Using GPS Radio Occultation to Monitor Sporadic-E

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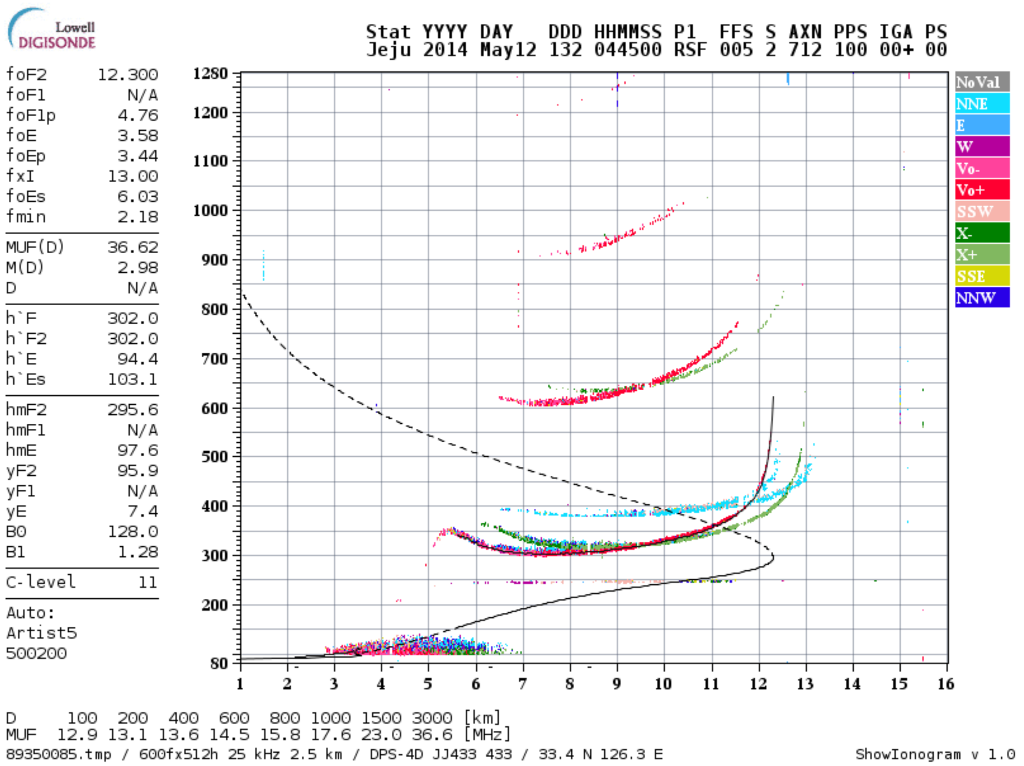
Overview

- Current global sporadic-E climatology
- Comparison of GPS radio occultation and ionosonde rates



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

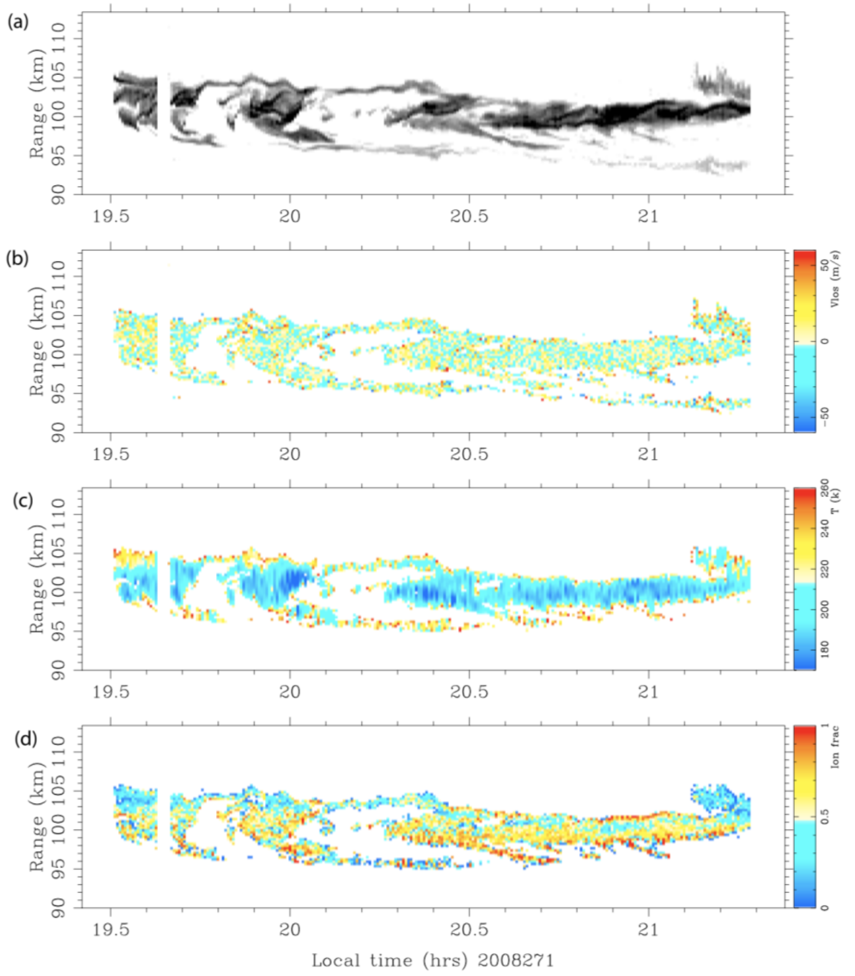
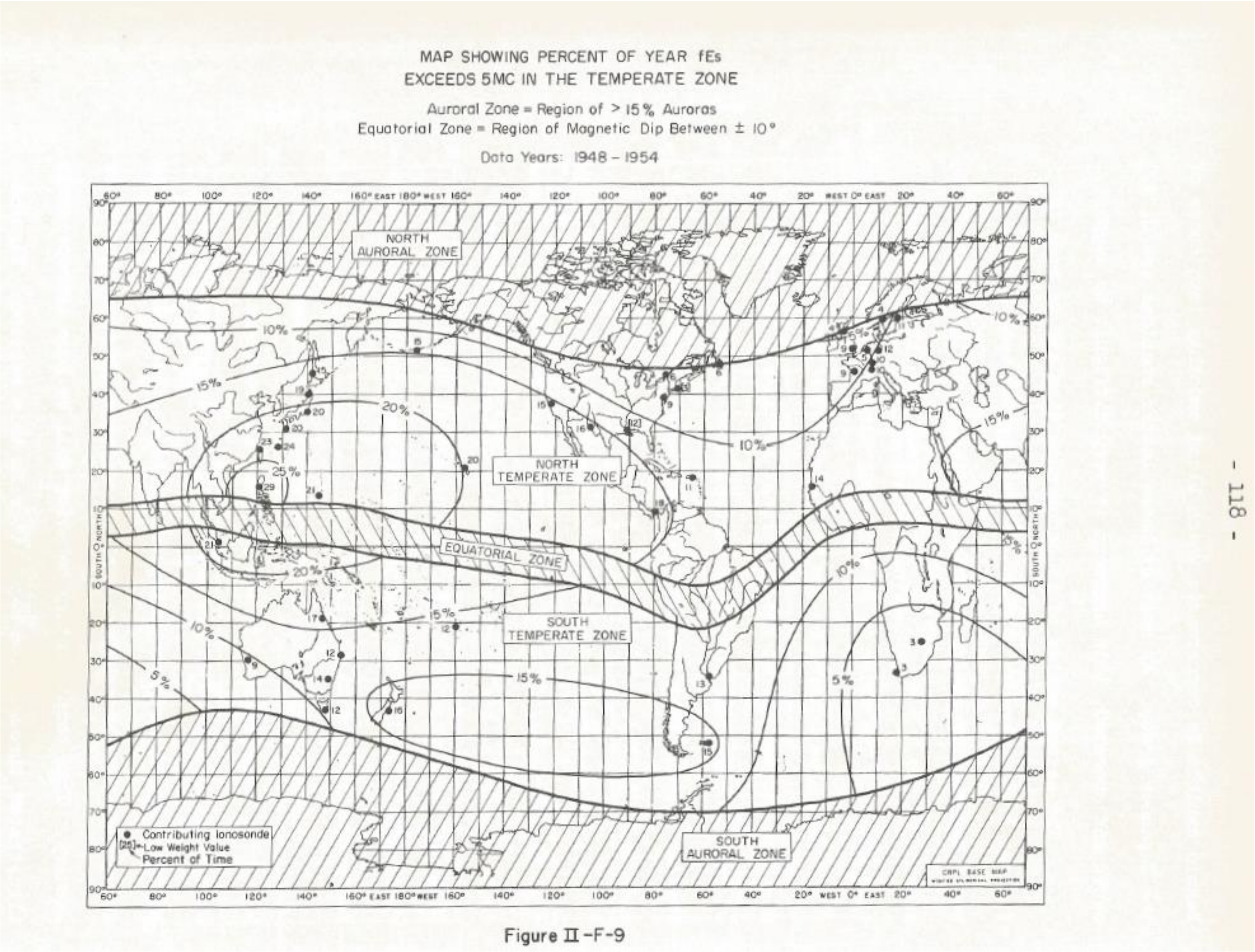


Figure 3. Sporadic *E* ionization layer observations made with the Arecibo incoherent scatter radar zenith-pointing line feed on September 27, 2008. (a) Relative density obtained from the magnitude of the first lag of the coded long pulse experiment. (b) Line-of-sight drifts. Red (blue) hues denote red (blue) shifts. (c) Temperature estimates. (d) Heavy metallic ion fraction estimates.

[Hysell et al., 2009]

Current E_s Climatology: Ionosondes

- Smith provided the first global view of sporadic-E in the 1950’s
- Climatology based primarily on ionosonde measurements
- Limited measurements over oceans, etc.
- These occurrence rates remain widely used today



[Smith, 1957]

Current E_s Climatology: Radio Occultation

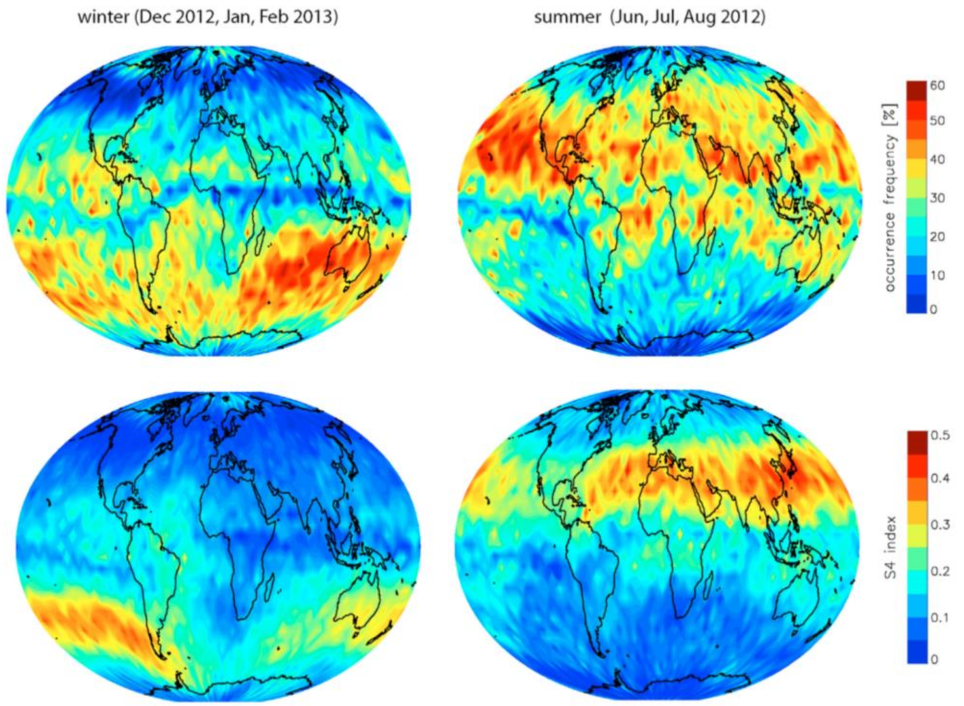


Fig. 3. Global distribution of sporadic E occurence (upper row) and sporadic E intensity (lower row) for northern winter (left column) and northern summer (right column) conditions. The plots are produced from 3-monthly means centered around July 2012 and January 2013. They have a latitude/longitude resolution of 5° × 5°.

[Arras and Wickert, 2018]

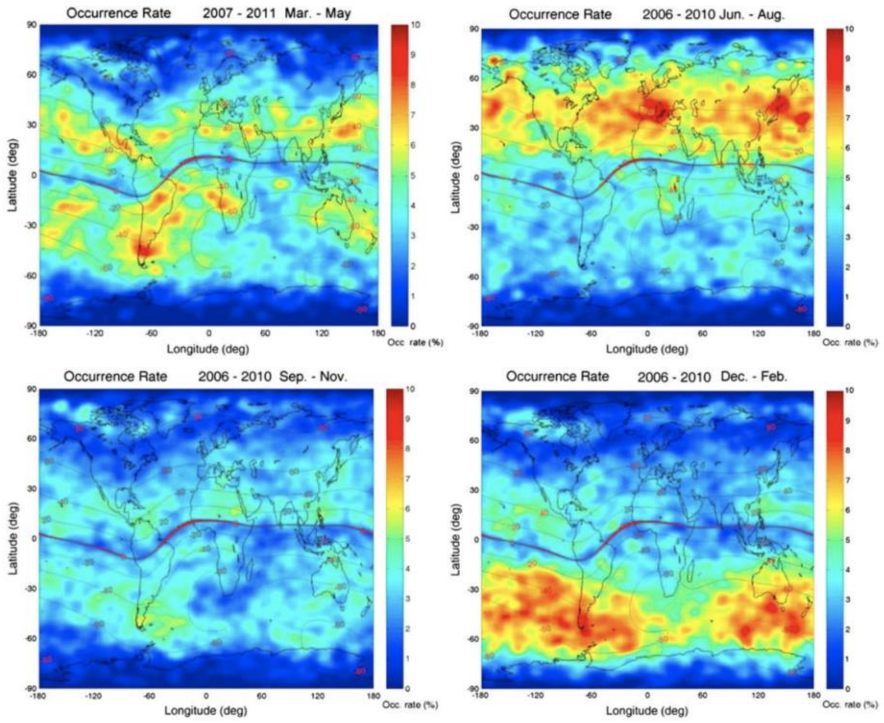


Figure 6. Occurrence rate of COSMIC-retrieved *Es* layer for different seasons. Thin curves signify geomagnetic latitude contours and the thick curve is the geomagnetic equator.

[Chu et al., 2014]

- GPS-RO provides global coverage of E_s
- However, analysis of RO signals is non-trivial and current E_s occurrence rate estimates vary by a factor of ~5
- Need a way to validate GPS-RO occurrence rates: comparison with ionosondes

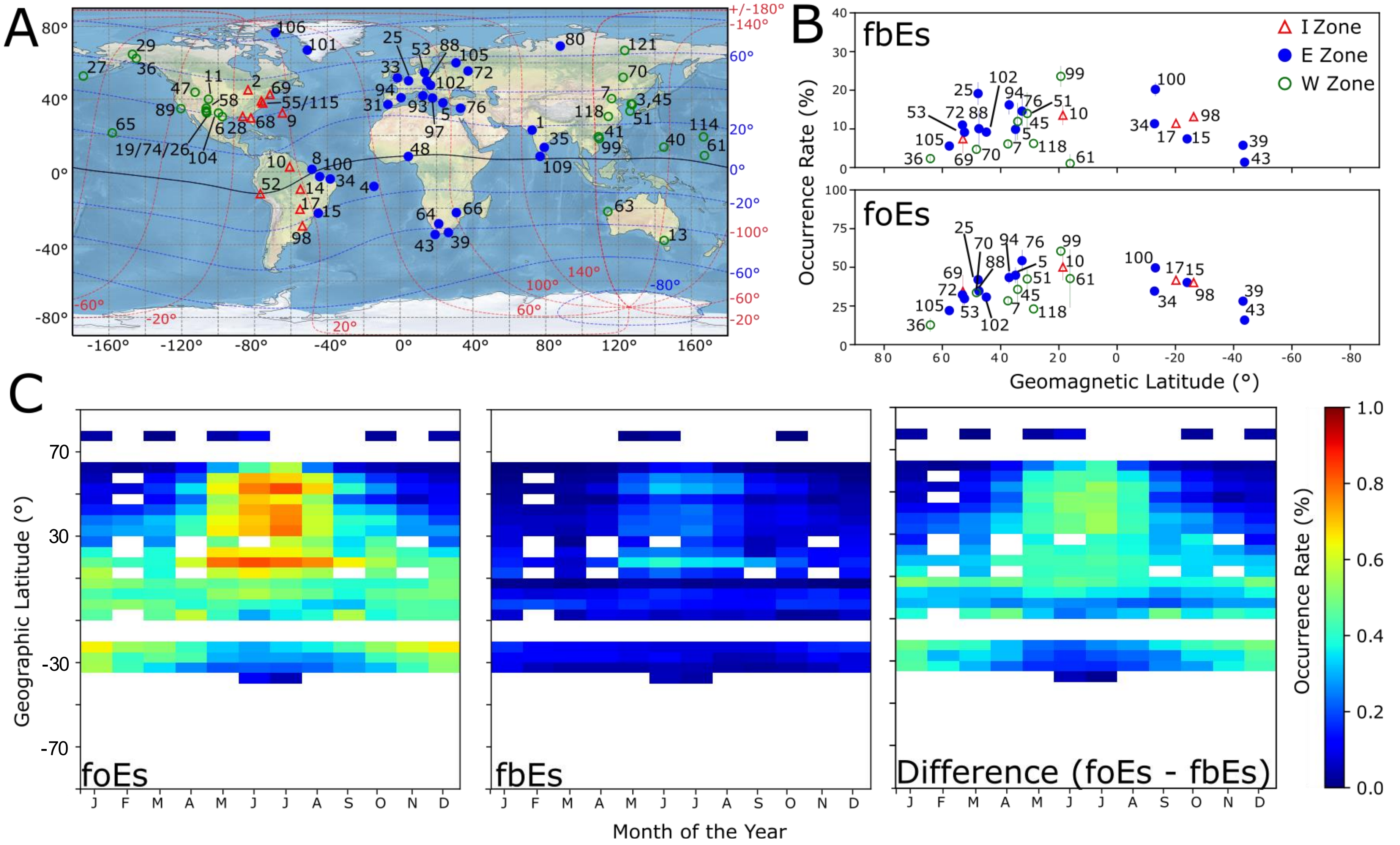
Updated Ionosonde Occurrence Rates

foEs or fbEs > 3 MHz

(A) Map of Digisonde sites with ARTIST5 data used in analysis

(B) Occurrence rates as a function of geomagnetic latitude: all seasons

(C) Monthly foEs and fbEs averages as a function of geographic latitude



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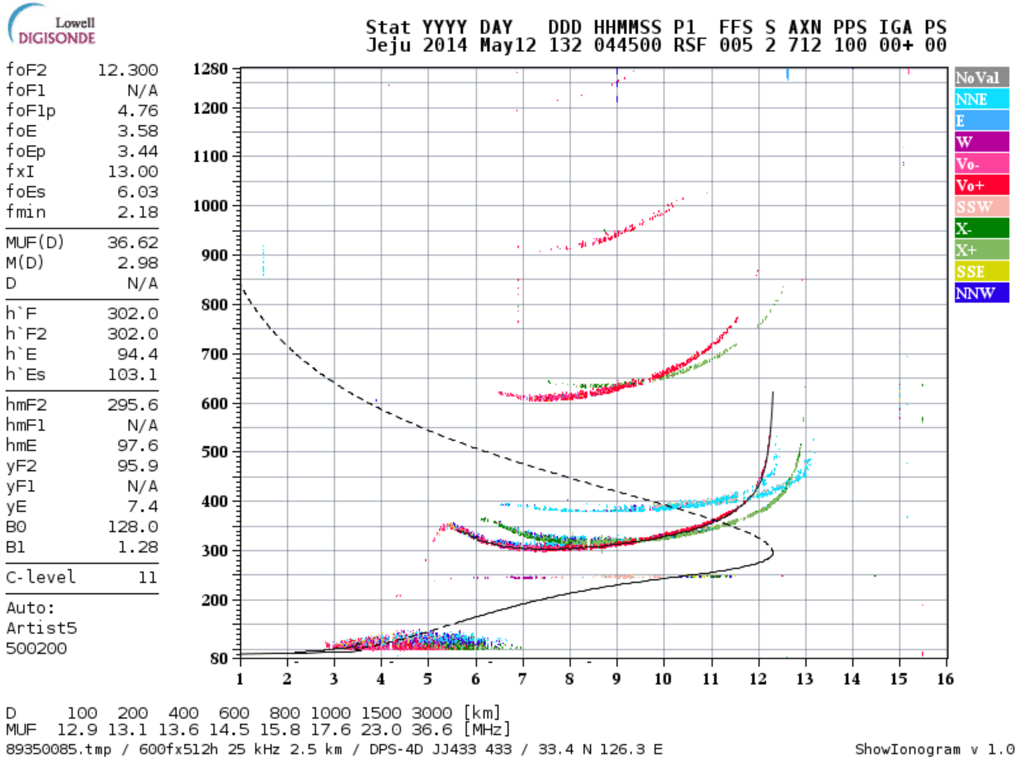

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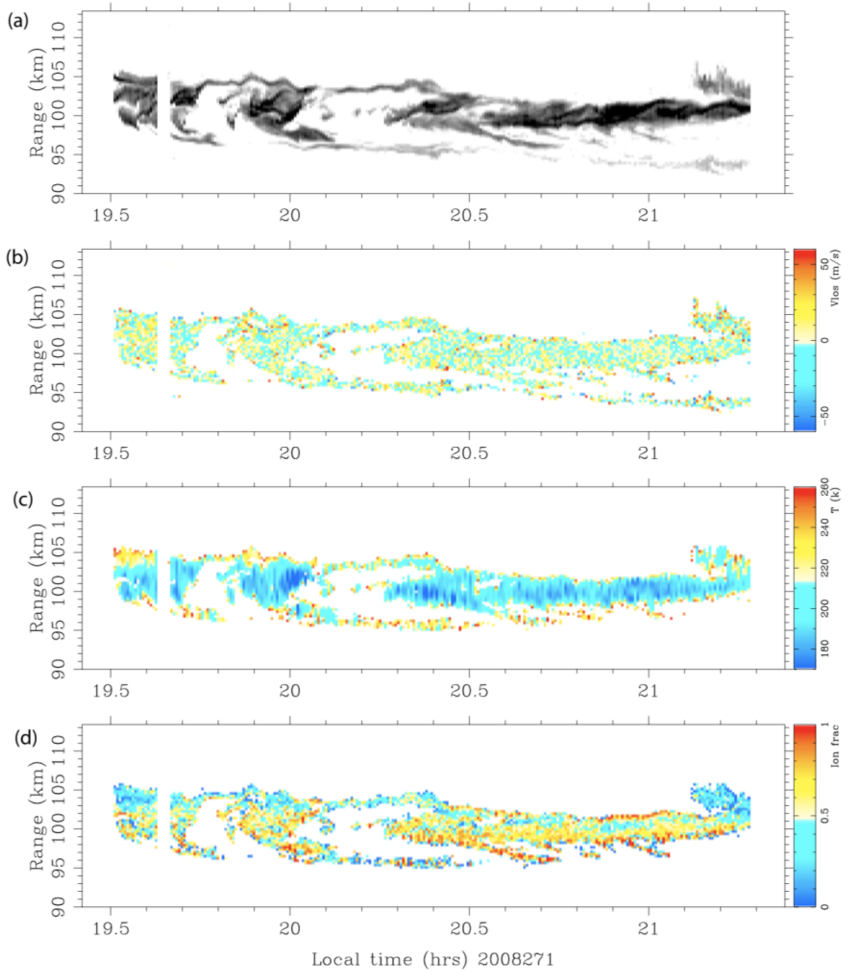

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[Hysell et al., 2009]

GPS-RO Techniques

- Five GPS-RO based techniques for monitoring sporadic-E are compared using COSMIC-1 measurements from 2010-2017 (https://cdaac-www.cosmic.ucar.edu/)
- Binary threshold either defined by initial study or calculated fbEs > 3.0 MHz
  - Note: GPS-RO measures fbμEs (Haldoupis, 2019)

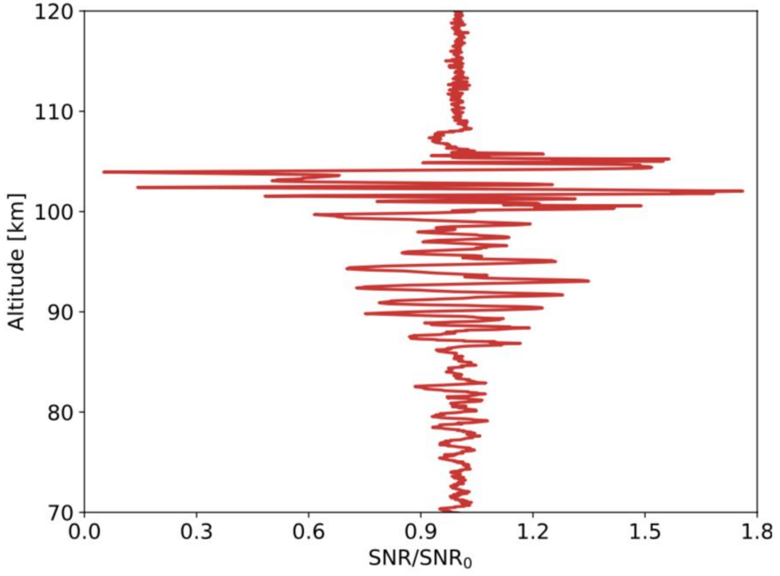


Fig. 5. An example of the normalized SNR for the L1 signal as a function of altitude. The characteristic u-shape used to calculate the sporadic-E cloud thickness is present near 103 km.

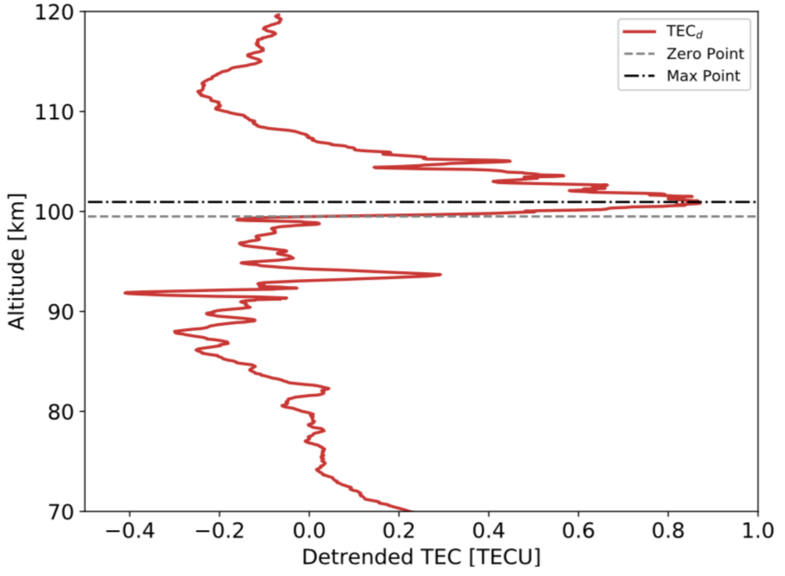


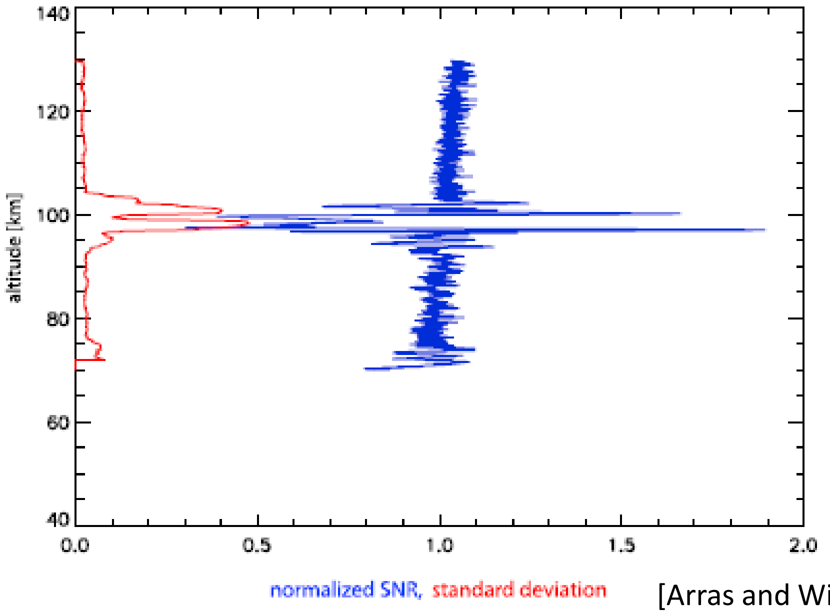
Fig. 3. An example of the detrended TEC, TEC_d, used to calculate the altitudes corresponding to the TEC perturbation, ΔTEC, caused by a sporadic-E layer. The dash-dot line corresponds to the altitude of peak TEC_d while the dashed line is associated with the first zero point below the peak (base).

[Gooch, 2020]

GPS-RO Techniques

- Yu et al. (2020) technique:
  - Based on 1 Hz S_4 calculation
  - Derived from a global fit to ionosonde data

$$(foEs - 1.2)^2 = 13.62 \times S_{4,Max}$$



[Arras and Wickert, 2018]

- Chu et al. (2014) technique:
  - 1 Hz sampling rate (ionPhs from CDAAC)
  - Three criteria must be satisfied simultaneously:
    1. L_1 and L_2 phase perturbations must exceed 5 cm
    2. Excess phase ratio of ΔL_2 to ΔL_1 within 1.5-1.8
    3. Amplitude of normalized L_1 SNR perturbation greater than 0.01

- Arras and Wickert (2018) technique:
  - 50 Hz L1 SNR (atmPhs from CDAAC) data
  - Empirically determined standard deviation threshold of 0.2 within 10 km altitude range

GPS-RO Techniques

- Niu et al. (2019) technique:
  - 1 Hz L_1 and L_2 phase data
  - Background TEC (TEC_b) calculated using an 11-point low-pass filter

$$TEC(z) = TEC_b(z) + \Delta TEC(z)$$

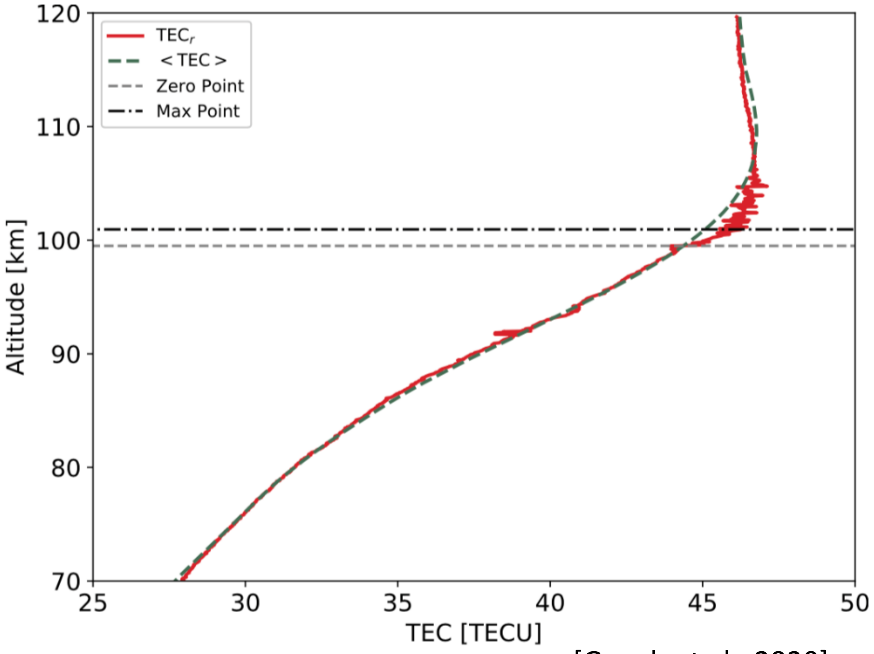
  - S-index is vertical gradient of the TEC perturbation

$$S = \frac{d(\Delta TEC)}{dz}$$

  - S_{max} = maximum S-index in E-region

$$S_{max}\left[\frac{\text{TECU}}{\text{km}}\right] = 0.0502\ \text{foEs}[\text{MHz}] - 0.0304$$

- Gooch et al. (2020)
  - 50 Hz L_1 and L_2 phase data
  - Calculate slowly varying background TEC (<TEC>) using a Savitzky-Golay filter with a 25 km window
  - Detrend TEC and convert to n_e



[Gooch et al., 2020]

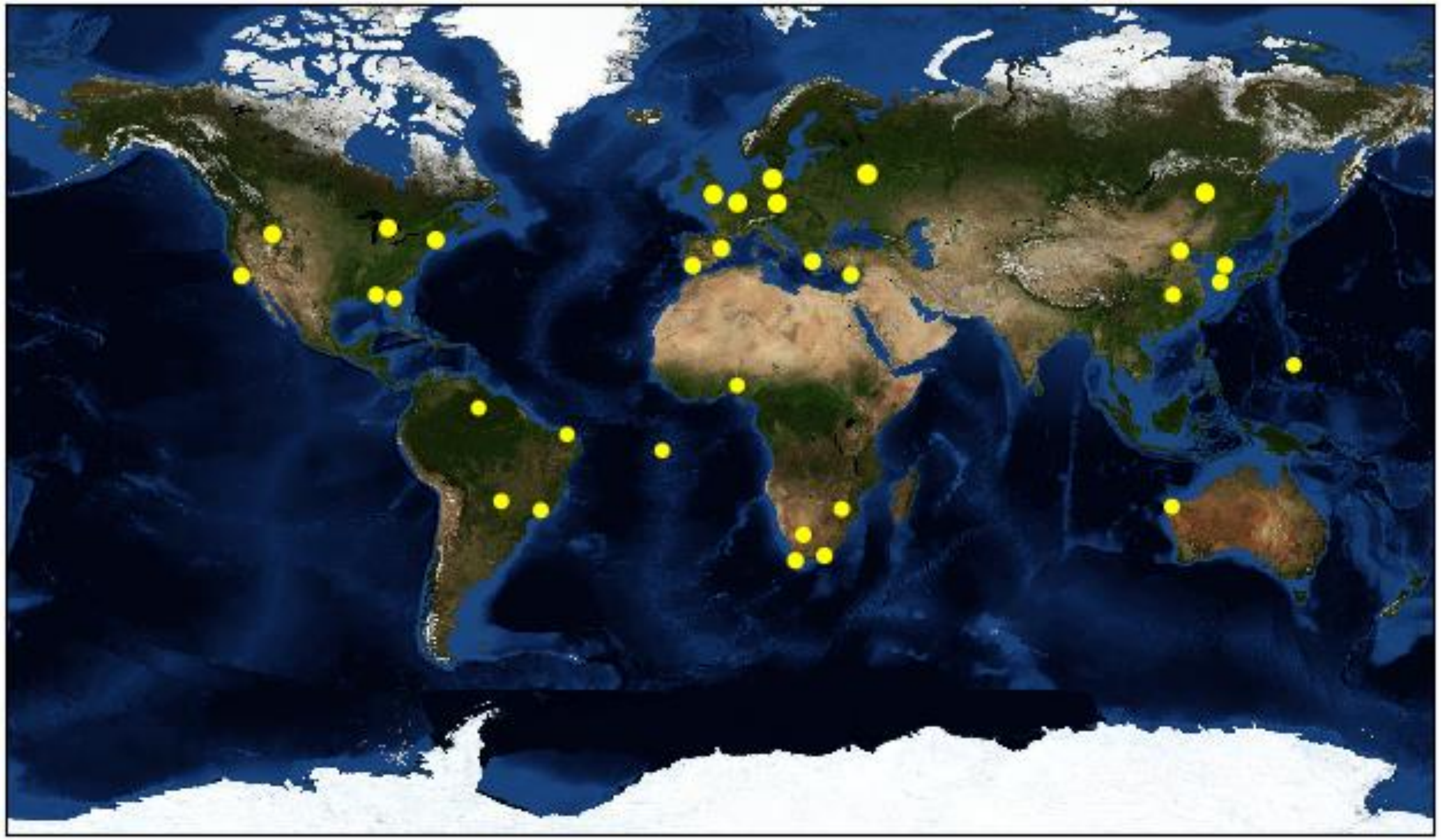
$$\Delta n_e \sim \frac{(TEC - \langle TEC \rangle)}{\left(2\sqrt{2r\Delta r}\right)}$$

Comparison Criteria

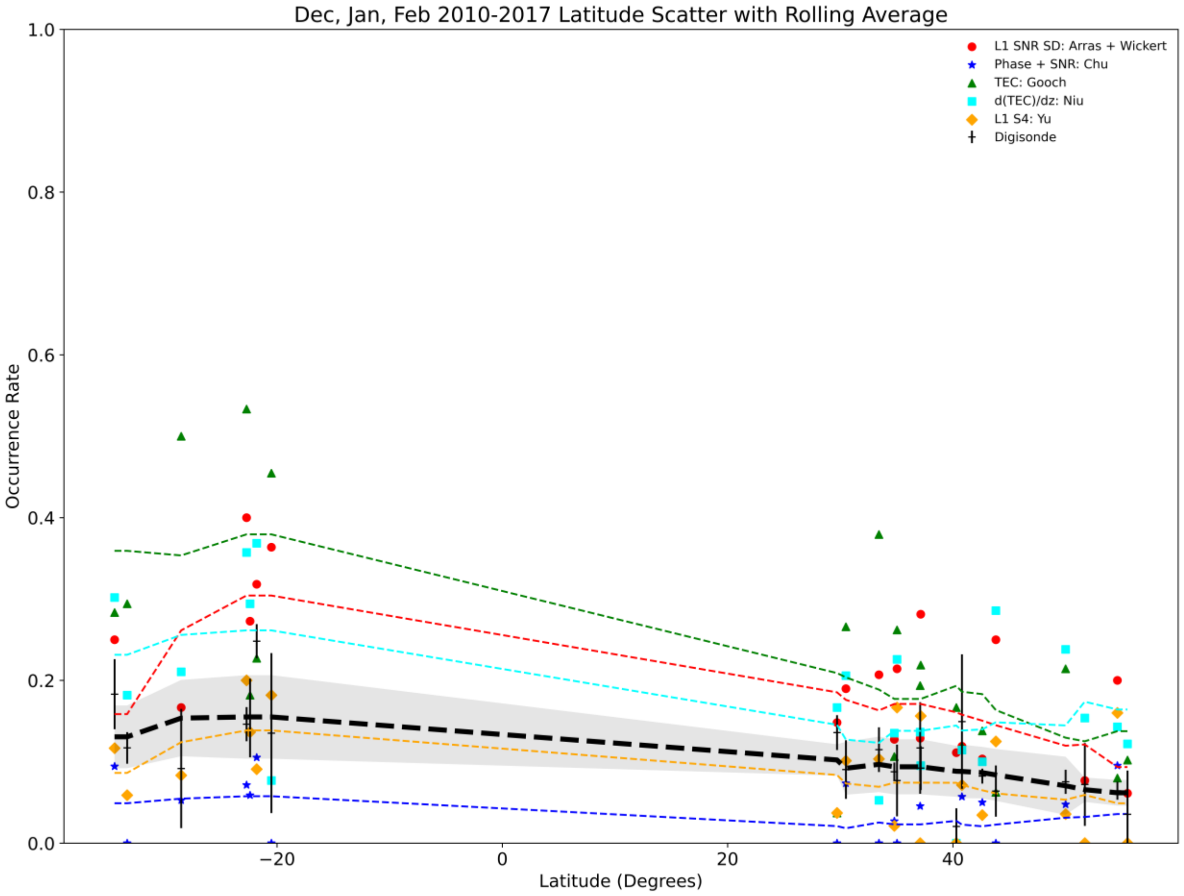
- Count number of RO tangent points with 100 km altitude within 170 km (average length of sporadic-E: Cathey, 1969) of each Digisonde site

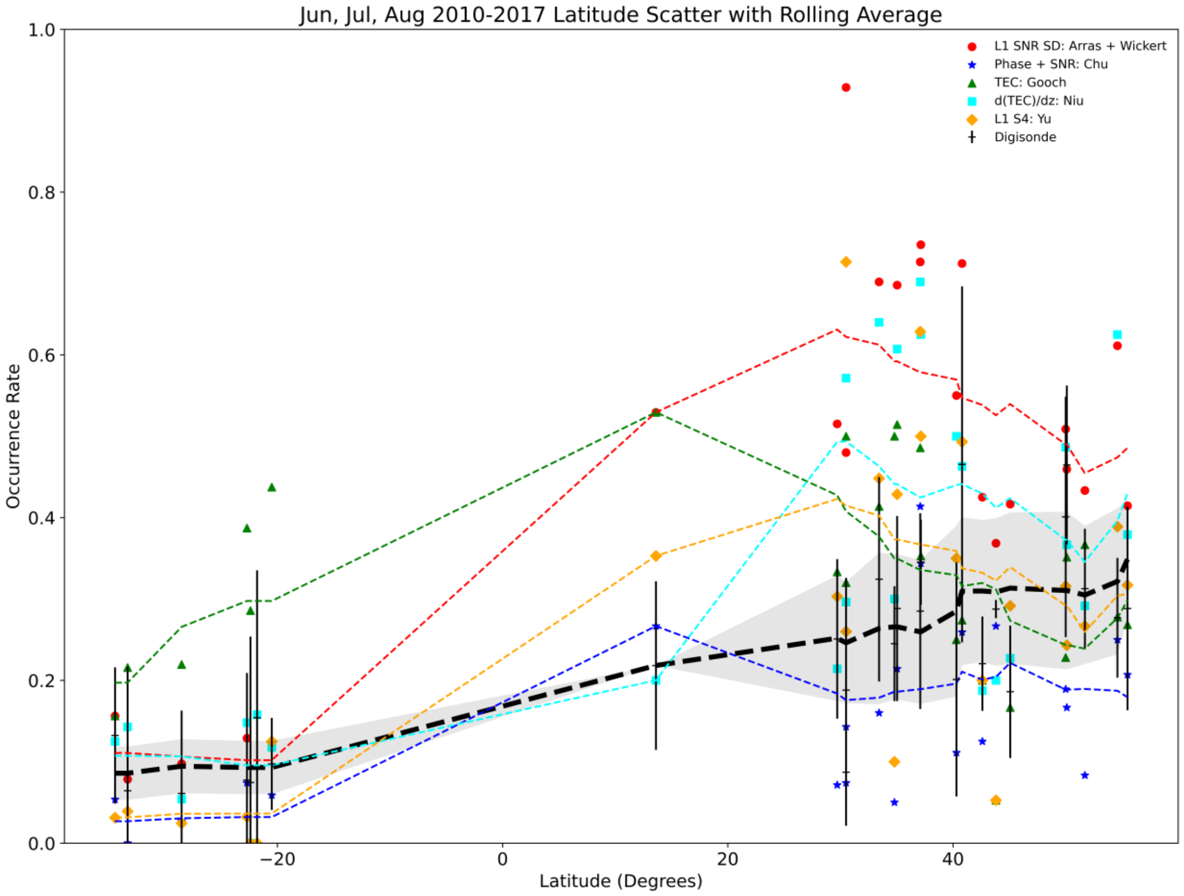
- Use the binary sporadic-E thresholds for each GPS-RO technique to count the number of occurrences for each site

- Separate the occurrence rates by season and compare to Digisonde rates

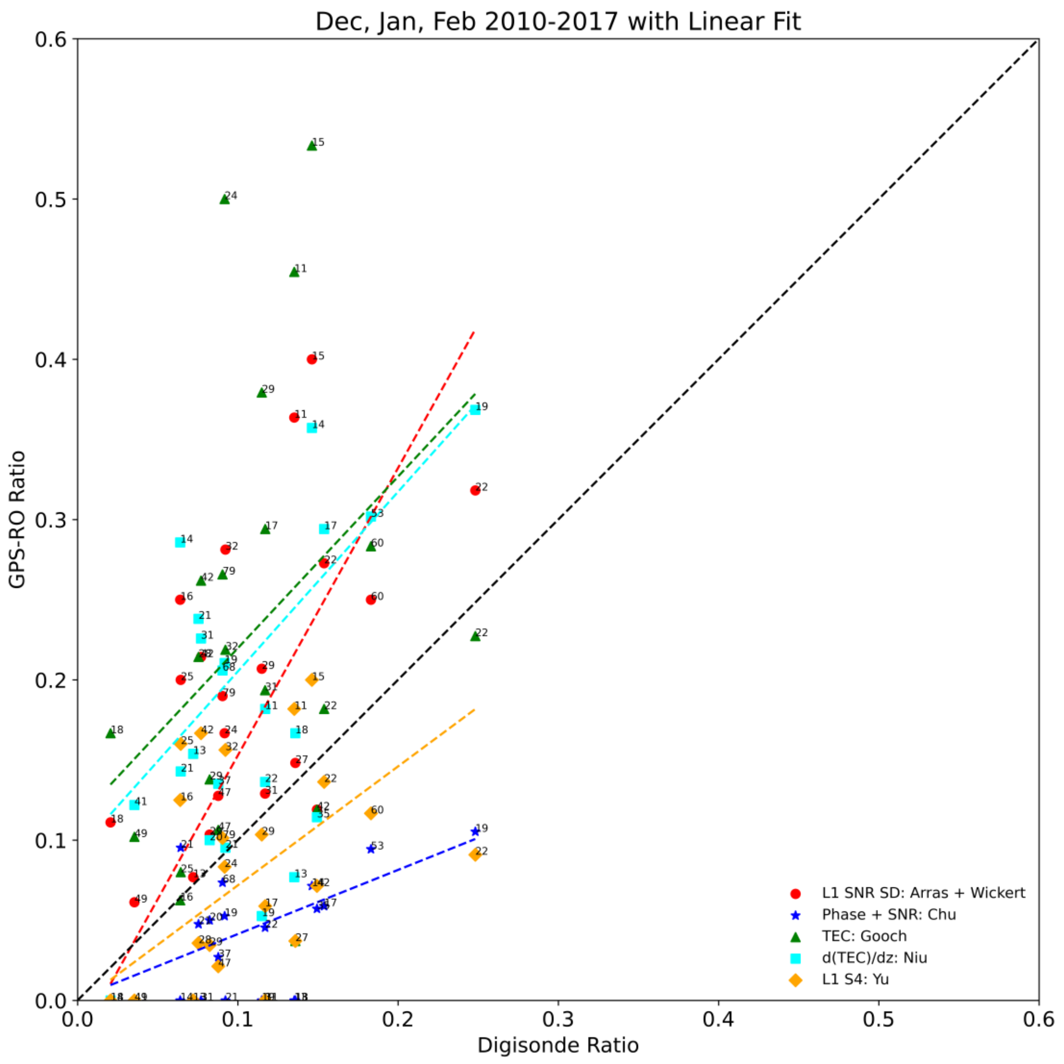


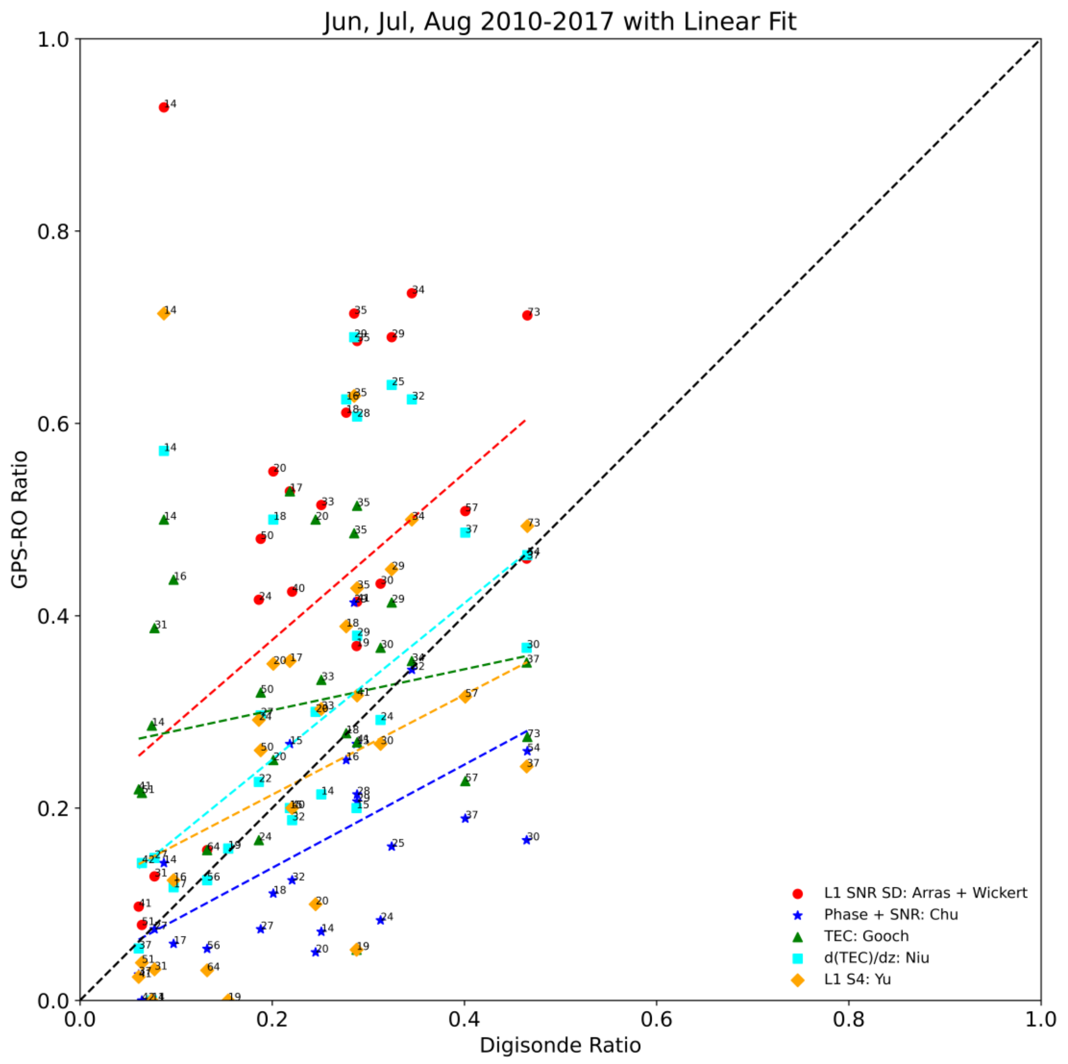
Results: Summer and Winter



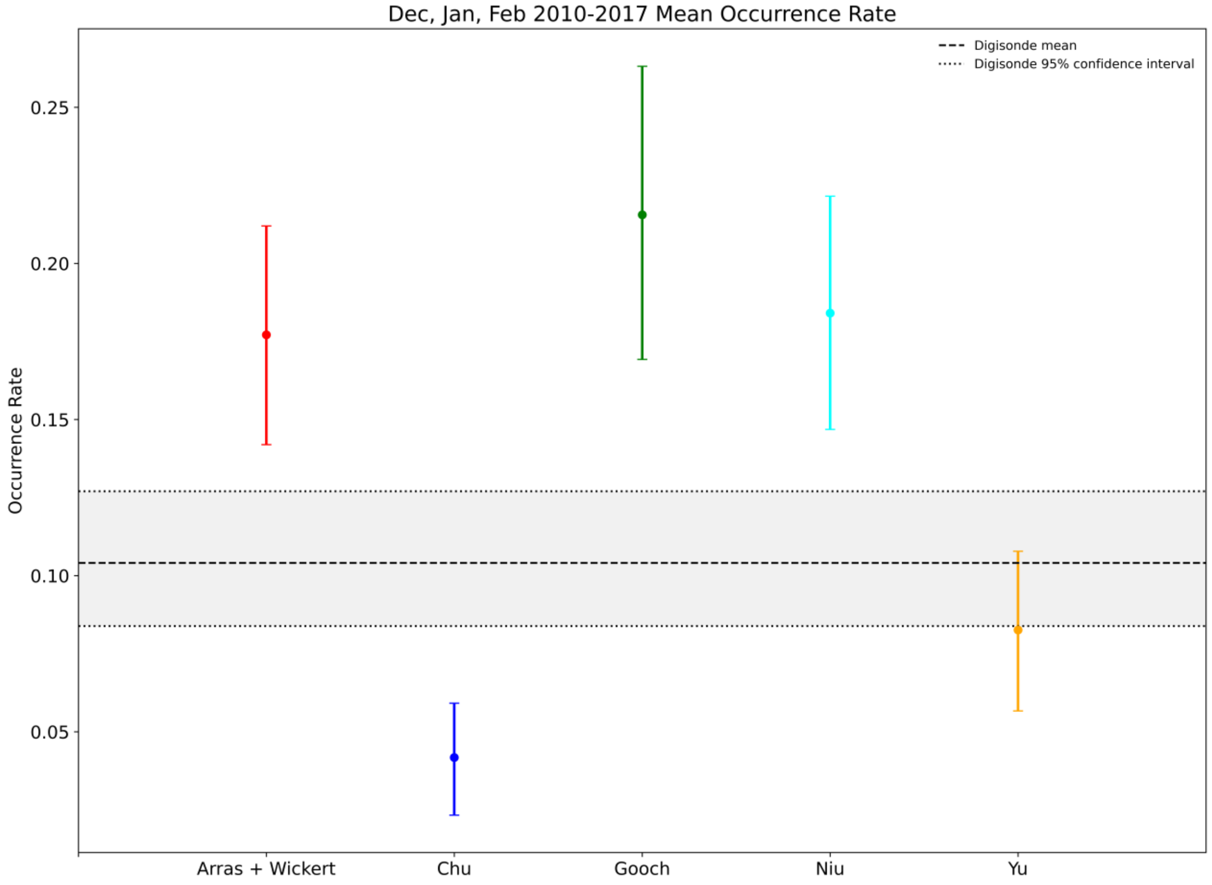


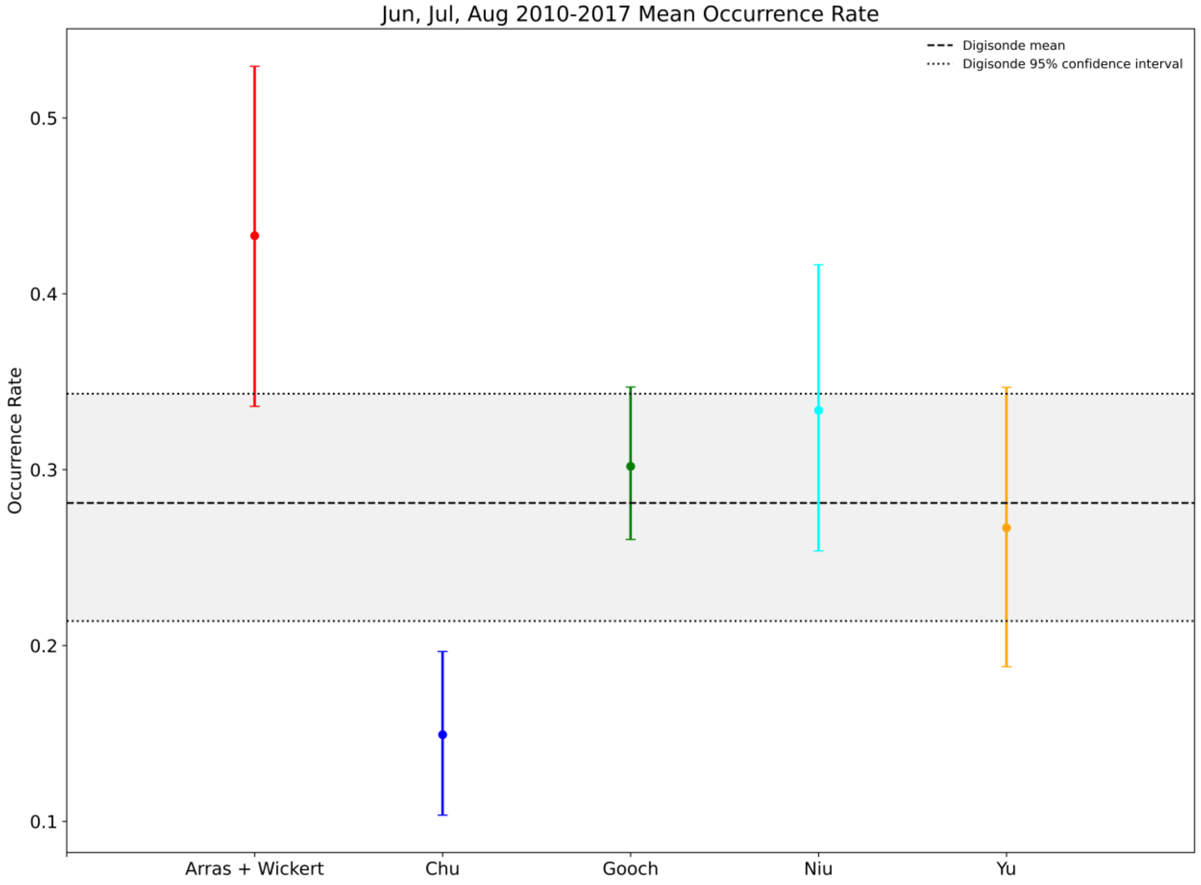
Occurrence Rates: Linear Fit





Bootstrapping Means





Conclusions

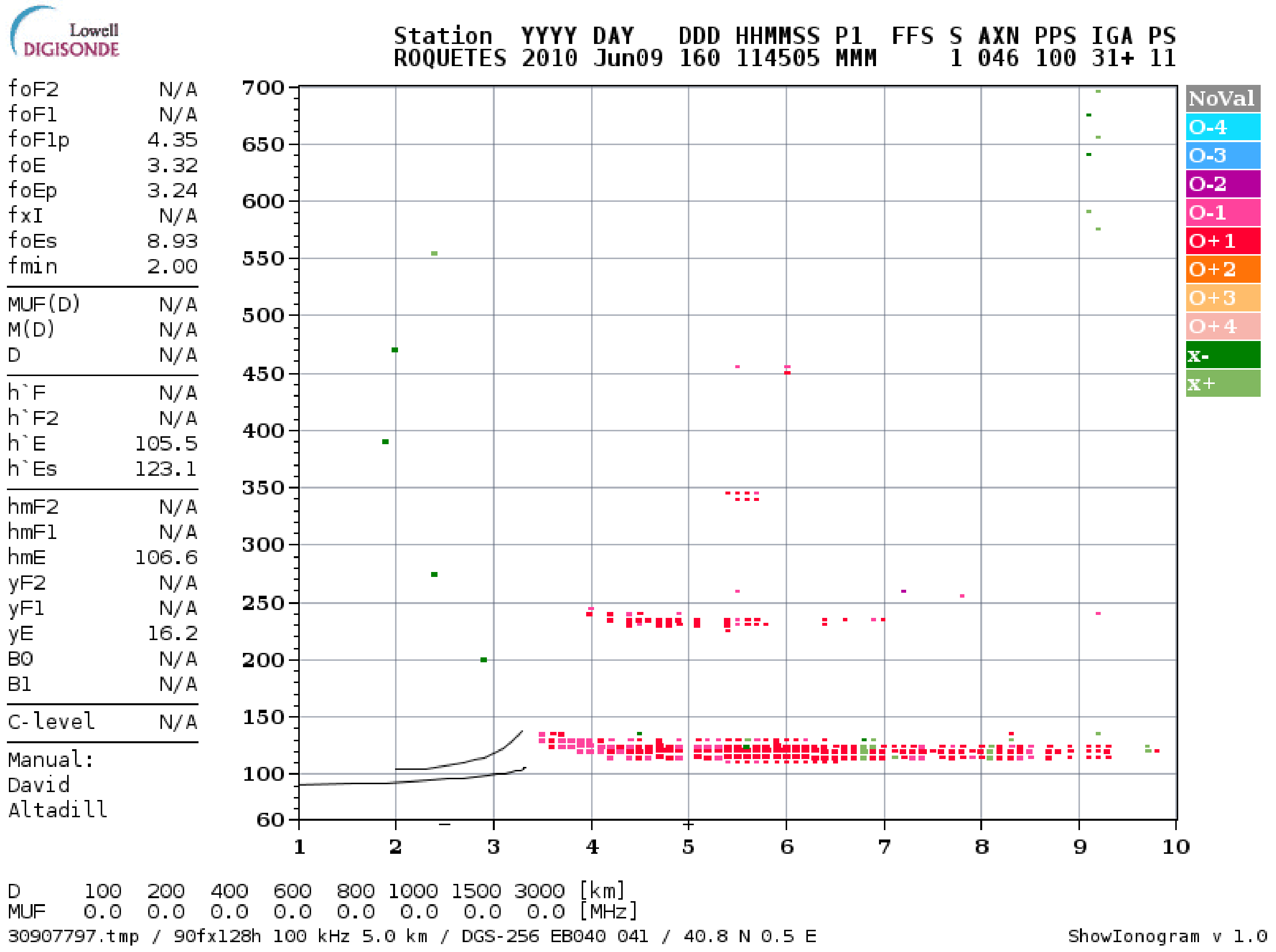
- ARTIST-5 autoscaling of Digisonde ionograms provides the "ground-truth" for sporadic-E foEs and fbEs occurrence rates

- Limited number of ionosonde sites make global occurrence rate calculations difficult: need to include GPS-RO data

- Overall, the Yu et al. (2020) S_4 GPS-RO technique showed the closest agreement with ionosonde measurements during the span of 2010-2017

- Next step: use the S_4 technique in combination with Digisonde data to develop an updated global climatology

Questions?



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