Exploring Ionospheric Behavior

Analysis of ionosonde trends and comparison to nearby riometer activities

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Background & Motivation

The Ionosphere

- Layer of free electrons and ions
- 50 – 1000 km above Earth's surface [1]
- Sub-regions: D, **E**, and F
- Makes long-distance radio communication possible

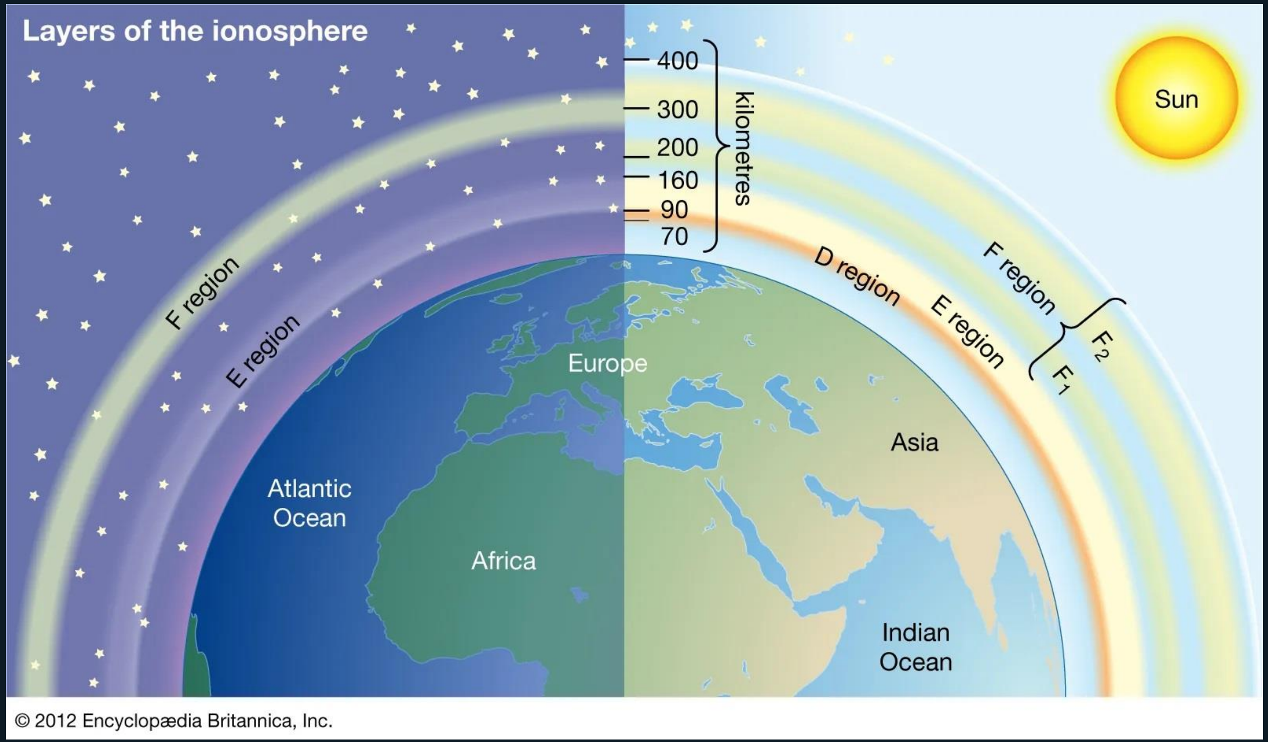

Fig: Diagram of the layers of the ionosphere [1]

Ionosonde

- Radar system looking vertically upwards [2]
- Measures electron density of ionosphere
- Send radio signals (0.1-20MHz [3]) vertically
- Derive information from
  - Time taken for waves to reflect back
  - Frequency shifts experienced by signals

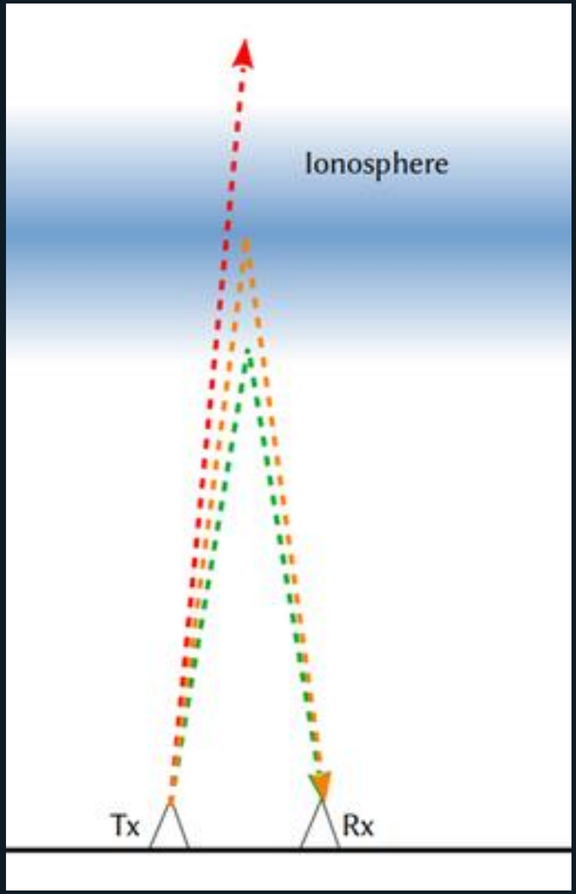

Fig: Signals of different frequencies are reflected at different altitudes, or escape into space [2]. Tx = transmitter, Rx = receiver.

GIRO Database

- A large database of ionosonde parameters
- Database I used for this project
- Often used to look at statistical trends in ionospheric behavior

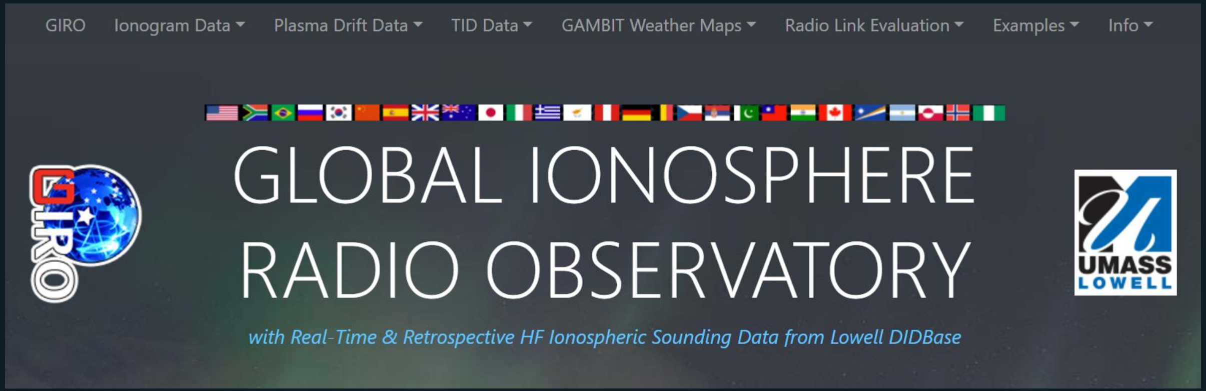

Fig: Screenshot of the Global Ionosphere Radio Observatory (GIRO) homepage

Relevant Ionosonde Parameters

- Ionosonde parameters from GIRO I have analyzed
  - hEs (KM): Height of the sporadic E trace
  - foEs (MHz): Critical frequency of the sporadic E layer
  - foF2 (MHz): Critical frequency of the F2 layer

Riometer

- Measures the amount of cosmic radio noise that can pass through the ionosphere
- The power that the riometer receives will change with the ionospheric electron density
- Measures enhanced absorption in D layer

Fig: New hyperspectral riometer built by the University of Calgary space physics group. Picture is from Poker Flat Research Range where the riometer was used in coordination with a NASA rocket experiment.

University of Calgary Riometer Database

- Database I used for this project
- Records absorption in dB and raw signal in volts

Motivation for Investigation

- GIRO database had lots of "fill values"
- Noticed the discrepancies had connection to high activity of nearby riometers
- This has not been systematically studied before as riometers are not used as much

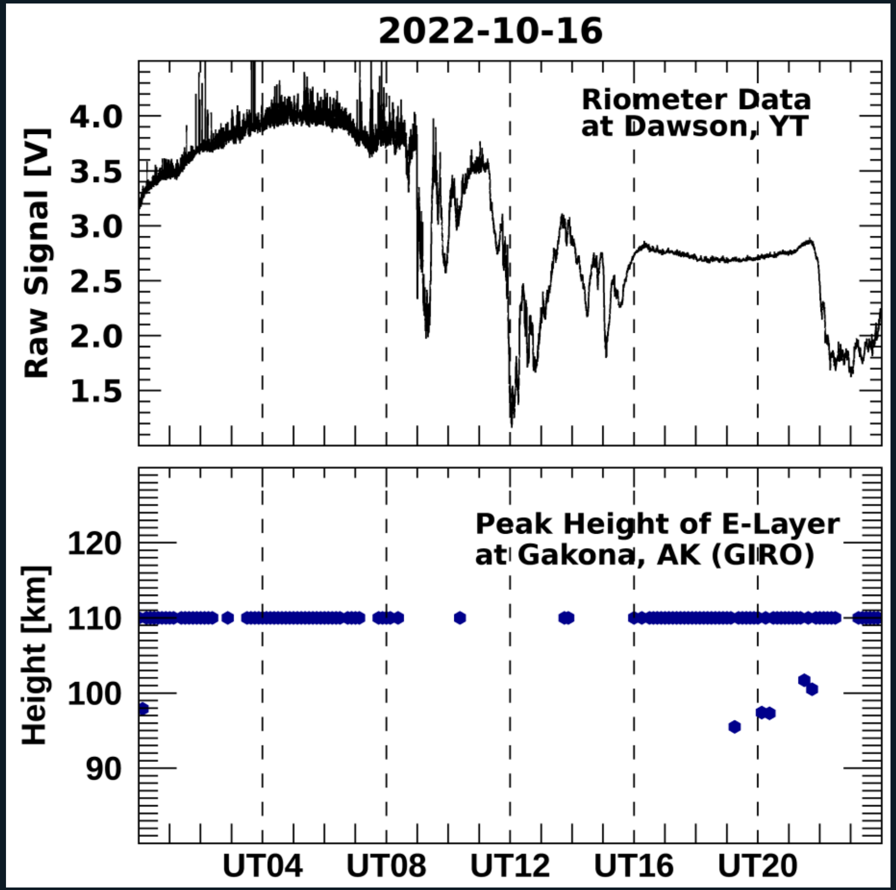

Fig: [Top] Raw riometer signal from Dawson, YK riometer (30MHz single beam system). [Bottom] GIRO database height of the ionospheric E-layer. Figure by Josh Houghton

Method of Investigation

Locations

- Focus on the Gakona, Alaska ionosonde and the Dawson, Yukon riometer
- Approximately 349km apart

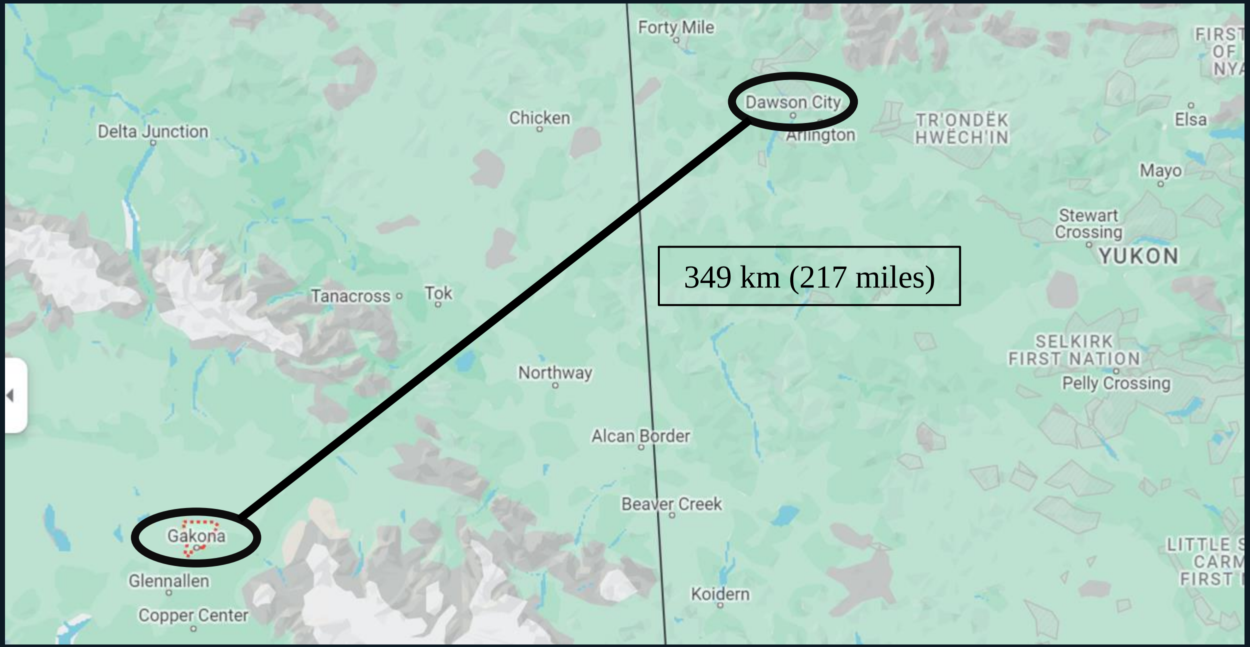

Fig: Ionosonde location Gakona, AK and riometer location Dawson, YK circled on a map

Focus on 2012

- Plotted foEs (sporadic E layer critical frequency) and foF2 (F2 layer critical frequency) ionosonde parameters against time for years 2012 – 2022
- Focused on one year
  - 2012 provided consistent data

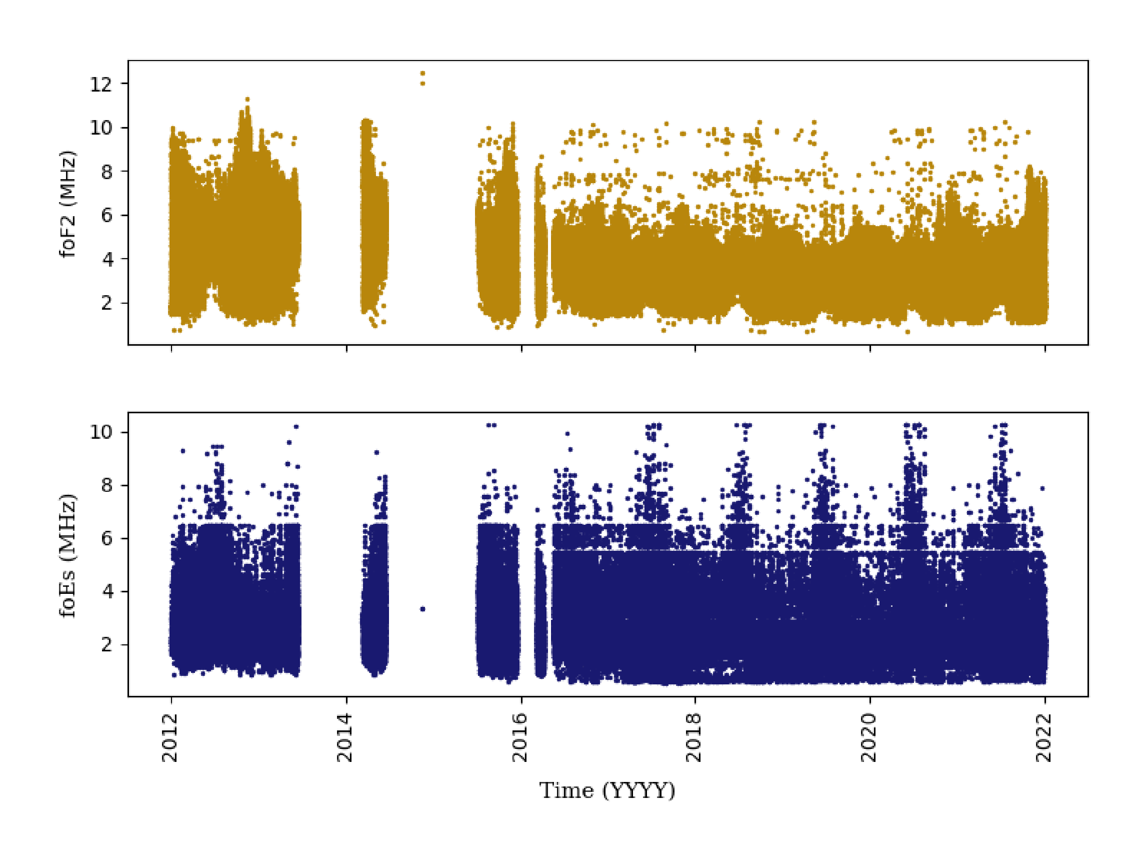

Fig: [Top] F2 layer critical frequency, foF2 (MHz) and [bottom] sporadic E layer critical frequency, foEs (MHz) against time for 10 years (2012 – 2022)

Zooming In: March 3rd, 2012

- Focused on one day in 2012 with absorption values > 3dB
- Plotted hEs, foEs, and riometer absorption against common time axis for that day
- Observation: drop in hEs and foEs values and data points as absorption peaks

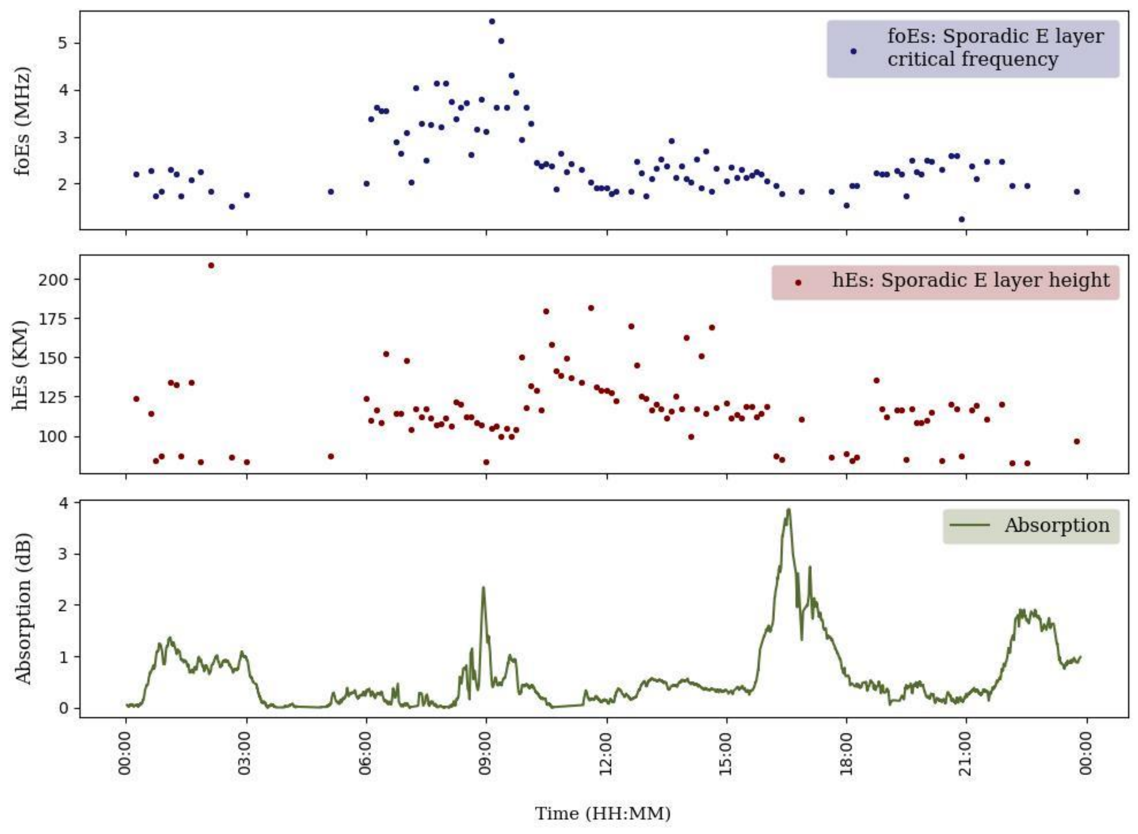

Fig: [Top] Sporadic E layer critical frequency foEs in MHz, [middle] minimum virtual height of the sporadic E trace hEs in KM, and [bottom] riometer absorption in dB against common time axis for 03-03-2012

Analysis of 12 Days

- Chose 12 days in 2012 with the highest count of absorption measurements > 3dB
- Plotted hEs, foEs, and riometer absorption against common time axis for each day
- Observation: same trend as before with hEs and foEs data points dropping when absorption peaks

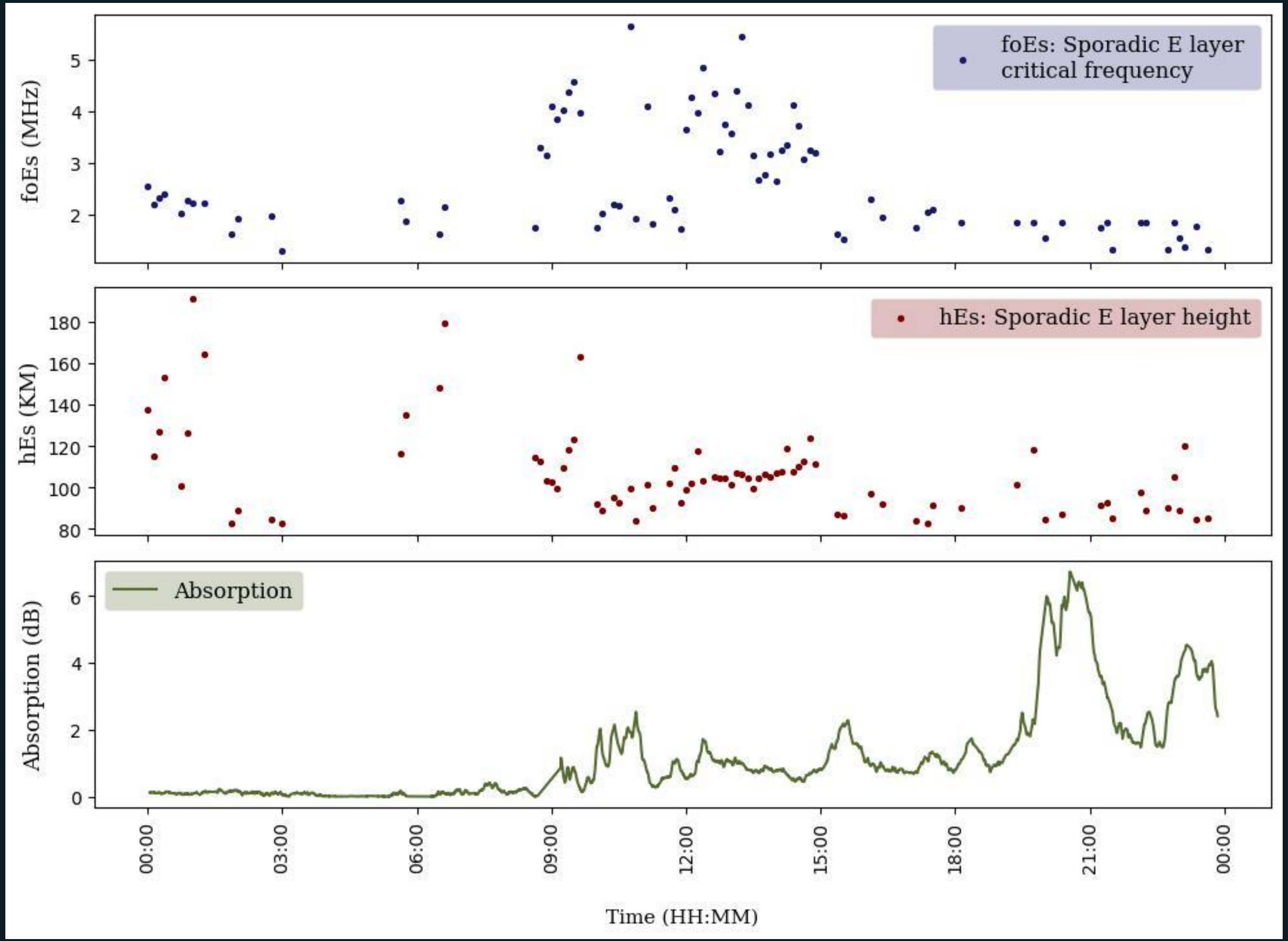

Fig: [Top] Sporadic E layer critical frequency foEs in MHz, [middle] minimum virtual height of the sporadic E trace hEs in KM, and [bottom] riometer absorption in dB against common time axis for 03-01-2012

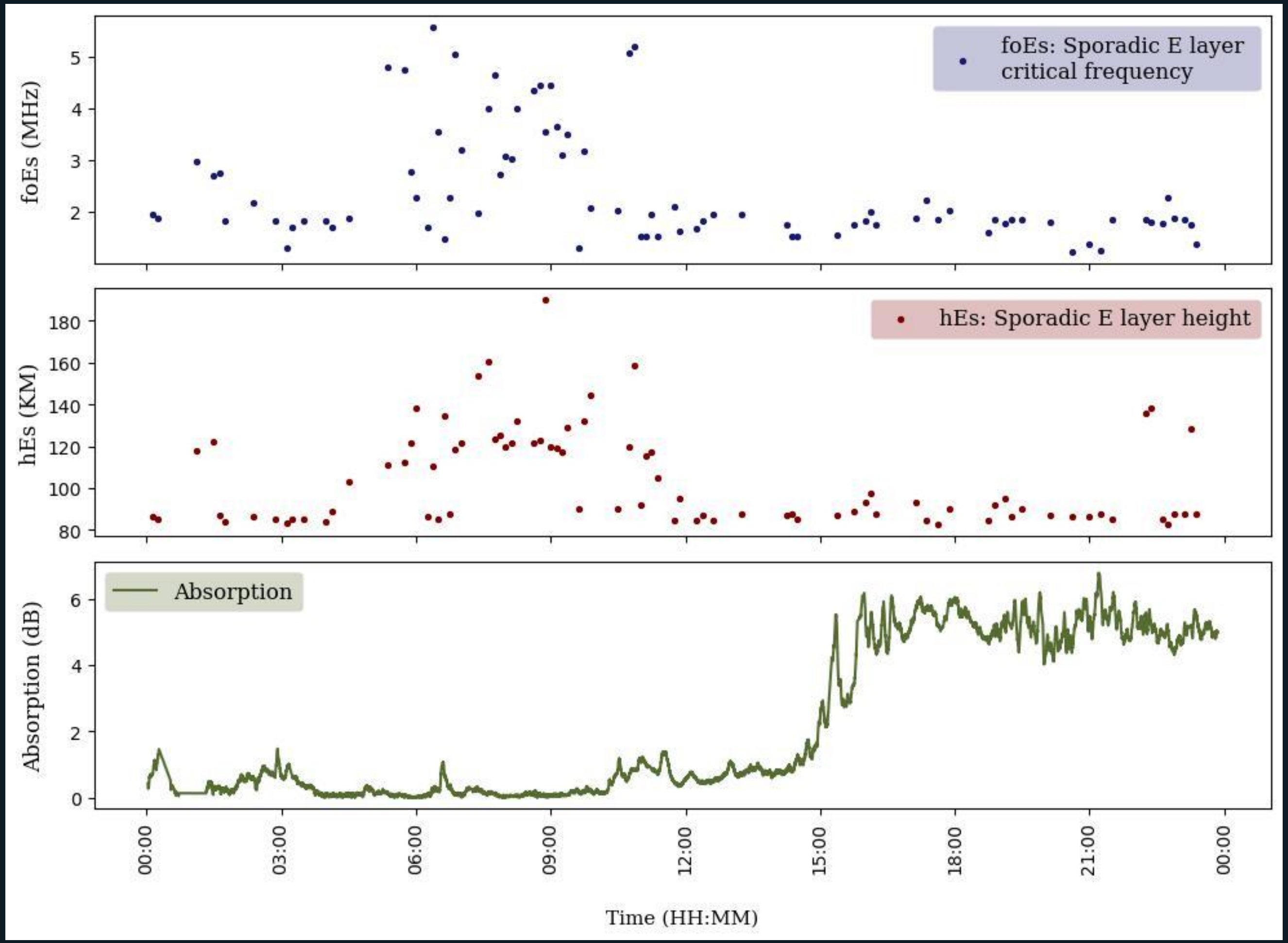

Fig: [Top] Sporadic E layer critical frequency foEs in MHz, [middle] minimum virtual height of the sporadic E trace hEs in KM, and [bottom] riometer absorption in dB against common time axis for 03-07-2012

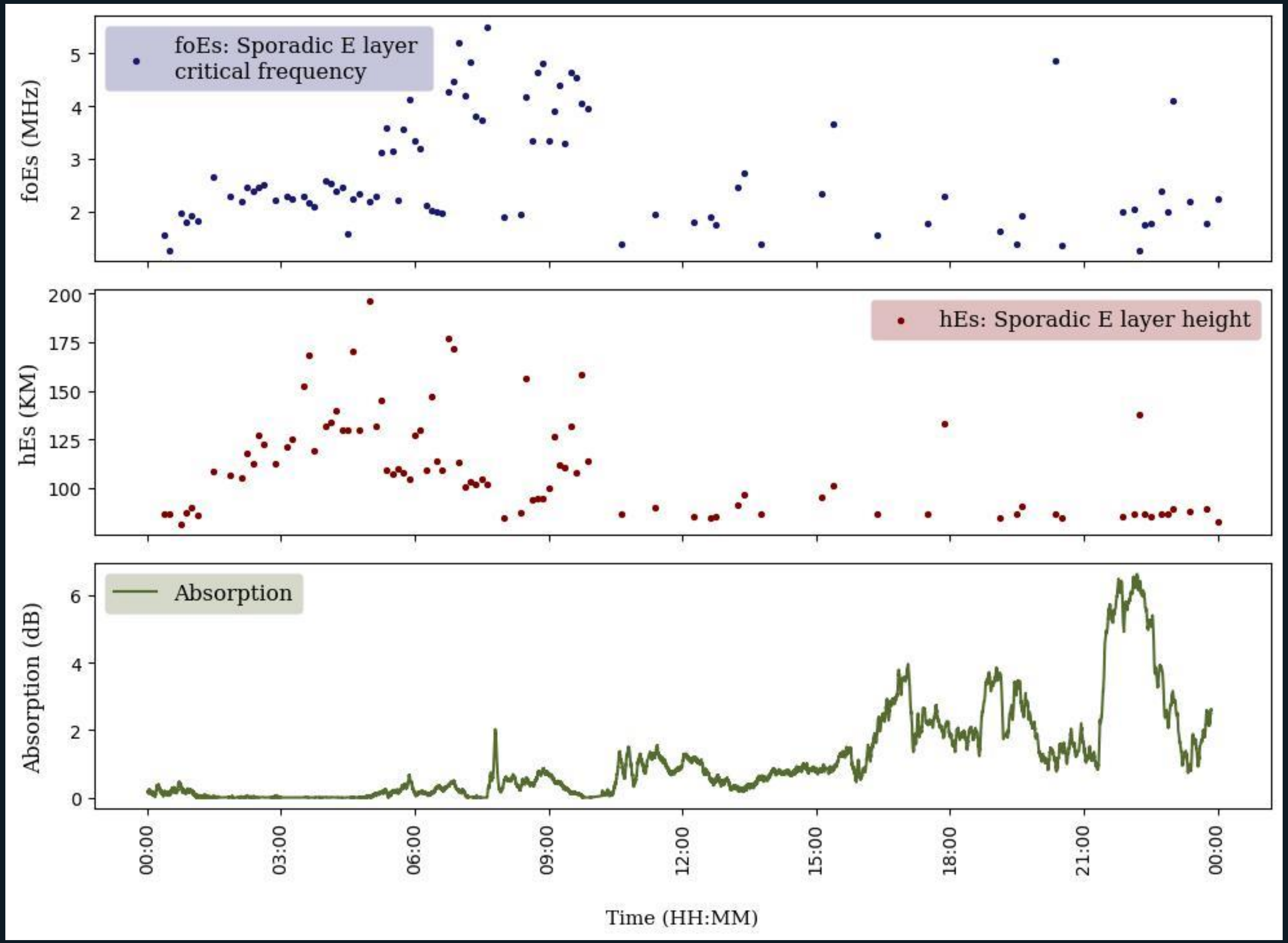

Fig: [Top] Sporadic E layer critical frequency foEs in MHz, [middle] minimum virtual height of the sporadic E trace hEs in KM, and [bottom] riometer absorption in dB against common time axis for 04-25-2012

Results & Discussion

Height vs Absorption

- Plotted hEs (height of Es layer) against average absorption for a 7.5 minute period
- Shows the decrease in the heights and decrease in the spread of heights of the sporadic E layer as the absorption increases

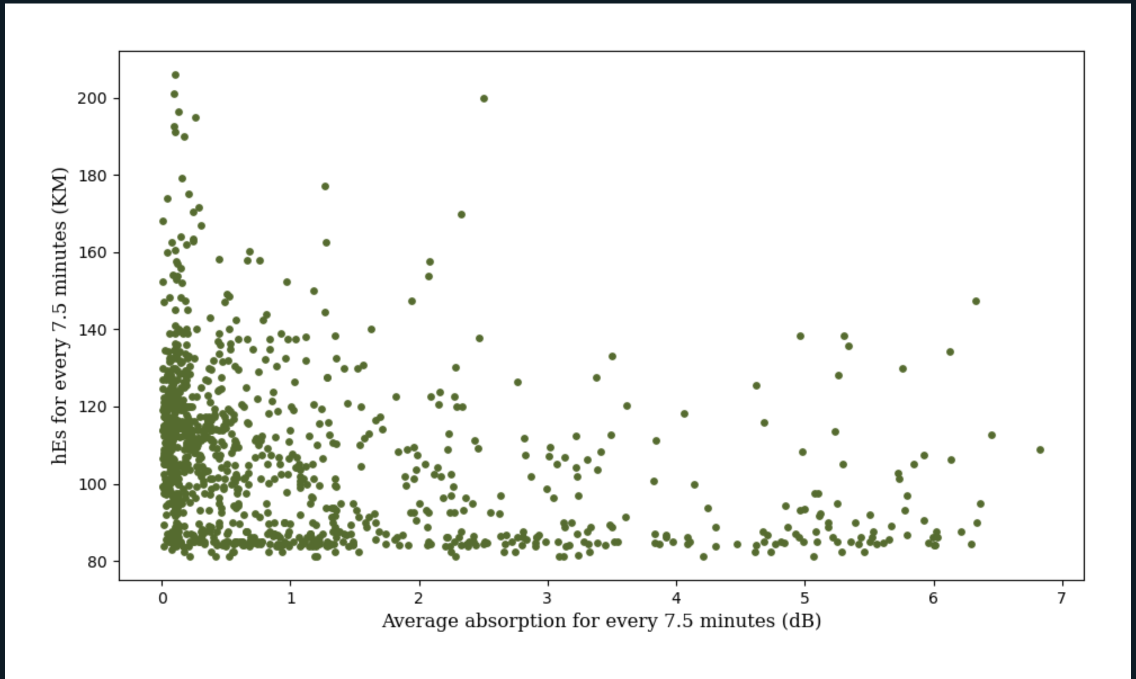

Fig: Virtual height of the sporadic E layer, hEs (KM) as a function of average absorption (dB) for a 7.5-minute period for 12 UT days in 2012

Height vs Absorption

- As the absorption increases, most of the height lies between 80 – 100 km
- The D layer starts at 90km
- Shows E layer lowering to the D layer region – region from which the riometer reports its values

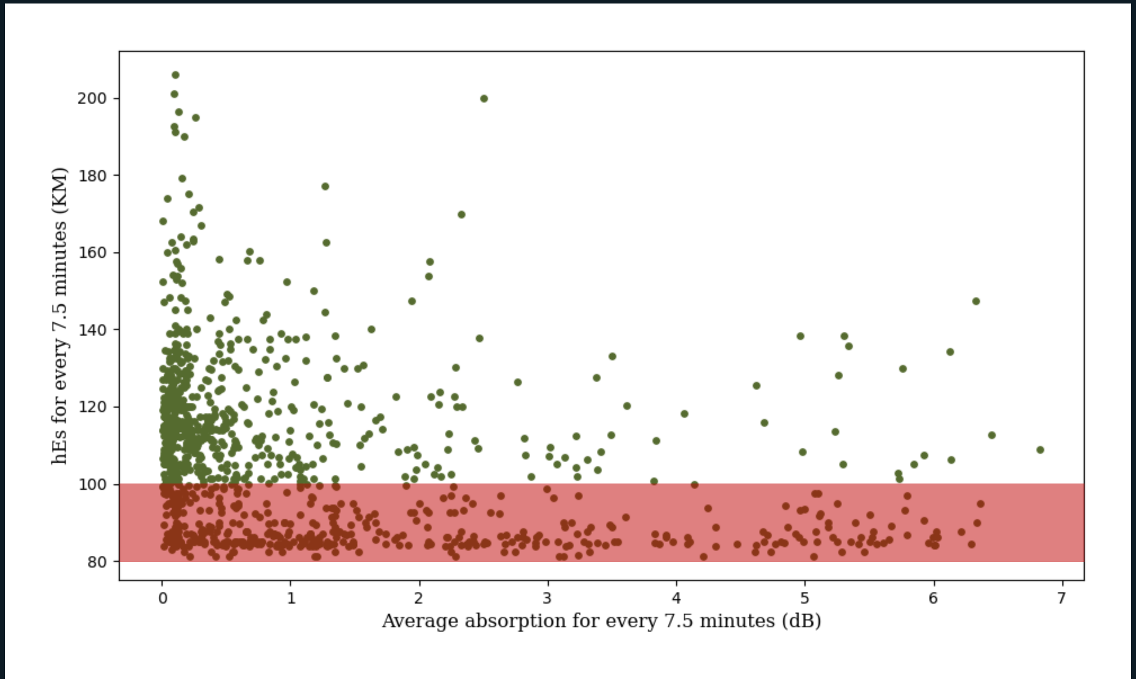

Fig: Virtual height of the sporadic E layer, hEs (KM) as a function of average absorption (dB) for a 7.5-minute period for 12 UT days in 2012; red shaded region to emphasize heights between 80-100 km

Why It's Expected

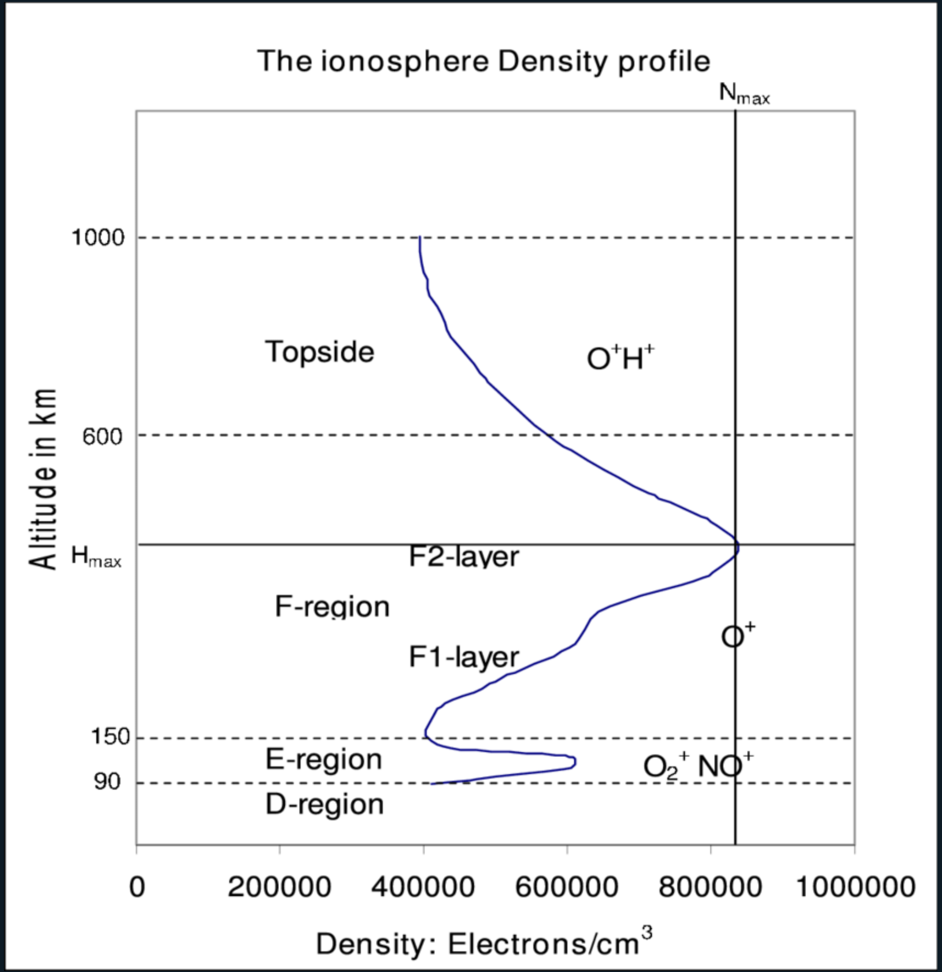

Fig: Diagram of altitude (km) against electron density (electrons/cm^3) of the layers of the ionosphere [5]

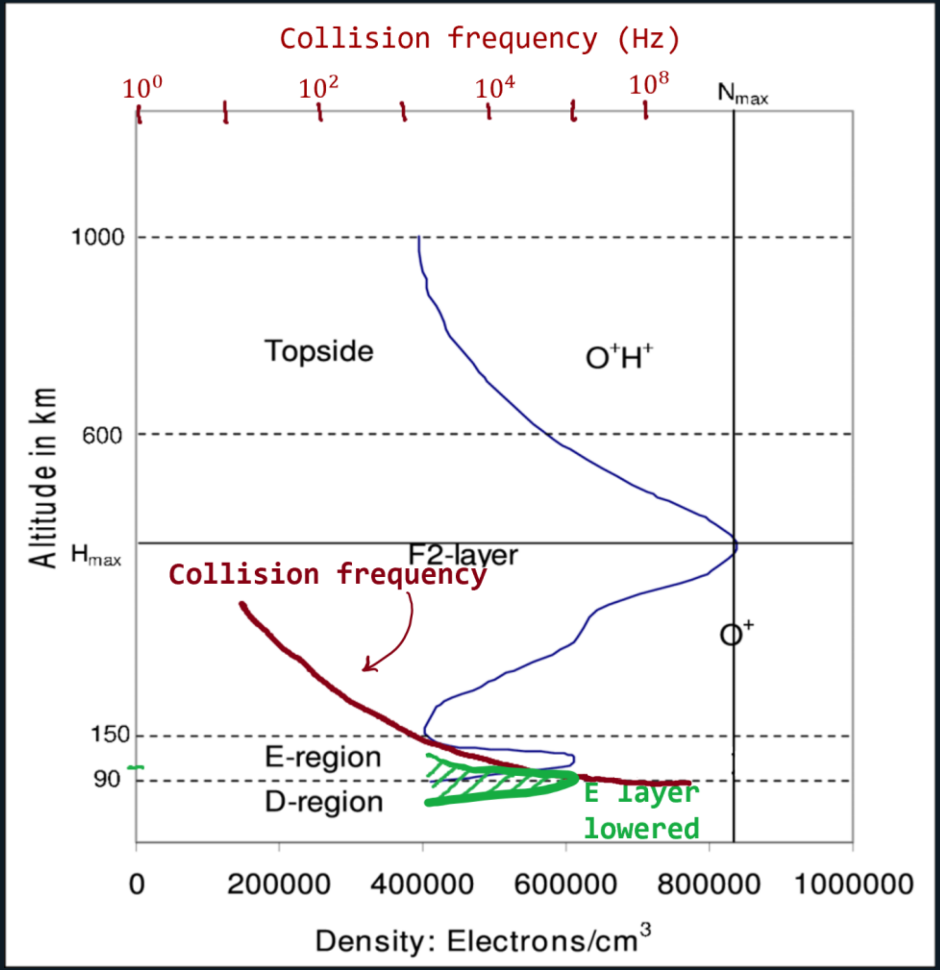

Fig: Annotated diagram of altitude (km) against electron density (electrons/cm^3) and collision frequency (Hz) of the layers of the ionosphere; additional annotation of "lowered" E layer trend (green) of altitude against density

The Physics

- E layer “lowered”; overlaps with D layer
- Appleton-Hartree equation [4]: as density gets to lower altitudes where collision frequency, v, is higher – observed absorption, A, is higher

$$A = 4.6 \times 10^{-5} \int_h \frac{N_e \cdot \nu}{\nu^2 + (\omega \pm \omega_L)^2} \, dh \, dB \quad (1)$$

where N_e: electron density (m^{-3}); ν: electron collision frequency; ω: angular frequency of the radio wave; ω_L: electron gyrofrequency; h: height; dB: unit decibels

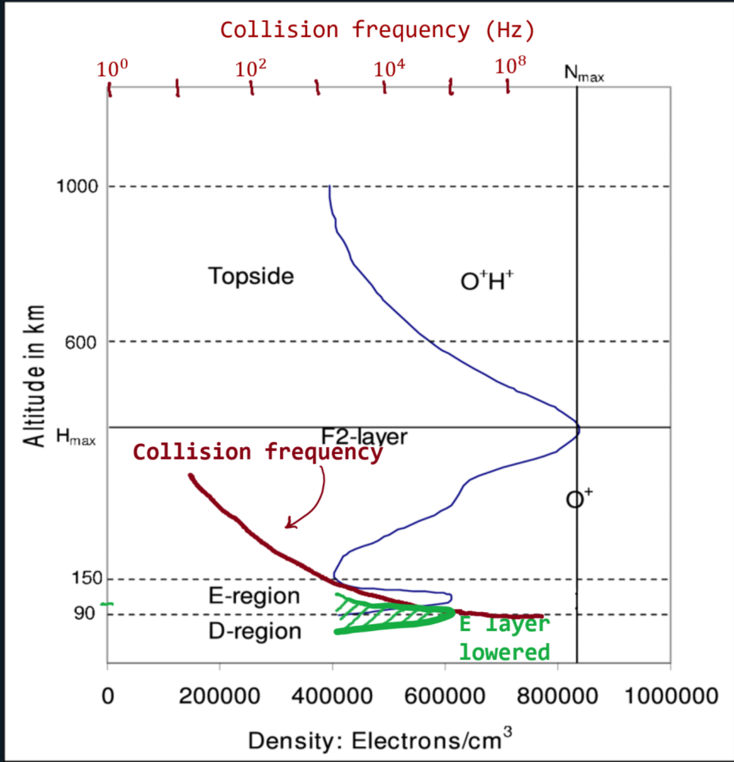

Fig: Annotated plot of altitude (km) against electron density (electrons/cm³) and collision frequency (Hz) of the layers of the ionosphere; additional annotation of “lowered” E layer trend (green) of altitude against density

Consistent With the Physics

- Plot is consistent with the equation – the heights at high absorptions are lower
- Absorption is high enough to cover both the Gakona ionosonde and Dawson riometer measurements

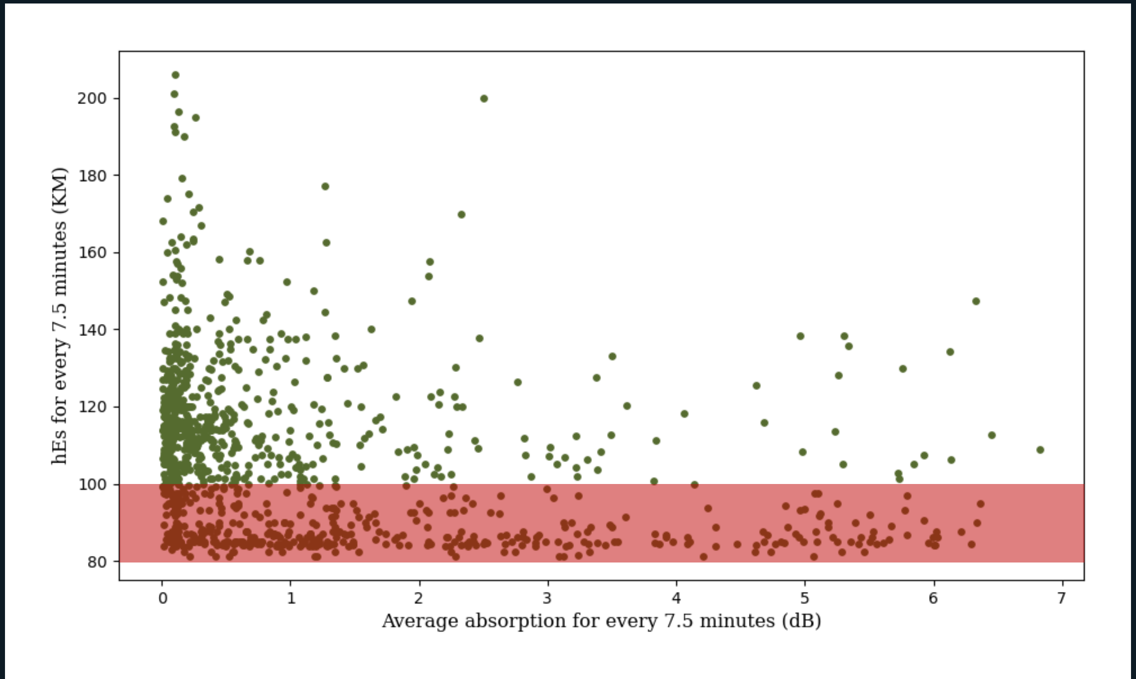

Fig: Virtual height of the sporadic E layer, hEs (KM) as a function of average absorption (dB) for a 7.5-minute period for 12 UT days in 2012; red shaded region to emphasize heights between 80-100 km

Points Per Hour

- Plotted the number of hEs points reported per hour against the average absorption for that hour for the 12 days
- Statistically significant drop in measurement count?

Points Per Hour: Result

- The ionosonde does not report as many values as absorption increases

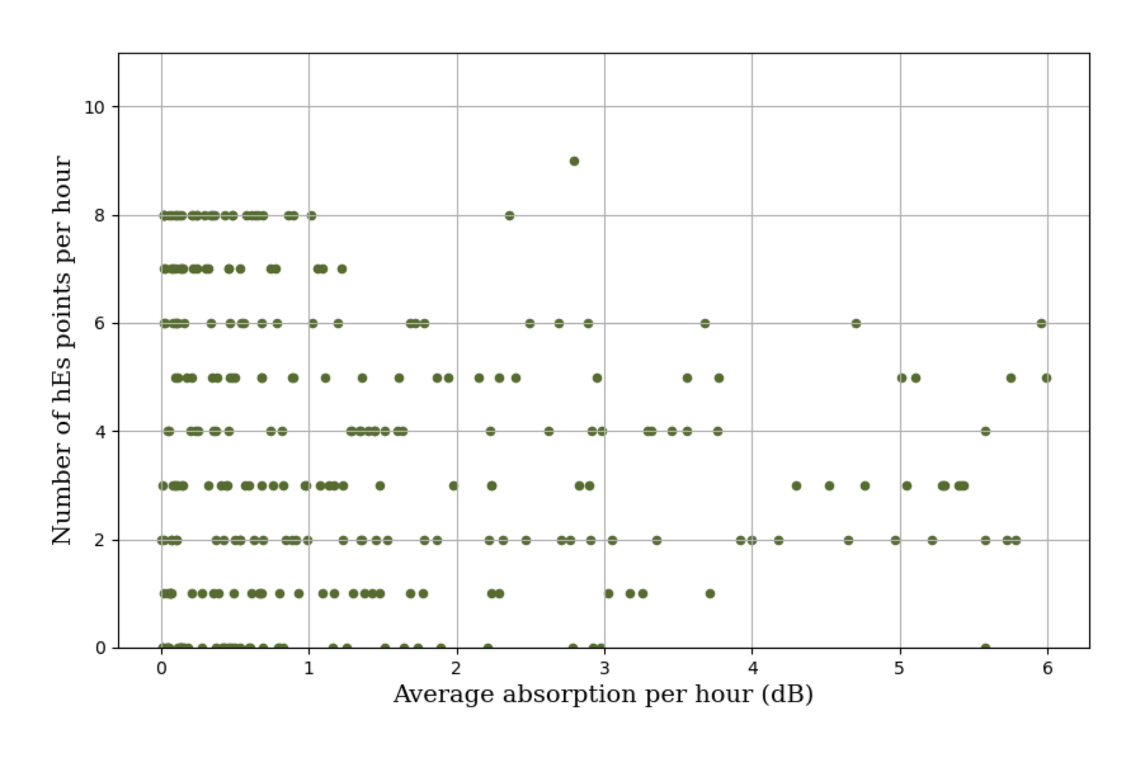

Fig: The number of hEs (Virtual height of the sporadic E layer) points per hour as a function of average absorption per hour (dB) for 12 UT days in 2012

Probability

- 7 data points indicate the ionosonde functioning properly and 8 indicate perfectly functioning ionosonde
- The probability of the ionosonde functioning properly drops starting at just under 1.5dB

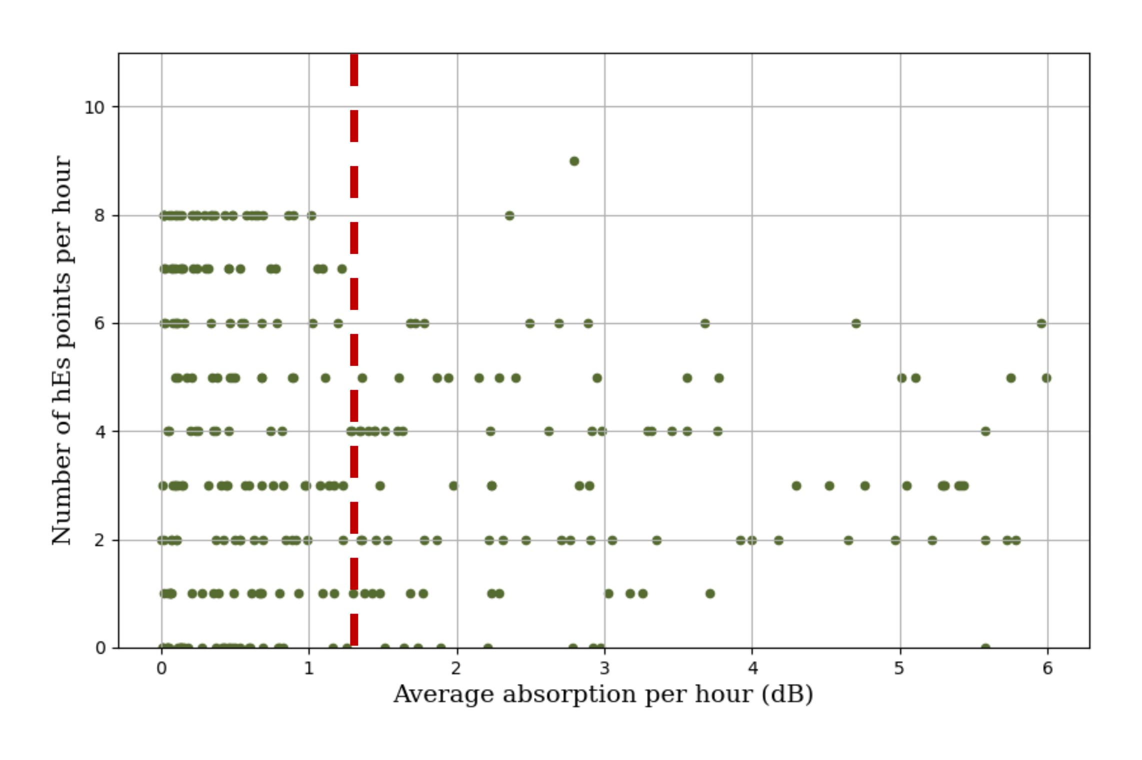

Fig: The number of hEs (Virtual height of the sporadic E layer) points per hour as a function of average absorption per hour (dB) for 12 UT days in 2012; red dotted line indicating point where the probability of the ionosonde working properly drops

Making Sense

- Appleton-Hartree equation [4]: when angular frequency of the radio wave, ω, decreases, the absorption, A, increases

$$A = 4.6 \times 10^{-5} \int_h \frac{N_e \cdot \nu}{\nu^2 + (\omega \pm \omega_L)^2} \, dh \, dB \tag{1}$$

where N_e: electron density (m^{-3}); ν: electron collision frequency; ω: angular frequency of the radio wave; ω_L: electron gyrofrequency; h: height; dB: unit decibels

- Absorption could be high enough that the ionosonde does not receive a reflected wave back to report

Complex Relationship

- Sometimes the ionosonde was not working even when the riometer absorption was low
- High frequency absorption not the only factor to the Gakona ionosonde functioning properly

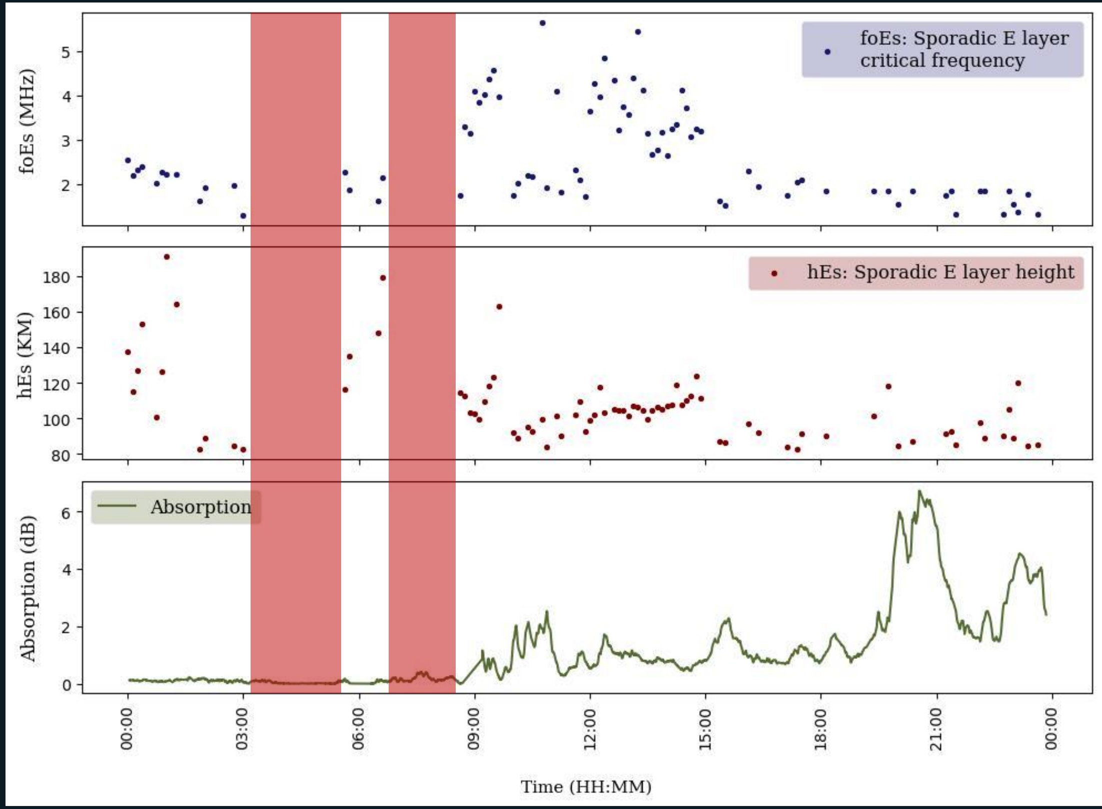

Fig: [Top] Sporadic E layer critical frequency foEs in MHz, [middle] minimum virtual height of the sporadic E trace hEs in KM, and [bottom] riometer absorption in dB against common time axis for 03-01-2012; red shaded regions are the times when the ionosonde was not working when absorption was low

Conclusion

Main Conclusion

- Trend indicating a correlation between high riometer activity at Dawson and the ability of the Gakona ionosonde to measure the E layer
- Higher riometer absorption is associated with a lack of measurements from the ionosonde
- This is consistent with HF radio wave absorption interfering with the ionosonde's sounding technique (bouncing radio waves)
- Exercise caution when using ionosondes during periods of high activity, whether statistically or during particularly active times, as ionosonde bias may occur at low absorptions.

Additional Conclusions

- High frequency (HF) absorption is not the only factor determining ionosonde’s ability to measure the E layer
- More research is needed to understand the detailed connection between absorption and the functionality of the ionosonde

References

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[2] Anon (n.d.), Ionosonde, *PITHIA*. Available from: https://pithia-nrf.eu/activities-results/outreach/space-weather-research-instruments/ionosonde (Accessed 3 November 2023)

[3] Fung, S. F., and V. Sonwalkar (2022), Ionosondes, Ionosondes - an overview | ScienceDirect Topics. Available from: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/ionosondes (Accessed 2 April 2024)

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[5] Sibanda, P. (2014), Particle Precipitation Effects on the South African Ionosphere, Research Gate, 18. Available from: https://www.researchgate.net/publication/29806954_Particle_precipitation_effects_on_the_South_African_ionosphere#fullTextFileContent (Accessed 2 April 2024)