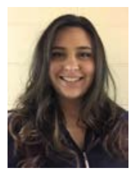
A Survey of HF Doppler TID Signatures Observed Using a Grape in New Jersey

Veronica Romanek (1), Nathaniel A. Frissell (1), William Liles (2), John Gibbons (3), Kristina Collins (3), David Kazdan (3)

(1) The University of Scranton, (2) HamSCI Community, (3) Case Western Reserve University



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INTRODUCTION

The Grape Personal Space Weather Station(PSWS) is an instrument that has been developed by members of the Ham Radio Science Citizen Investigation (HamSCI) community from Case Western Reserve University (Collins et. al., 2021a (https://hamsci.org/publications/hf-propagation-measurement-techniques-and-analyses), 2021b (https://hamsci.org/publications/low-cost-citizen-science-hf-doppler-receiver-measuring-ionospheric-variability)). It is a small measurement platform that can be used to make ground-based observations of the space environment. It comprises a Raspberry Pi 4B, a Leo Bodnar mini GPS Discipline Oscillator (GPSDO), and a custom receiver board. It is constantly collecting data and works by using a single channel and antenna. There are currently 15 Grapes set up and collecting data around the United States including places like Ohio, New Jersey, Pennsylvania, and others. This poster will focus on the specific use of a Grape Personal Space Weather Station and its use in obtaining data on various disturbances detected in the ionosphere. The Grape contributing data to this poster is located in Northwest New Jersey.

EXPLANATION OF WWV

(FIGURE 1) This is a picture of the 15 MHz antenna from WWV. The 10 MHz are of a similar design. *Source: National Institute of Standards and Technology (NIST) (http://file:///C:/Users/HP/AppData/Local/Packages/microsoft.windowscommunicationsapps_8wekyb3d8bbwe/LocalState/Files/S0/3/Attachments/sp250-67[4043].pdf).*

About WWV

WWV is a radio station located in Fort Collins, Colorado. It is well-known as a United States Frequency Standard which is extremely accurate as to what frequency it is transmitting on. The station runs in the HF (High Frequency) range of the radio spectrum. WWV transmits at 2.5 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz, and experimentally on 25 MHz. For the purposes of this poster, we will consider the transmission that occurs at 10 MHz. Similarly, the station transmits a very accurate time signal, with an error margin of 10^-7 seconds. The station operates by using 10,000 W. Another important consideration is that the station is continuously transmitting at all hours of the day, every day of the week. This means that it can be monitored constantly and used to observe disturbances in the ionosphere at any given point in time, which is why it is being monitored by the Grape. WWV utilizes an omnidirectional half-wave vertical antenna. (History of Radio Station, 2021)

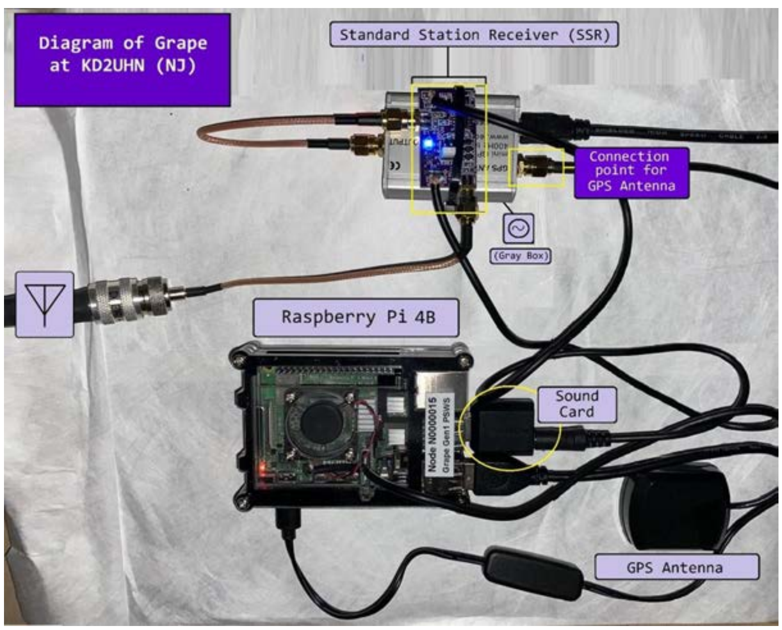
METHOD/ EXPERIMENT

Where is the KD2UHN Grape?

(FIGURE 2) The map shown above depicts the path traveled by radio waves transmitted by WWV (left) and received by KD2UHN (right). Notice, due to the distortions of a 2-Dimensional map, the radio wave does not propagate in a straight line on the map, so the Great Circle Path appears curved. This map was generated using cartopy in the Python language.

What is the Grape?

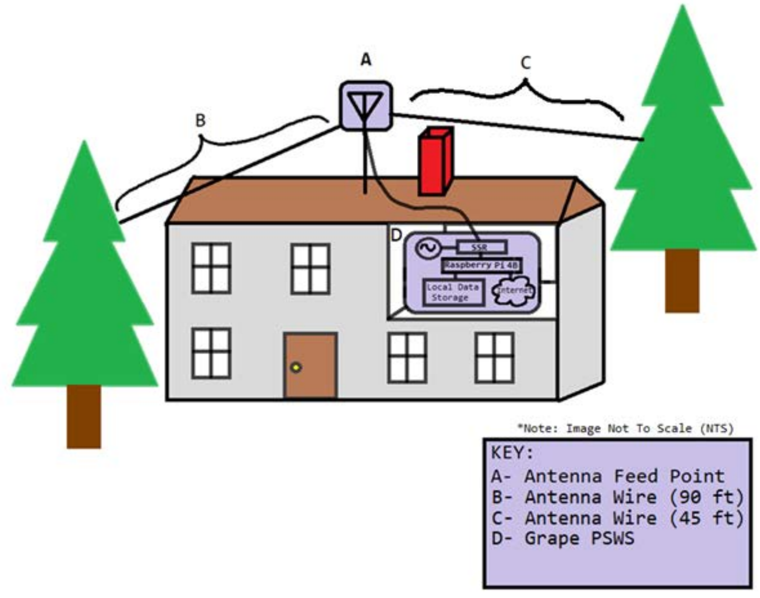
The Grape PSWS consists of a Leo Bodnar mini GPS Discipline Oscillator (GPSDO), a sound card, a custom receiver board, and a Raspberry Pi 4B which the processing software runs on. It is operated by using a single WWV transmitter and a Buckmaster Off Center Fed (OCF) Dipole Antenna. The Grape itself is powered via a regular household outlet. The GPSDO maintains a frequency stability of better than ±0.001 Hz at 10 MHz (Gibbons, 2021)



(FIGURE 3) The picture shown above depicts the setup and orientation of the Grape located in Northwest New Jersey. As outlined in the picture, the coaxial cable from the antenna connects to the Standard Station Receiver (SSR). The GPSDO also connects to the SSR. The 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 Off-Center Fed (OCF) Dipole Antenna of the Grape continuously receives WWV signals at 10 MHz. At the same time, the GPS antenna is listening to signals from the GPS satellites. The GPSDO uses the signal received by the GPS antenna to produce a very stable 9.999 MHz output signal. *The receiver board mixes the signals received by the OCF Dipole Antennas (10 MHz from WWV) with the 9.999 MHz signal produced by the GPSDO to produce a difference signal of 1 kHz to provide an analog signal to the sound card. The sound card takes this analog signal that from the Grape and digitizes it and sends it to the RPi4B. The incoming signal is analyzed using the frequency analysis mode of the popular fldigi software package. A figure displaying the measurements is automatically produced each day at 00:00 UTC.

Northeast NJ Grape



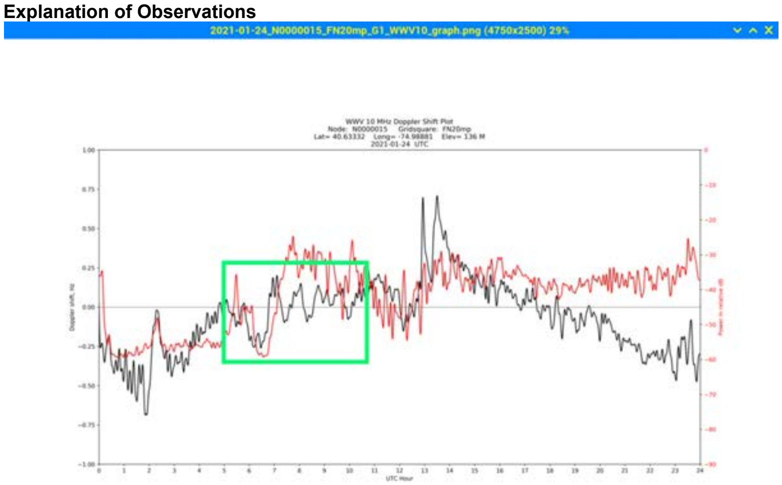
(FIGURE 4) The picture shown above depicts the setup of the Grape. The Buckmaster OCF Dipole Antenna is mounted roughly 30 feet high, on top of the roof. The wires (notated as B and C in the image) connect to the antenna feed point and are an approximate cumulative length of 135 feet (one side is 90 feet, the other is 45 feet long). There is about 25 feet of coaxial cable running from the antenna to the Grape. The orientation of the Grape at point D can be seen with a clearer depiction in Figure 3.

The Grape is a small measurement platform that can be used to make ground-based observations of the space environment. It comprises a Raspberry Pi 4B, a Leo Bodnar mini GPS Discipline Oscillator (GPSDO), and a custom direct down conversion receiver board. It is constantly collecting data and works by using a single channel and antenna.

The Grape is constantly collecting data, and that data is uploaded to a data base at 00:00 UT each day. The Grape is able to measure frequency variations of received signals, and uses a Single Frequency Discipline Oscillator for an accurate frequency standard. To measure the time delay between WWV and the Grape in New Jersey, calculations were performed by using the Great Circle Distance to determine the bearing angle between the station and WWV in Colorado, which was done in Python. This was used to determine the time variation in received signals between the two stations as radio waves propagate by refracting off the ionosphere. At 00:00 UT each day, a graph is output which shows the data from the previous day.

OBSERVATIONS

Explanation of Observations

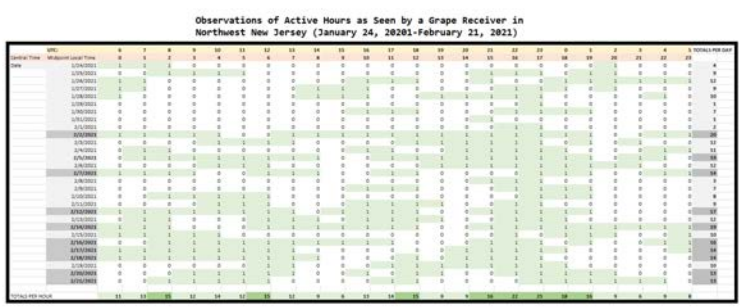


(FIGURE 5) As discussed in the methods section, a graph generated using the data collected by the Grape is shown above (NJ). The black line represents the change in the received WWV carrier frequency from 10 MHz in Hz. The red line represents measured signal strength. This graph provides a visual understanding of what the Grapes are looking to find: ionospheric disturbances. One such disturbance is outlined above in the green box. The box outlines a sinusoidal movement detected in the received frequency by the Grape. This movement can be attributed to an ionospheric disturbance.

The reason it is received like this is because radio waves propagate by ionospheric refraction. The ionosphere is a collection of ionized particles, and an ionospheric disturbance causes the densities of the ions and electrons to change, which means the radio waves are refracting off of changing heights of the ionosphere, which creates a sinusoidal-like reading of the frequency as shown above.

Grape Observations at KD2UHN

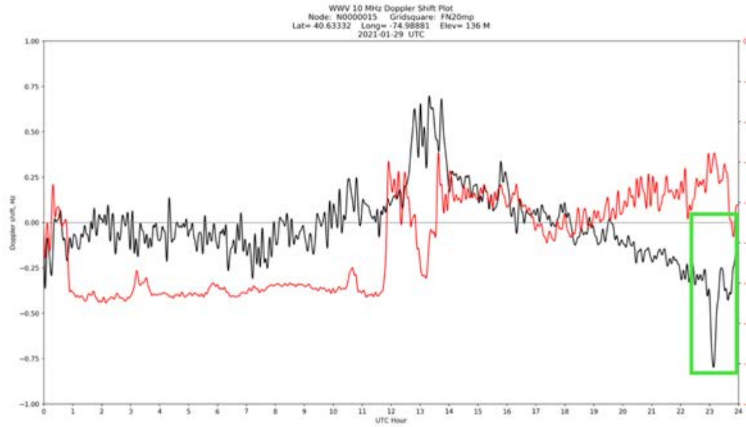
The way in which the ionospheric disturbances are observed from the Grape data is by looking at the variation in Doppler shift (Hz). The author manually inspected each figure that was generated and created a spreadsheet using Microsoft Excel that looked at the patterns and categorized which hours had observed ionospheric disturbances each day. That data was then converted to a scatter plot to include a better visualization of correlated behavior between time and the Doppler Shift (Hz). The way that active hours were categorized is as follows:


Observations of Active Hours as Seen by a Grape Receiver in Northwest New Jersey (January 24, 20201-February 21, 2021)

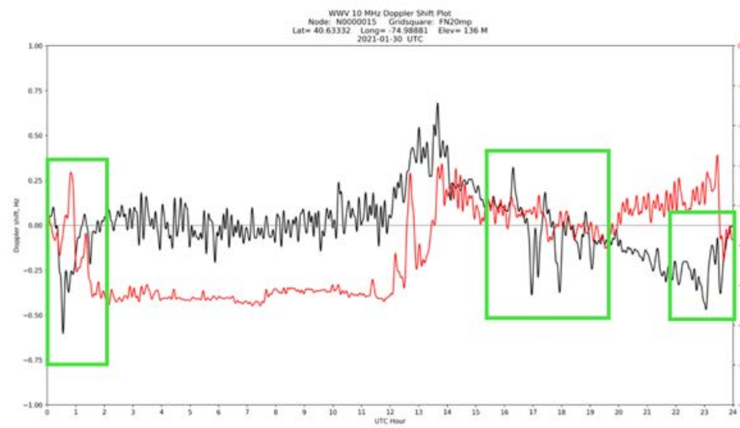
(FIGURE 6) This image depicts the active hours observed by the Grape at KD2UHN.

The hours with "1" were considered to be ionospherically active hours, while those with "0" were considered to be quiet. Active hours are those that have a distinct change in Doppler Shift (the black line) that is very close to +0.25 Hz or greater. If the shift was close to 0.25 Hz, but not followed by a sinusoidal pattern, and did not appear to be distinctly different from the preceding and following hours, then that hour was not noted as an active hour. The author selected only times that had oscillation periods of about 15 minutes or greater. Active hours are frequently followed by other active hours, forming a sinusoidal-like shape. Note that each day, during sunrise there is a sudden peak in the measured Doppler Shift. During sunset, there is a sudden drop in the Doppler Shift. This observation is consistent with those discussed by other authors (Cerwin, 2020 (http://file:///C:/Users/HP/AppData/Local/Packages/microsoft.windowscommunicationsapps_8wekyb3d8bbwe/LocalState/Files/S0/3/Attachments/Cerwir
It is also important to consider that these are very early results and so there is limited data to consider when making these observations.

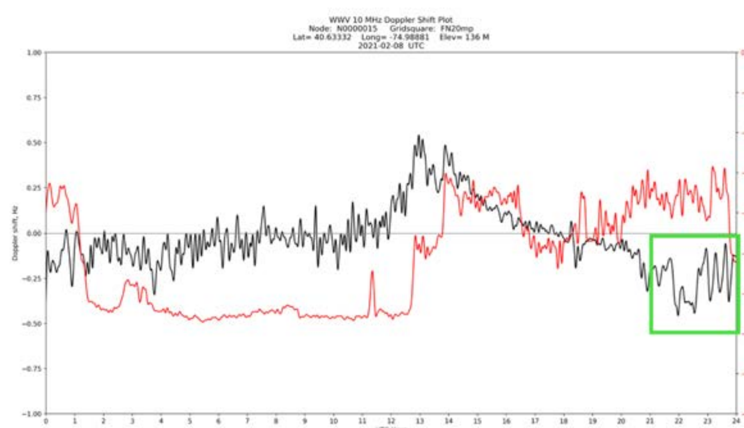
TID Examples



(FIGURE 7) The graph shown above depicts a relatively quiet day in the ionosphere. With the exception of the last hour, as notated by the green box, there are no clear variations in Doppler Shift to indicate the detection of an ionospheric disturbance.



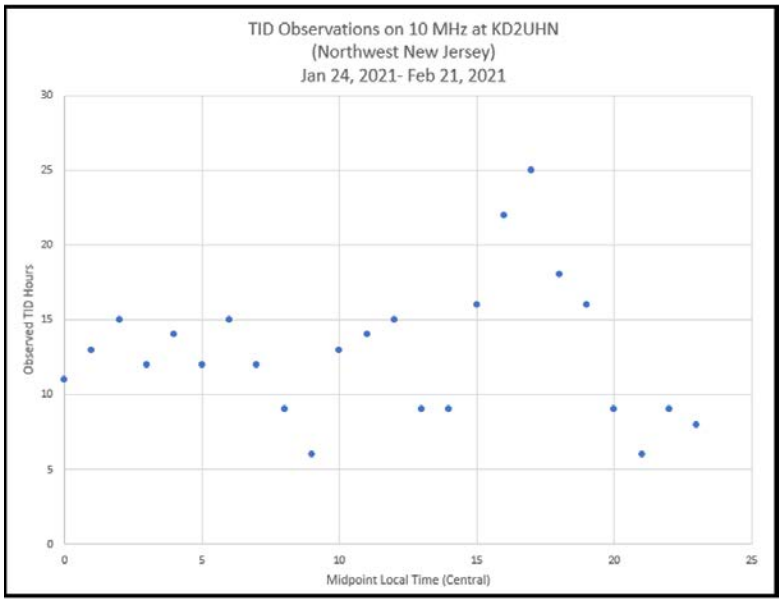
(FIGURE 8) The image above shows another active day. Notice the sinusoidal movement that was detected on this day. This movement is outlined by the green boxes.



(FIGURE 9) The day shown above is an example of a relatively quiet day in the ionosphere as detected by the Grape. The green box outlines the only disturbance that was observed this day, in the last few hours. Notice how the rest of the day includes no clear sinusoidal variation in Doppler Shift.

Active Hour Distribution

The distribution of active hours observed by the Grape in the time frame discussed in this poster was graphed. The resulting figure is shown below. This figure depicts the correlation of the midpoint local time to the observed Traveling Ionospheric Disturbances (TIDs). It can be seen from the figure that the data collected thus far suggests 15:00 Midpoint Local Time to 20:00 Midpoint Local Time to be the hours with the most observed TID activity.



(FIGURE 10) The graph above shows the distribution of total active hours between January 24, 2021 and February 21, 2021.

CONCLUSION

Summary and Conclusion

In conclusion, The Grape Personal Space Weather Station (PSWS) is making observations consistent with those expected of Traveling Ionospheric Disturbances. A statistical study of Traveling Ionospheric Disturbance (TID) occurrence was conducted with observations recorded from January 24th to February 21st 2021. While the results are relatively early, they suggest TID signatures are most prevalent during the hours of 21:00 UTC to 02:00 UTC (or 15:00 Midpoint Local Time- 20:00 Midpoint Local Time).

FUTURE WORK / ACKNOWLEDGEMENTS

Future Work

In the future, the authors will investigate the observations of other Grapes located around the United States. One such Grape is located in Northeast Pennsylvania. The image below depicts the Great Circle Path between this Grape and WWV:

(FIGURE 11) This is a depiction of the path traveled by radio waves transmitted by WWV and the Grape located at W2NAF in Northeast Pennsylvania. KD2UHN can be seen as a reference for where this is.

Furthermore, the authors plan to expand the time range of observations used in this statistical study as well as refine the statistical study methodology. The authors will explore the physical mechanisms for TID production by combining the data presented in this poster with data from other sources to help diagnose methods of TID production. In a matter of years the authors will be working with physical models to further the understanding of TIDs. In addition, other authors are consistently proposing physical mechanisms for TIDs and the authors of this poster will see if those suggestions match the data that is collected by the Grapes.

Acknowledgements

The authors gratefully acknowledge the support of NSF Grants AGS-2002278, AGS-1932997, and AGS-1932972. We also acknowledge the use of the WWV station located in Fort Collins, Colorado. Furthermore, we acknowledge the use of Free Open Source Software projects including Ubuntu Linux, Python, Matplotlib, CartoPy, NumPy, Pandas, IterTools, and others.

REFERENCES

Lombardi, M. A., Nelson, G. K., Okayama, D. T. (2005), NIST Time and Frequency Radio Stations: WWV, WWVH, and WWVB. National Institute of Standards and Technology.