GNSS Radio Occultation Measurements of Sporadic-E Layers

AIR FORCE INSTITUTE OF TECHNOLOGY

SuperDARN Workshop
June 2025

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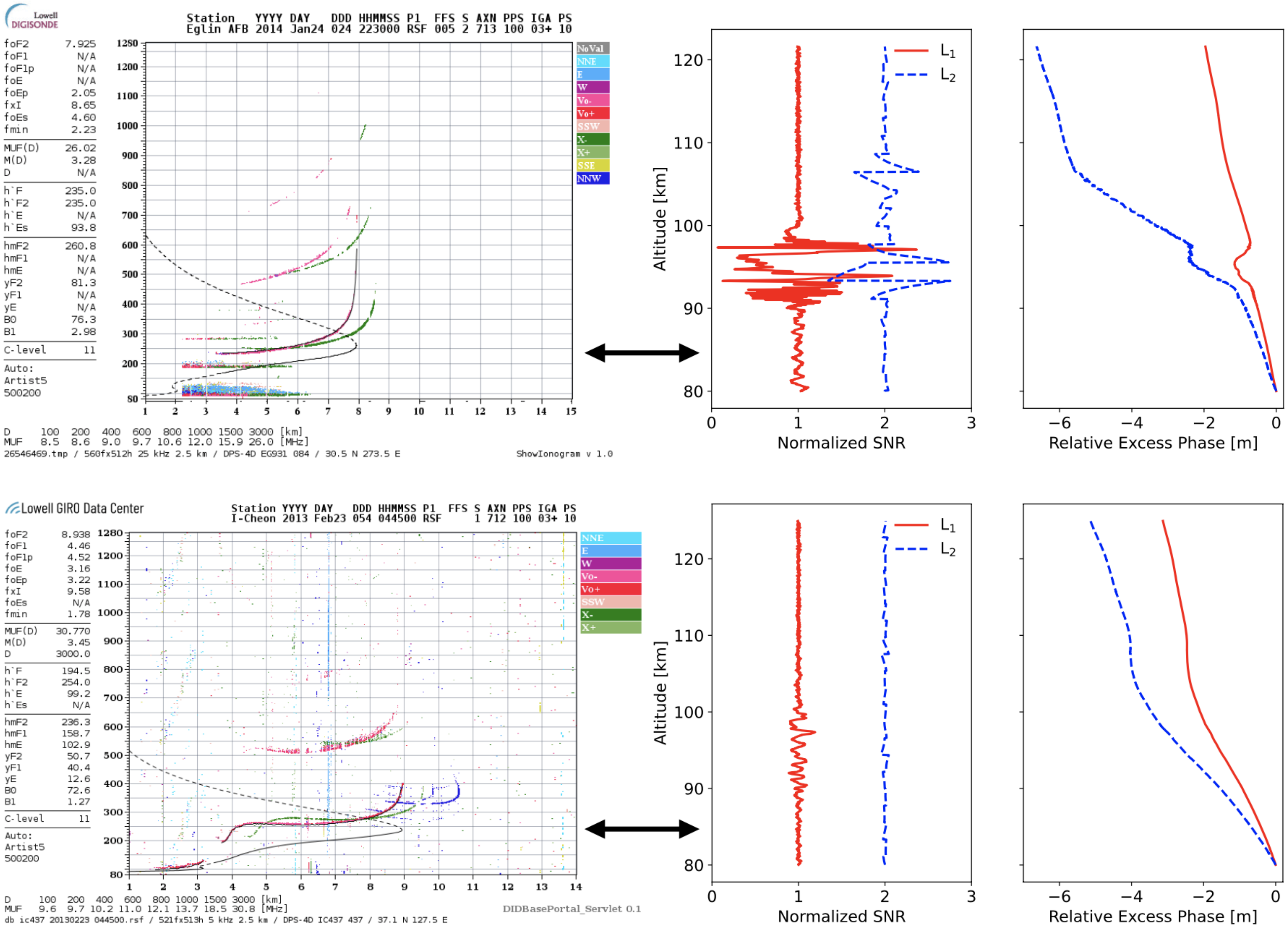
The Problem

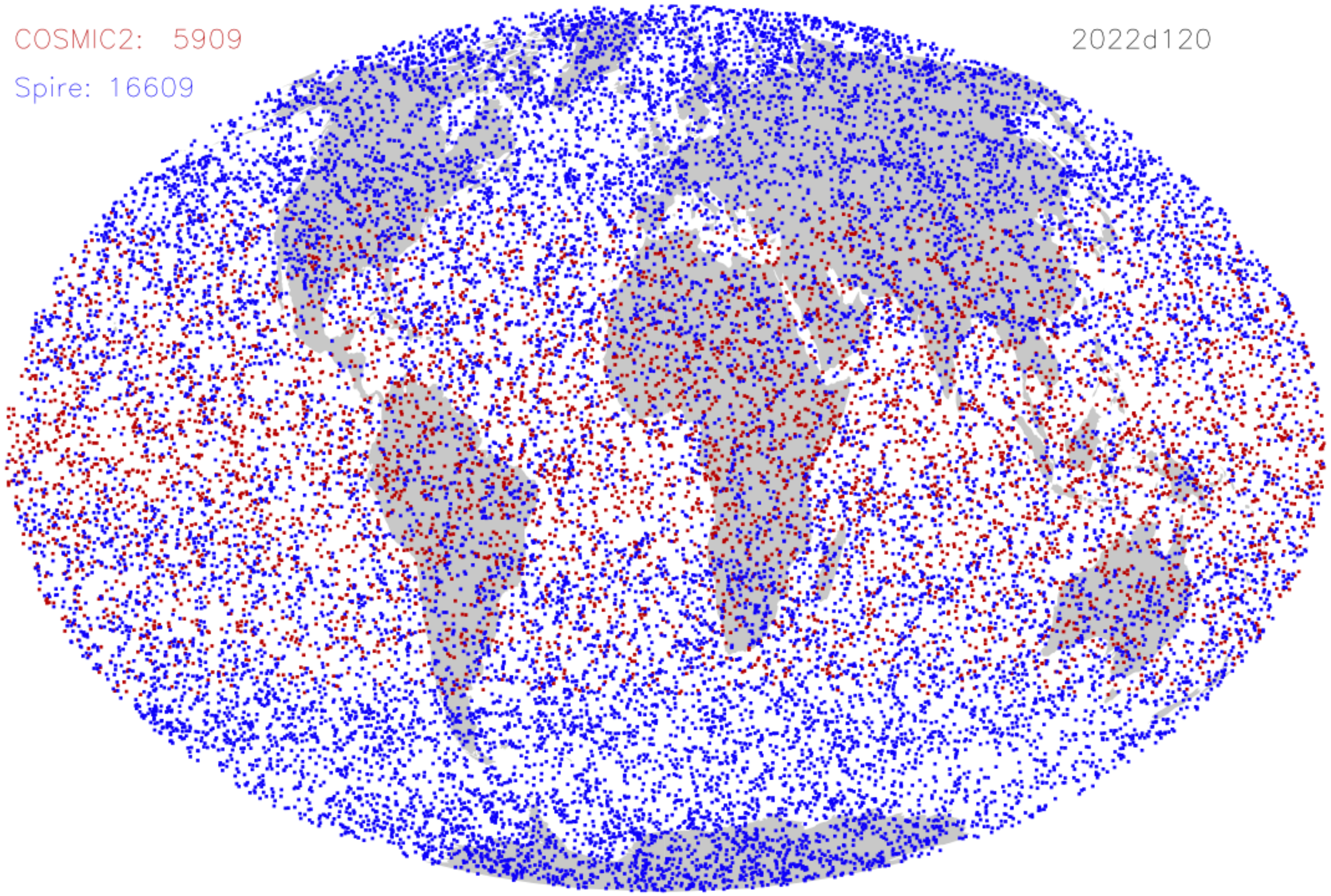
- Sporadic-E measurements are not available in locations without sounders or radars
- GNSS Radio Occultation (RO) has shown promise, but the mapping between RO perturbations & sporadic-E characteristics is non-trivial
- Solution: improve RO techniques by comparing & combining with ionosondes



[Emmons et al., 2023]

Overview

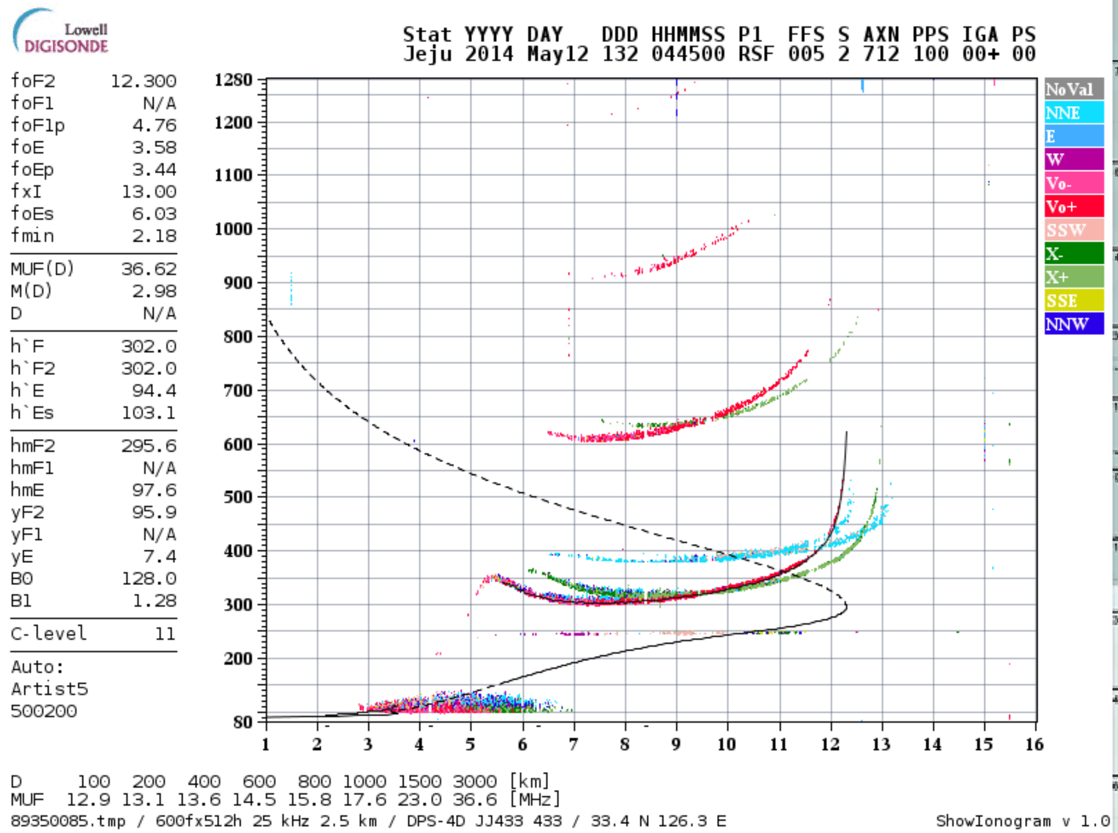
- GNSS Radio Occultation (RO) Measurements of Sporadic-E
  - Techniques
  - Limitations
- Global Empirical Model of Sporadic-E Occurrence Rates (GEMSOR)



[Courtesy of Dong Wu]

Measuring Sporadic-E: Ionosondes

- Ionosondes provide a direct measurement of sporadic-E layers
- Global coverage with large gaps (oceans, arctic, etc.)

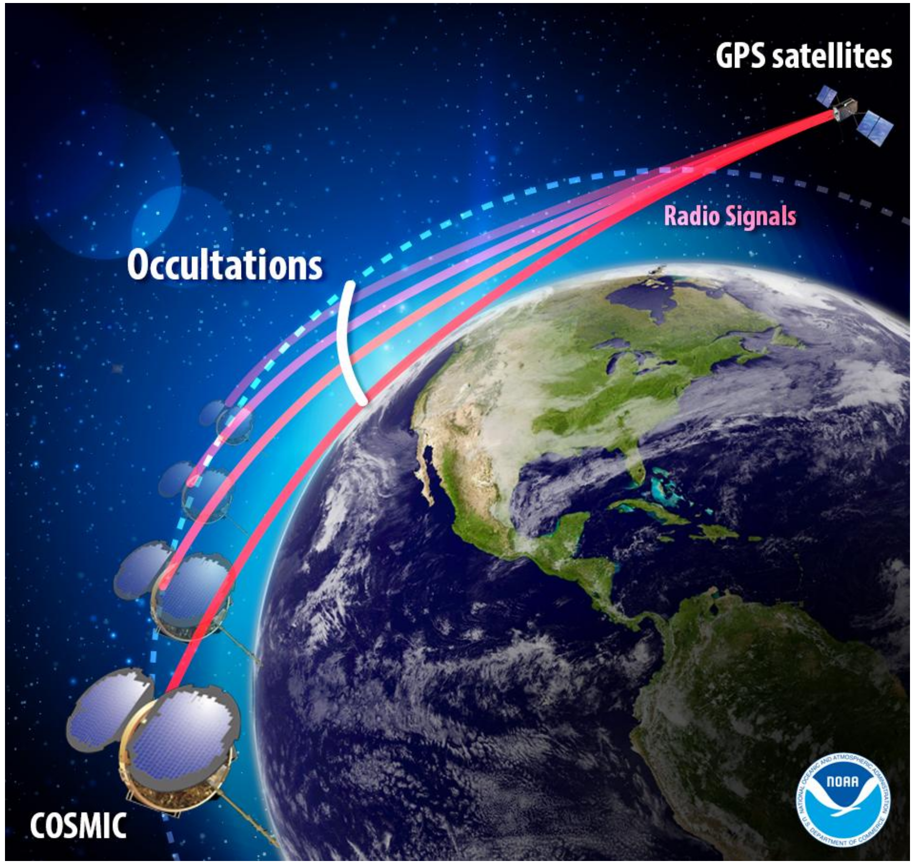


[https://ulcar.uml.edu/DIDBase/]

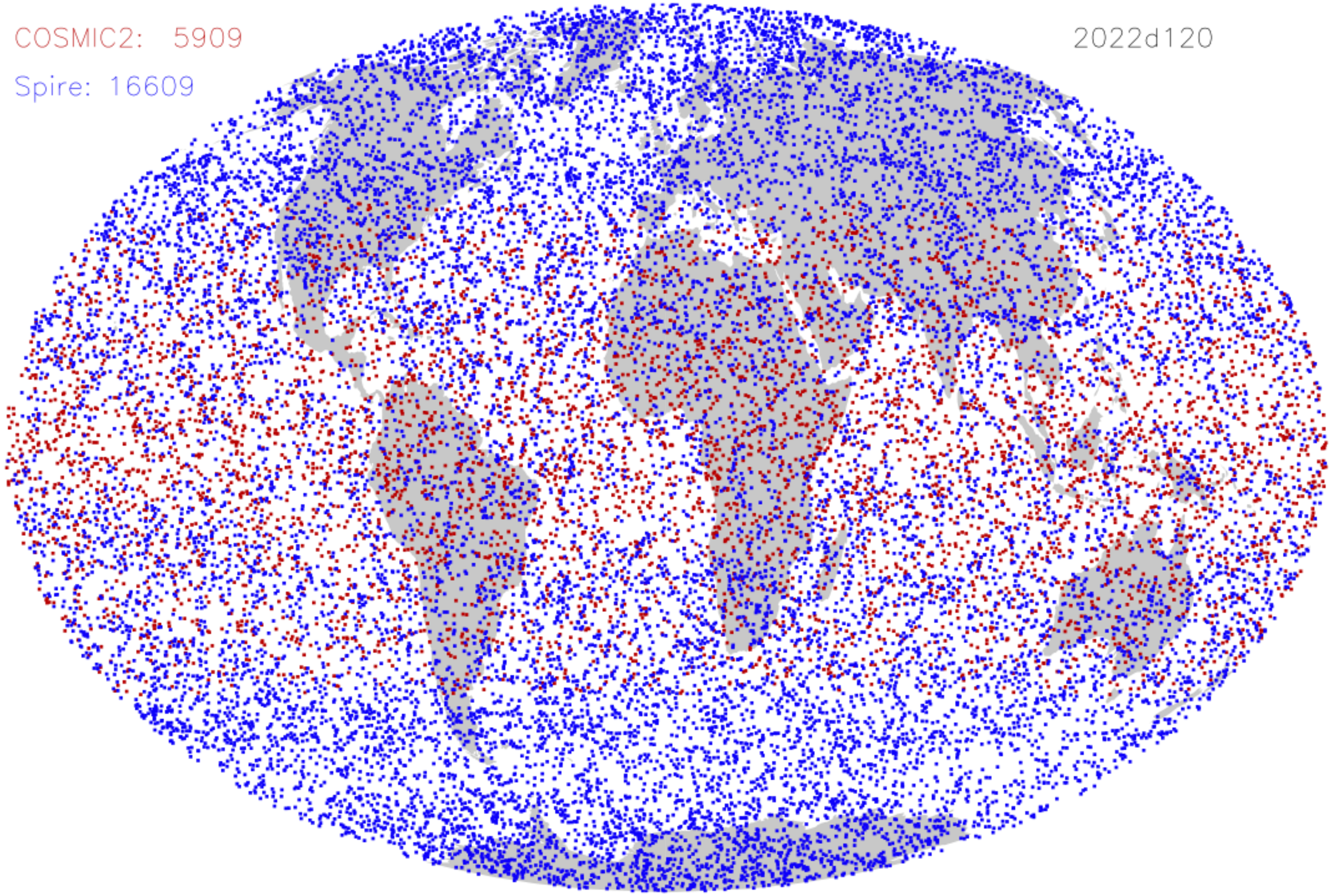
[http://giro.uml.edu/]

GNSS Radio Occultation

- GNSS-RO techniques use two satellites (GNSS and LEO) to probe the path between
- COSMIC-II and Spire (commercial CubeSats) currently provide over 20K daily occultations



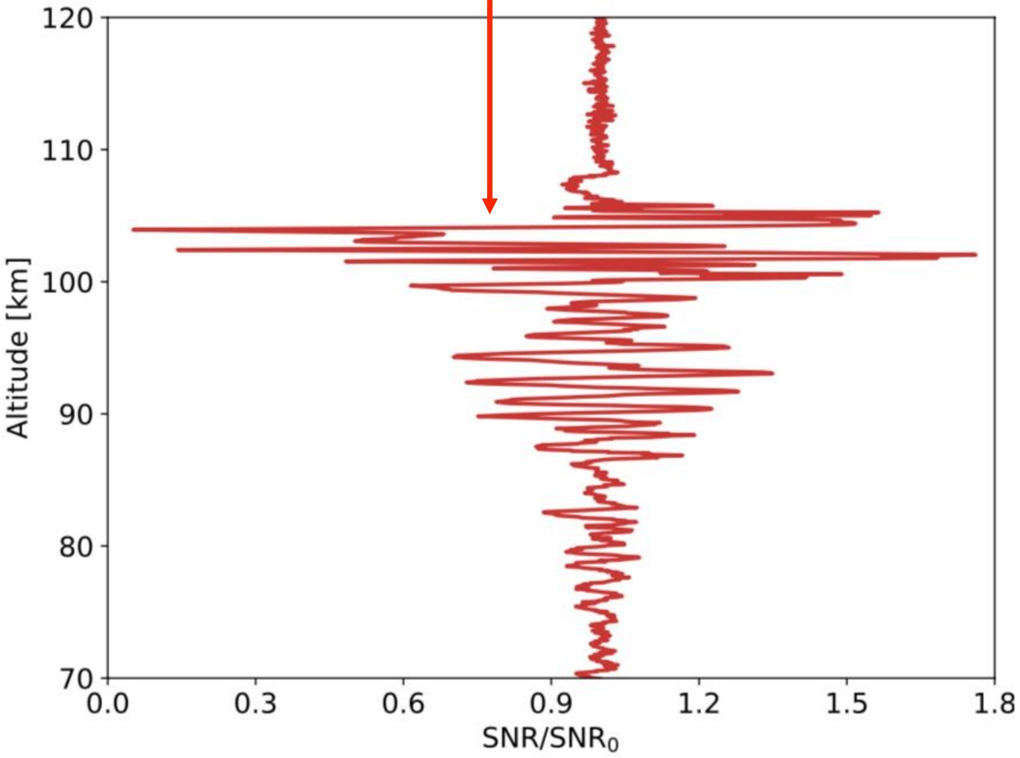
[https://www.nesdis.noaa.gov/current-satellite-missions/currently-flying/cosmic-2]



[Courtesy of Dong Wu]

GNSS-RO Measurements of E_s

- GNSS-RO has ideal geometry for locating/monitoring thin ionospheric disturbances like E_s
- Two overarching approaches for characterizing sporadic-E
  - Phase perturbations (TEC)
  - Amplitude fluctuations (S_4)



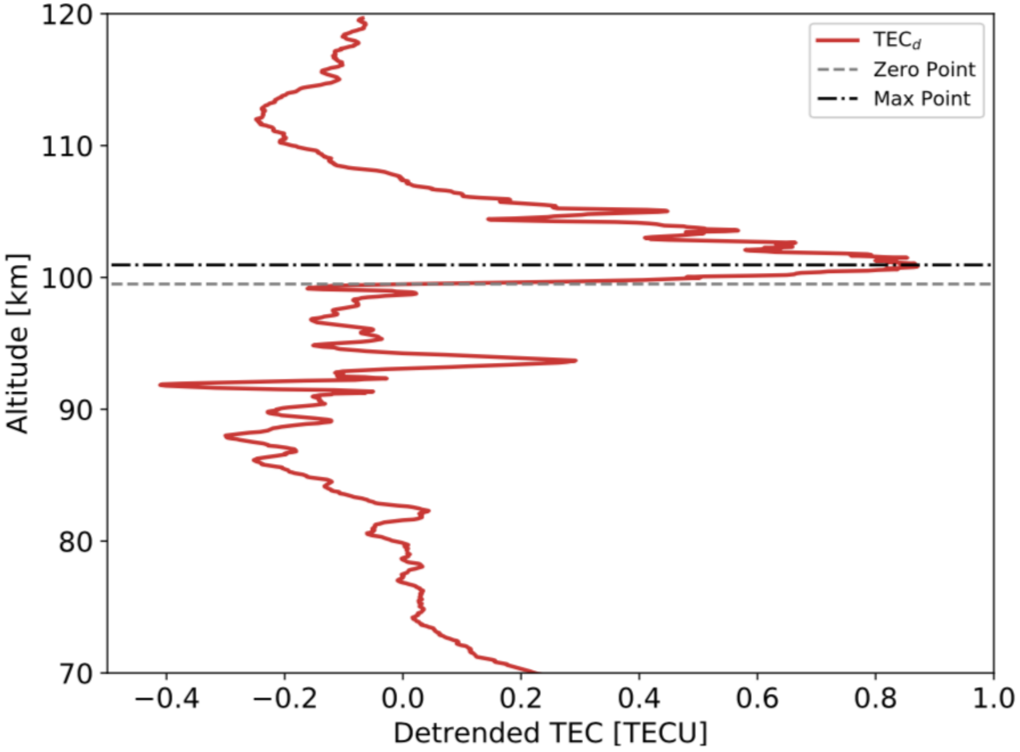


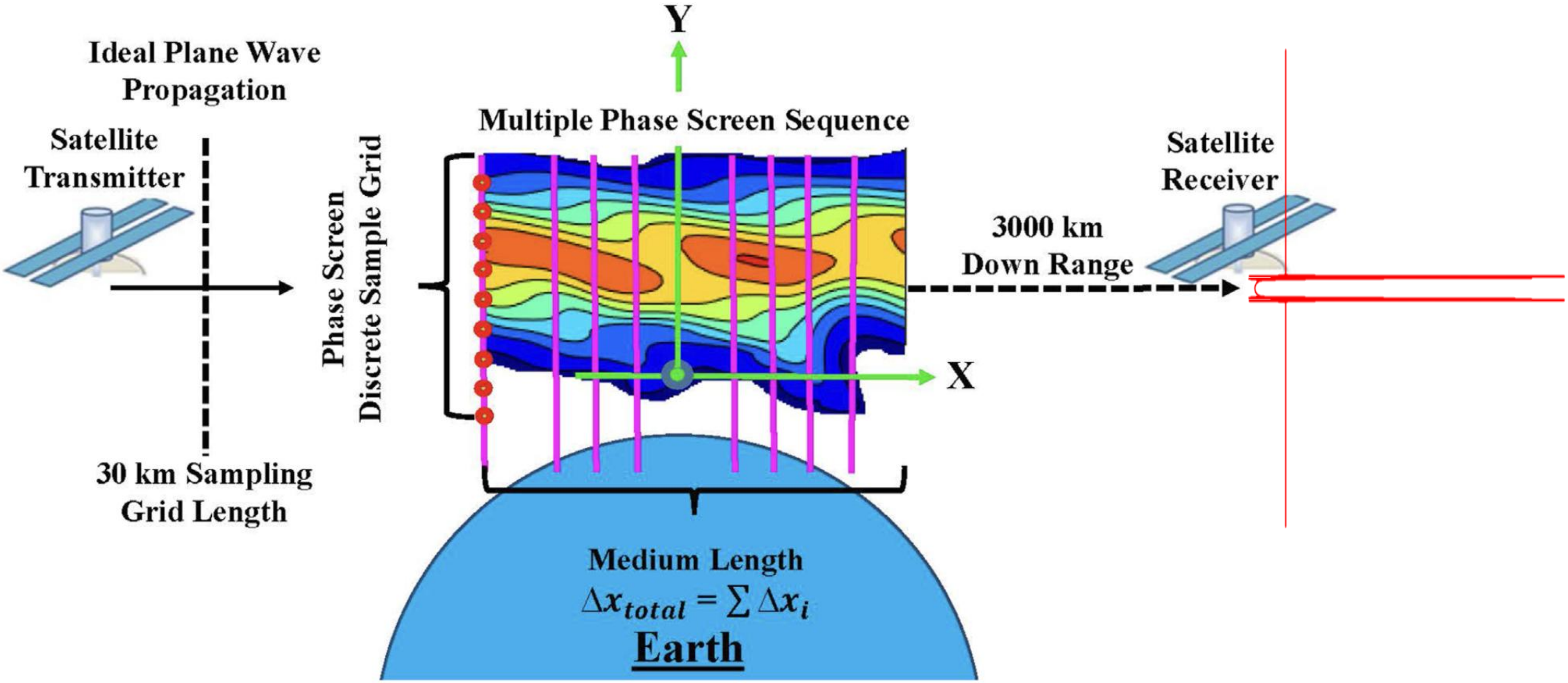
Fig. 3. An example of the detrended TEC, TEC_d, used to calculate the altitudes corresponding to the TEC perturbation, ΔTEC, caused by a sporadic-E layer. The dash-dot line corresponds to the altitude of peak TEC_d while the dashed line is associated with the first zero point below the peak (base).

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

$$\Delta n_e \approx \frac{TEC_r - \langle TEC \rangle}{2\sqrt{2r\Delta r}}$$

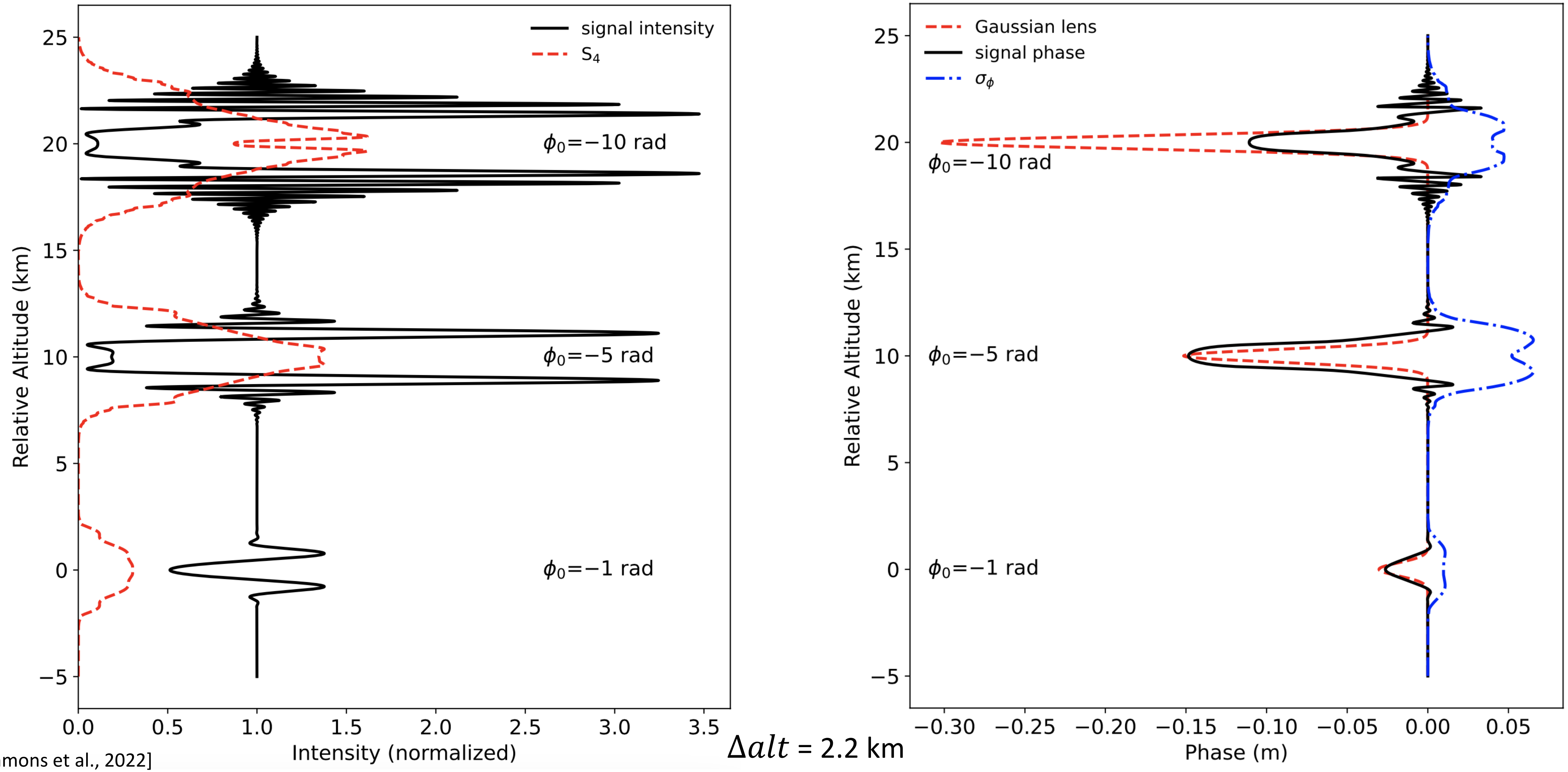
[Gooch et al., 2020]

Modeling Sporadic-E Impacts to RO Signals



[Knisely and Emmons, 2023]

GPS L1 Amplitude & Phase for Various E_s Lens Strengths - Gaussian Lens

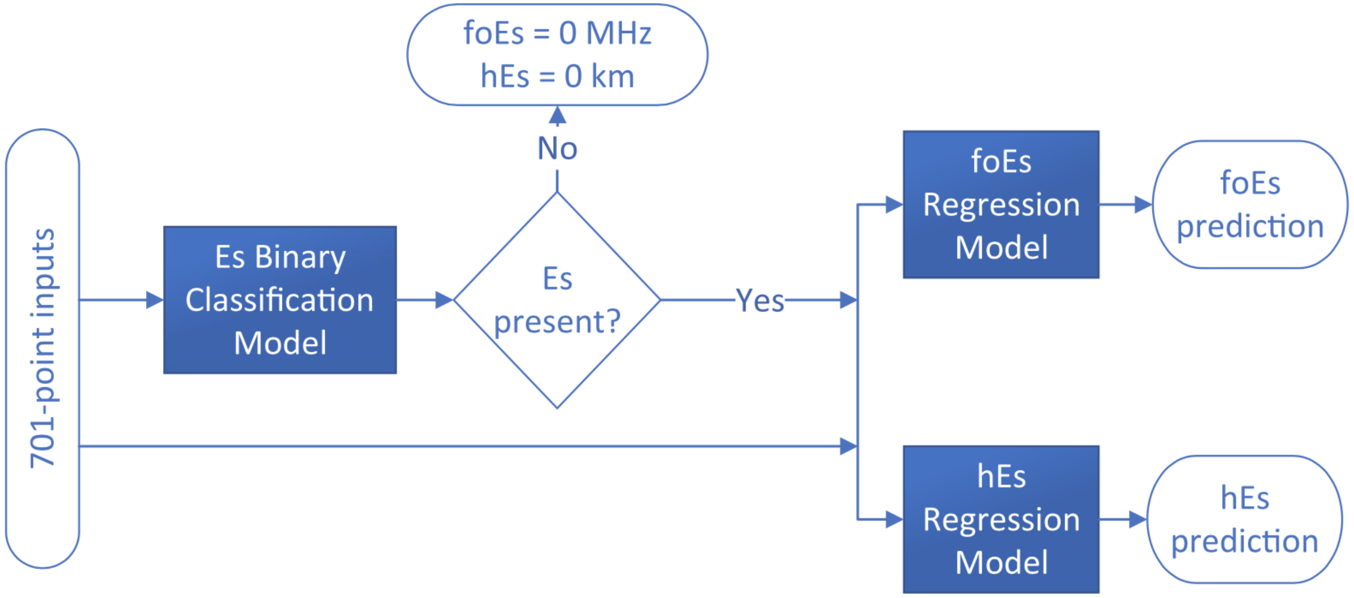


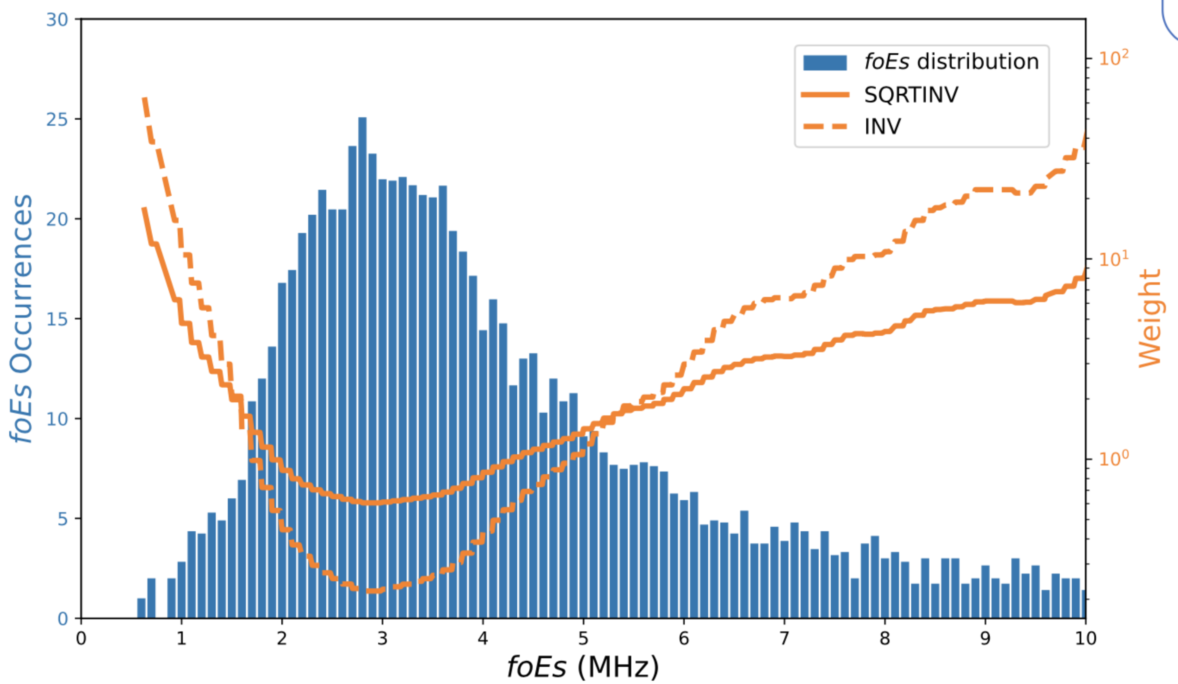
Δalt = 2.2 km

[Emmons et al., 2022]

Convolution Neural Network (CNN) Approach

- Ellis et al. (2024) used a CNN to characterize E_s from RO observations
- Ionosondes used as ground-truth: 150 km separation & 30 min → 36,521 samples



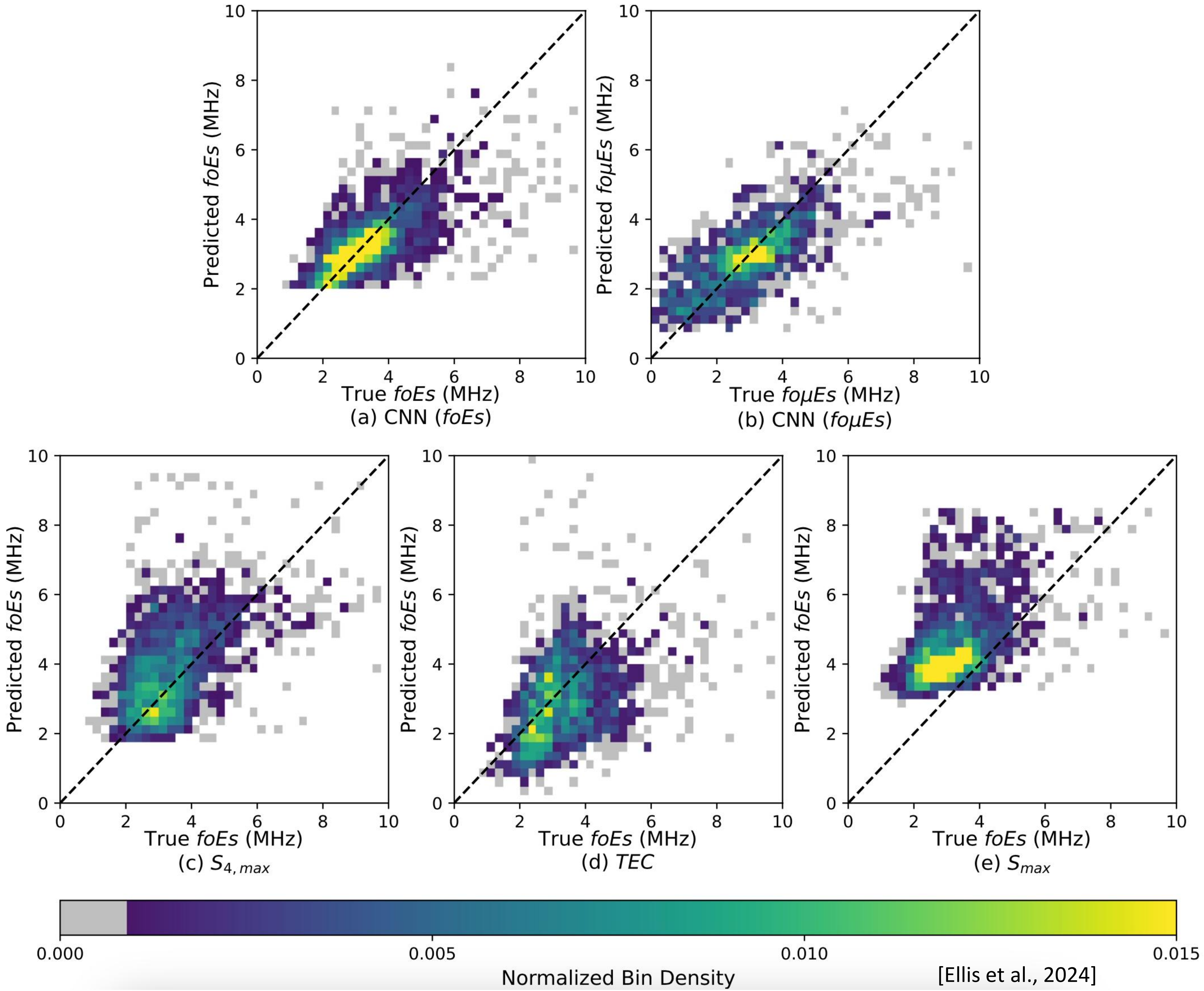


- Results show significant improvement over standard RO techniques
- Binary Classification Model implemented first:
  - If E_s present then predict foEs & hEs

CNN Intensity Estimates

- CNN shows significant improvement in foEs estimates compared to traditional techniques

- MAE ≈ 0.6 MHz



[Ellis et al., 2024]

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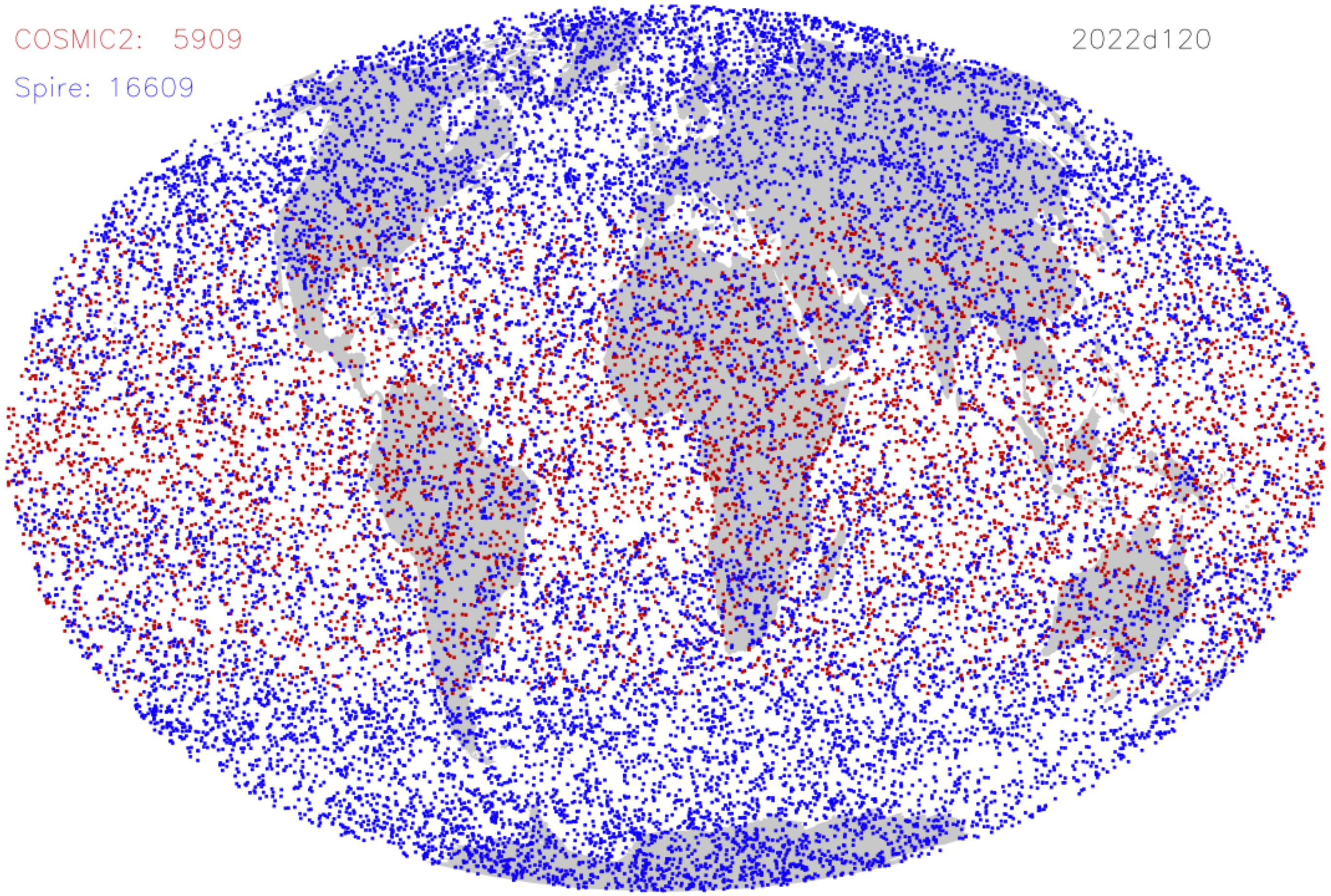
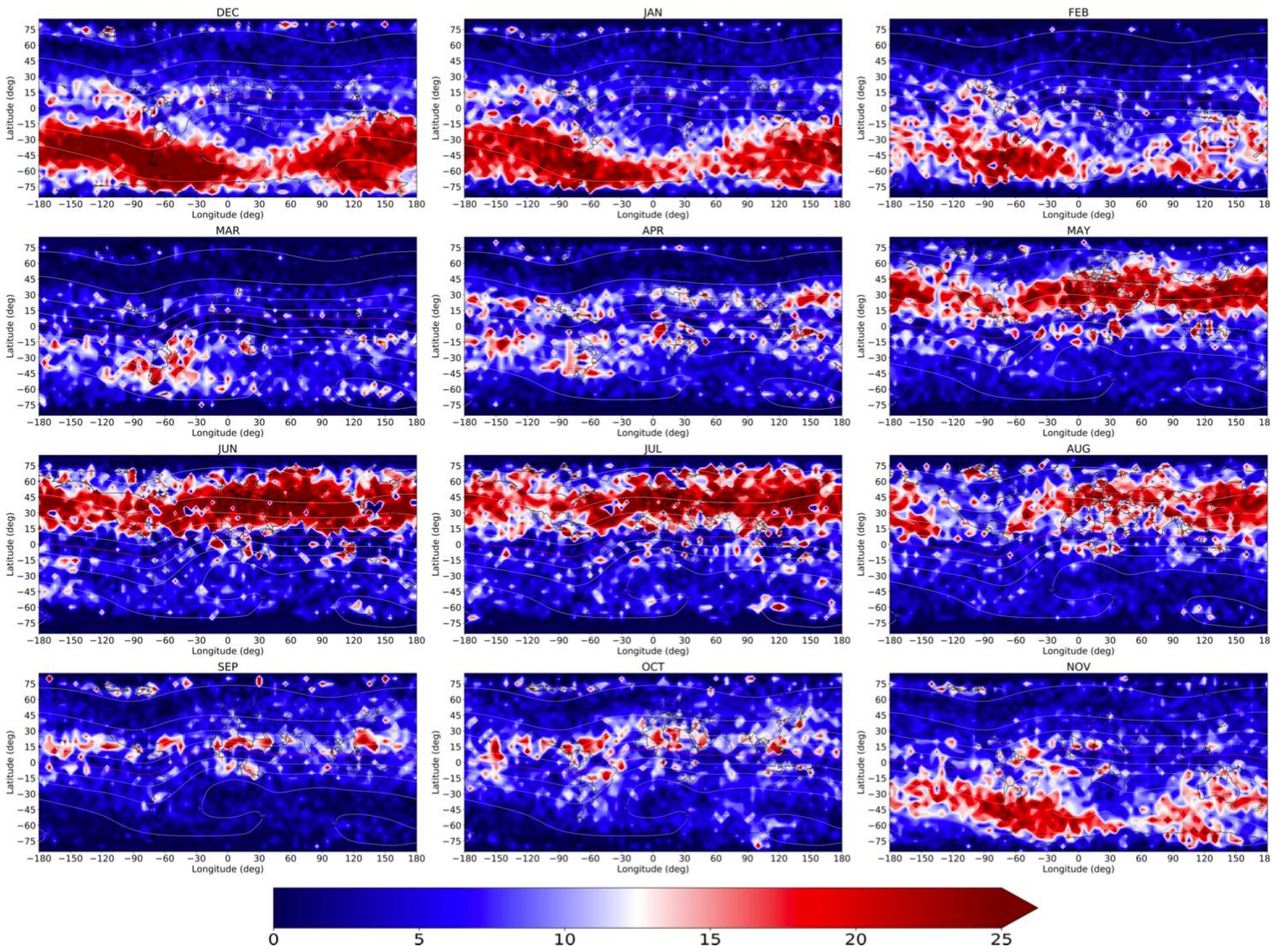


[Courtesy of Dong Wu]

fbEs $\geq$ 3 MHz Occurrence Rates (%)

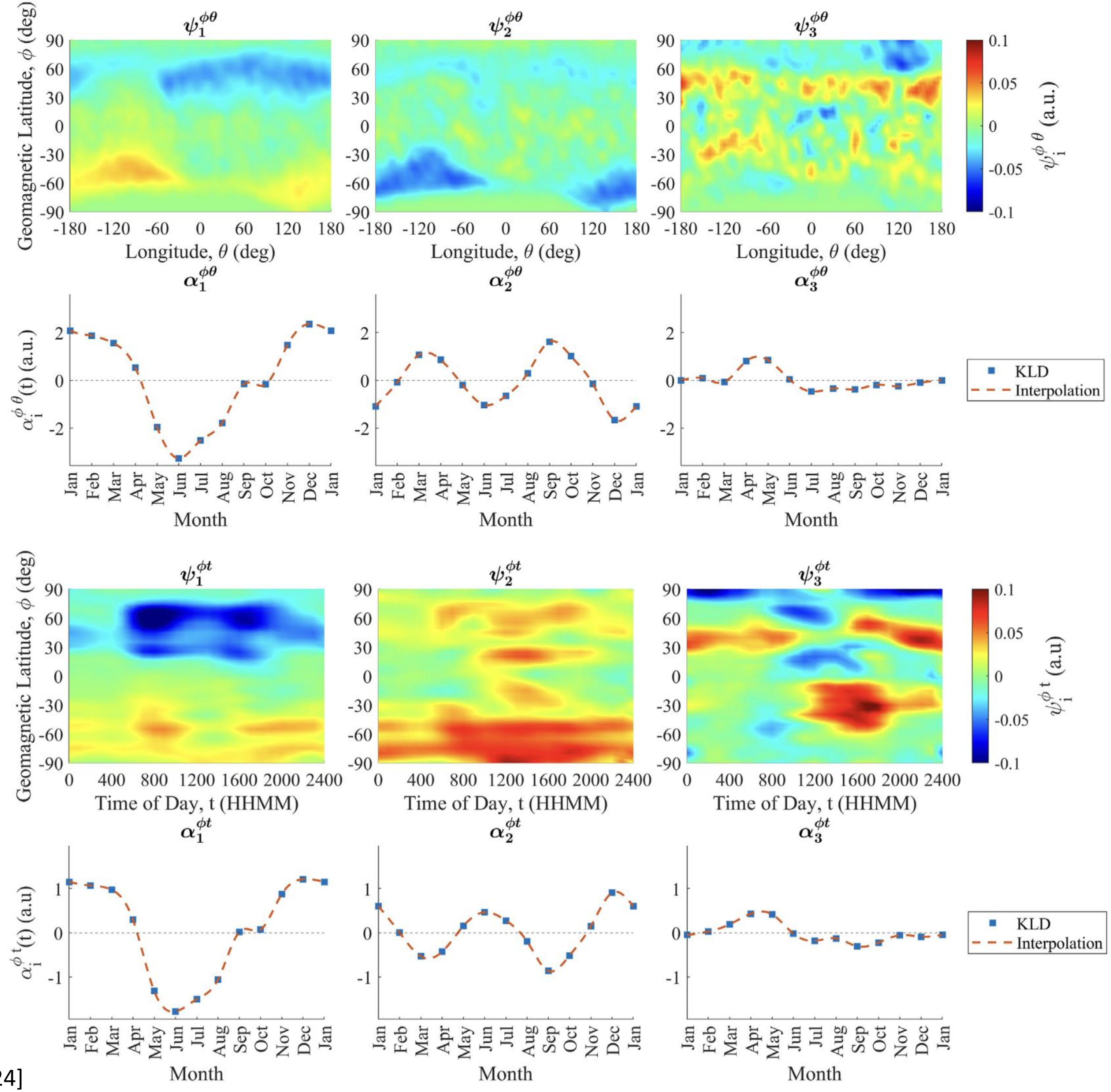


- 3.2 million ionograms with 3 million COSMIC-I occultations from 2006-2019
- Limited to $5° \times 5°$ latitude-longitude or $5° \times$ 12 minute bins averaged over a month

[Hodos et al., 2022]

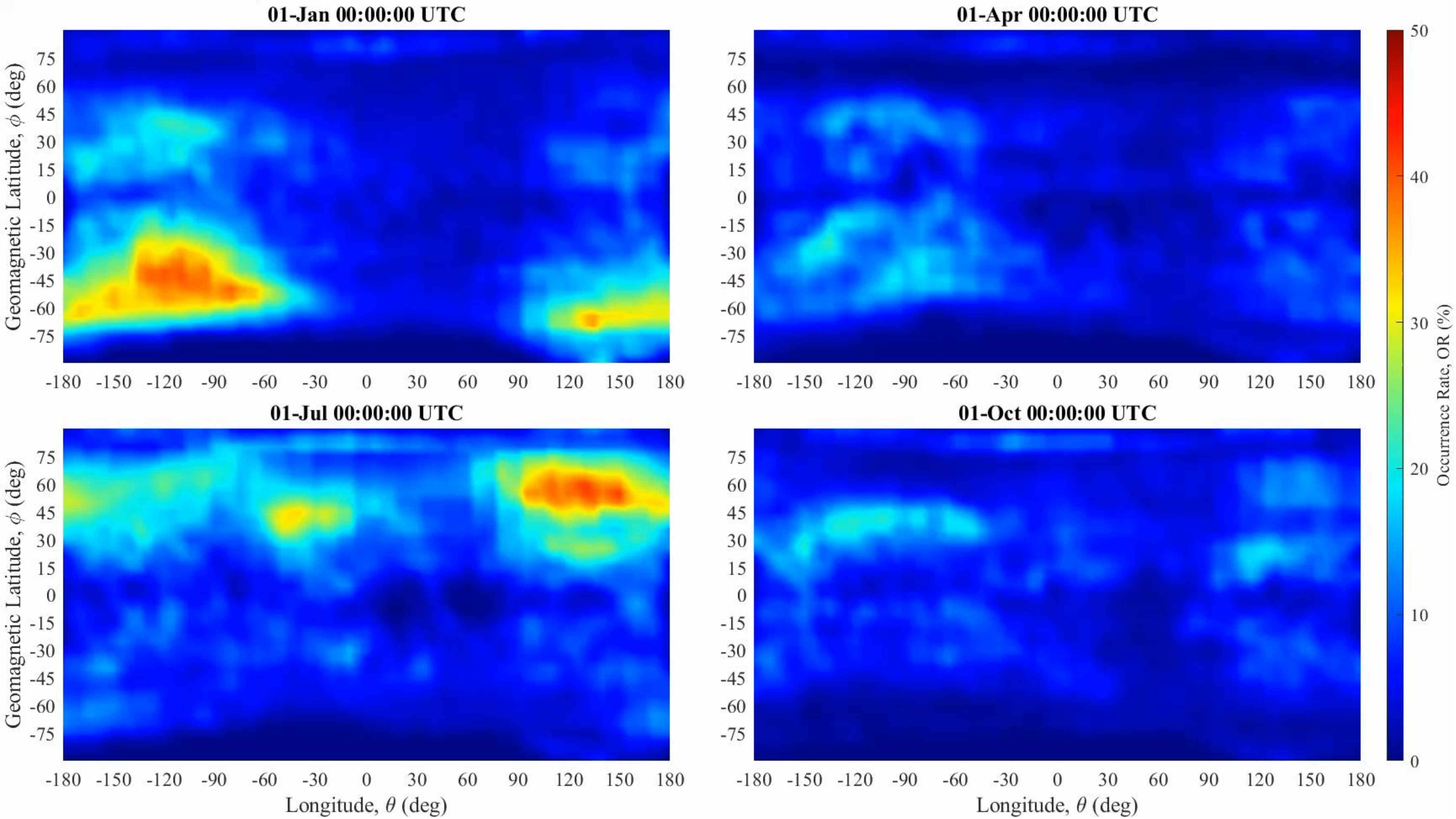
KLE Modes & Combining Datasets

- To increase temporal resolution, a Karhunen-Loève Expansion (KLE) was implemented
- Then, spatial & temporal data were combined & scaled such that:
  - Relative temporal trends remain unchanged
  - Time profile scaled & shifted such that daily average matches spatial data
  - $0\% \leq OR \leq 100\%$



[Parsch et al., 2024]

Global Empirical Model of E_s Occurrence (GEMSOR)

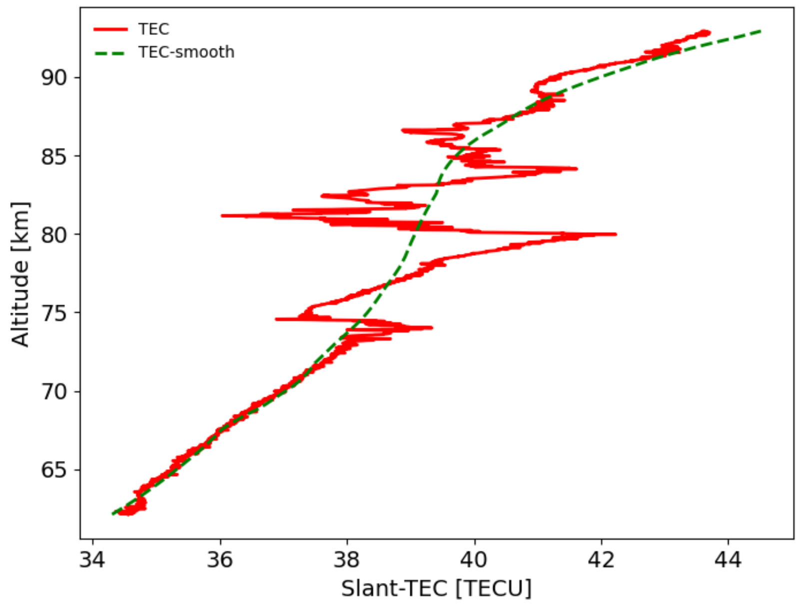


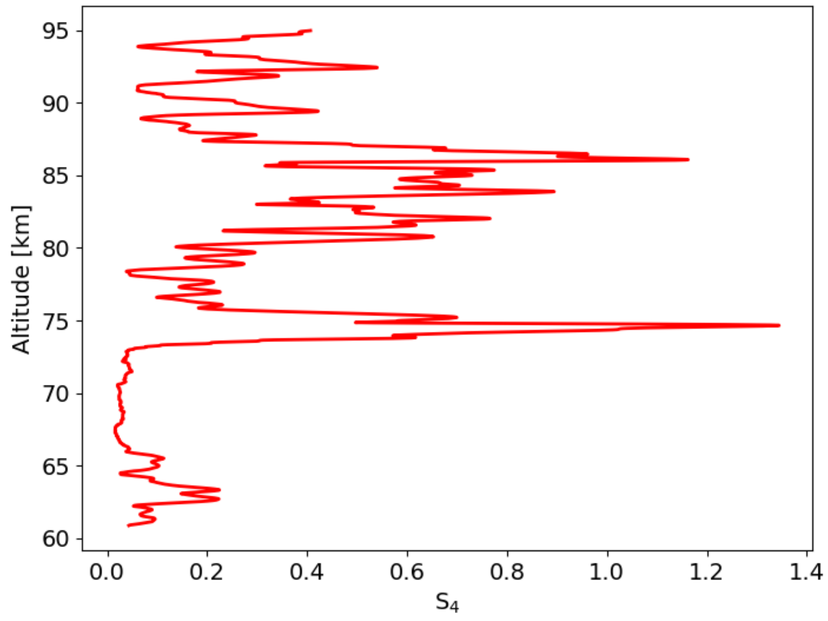
Summary

- Monitoring disturbances globally is challenging, but GNSS radio occultation (RO) provides truly global coverage to cover gaps in ionosonde networks

- CNN model shows significant improvement in detection and classification

- GEMSOR model provides climatological occurrence rates for fbEs ≥ 3 MHz; publicly available in Open Science Framework (GEMSOR-OSF) or via NASA/CCMC





Double Sporadic-E!

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5. Ellis, J. A., Emmons, D. J., & Cohen, M. B. (2024). Detection and classification of sporadic E using convolutional neural networks. Space Weather, 22(1), e2023SW003669.
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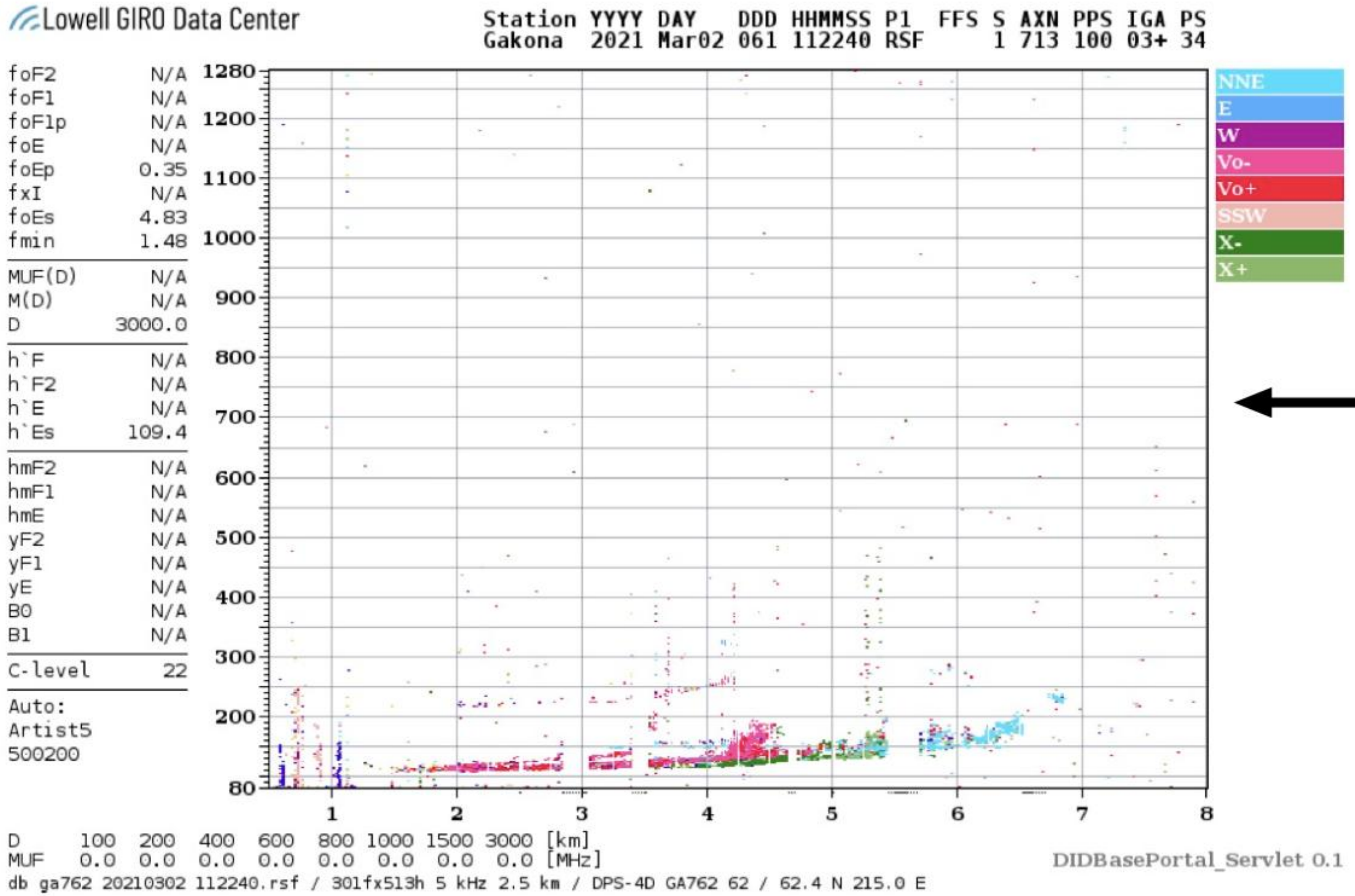
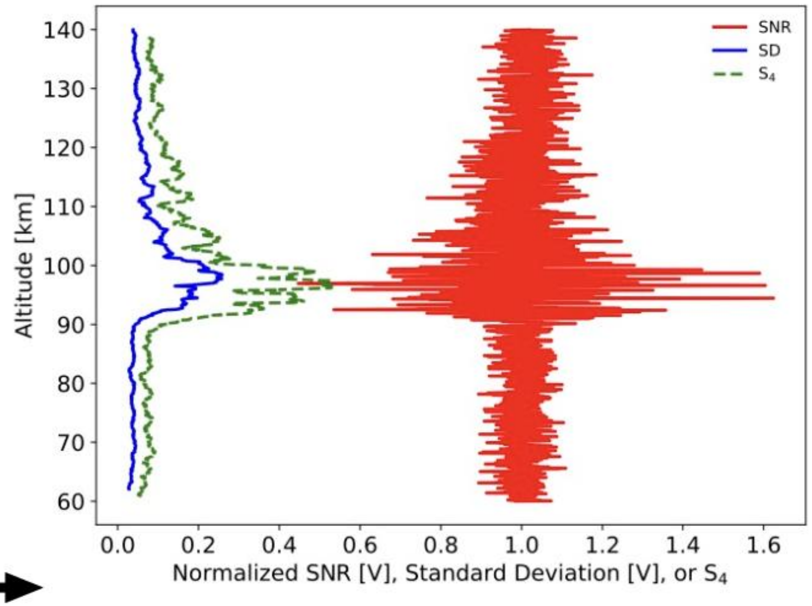
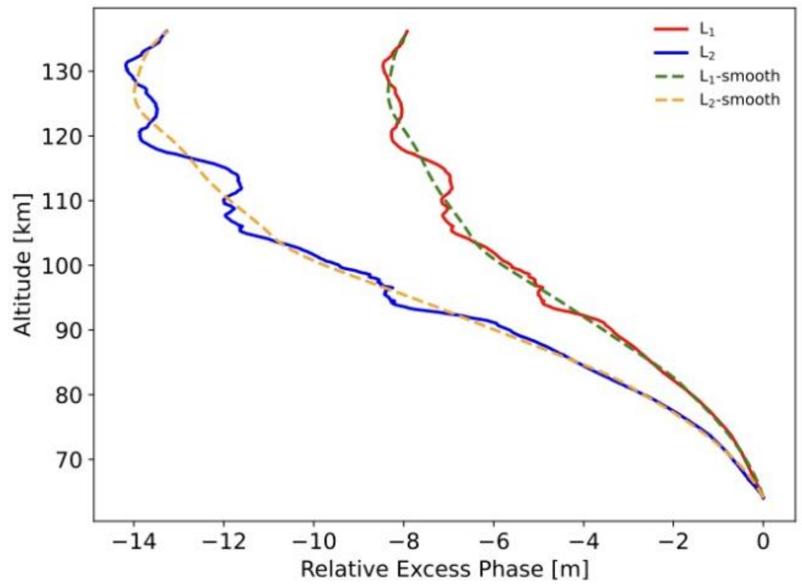
7. Parsch, E. V., Franz, A. L., Dao, E. V., Wu, D. L., Swarnalingam, N., Salinas, C. C., & Emmons, D. J. (2024). Global Empirical Model of Sporadic-E Occurrence Rates. Frontiers in Astronomy and Space Sciences (e-ISSN 2296-987X).

Backup Slides: Auroral-E

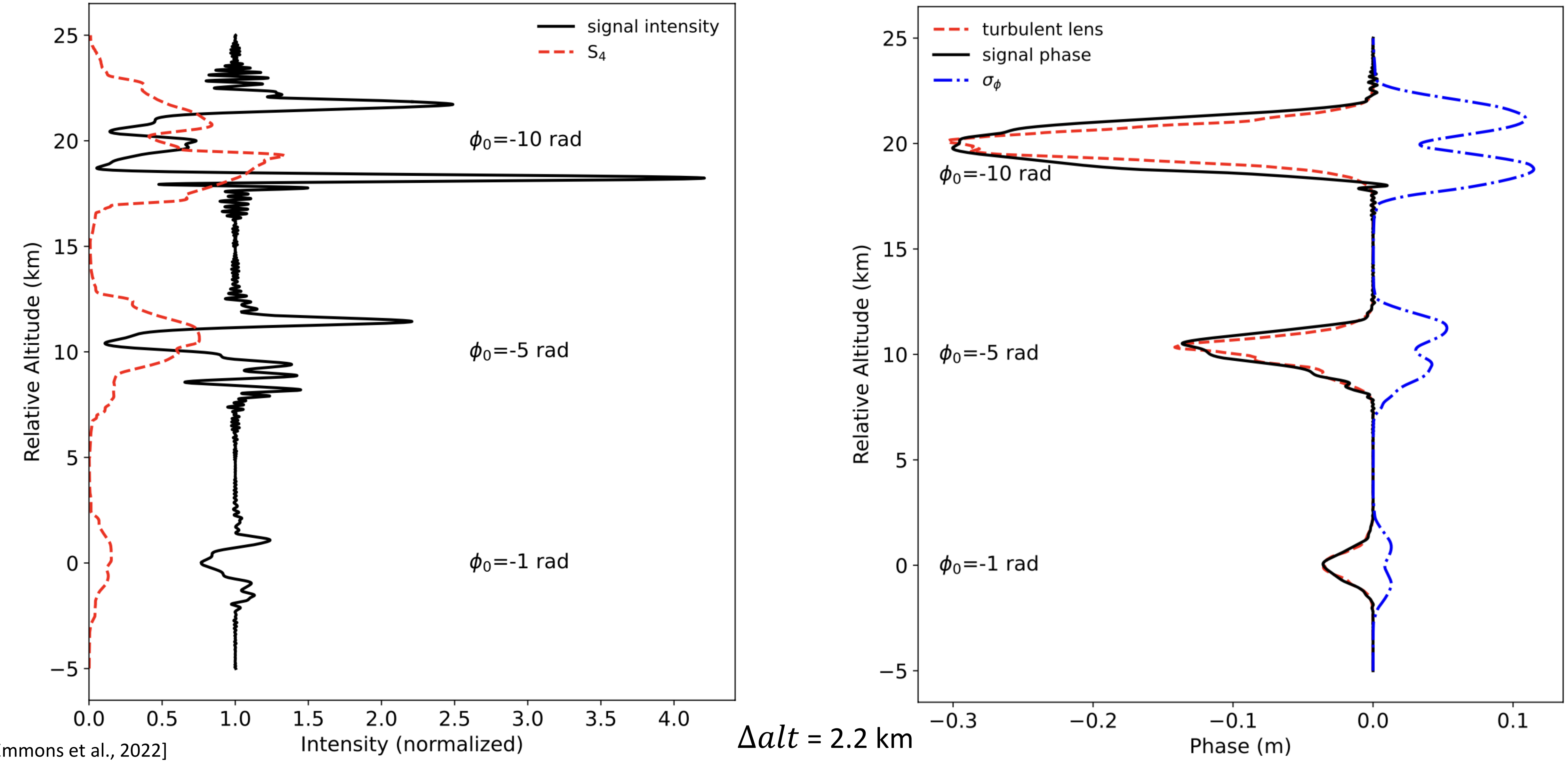






[Roberts, 2024]

GPS L1 Amplitude & Phase for Various E_s Lens Strengths - Gaussian Lens w/ Turbulence



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