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# Mid-latitude Irregularities in the Early Results from the Ionospheric Sounding Mode Using Chirp Ionosondes of Opportunity for the HamSCI Personal Space Weather Station

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## Abstract

The objective of the Ham Radio Science Citizen Investigation (HamSCI) Personal Space Weather Station (PSWS) project is to develop a distributed array of ground-based multi-instrument nodes capable of remote sensing the geospace system. This system is being designed with the intention of distribution to a large number of amateur radio and citizen science observers. This will create an unprecedented opportunity to probe the ionosphere at finer resolution in both time and space as all measurements will be collected into a central database for coordinated analysis.
Individual nodes are being designed to service the needs of the professional space science researcher while being cost-accessible and of interest to amateur radio operators and citizen scientists. At the heart of the HamSCI PSWS will be a high performance 0.1 – 60 MHz software defined radio (SDR) [1] with GNSS-based precision timestamping and frequency reference. This SDR is known as the TangerineSDR and is being developed by the Tucson Amateur Packet Radio (TAPR) amateur radio organization. The primary objective of PSWS system is to gather observations to understand the short term and small spatial scale ionospheric variabilities in the ionosphere-thermosphere system. These variabilities are important for understanding a variety of geophysical phenomena such as Traveling Ionospheric Disturbances (TIDs) [2], Ionospheric absorption events, geomagnetic storms and substorms. We present early results showing the irregularities in the mid-latitude ionosphere from an ionospheric sounding mode that we intend to implement on the PSWS system, currently implemented on an Ettus N200 Universal Software Radio Peripheral (USRP) using the open source GNU Chirpsounder data collection and
analysis code.

## 1 Introduction

The HamSCI is a collective that allows university researchers to collaborate with the amateur radio community in scientific investigations. The objective of the Ham Radio Science Citizen Investigation (HamSCI) Personal Space Weather Station (PSWS) project is to develop a distributed array of ground-based multi-instrument nodes capable of remote sensing the geospace system. The primary objective of the PSWS system is to gather observations to understand the short term and small spatial scale ionospheric variabilities in the ionosphere-thermosphere system. These variabilities are important for understanding a variety of geophysical phenomena such as Traveling Ionospheric Disturbances (TIDs), Ionospheric absorption events, geomagnetic storms and substorms. We present early results of an ionospheric sounding mode that we intend to implement on the PSWS system, currently implemented on an Ettus N200 Universal Software Radio Peripheral (USRP) using the open-source GNU Chirpsounder data collection and
analysis code.

## 2 HamSCI: PSWS

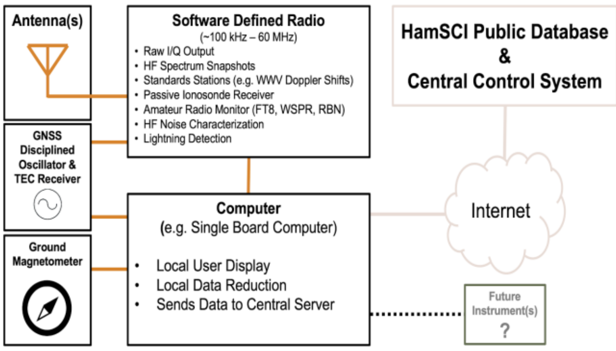


**Figure 1.** An architecture of the Personal Space Weather Station (PSWS). The chief component of the PSWS is a software defined radio receiver with frequency coverage from approximately 100 kHz to 60 MHz. A dual-frequency Global Navigation Satellite System (GNSS) receiver chip will be used to serve as a highly stable frequency reference. A local computer will coordinate operation of all attached instruments, handle local data reduction, provide a local user interface or display, send data back to a central database, and receive commands and updates from the central control system.

The HamSCI PSWS [3] is being developed as a collaborative project under the Ham Radio Science Citizen Investigation (HamSCI) collective, led by the University of Scranton with collaborators at Case Western Reserve University, the New Jersey Institute of Technology (NJIT), the University of Alabama, the MIT Haystack Observatory, Tucson Amateur Packet Radio (TAPR), and volunteers from additional universities and the amateur radio community. The PSWS comes in two flavors: a performance-driven FPGA-based software defined radio version (TangerineSDR) and a low-cost version (Grape). The goal of the current project at the University of Scranton is to develop an ionospheric sounding mode that will be implemented on the Performance-Driven (TangerineSDR) PSWS model. The mode currently being implemented is Juha Vierinen's GNU Chirpsounder2, which generates oblique ionograms from FM Chirp Ionosonde Signals of Opportunity.

## 3 Methodology

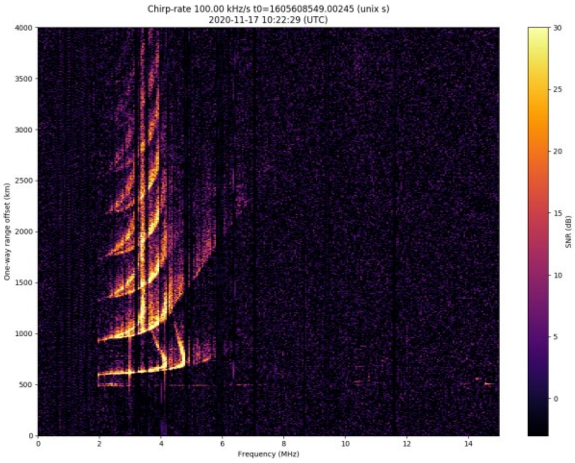


**Figure 2.** An ionogram processed with Chirpsounder2 software showing the single-hop and the multi-hop propagation of high-frequency (HF) radio waves transmitted from Relocatable Over-the-Horizon Radar (ROTHR) site in Virginia to Spring Brook, Pennsylvania - the receiver station on Nov. 17, 2020. A movie of the ionograms as received for the day Nov 17, 2020 is available here: https://www.youtube.com/watch?v=Z085Kd-XDQo .

The software Chirpsounder2 (https://github.com/jvierine/chirpsounder2) can be used to detect chirp sounders and over-the-horizon radar transmissions over the air, and to calculate ionograms from them. The software relies on Digital RF recordings of HF. This is a new implementation of the GNU Chirp Sounder. This new version allows the automatic detection of chirps without prior knowledge of timing and chirp-rate. The process starts with a data capture with THOR/ (comes with DigitalRF), a USRP N2x0, a GPSDO, and a broadband HF antenna.

The following parts of the chirpsounder2 software are then implemented to plot the ionograms from the collected data:

**detect_chirps.py** # To find chirps using a chirp-rate matched filterbank

**find_timings.py** # To cluster detections and determine what chirp timings and chirp rates exist

**calc_ionograms.py** # To calculate ionograms based on parameters

**plot_ionograms.py** # To plot calculated ionograms

The steps are further illustrated in the block-diagrams:


**Figure 3.** The steps involved in data collection and execution of the Chirpsounder2 software package.


**Figure 4:** The Universal Software Radio Peripheral (USRP) N200 kit. Image Source: https://ettus.com/all-products/un200-kit


**Figure 5:** The receiver Location in Spring-Brook, Pennsylvania.

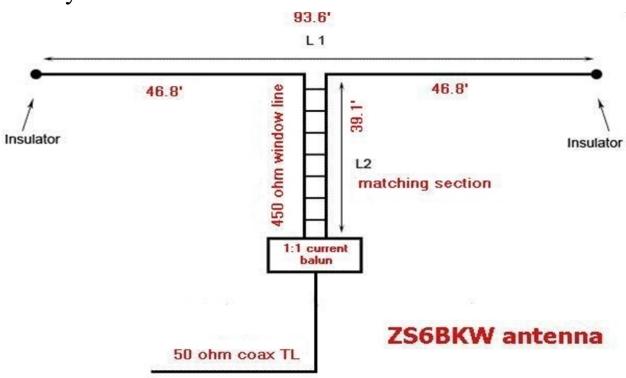


**Figure 6:** The ZS6BKW Multiband HF Antenna employed in receiving the HF signals at the receiver station. Image Source: https://www.awarc.org/the-zs6bkw-multiband-hf-antenna/

## 4 Results

From the ionograms created after receiving the chirp-signals and processing using the software package Chirpsounder2, the spread in the echoes received from the F-region traces are taken to be indicator of the irregularities [4] in the mid-latitude ionosphere. These ionograms – along with others with clean F-traces – are compared with GPS TEC maps [5] to see the (dis)similarities in the observations made from both the HF receiver at Scranton and GPS TEC observations.

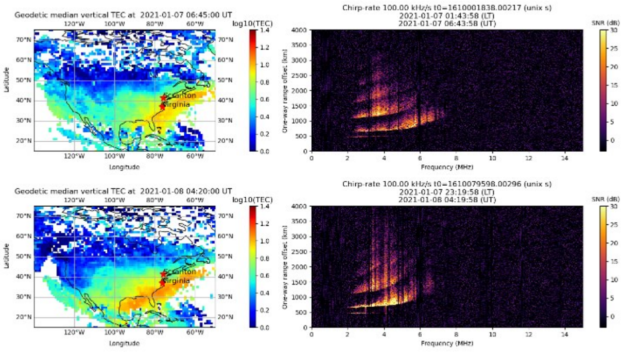

**Figure 7:** The echoes from the layers of ionosphere as received in the high-frequency (HF) radio waves transmitted from Relocatable Over-the-Horizon Radar (ROTHR) site in Virginia to Spring Brook, Pennsylvania - the receiver station on Jan. 07-08, 2021 are compared with the GPS TEC maps. The spread in the traces is also seen in the increased TEC values in the GPS TEC maps.

The GPS TEC observations don't always correlate well with HF observations as in the figure below. For two days' of data we have analyzed so far, it has happened mostly during local day time.

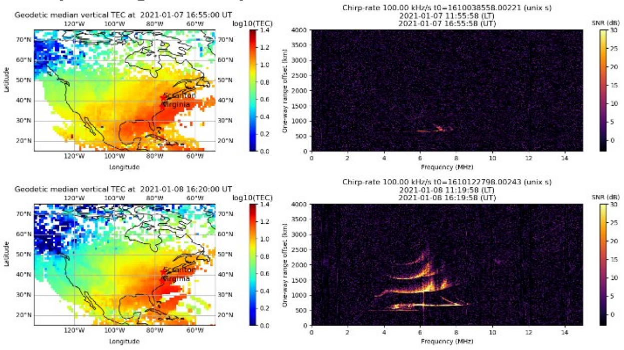

**Figure 8:** The echoes from the layers of ionosphere as received in the high-frequency (HF) radio waves transmitted from Relocatable Over-the-Horizon Radar (ROTHR) site in Virginia to Spring Brook, Pennsylvania - the receiver station on Jan. 07-08, 2021 are compared with the GPS TEC maps. The sharp F-region trace doesn't correlate with increased TEC values in the GPS TEC maps.

# 5 Conclusions

HamSCI PSWS is a Distributed Array of Small Instruments (DASI) project for making geospace and ionospheric measurements for both citizen scientists and the professional research community. FM Chirp Ionosondes are widely distributed around the world and serve as a signal of opportunity for the generation of oblique ionograms using PSWS hardware. We have implemented a proof-of-concept receiver station using GNU Chirpsounder2 software by Juha Vierinen. The software is used to process the received signals and is further processed to study the spread in the echoes from the layers of the ionosphere – suggestive of the irregularities in the mid-latitude ionosphere and are compared with the GPS TEC maps. We have found both the cases of correlation and anti-correlation between the mid-latitude irregularities and increased TEC activity as seen in the GPS TEC maps. In our future work, we aim to further study these irregularities to characterize them, understand the source of these irregularities and the underlying reasons for the correlation and the anticorrelation with the GPS TEC observations.

# 6 Acknowledgements

The authors gratefully acknowledge the support of NSF Grant AGS-2002278, AGS-1932997, and AGS-1932972. GNU Chirpsounder2 is available from https://github.com/jvierine/chirpsounder2.

# 7 References

1. Bostan, S. M., Urbina, J. V., Mathews, J. D., Bilén, S. G., & Breakall, J. K. (2019), "An HF Software-Defined Radar to Study the Ionosphere", *Radio Science,* 54(9), 839–849, https://doi.org/10.1029/2018rs006773.

2. Heitmann, A. J., Cervera, M. A., Gardiner-Garden, R. S., Holdsworth, D. A., MacKinnon, A. D., Reid, I. M., & Ward, B. D. (2018), "Observations and Modeling of Traveling Ionospheric Disturbance Signatures From an Australian Network of Oblique Angle-of-Arrival Sounders", *Radio Science*, 53(9), 1089–1107. https://doi.org/10.1029/2018rs006613

3. Frissell, N. A., Joshi, D., Collins, K., Montare, A., Kazdan, D., Gibbons, J., Mandal, S., Engelke, W., Atkison, T., Kim, H., Gerrard, A. J., Vega, J. S., Cowling, S. H., McDermott, T. C., Ackermann, J., Witten, D., Silver, H. W., Liles, W., Cerwin, S., Miller, E. S. (2020). HamSCI Distributed Array of Small Instruments Personal Space Weather Station (DASI-PSWS): Architecture and Current Status (Invited). NSF CEDAR (Coupling, Energetics, and Dynamics of Atmospheric Regions). http://cedarweb.vsp.ucar.edu/wiki/index.php/2020_Workshop:MainVG

4. Artificial and Natural Disturbances in the Equatorial Ionosphere: Results from the MOSC Experiment and the C/NOFS Satellite Mission (https://dlib.bc.edu/islandora/object/bc-ir%3A108706)

5. Anthea Coster, MIT/Haystack Observatory. (2021) Data from the CEDAR Madrigal database. Available from https://w3id.org/cedar?experiment_list=experiments4/2021/gps/07jan21&file_list=gps210107g.001.hdf5