Variability Analysis of High-Frequency Radio Signals: Insights from Doppler Measurements between Colorado and New Jersey

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Research Experiences For Undergraduates

Introduction

- High Frequency (3-30 MHz) signals are used for radio communications across the globe.
- Analysis of the Doppler residuals of these signals can be used to sense the bottom side of the ionosphere.

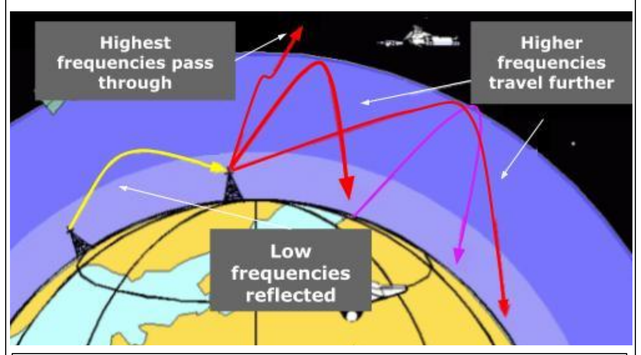

Figure 1: A diagram indicating the relationship between the frequency of an HF signal and its path of travel through the ionosphere. Recreated from Space Weather Prediction Center[1].

- The Ham Radio Science Citizen Investigation (HamSCI) group has worked to develop and distribute a network of Personal Space Weather Stations (PSWS) to measure ionospheric phenomena.

Locations of Proposed Grape 2 Receivers

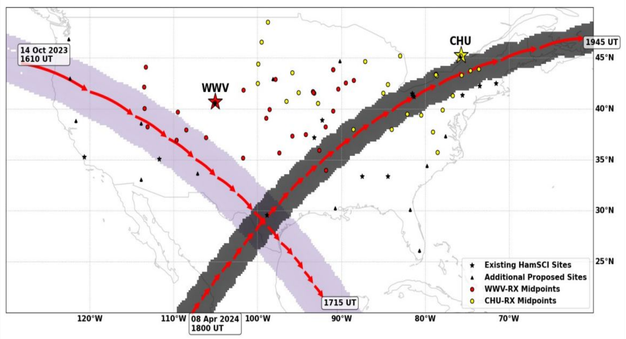

Figure 2: A diagram indicating the proposed distribution of Grape receivers. In light purple is the path which the annular solar eclipse traversed in October 2023, and in grey is the path that the total solar eclipse traversed in April of 2024.

- A Grape V1 PSWS node, a type of radio receiver, can continuously monitor a single frequency band.

Objectives

- Evaluate the capabilities of the Grape V1 receiver with respect to Doppler residuals on a ground-ground link.
- Identify and characterize patterns in residual data.
- Correlate patterns with relevant geospace phenomena.

Methodology

- A Grape V1 low-IF receiver (K2MFF) was installed and tuned to 10MHz at the Newark Institute of Technology (NJIT) in Newark, New Jersey.
- The 10MHz signal is generated by the radio station WWV in Fort Collins, Colorado.

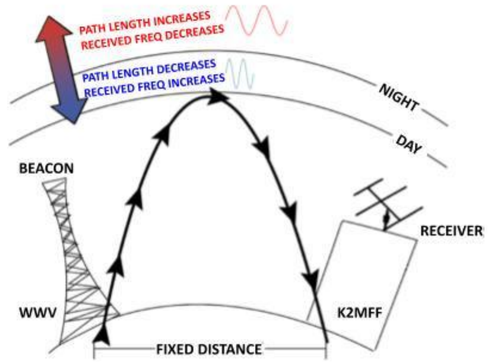

Figure 3: A diagram of the path of the 10 MHz signal. The ionosphere's exposure to sunlight during local day is associated with a blueshift for HF signals, and vice versa for local night. Recreated from Collins[2] et al.

- The difference between the peak signal received by the Grape and 10MHz is calculated to acquire its Doppler residual at a sampling rate of 1Hz.

Doppler Residuals at 40°42', -89°-36' (2022)

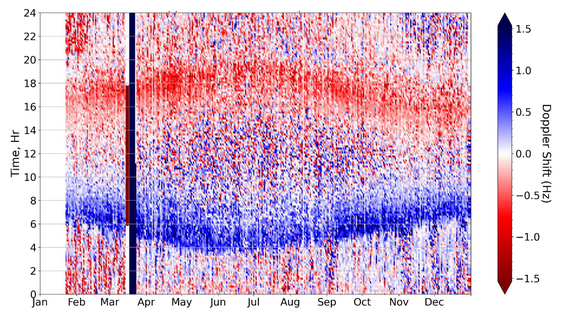

Figure 4: Residual data collected in 2022. The data has been timeshifted from Newark local time (GMT-5) to the time local to the midpoint of the 10 MHz signal propagation path in Illinois (40°42', -89°-36') (GMT-6).

Results

- Doppler residuals detected during the daytime are more stable than those received during the nighttime.
- Daytime Doppler residual measurements are Cauchy distributed, whereas nighttime readings are exponential power / lognormal distributed.

Best Fit PDFs (7-1-2021)

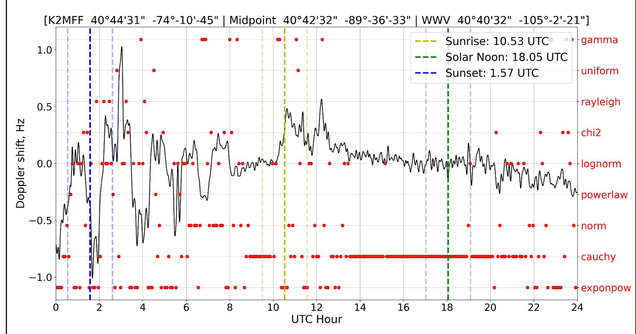

Figure 5: Residual data for July 1, 2021 overlain with red markers identifying the best fit probability distribution function for the 5-minute time bin. The bold blue line marks the UTC time for sunset, and the bold yellow line marks the UTC time for sunrise. The lines to the left and right of each mark the same times in Newark and Fort Collins, respectively.

2024 Total Eclipse

- A significant alteration from daily residual traces was detected during the event 2024 total eclipse.

Doppler Traces (4/1 - 4/8)

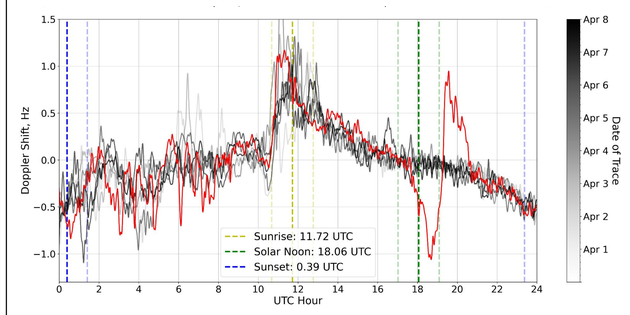

Figure 6: Doppler residual readings for 7 days of data collection prior to the total eclipse (data from dates closer to April 8 is colored darker grey) overlaid with the Doppler residual trace from April 8 in red.

Discussion

- Single-hop is the preferred transmission mode, so residual trends purely due to ionospheric variability.

3D Raytracing from WWV to K2MFF (2021-7-1)
TX: [40.68, -105.04] → RX: [40.74, -74.18] | Midpoint : [42.12, -82.6]

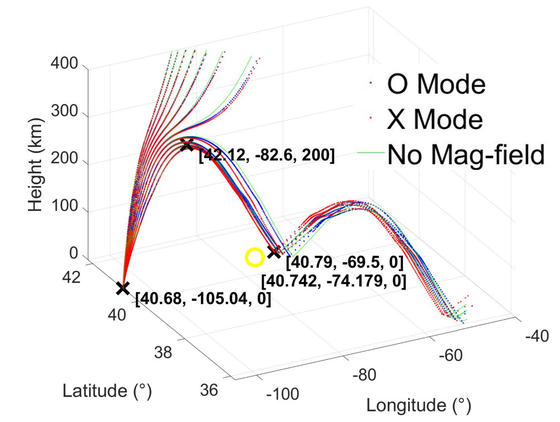

Figure 7: A 3D plot of the path which rays initially launched at 0°-10° elevation will take through the ionosphere. Reflection point is at an altitude of 200km (low F-region / high E-region).

Conclusions and Future Work

- Solar irradiation of the ionosphere above the midpoint was linked to signal residuals using the Grape receiver.
- A Cauchy distribution was associated with 5-minute bins of data collected between sunrise and sunset.
- The causes for fluctuations in residual measurements have not been isolated to a particular source.

Change in Total Electron Content (TEC)

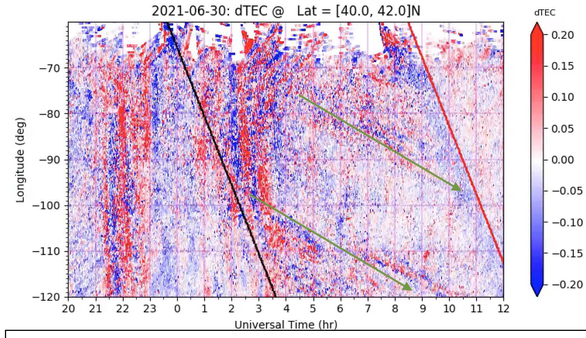

Figure 8: Delta TEC of the ionosphere along the 40th - 42nd line of latitude over time. Overdrawn lines highlight direction of moving ionospheric disturbances. Courtesy of Shunrong Zhang of MIT Haystack.

Acknowledgement

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References

[1] Ionosphere. Space Weather Prediction Center. https://www.swpc.noaa.gov/phenomena/ionosphere
[2] K. Collins, A. Montare, N. Frissell and D. Kazdan, "Citizen Scientists Conduct Distributed Doppler Measurement for Ionospheric Remote Sensing," in IEEE Geoscience and Remote Sensing Letters, vol. 19, pp. 1-5, 2022, Art no. 3504605, doi: 10.1109/LGRS.2021.3063361.

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