Exploring Ionospheric Variability Through Doppler Residuals: A Study Utilizing the HamSCI Grape V1 Receiver

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HamSCI Workshop

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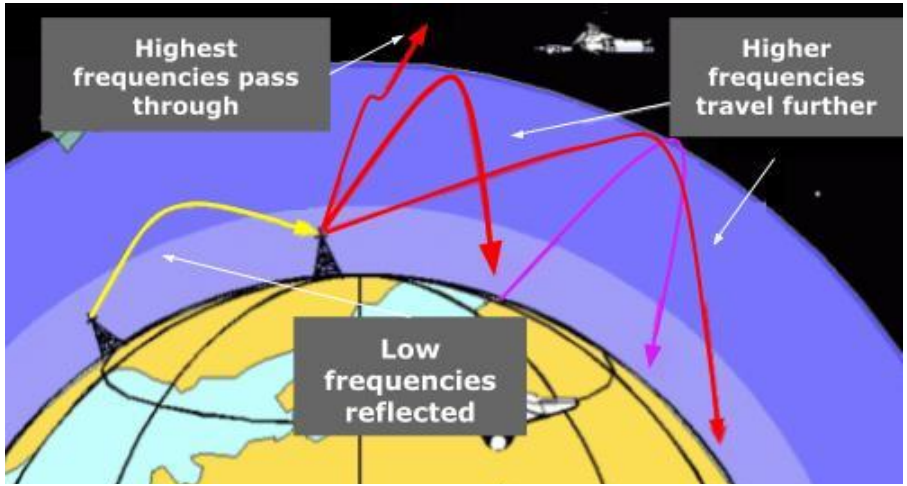
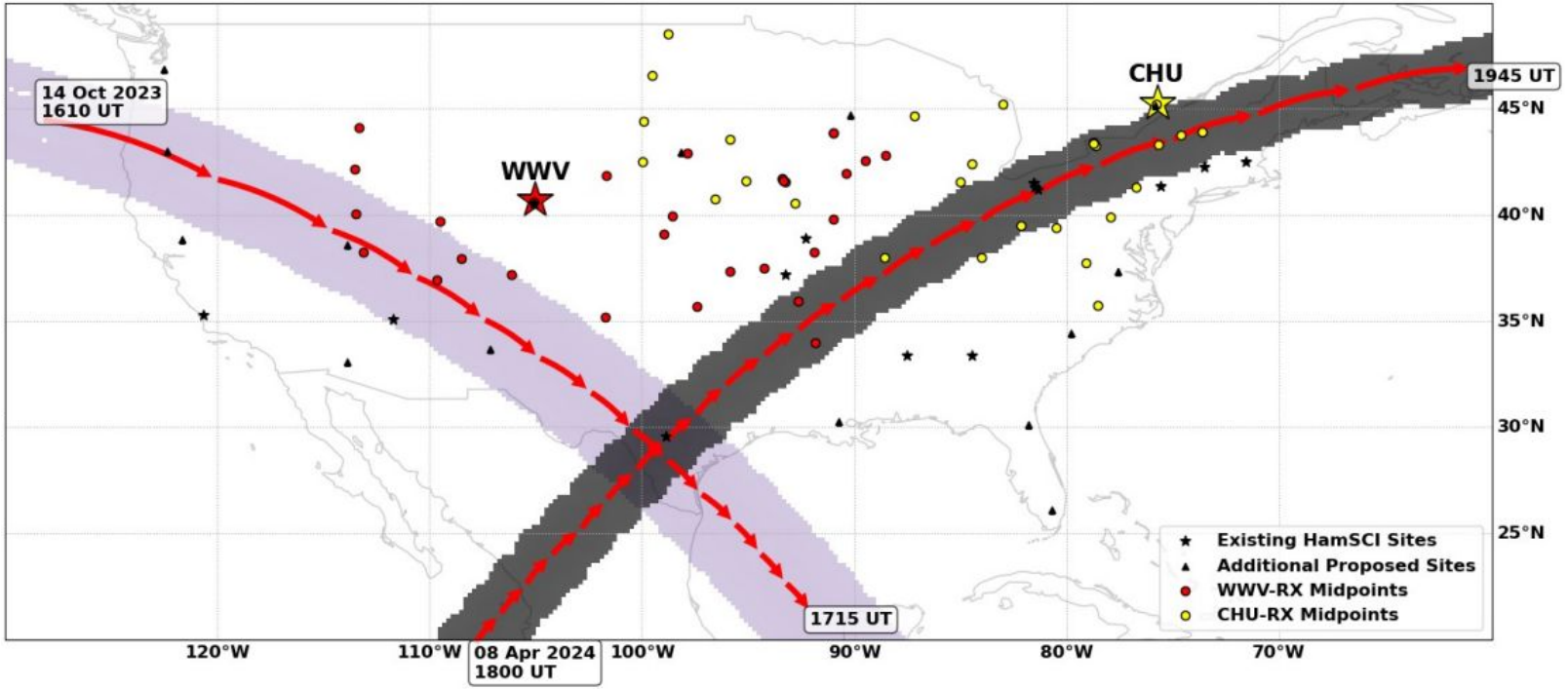
High Frequency Radio Signals

- **HF (3-30 MHz)** skywave signals used in global radio communications
- Doppler residuals of these signals can be used to remotely sense **bottomside ionosphere**
  - Fluctuations in TEC and electron density
- A **Grape V1** PSWS node can monitor a single HF channel with continuous time resolution along a single path (Collins[3] et. al.)



Adapted from: Space Weather Prediction Center[1]

Current / Future Grape Network Coverage



Objectives

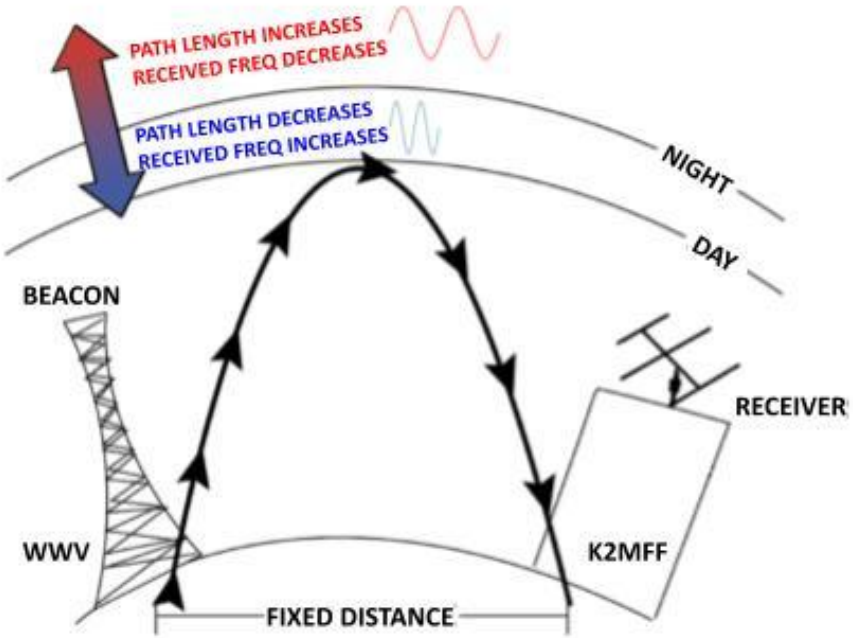
1. **Investigate** the behavior of HF signals with respect to doppler residuals over time

2. **Identify** and **characterize** periodic patterns found in residual data

3. **Correlate patterns** with relevant geospace phenomena

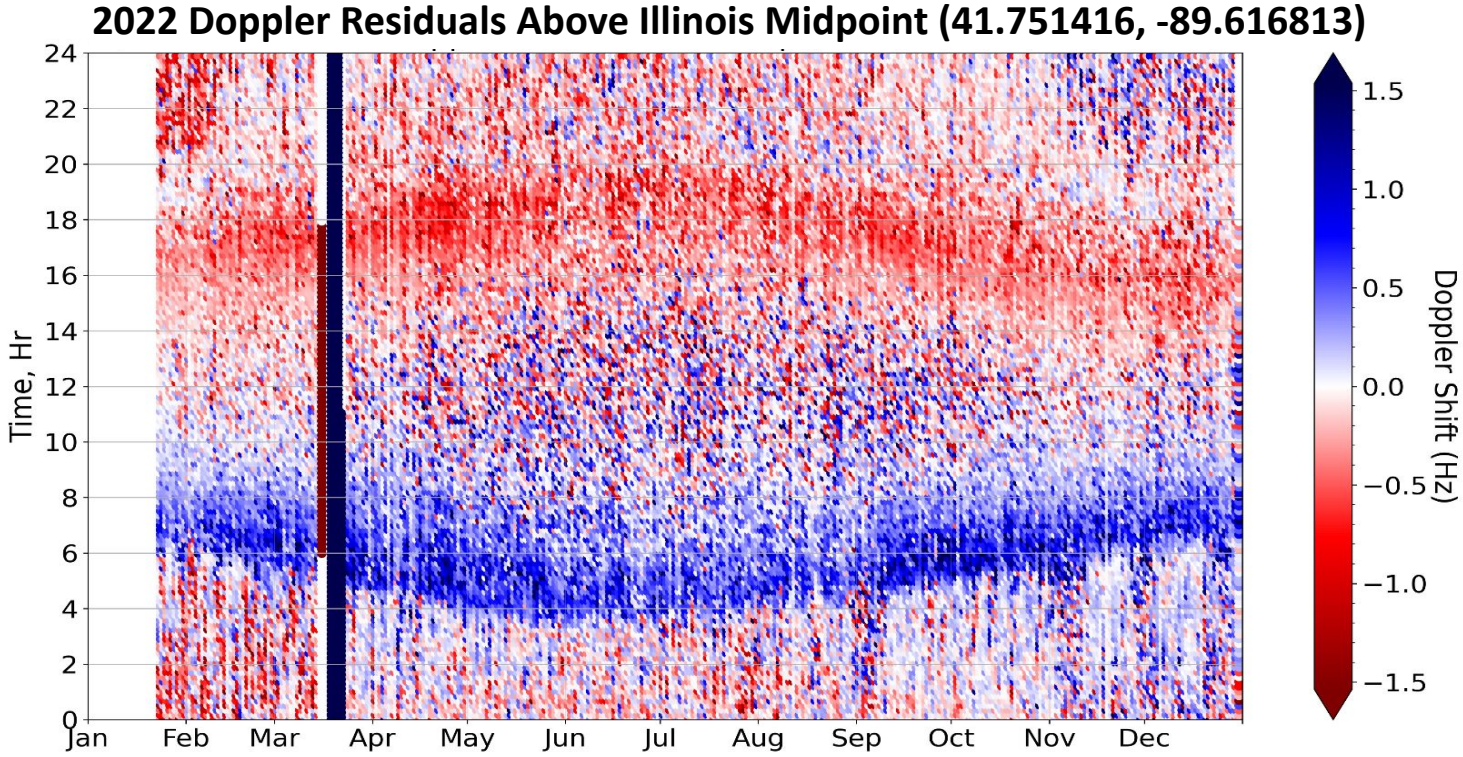
Methodology: Setup

- Grape V1 **low-IF receiver** (K2MFF) installed with a 30m inverted vee antenna tuned to 10MHz at NJIT in Newark, New Jersey
- 10MHz signal is generated by the NIST radio station **WWV** in **Fort Collins, Colorado**
  - GNSS disciplined oscillator produces an extremely stable signal
- **Difference** between peak received signal and 10MHz taken as 'doppler residual'
  - Sampling rate of 1Hz

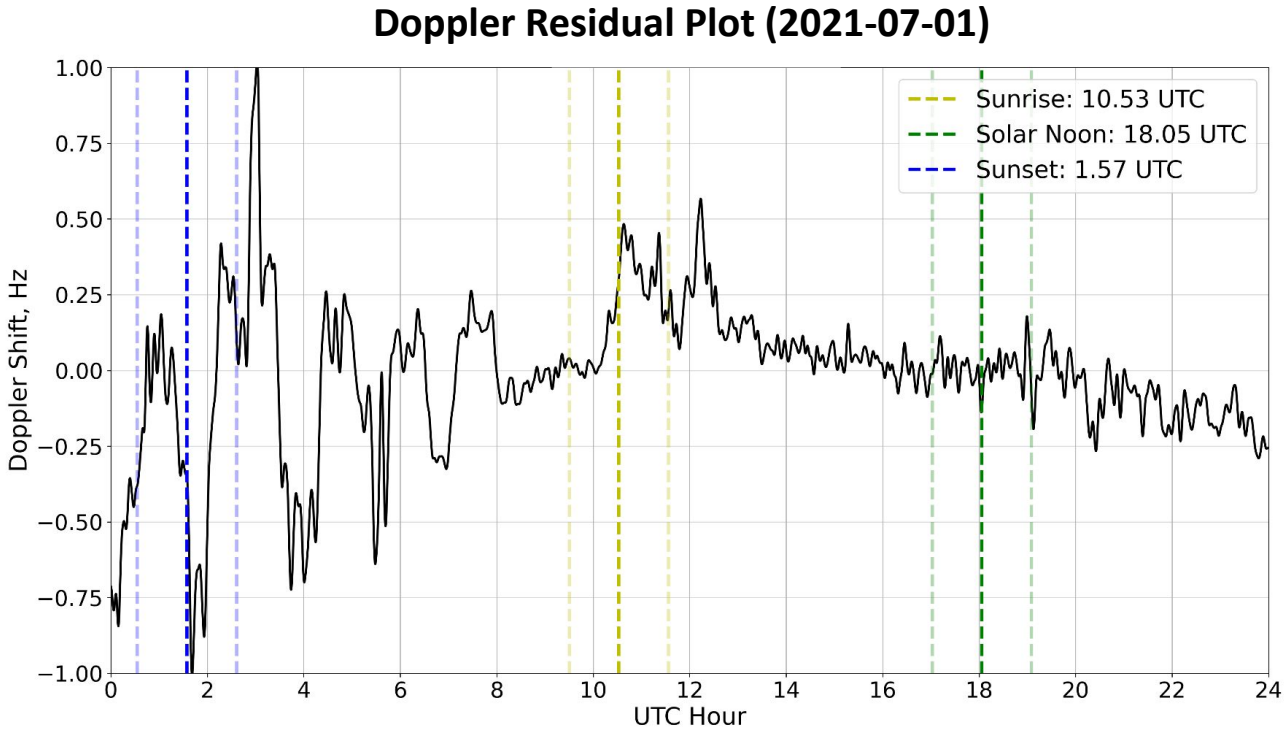


Adapted from: Collins[2] et al.

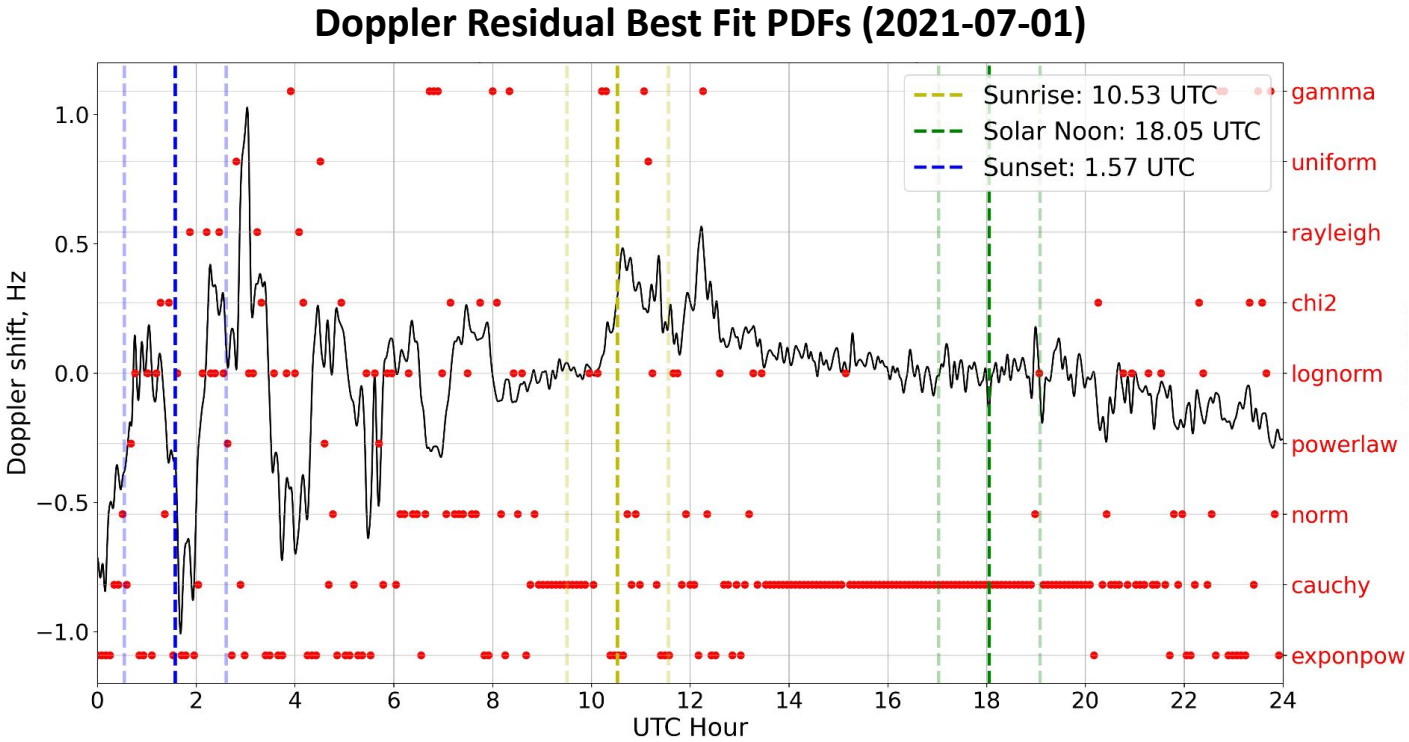
Methodology: Aggregate Data



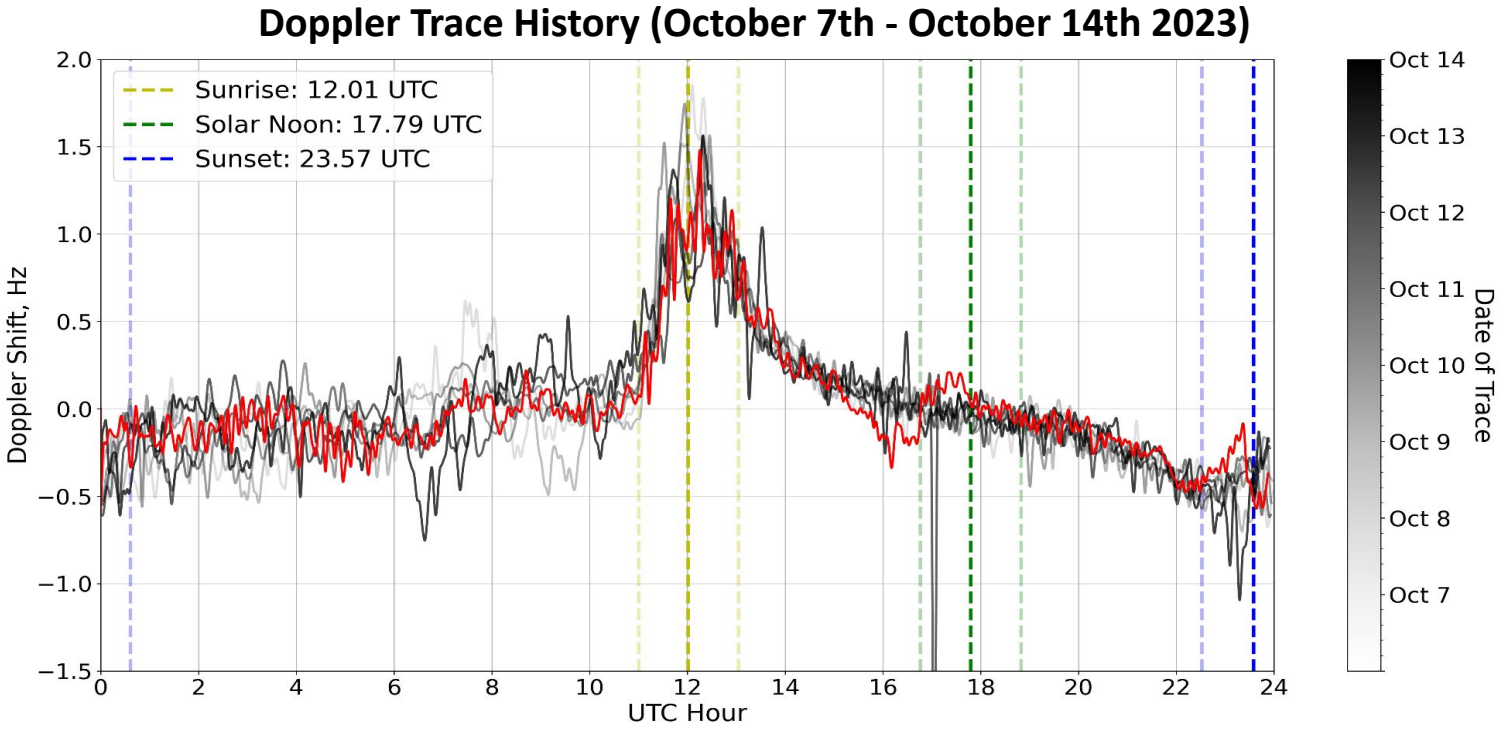
Methodology: 24-Hour Data



Results: Best Fit Probability Distribution



2023 Annular Eclipse



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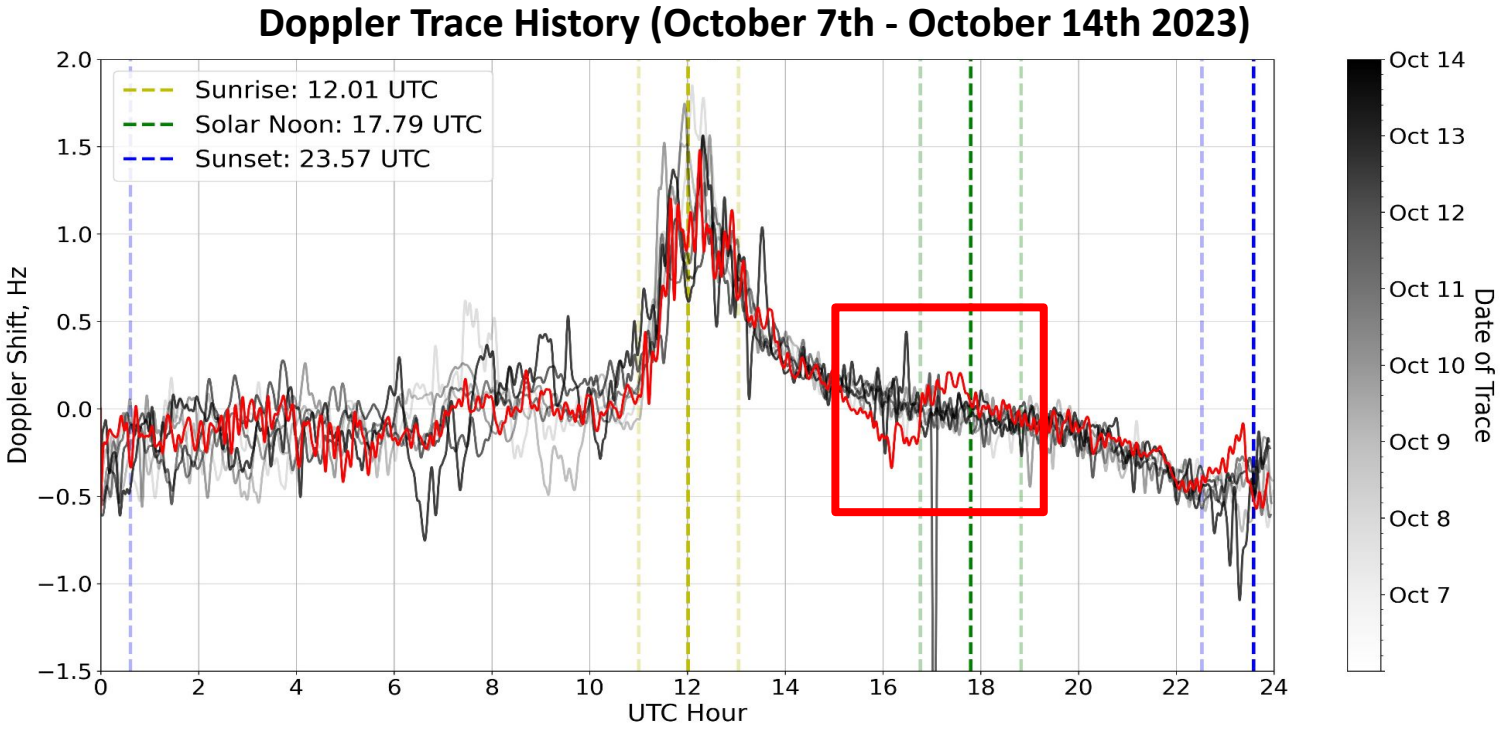

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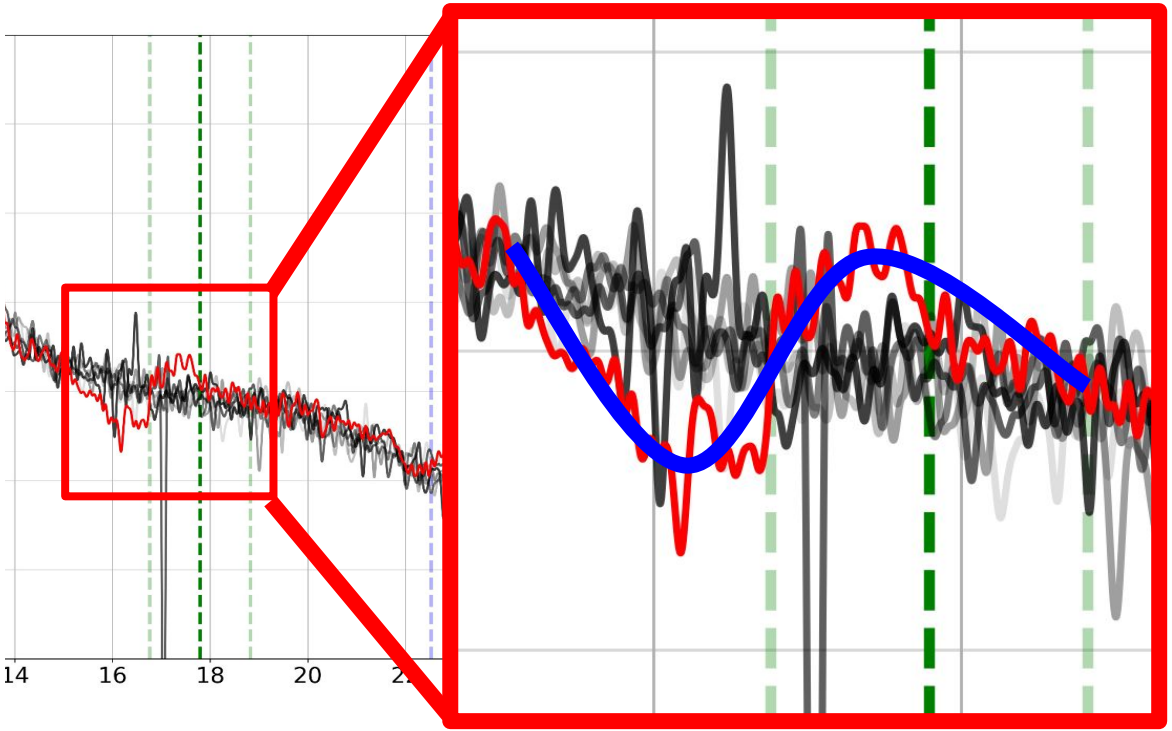
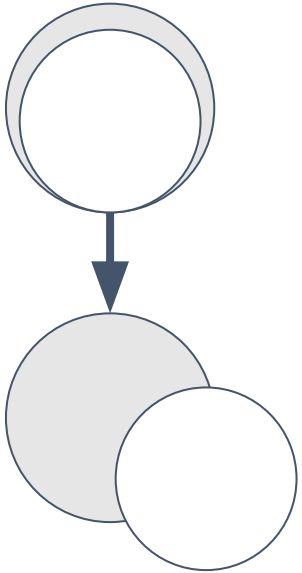


“S” - Feature



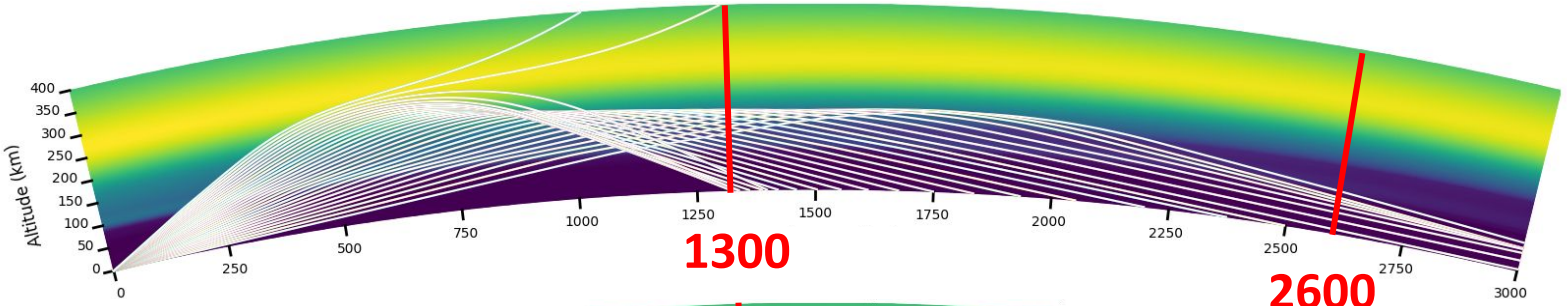
Deionization

Reionization

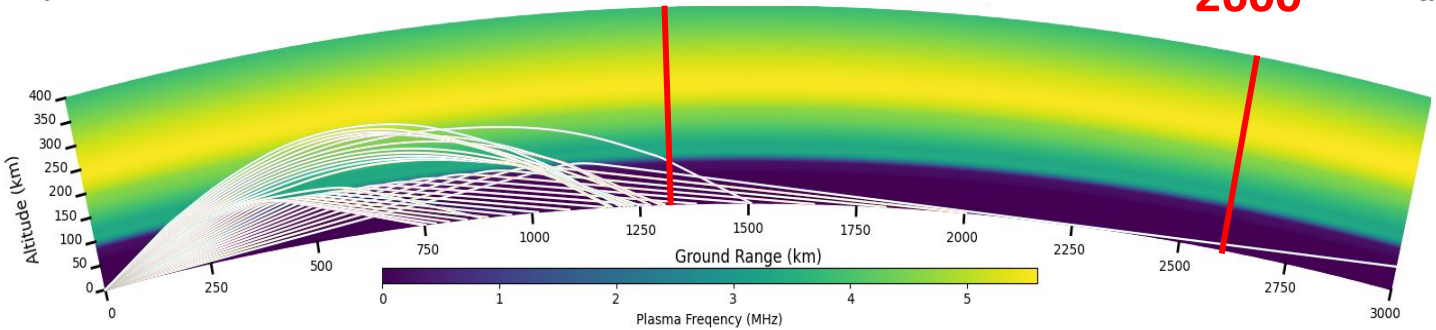
Results: Single Hop Ray Tracing

10 MHz Rays from WWV to K2MFF (7-1-2021)

1.57 UTC (Sunset)



18.05 UTC (Solar Noon)



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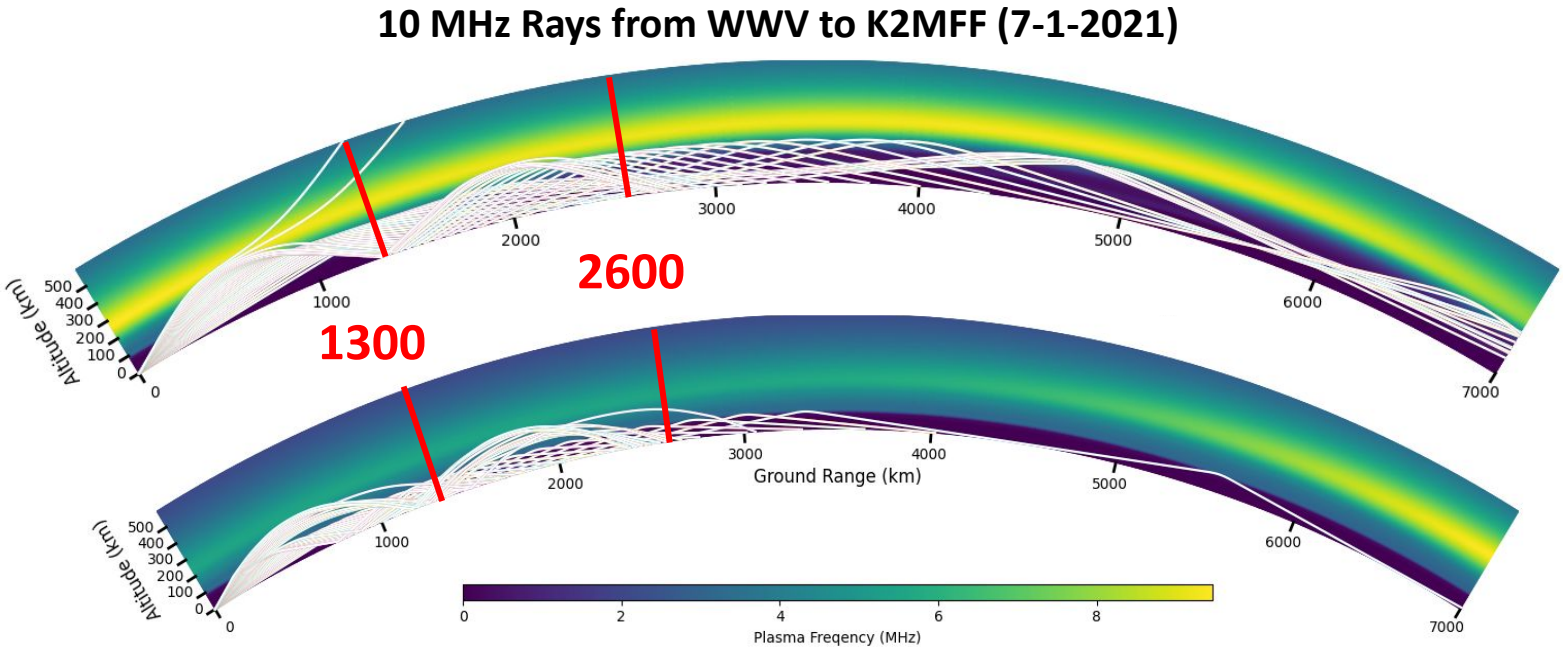
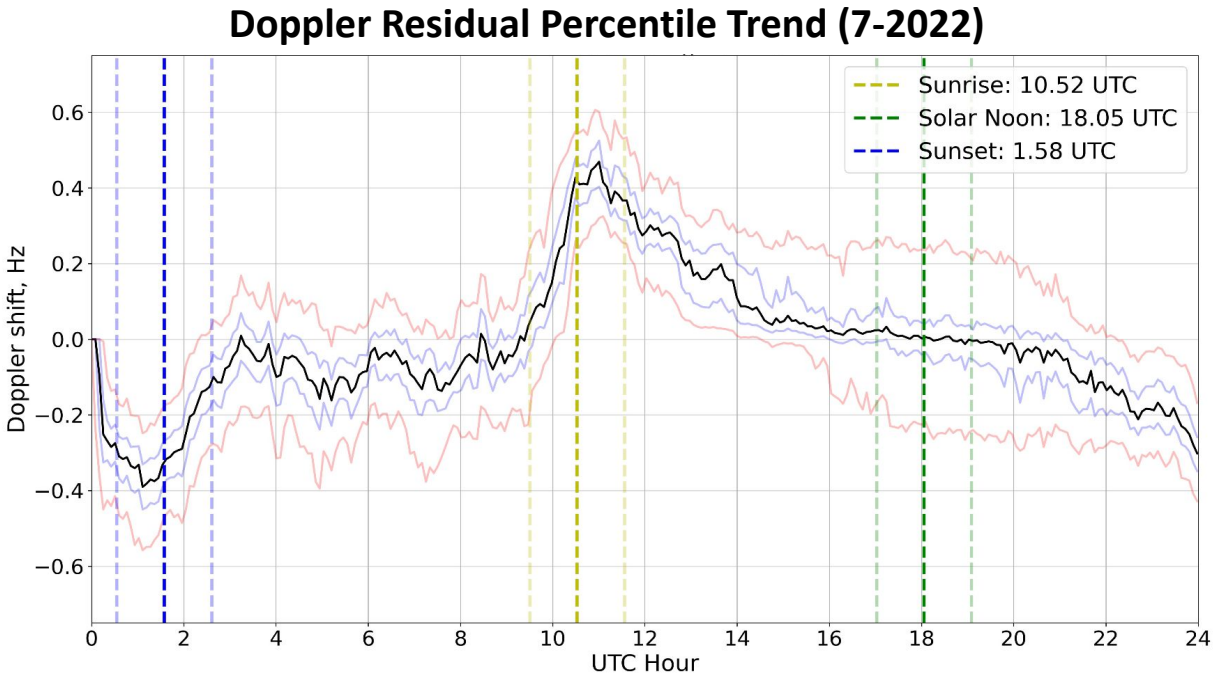


Discussion

- **Median** (50th percentile) was chosen as the most representative statistic to characterize **longer-term** residual trends



Conclusions

1. A connection between **incident solar irradiation** above the **midpoint** of HF signal travel was established

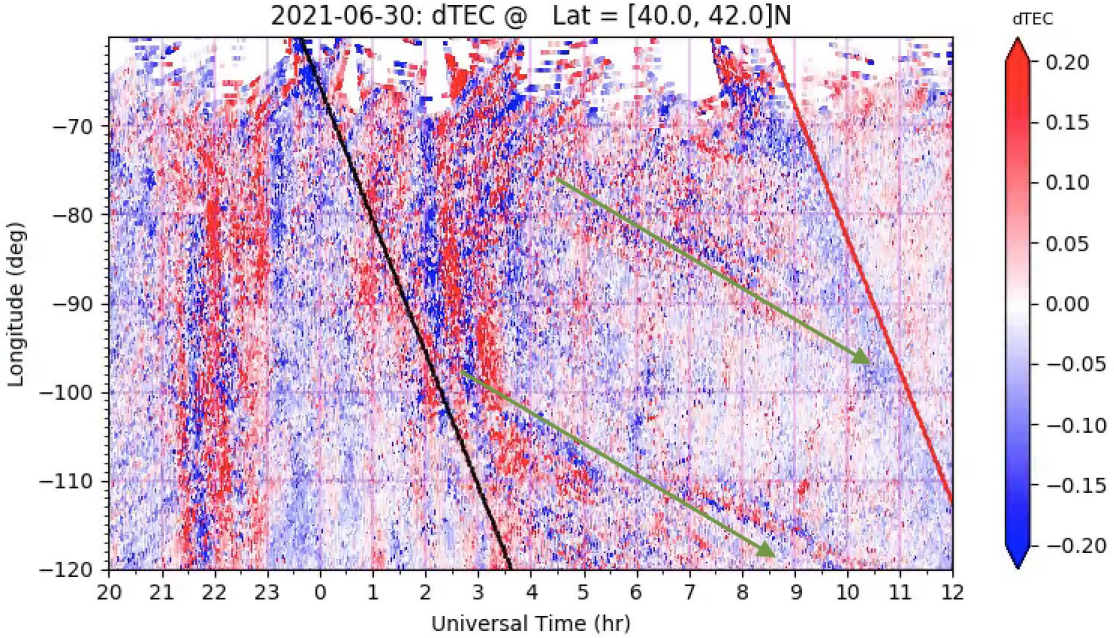
2. A strong **Cauchy distribution** was associated with 5-minute bins of data collected between sunrise and sunset

3. The Grape receiver was **sensitive** enough to detect changes in **ionospheric electron density** due to geospace phenomena

Future Work

- **Correlate** patterns in Grape dataset with other datasets monitoring **different geospace phenomena**

- Assess the impact of **multipath signal travel** on the signal



Courtesy of: Shunrong Zhang of MIT Haystack

Thank You – Questions?

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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.

[3] Collins, K., Gibbons, J., Frissell, N., Montare, A., Kazdan, D., Kalmbach, D., Swartz, D., Benedict, R., Romanek, V., Boedicker, R., Liles, W., Engelke, W., McGaw, D. G., Farmer, J., Mikitin, G., Hobart, J., Kavanagh, G., and Chakraborty, S.: Crowdsourced Doppler measurements of time standard stations demonstrating ionospheric variability, Earth Syst. Sci. Data, 15, 1403–1418, https://doi.org/10.5194/essd-15-1403-2023, 2023.