HF Doppler Observations of Traveling Ionospheric Disturbances in a WWV Signal Received with a Network of Low-Cost HamSCI Personal Space Weather Stations

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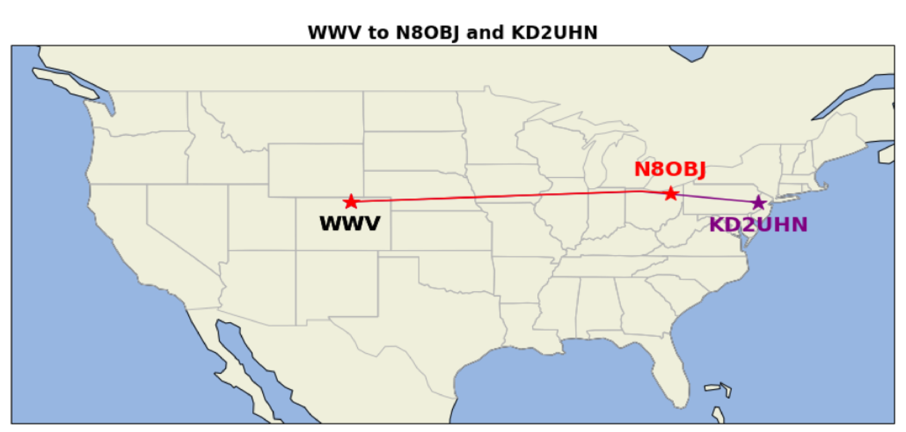
Abstract

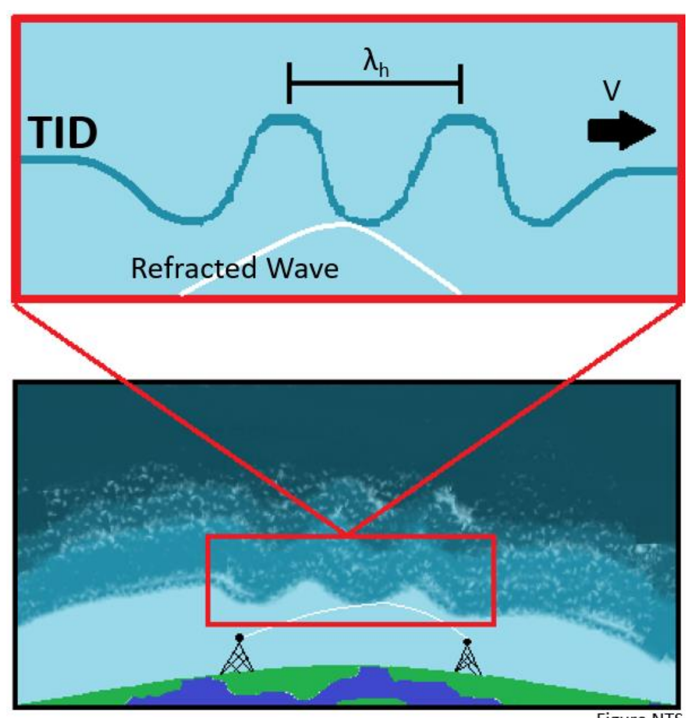
Traveling Ionospheric Disturbances (TIDs) are quasi-periodic variations in ionospheric electron density that are often associated with atmospheric gravity waves. TIDs cause amplitude and frequency variations in high frequency (HF, 3- 30 MHz) refracted radio waves. The authors present an analysis of observations of TIDs made with Ham Radio Science Citizen Investigation (HamSCI) Low-Cost Personal Space Weather Stations (PSWS) located in Northwestern New Jersey and near Cleveland, Ohio. The TIDs were detected in the Doppler shifted carrier of the received signal from the 10 MHz WWV frequency and time standard station in Fort Collins, CO. Using a lagged cross correlation analysis, we demonstrate a method for determining TID wavelength, direction, and period using the collected WWV HF Doppler shifted data.

Introduction

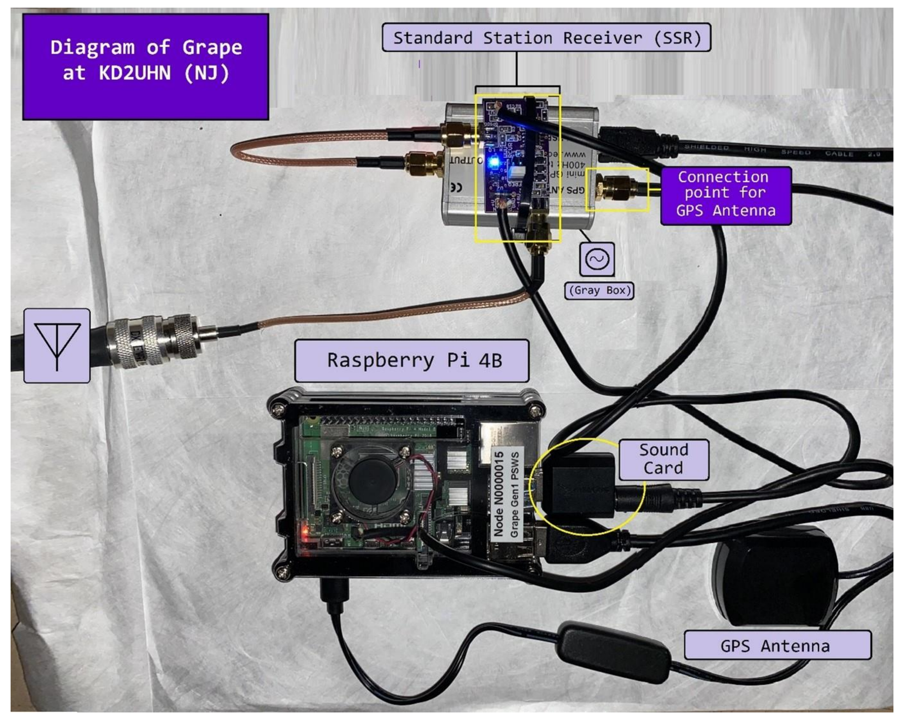


(FIGURE 1) The figure to the left depicts a map of a well-known United States Time Standard Station that transmits on extremely accurate frequencies (WWV) to 2 Grape Receivers discussed in this poster. There is currently a network of Grapes up and running across the USA, but the authors are particularly interested in these 2 due to their geographical locations, which are beneficial to studying the propagation direction of TIDs.

Traveling Ionospheric Disturbances (TIDs) are a space weather effect that are generated by propagating gravity waves or geomagnetic activity. These waves disturb the electron density in the ionosphere and create moving, wavelike irregularities of charged particles in a planet's atmosphere (TID). TIDs can have an impact on HF communications, GPS systems, and any other technology that relies on the ionosphere to work properly. It is important to study them because they can help to further the understanding of how energy moves from one place to another. The content of this poster explores TIDs detected via 2 Grape Personal Space Weather Stations (PSWS).



(FIGURE 2) The image above portrays a Traveling Ionospheric Disturbance (TID). Note that radio waves that refract off the ionosphere can be used to detect TIDs. This poster presents a method that can be used to determine their propagation direction, depicted by the black arrow near the top of the figure. Lambda indicates the TID wavelength and V indicates the TID velocity.

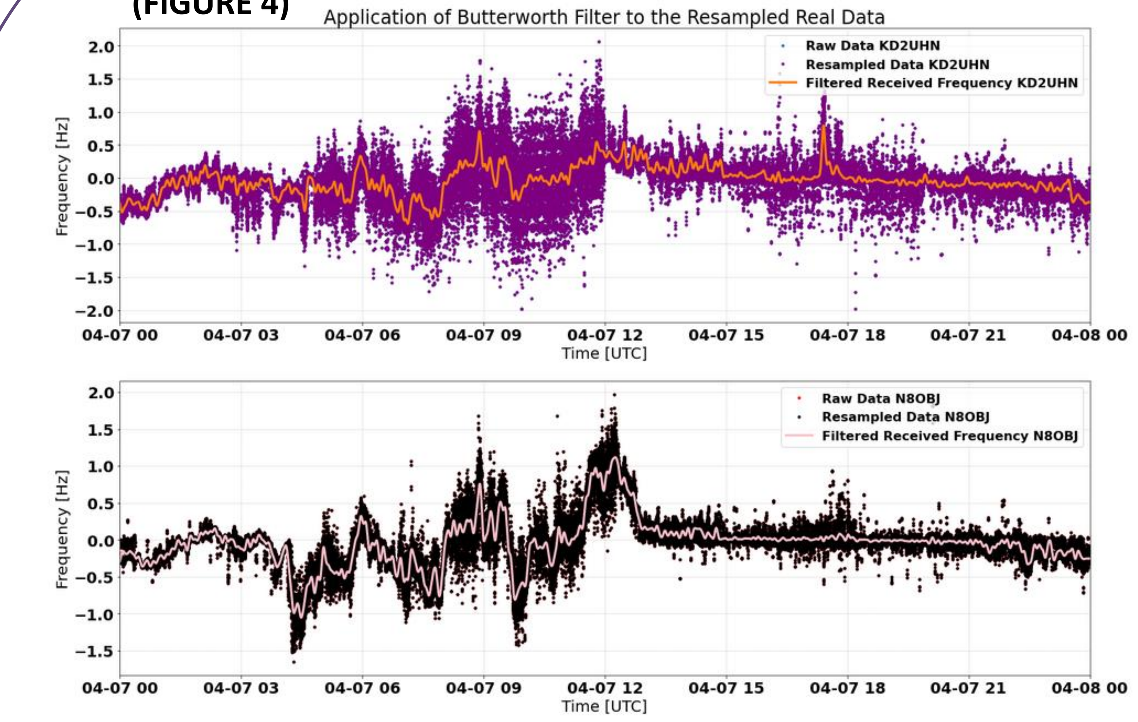


(FIGURE 3) This image depicts the setup and orientation of the Grape PSWS located in Northwest New Jersey. As outlined in the picture, the coaxial cable from the antenna connects to a Standard Station Receiver (SSR). A GPSDO also connects to the SSR. An SSR connects through a sound card to the Raspberry Pi 4B single board computer which allows the data to be transmitted and stored on the internet. The data collected each day can be accessed using a VPN into the Raspberry Pi 4B. That makes it accessible from remote locations.

The Grape Personal Space Weather Station is a small measurement platform that can be used to make ground-based observations of the space environment. It was developed by the Ham Radio Science Citizen Investigation (HamSCI) and its members at Case Western. Each day, the Grapes collect a dataset that is used to automatically output a figure showing the Doppler-shifted data from that same day.

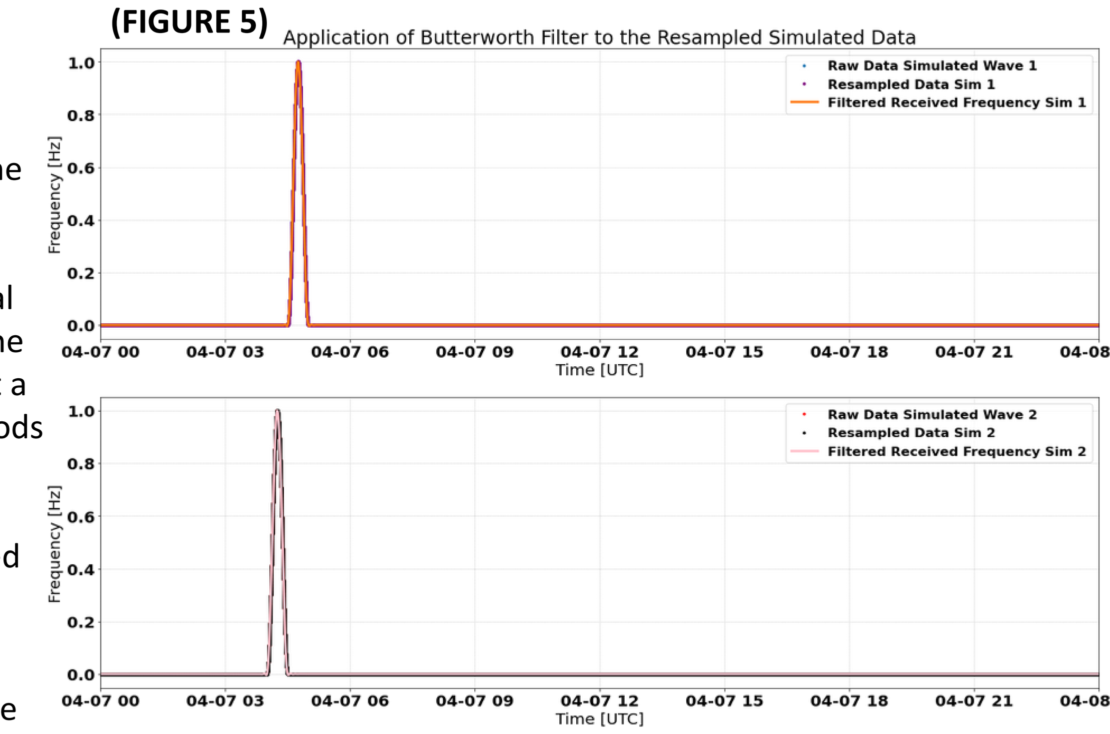
Method and Data Analysis

(FIGURE 4)

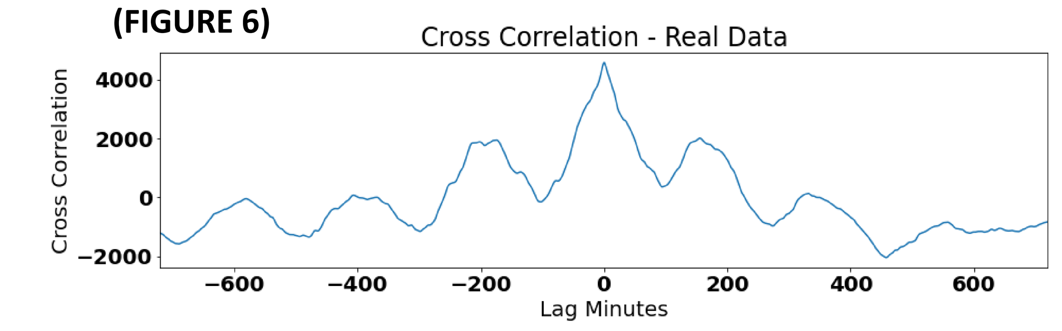


(FIGURES 4 and 5) The figure to the left depicts a resampled and interpolated Doppler shifted 10 MHz carrier frequency from WWV. This data was collected on April 7, 2021. The top figure shows data collected from KD2UHN in NJ, and the bottom one shows data from N8OBJ in OH. As indicated in the legend, the thin line in the middle of each plot represents frequency data that has been passed through a lowpass Butterworth filter. The figure to the right depicts two artificial "pulses". These pulses were generated by manipulating cosine waves in Python. The purpose of these pulses is to represent a fragment of a TID that can be used to explore possible methods to ultimately determine its propagation direction. Simulated Wave 1 has been offset 30 minutes from Simulated Wave 2. Because the authors know which wave is seen first (Simulated Wave 2), they will be able to determine the direction that a real TID is moving, once this process is applied to real data.

(FIGURE 5)

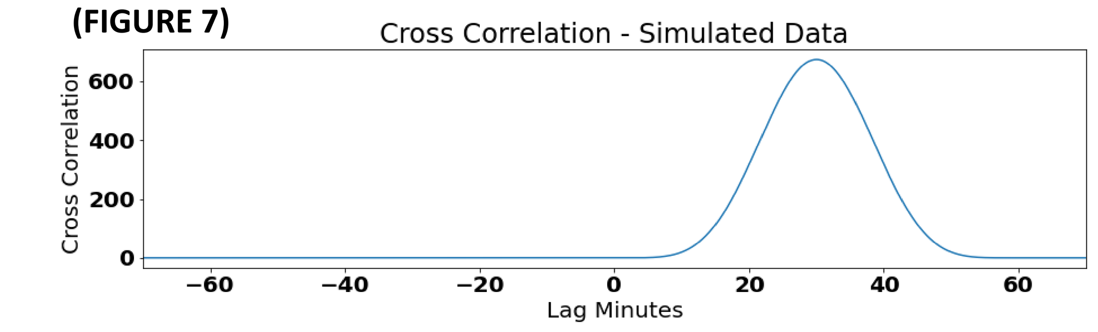


(FIGURE 6)

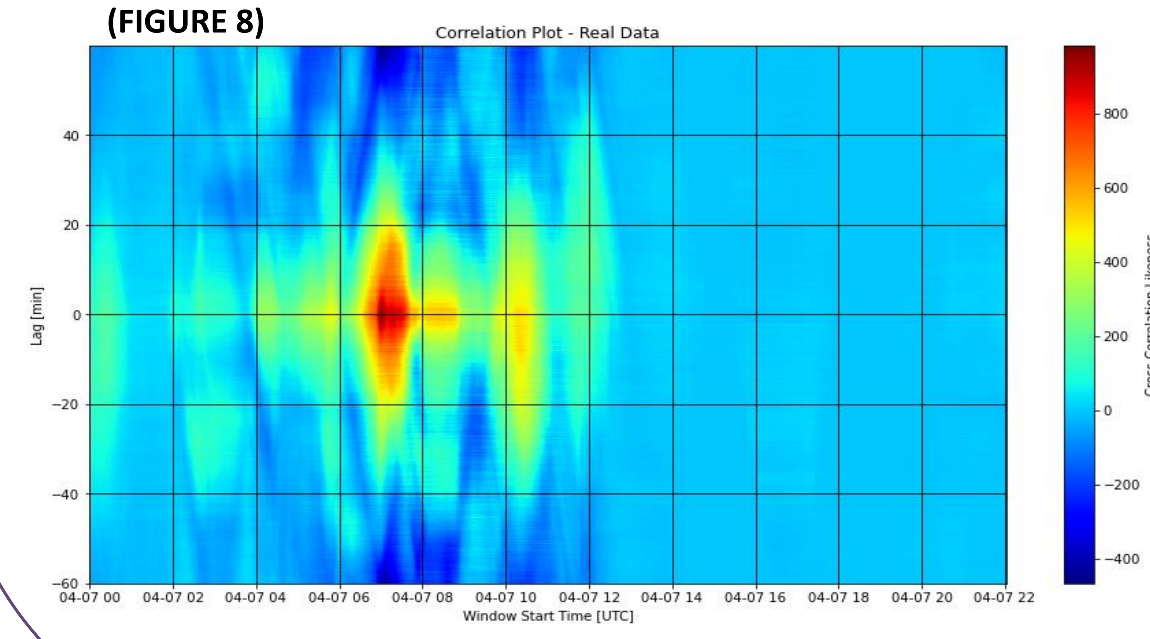


(FIGURES 6 and 7) show a cross correlation of the data above each respective plot. The highest peak in the figure indicates the point of greatest correlation, or where the waves line up the most. The location of the peak with respect to the x axis shows how far apart the wave (or TID) was spotted at each station. The real data (left) suggests that the TID detected on April 7, 2021 was seen at relatively the same time by both KD2UHN in NJ and N8OBJ in OH. The data on the right was intentionally created to show how the lag value can help to understand where a TID occurs first.

(FIGURE 7)

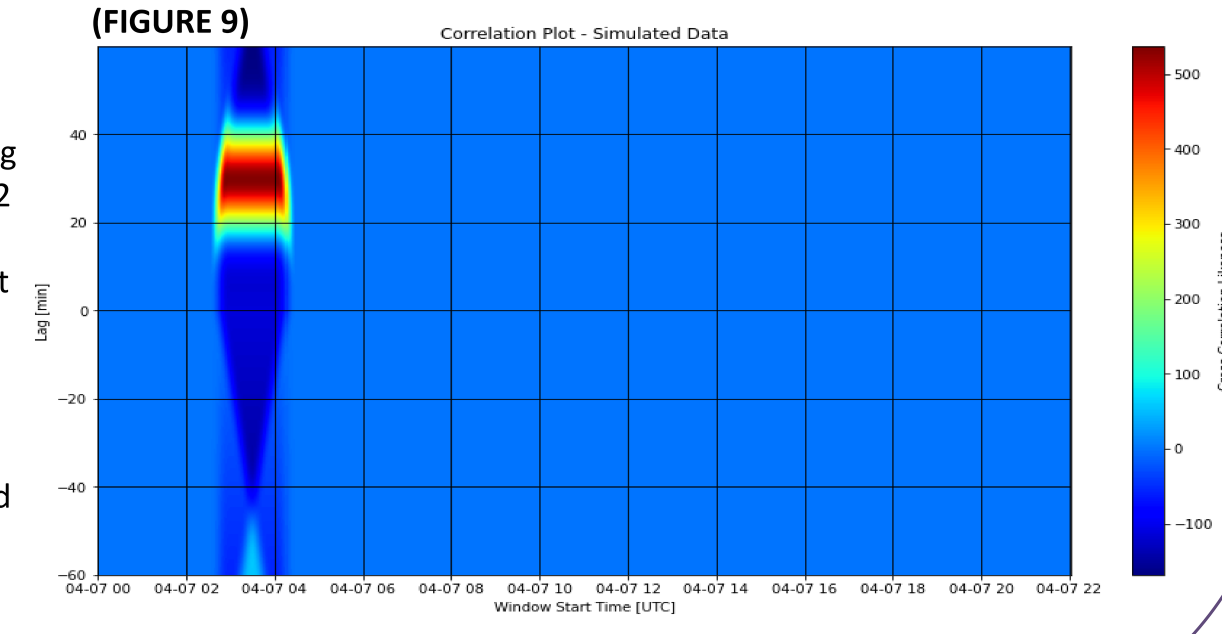


(FIGURE 8)



(FIGURES 8 and 9) depict a sliding cross correlation of the respective real (left) and simulated (right) data. To complete this process, the authors created 2 minute sliding windows that move across an entire day in increments of 2 hours. As the windows slide, a cross-correlation is performed. Then, this data is plotted as a pseudocolor plot that shows the lag values (or how far apart the TID was detected at each station) which is also seen in Figures 6 and 7, the time of day, and the correlation likeness for the TID detected by each station. By looking at this data, it becomes possible to determine where the TID was spotted first. The current orientation of the 2 stations discussed in this poster (KD2UHN and N8OBJ) allows for determining which station first sees the TID and by how much time.

(FIGURE 9)



Conclusion

In conclusion, a method is actively being developed to determine which of 2 stations observes Traveling Ionospheric Disturbances (TIDs) detected by the Grape PSWS first. This poster shows the results of this process being used on both simulated data as well as real data that has been collected with 2 different Grape Personal Space Weather Stations, one of which is located in New Jersey (KD2UHN) and the other of which is located in Ohio (N8OBJ). The purpose of the simulated data portrayed in this poster is to illustrate the process with known factors manipulated by the authors to allow for a better interpretation of real results from the data collected by the Grapes. The process described in this poster entails first collecting the data, then applying a lowpass Butterworth filter, and ultimately performing a sliding cross correlation. Then, a pseudocolor plot is generated that shows the lag value (how far apart the TID was detected at each station), the time of day it was detected, and the likeness of the correlation, to determine where the TIDs detected by each station line up best. With this process, it becomes possible to identify which station first saw the TID and how far apart the TID was observed by each Grape.

Future Work

In the future, the authors plan to expand upon the method discussed in this poster to be able to determine the propagation direction of a TID in any direction. To do this, they will begin to use data from 3 Grape receivers located in a triangular orientation within the United States. This type of layout of receivers would be ideal because it would allow for triangulation of the data over a known region, as opposed to the linear set-up being used now. Furthermore, the authors are going to work to develop a method to determine the wavelength of the TIDs they detect as well as the TID velocity.

References

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