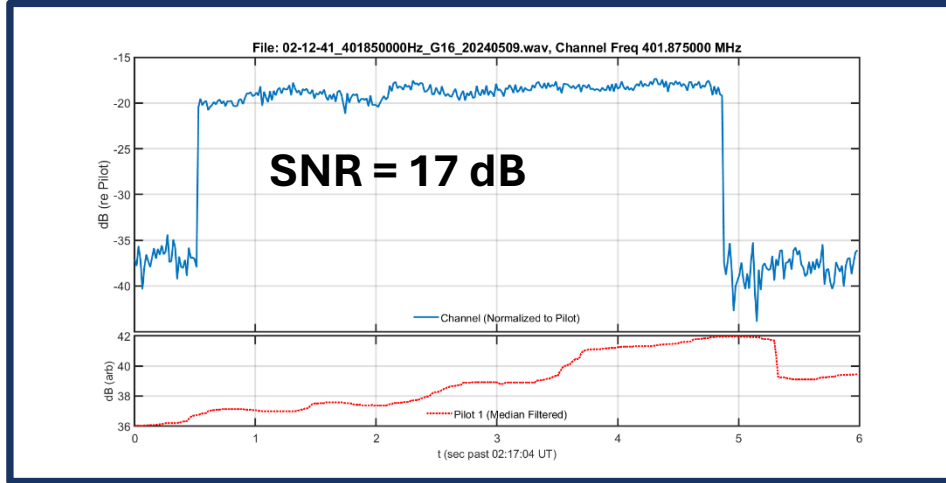
Time Series – Compensated for ALC

Amplitude Scintillation
During Storm

09 May 2024 (Quiet)

11 May 2024 (Storm)

Relatively Strong
Stations \Rightarrow SNR
“Headroom” to
Observe
Fluctuations



Station 4549AF34

Station 455050A0



Project Vision and Science



Establishing a Station: How Expensive?

Electronics Prices Benefit from GOES Hobbyist Market

- RTL-SDR or similar: ~\$40
- Nooelec GOES preamp: ~\$45
- Dish and feed are probably the limiting expense
 - Surplus? eBay? Hamfest?
 - New 1.2-m parabolic dish w/ linearly polarized feed (upper right): ~\$579

$$G_{1.2m} = (1.2/3.1)^2 G_{3.1m} \text{ (Gannon storm data)} \Rightarrow -8.2 \text{ dB}$$

Marginal?

$$G_{1.2m} = 10 \log_{10}(\eta A 4\pi / \lambda^2)$$

$$\approx 10 \log_{10} \left(0.5(1.13 \text{ m}^2) \frac{4\pi}{(0.178 \text{ m})^2} \right)$$

$$\approx 23.5 \text{ dBi}$$



23.5 dBi
(Probably
Marginal)

Antenna Image from

<https://technicalantennas.com>



Nooelec GOES Weather Satellite Mesh Antenna - 21dBi Parabolic Antenna w/ 1.7GHz Center Frequency, 200MHz+ Bandwidth, LMR400 Feed Cable with Male SMA Connector, Mounting Hardware, & 2 Year Warranty

Visit the Nooelec Store

4.2 ★★★★★ (52)

Amazon's Choice

21 dBi

(Marginal)

\$99⁹⁵

FREE Returns

Get \$50 off instantly. Pay \$49.95 upon approval for Amazon Visa.

Antenna	Satellite
Brand	Nooelec
Color	Black, White
Number of Channels	1
Impedance	21 Ohms
Product Dimensions	38.98"L x 24.02"W x 14.96"H
Manufacturer	Nooelec Inc.

Antenna Image from [Nooelec Store at amazon.com](https://www.amazon.com)

[amazon.com](https://www.amazon.com)



Processing Pieces Needed

BC Planning to Establish a Station for GOES-East and Develop Software Tools

- Observe DCS downlink at a few L-band monitoring stations
- Routine raw data collection – few days' buffer, 164 GB/day
- Decimation of traces to ~50 Hz power data (~1.6 GB/day storage)
- Identify probable scintillation cases and compute S_4 , when meaningful
- Match S_4 measurements with DCP IPP locations (must QA the DCP positions)
- Ideally make scintillation maps in real time

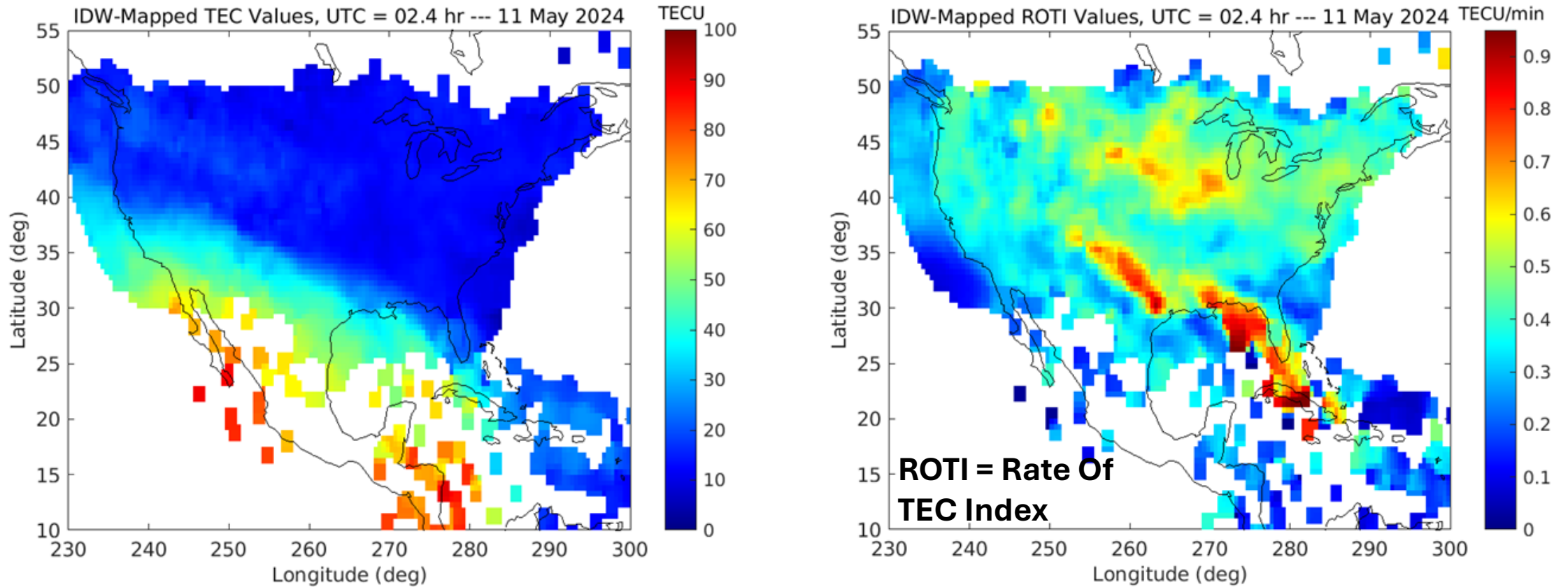


Product Hierarchy

Comparison to Traditional GNSS TEC

Could Make a 402-MHz S_4 Map Analogous to These Using a *Single Receiver*

Mapped Madrigal TEC (Left) and Derived ROTI (Right) – 11 May 2024, 0226 UT – 100s Receivers



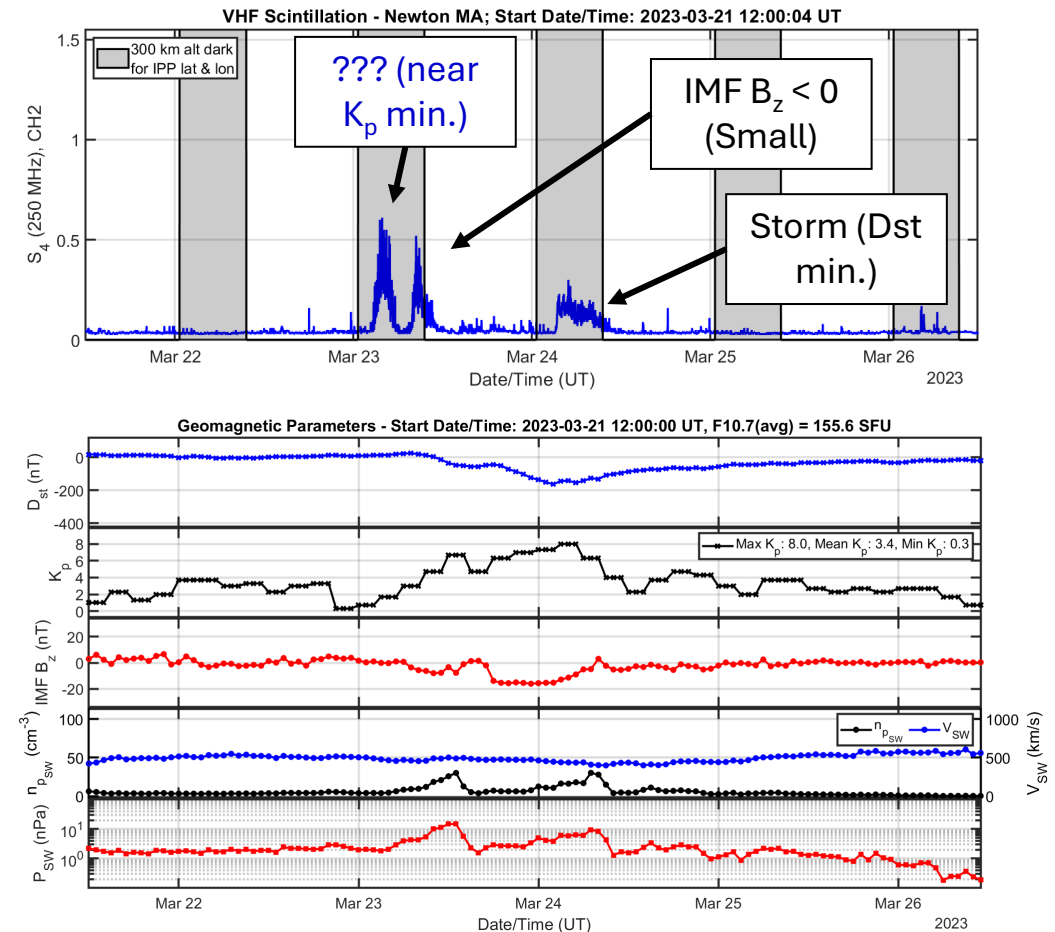
Maps Courtesy R. Pradipta, Boston College, Institute for Scientific Research



Mid-Latitude Scintillation Science

More Interesting Than Perhaps Thought

- SPARTA: Jan 2022 through Mar 2026 study
 - 61 cases of mid-latitude scintillation, storms or both
 - Not as common as, say, equatorial scintillation: ~140 nights/yr at some locations
- Mid-latitude scintillation sources not well characterized without spatial information
 - Sometimes high-latitude irregularities (e.g., auroral oval) with equatorward excursions in storms
 - Sometimes low-latitude irregularities (e.g., equatorial plasma bubbles) with poleward excursions in storms
 - Other cases not clear (e.g., **first S_4 peak at right**)



Geomagnetic / Solar Wind Data: Papitashvili, Natalia E. and King, Joseph H. (2020), "OMNI Hourly Data" [Data Set], NASA Space Physics Data Facility, <https://doi.org/10.48322/1shr-ht18>, Accessed on 13 Feb 2026.



Concluding Remarks



Conclusions

DCS Provides Signals of Opportunity for Hemispheric Scintillation Monitoring Where Citizen Science Can Contribute

- GOES DCP rebroadcasts are suitable for wide-area scintillation monitoring
- Downlink L-band station within citizen scientist reach
- Technical challenges: short transmissions, low duty cycle, meaningful assembly into map
- Programmatic challenges: *downlink spectrum defense*, cost-cutting on GOES follow-on (GeoXO)
- BC ISR pursuing multiple parallel paths: formal NASA proposal, senior capstone engineering project, HamSCI



“MIDAS” Senior Project Team,
BC Engineering



Acknowledgments

- NASA Space Weather Research and Technology Applications (SPARTA) Center, Dr. Keith Groves (PI), Boston College
- Boston College ISR, Dr. Charles Carrano and Dr. Rezy Pradipta
- NOAA/NESDIS, GOES DCS Program Office, Mr. William Dronen
- Microcom Environmental, Mr. Brett Betsill and Mr. Daniel Gillies



Backup Slides



Phase Screen Model

“Propagator” = Modern Huygens Principle

Phase Screen

$$\phi(x) = -\lambda r_e \Delta N_{tot}(x)$$

Propagator (Field Amplitude)

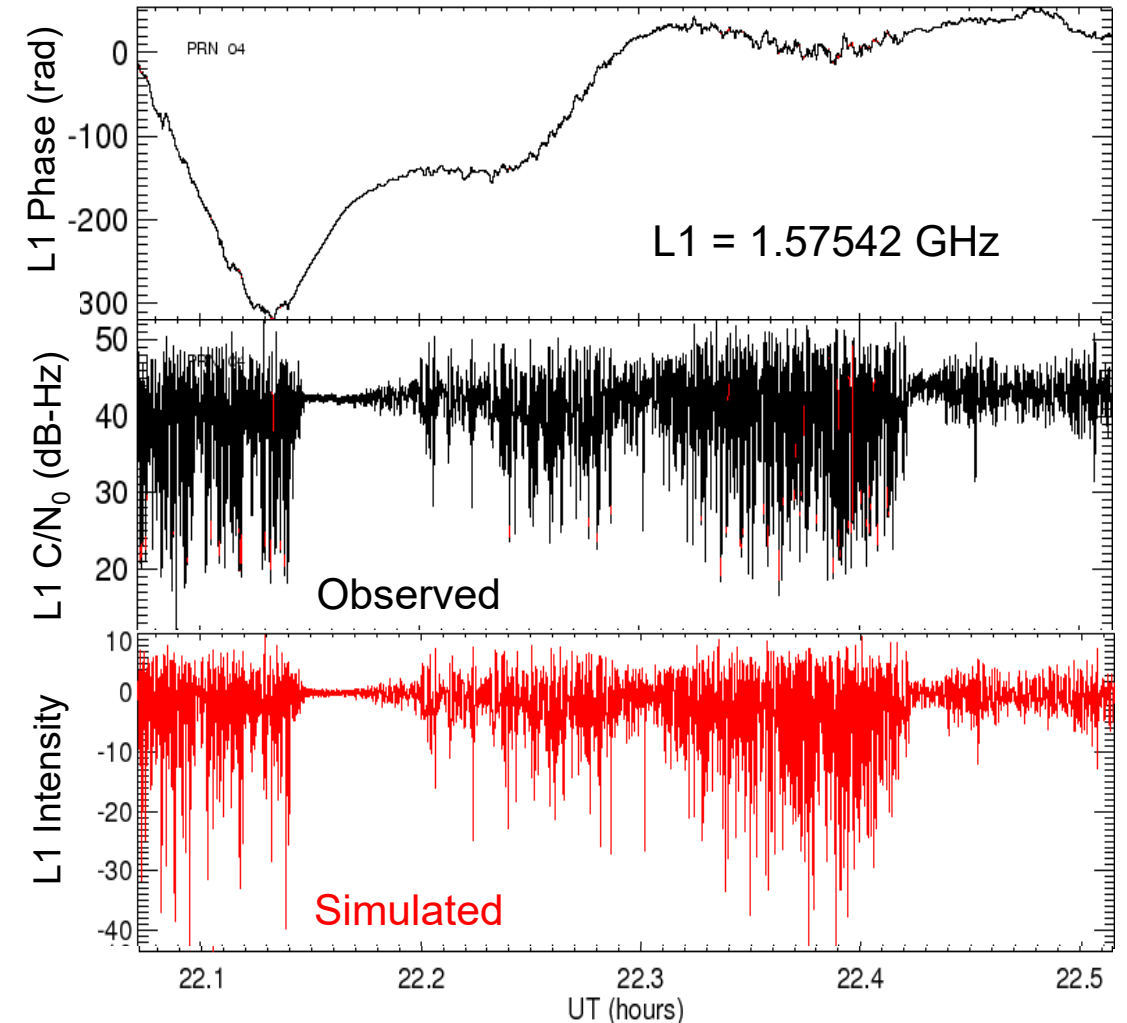
$$A(x, z) = \frac{e^{-i\pi/4}}{\sqrt{\lambda z}} \int \frac{e^{i\phi(\xi)}}{A(x, 0)} \exp\left[i\pi \frac{(x - \xi)^2}{\lambda z}\right] d\xi$$

Intensity (Power)

$$I(x, z) = |A(x, z)|^2$$

If we sample TEC fast enough to resolve Fresnel-scale ($\sqrt{\lambda z}$) structures, **scintillation can be simulated with high fidelity**

Simulation Courtesy: C. Carrano, Boston College
Institute for Scientific Research

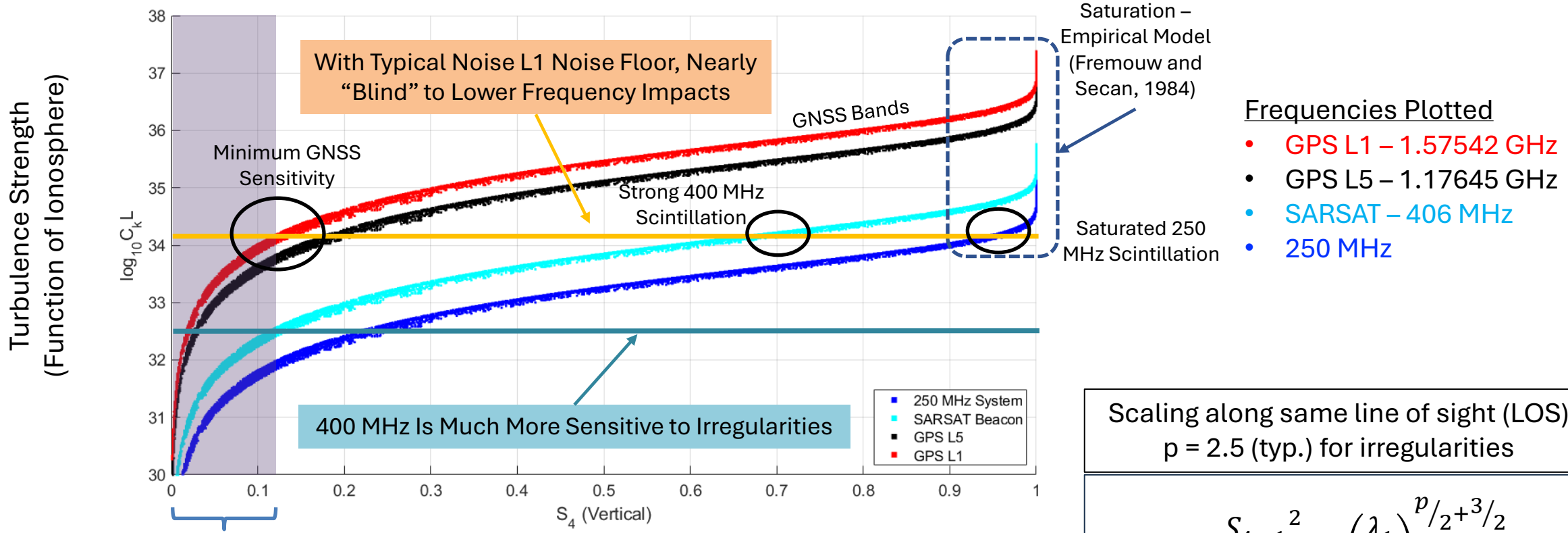


Ascension Island (7.98°S, 14.4°W, 15°S dip latitude)
NovAtel GSV4004 receiver



Frequency-Dependent S₄ Sensitivity (Equatorial)

By the Time S₄ Registers at GPS L1, Lower Bands Are Already Strongly Impacted



- Frequencies Plotted**
- GPS L1 – 1.57542 GHz
 - GPS L5 – 1.17645 GHz
 - SARSAT – 406 MHz
 - 250 MHz

Typical S₄ “Noise Floor” – Receiver Is Insensitive below This Level

Vertical Amplitude Scintillation (Impacts to a Narrowband Channel)

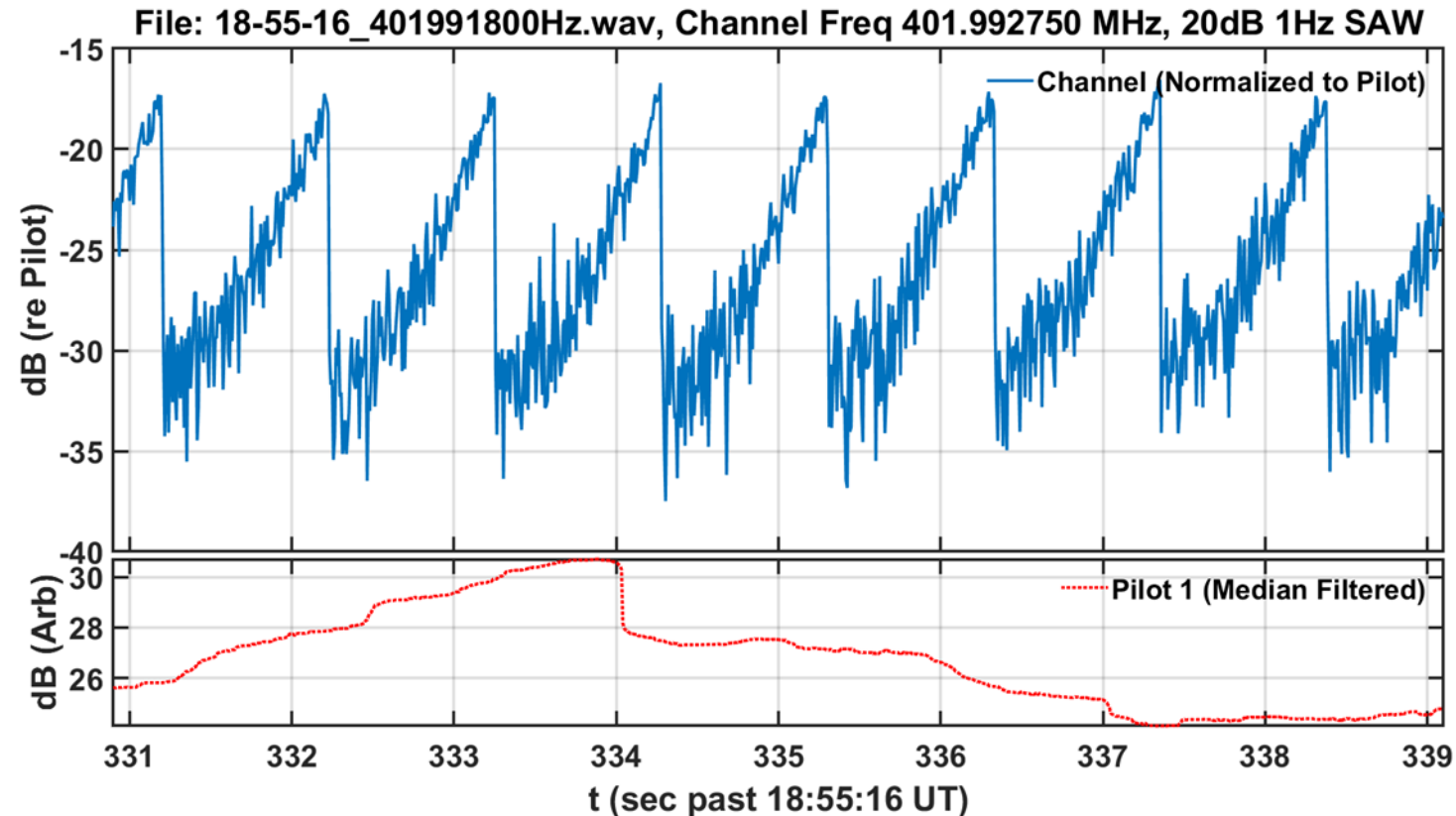
Scaling along same line of sight (LOS)
p = 2.5 (typ.) for irregularities

$$\frac{S_{4w1}^2}{S_{4w0}^2} = \left(\frac{\lambda_1}{\lambda_0}\right)^{p/2+3/2}$$



Transponder Response Verification

Team Tested Artificial Signal Modulation with Transmissions from Microcom
(Maryland, US) in June 2024



Achieved test goals:

- Verified that transponder frequency response appears adequate
- Demonstrated an ALC Compensation Method

Tested Cases with and Without DCP Modulation, Plus Other Waveform Patterns & Frequencies

Reproduced 20 dB, 1 Hz Sawtooth Wave Broadcast from Microcom to GOES-16 (Top); ALC Effects on Pilot Channel Amplitude (Bottom)

