Modeling HamSCI HF Doppler Observations with PyLAP/SAMI3 in Preparation for the 2023/2024 North American Solar Eclipses

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Abstract

The HamSCI Personal Space Weather Station (PSWS) network is composed of ground-based space physics instrumentation aimed at Citizen Scientists and the amateur radio community. This instrumentation includes Grape receivers, which are low-cost high frequency (HF) Doppler receivers that use GPS-disciplined oscillators to make precise frequency measurements of signals from standards such as WWV. These measurements can provide insight into ionospheric variability, including Traveling Ionospheric Disturbances (TIDs), diurnal variations, and ionospheric impacts due to Solar eclipses. Plans are underway to use this system to take ionospheric measurements during the upcoming October 14, 2023 annular and April 8, 2024 total North American solar eclipses. These observations, combined with eclipsed versions of physics-based SAMI3 ionospheric model, will be used to address the following research questions: (1) How do dawn and dusk ionospheric variability change with local time, season, latitude, longitude, frequency, distance, and direction from the transmitter, (2) how is the ionospheric effect symmetric with respect to onset and recovery, (3) how are eclipse effects similar to typical diurnal variations, (4) will the multipath HF mode-splitting be similar to the effect of dawn, and (5) would these behaviors be different for two different eclipses? This poster presents initial SAMI3 model predictions of the eclipsed ionospheres and demonstrates the use of the PyLAP raytracing toolkit to model HF Doppler Observations collected by Grape receivers.

Fig. 1 Eclipse Paths for the 2023 annular eclipse (in red) and the 2024 total solar eclipse (blue).

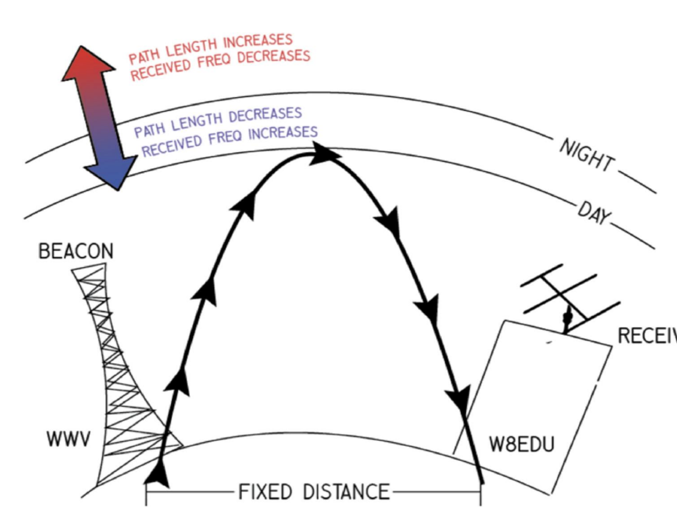
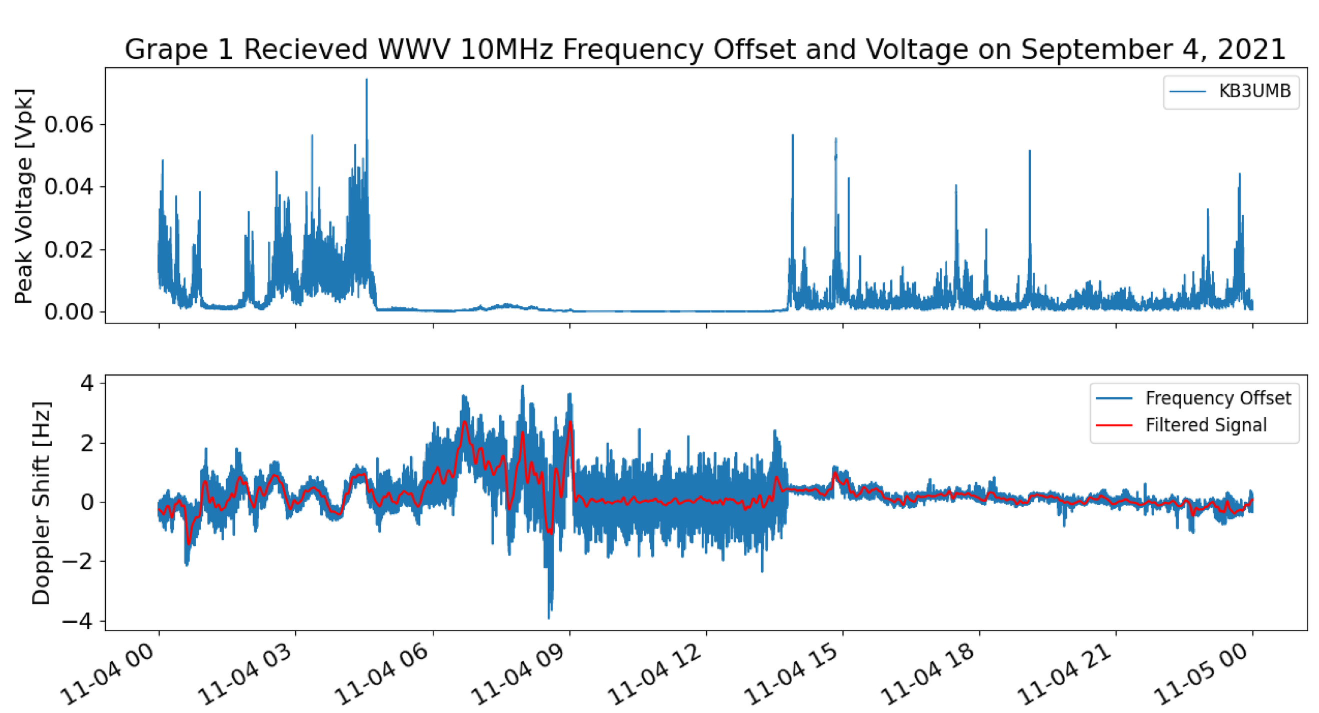


Fig. 2 Basic ionospheric signal propagation model undergoing doppler shift. Image from K. Collins (2021).

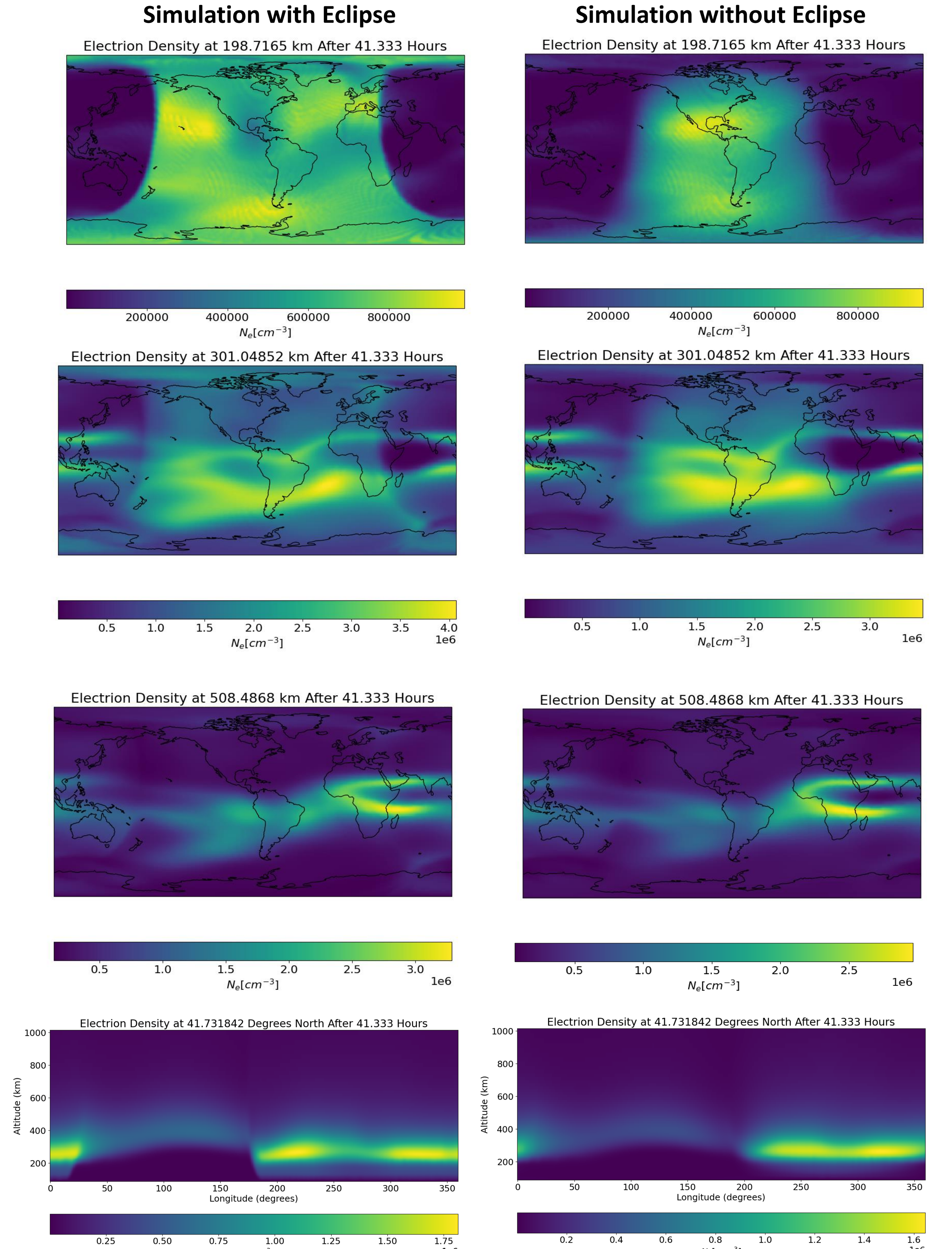
Method and Data

If we want to gain an insight into the behavior of a signal passing through a varying ionosphere, we need to consider the possible state of the medium itself, and the behavior of electromagnetic waves refracting through the medium. The SAMI3 model makes an estimate of the state of the atmosphere caused by an eclipse, whereas the PyLAP will give us a way to visualize the path of a signal from WWV to a Grape receiver.



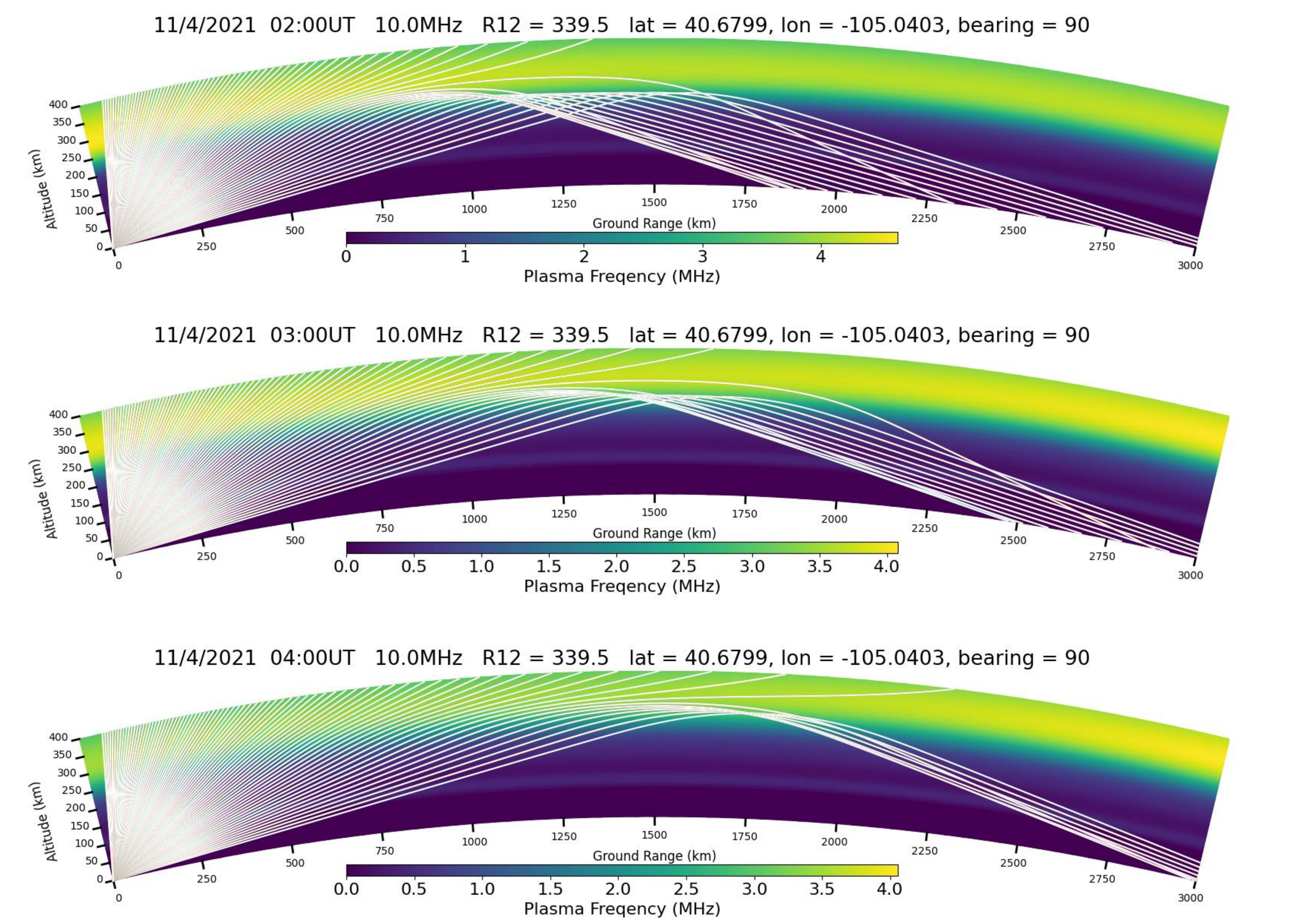
The SAMI3 Simulation for the 2023 Eclipse is an initial result provided by J. Huba. After interpolation steps, the graphs below show the electron density of the atmosphere at various altitudes, as well as a vertical cut across a close latitude to WWV. The PyLAP images are generated based on the location and frequency of the WWV 10 MHz transmitting antenna in Fort Collins, Colorado using the International Reference Ionosphere (IRI), which does not account for eclipse effects. The grape data shown for the same date was collected by A. Montare in Collegeville, Pennsylvania.

Simulation with Eclipse | **Simulation without Eclipse**



Discussion

We can see the deviation in the Grape data (just before sunrise) caused by an ionospheric oscillation with large scale (1-3 hour) period which varies from the smooth, modeled transition above. Further work may focus on smoothing the current SAMI3 simulation and integrating it with the current PyLAP ionospheric simulation, which is based on IRI 2016, to account for more localized ionospheric variation and resulting change in the path of the signal.



Acknowledgements

This work would not be possible without Kristina Collins, John Gibbons and the HamSCI Grape PSWS Group, as well as Nathaniel Frissell and the PyLAP team at the University of Scranton. The SAMI3 model information was generated and provided by Joe Huba.

The results in this poster were obtained using the HF propagation toolbox, PHaRLAP, created by Dr Manuel Cervera, Defence Science and Technology Group, Australia (manuel.cervera@dst.defence.gov.au). This toolbox is available from https://www.dst.defence.gov.au/opportunity/pharlap-provision-high-frequency-raytracing-laboratory-propagation-studies.

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References

Nelson GK, Lombardi MA, and Okayama DT, National Institute of Standards and Technology (2005) NIST Time and Frequency Radio Stations: WWV, WWVH, and WWVB. (Technology Administration, Department of Commerce), NIST Special Publication 250-67.

Kristina Collins, John Gibbons, David Kazdan, & Nathaniel Frissell. (2022). Grape V1 Data: Frequency Estimation and Amplitudes of North American Time Standard Stations [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7690381

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.

Collins, K., Montare, A., Frissell, N. A., & Kazdan, D. (2021). Citizen Scientists Conduct Distributed Doppler Measurement for Ionospheric Remote Sensing. IEEE Geoscience and Remote Sensing Letters. doi: 10.1109/LGRS.2021.3063361

Gibbons, J., Collins, K., Kazdan, D., & Frissell, N. (2022). Grape Version 1: First prototype of the low-cost personal space weather station receiver. HardwareX, 11, e00289. doi: 10.1016/J.OHX.2022.E00289