Observations of Mid-latitude Irregularities Using the Oblique Ionosonde Sounding Mode for the HamSCI Personal Space Weather Station

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The spread in the echoes of high-frequency (HF, 3-30 MHz) radio waves from the F-region of the ionosphere was one of the earliest indications of plasma density irregularities in the mid-latitude F region ionosphere. Although mid-latitude spread F has been widely studied, the plasma instability mechanisms that create these irregularities are still largely unknown. This phenomenon can cause radio wave scintillation effects that degrade the performance of human-made technologies such as satellite communications and Global Navigation Satellite Systems (GNSS). Understanding these irregularities so that they can be anticipated and mitigated are important aspects of space weather research. The occurrence climatology and variability can also be helpful in validating models of these irregularities. Here, we present signatures of mid-latitude irregularities observed in oblique ionograms received near Scranton, PA transmitted by the Relocatable Over-the-Horizon Radar (ROTHR) in Chesapeake, Virginia. These observations are collected with the GNU Chirpsounder2 software, an open source software package capable of creating ionograms from frequency modulated (FM) chirp ionosondes. This ionospheric sounding mode will be implemented in the currently under-development Ham Radio Science Citizen Investigation (HamSCI) Personal Space Weather Station (PSWS), a ground-based multi-instrument system designed to remote-sense the ionosphere using signals of opportunity. Using the data from the oblique ionograms, we generate the Range Time Intensity (RTI) plots that show ionospheric dynamics through measured path length variations as a function of time. We also compare the RTI plots with Range-Time-Parameter (RTP) plots from the SuperDARN HF radar in Blackstone, Virginia which commonly observes direct backscatter from decameter-scale irregularities within the region of ionosphere traversed by the ROTHR signal.

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Abstract

The spread in the echoes of high-frequency (HF, 3-30 MHz) radio waves from the F-region of the ionosphere was one of the earliest indications of plasma density irregularities in the mid-latitude F region ionosphere. Although mid-latitude spread F has been widely studied, the plasma instability mechanisms that create these irregularities are still largely unknown. This phenomenon can cause radio wave scintillation effects that degrade the performance of human-made technologies such as satellite communications and Global Navigation Satellite Systems (GNSS). Understanding these irregularities so that they can be anticipated and mitigated are important aspects of space weather research. The occurrence climatology and variability can also be helpful in validating models of these irregularities. Here, we present signatures of mid-latitude irregularities observed in oblique ionograms received near Scranton, PA transmitted by the Relocatable Over-the-Horizon Radar (ROTHR) in Chesapeake, Virginia. These observations are collected with the GNU Chirpsounder2 software, an open source software package capable of creating ionograms from frequency modulated (FM) chirp ionosondes. This ionospheric sounding mode will be implemented in the currently under-development Ham Radio Science Citizen Investigation (HamSCI) Personal Space Weather Station (PSWS), a ground-based multi-instrument system designed to remote-sense the ionosphere using signals of opportunity. Using the data from the oblique ionograms, we generate the Range Time Intensity (RTI) plots that show ionospheric dynamics through measured path length variations as a function of time. We also compare the RTI plots with Range-Time-Parameter (RTP) plots from the SuperDARN HF radar in Blackstone, Virginia which commonly observes direct backscatter from decameter-scale irregularities within the region of ionosphere traversed by the ROTHR signal.

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

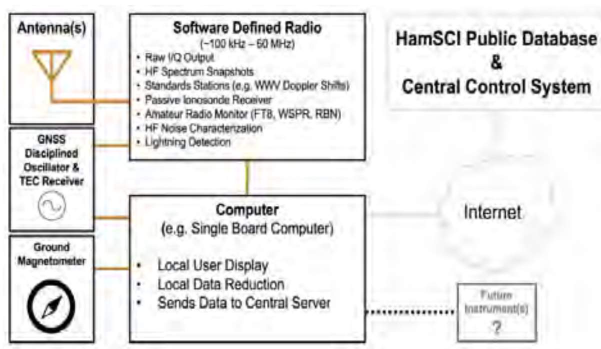

Figure 1. An architecture of the Personal Space Weather Station (PSWS). The chief component of the PSWS is a software defined radio receiver with frequency coverage from approximately 100 kHz to 60 MHz. A dual-frequency Global Navigation Satellite System (GNSS) receiver chip will be used to serve as 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

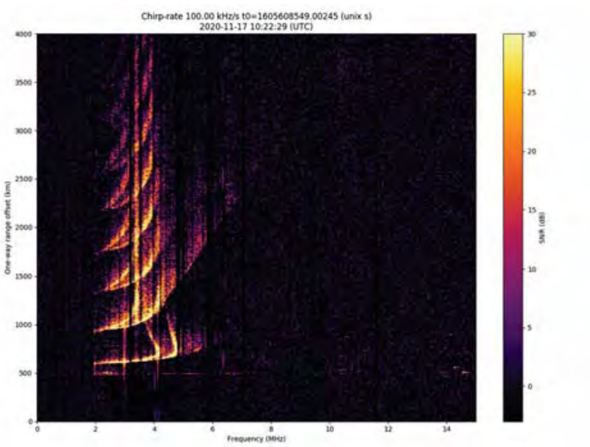

Figure 2. An ionogram processed with Chirpsounder2 software showing the single-hop and the multi-hop propagation of high-frequency (HF) radio waves transmitted from Relocatable Over-the-Horizon Radar (ROTHR) site in Virginia to Spring Brook, Pennsylvania - the receiver station on Nov. 17, 2020. A movie 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.

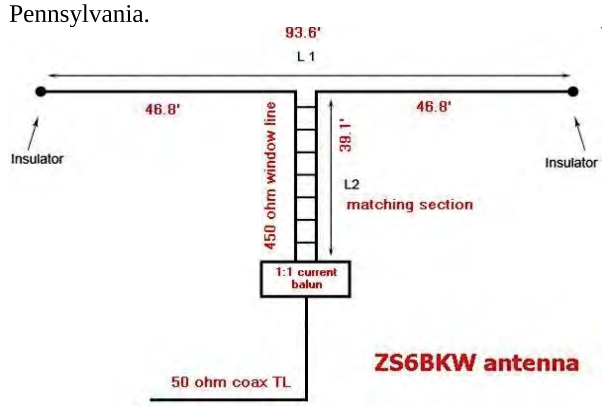

Figure 6: The ZS6BKW Multiband HF Antenna employed in receiving the HF signals at the receiver station. Image Source: https://www.awarc.org/the-zs6bkw-multiband-hf-antenna/

4 Results

The ionograms created after receiving the chirp-signals and processing using the software package Chirpsounder2 are used to construct a Range-Time-Intensity plot (keogram) showing the variations of the heights of the various ionospheric layers for a given day. We then compare these RTI plots with ionospheric scatter observations as observed in the Blackstone SuperDARN Radar along beam 13 (Fig. 7) .

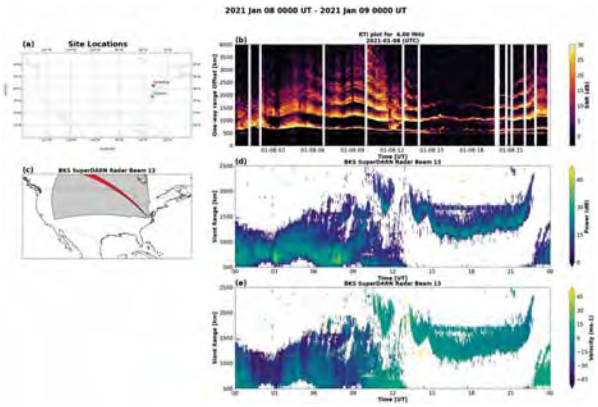

Figure 7: Spread-F signatures in RTI plot of the Ionosonde receiver (panel b) on Jan 8, 2021 compare well with enhanced ionospheric scatter observations between 0 – 12 UT along beam 13 of the Blackstone SuperDARN Radar.

For this day of comparison, the SuperDARN observations correlate well with the HF observations on spread-F days in the ionosphere in our preliminary investigation. We also construct a stack-plot of frequency-specific keogram showing the variation of the ionospheric layers for different frequencies (Fig. 8). These keograms show the variation of the ionospheric layers for various frequencies as observed by the HF receiver and for the chosen day of Jan 8, 2021, these variabilities are best observed for the 4 MHz frequency as seen in Fig. 8. The characterization and understanding of the sources of the ionospheric variabilities in the ionosphere-thermosphere system as seen in the various layers of the ionosphere in the RTI plot will be future work in our investigation.

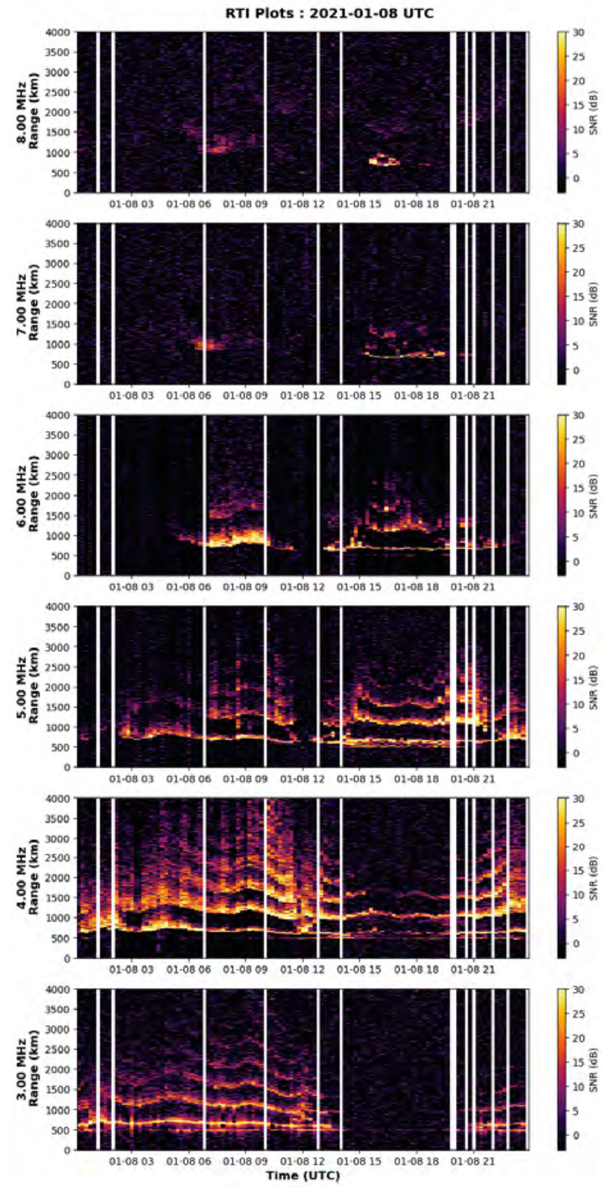

Figure 8: Spread-F signatures for various frequencies in RTI plot of the Ionosonde receiver on Jan 8, 2021.

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 variations in the heights of the F-region layers of the ionosphere. The variations are suggestive of Traveling Ionospheric Disturbances (TIDs) and it would require more work to establish the characteristics of the TIDs. The variabilities are compared with the SuperDARN observations and we find the SuperDARN observations correlate well with the HF receiver observations on spread-F days in the ionosphere in our preliminary investigation.

6 Acknowledgements

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The results published in this paper were obtained using the HF propagation toolbox, PHaRLAP, created by Dr. Manuel Cervera, Defence Science and Technology Group, Australia (manuel.cervera@dsto.defence.gov.au). This toolbox is available by request from its author.

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