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

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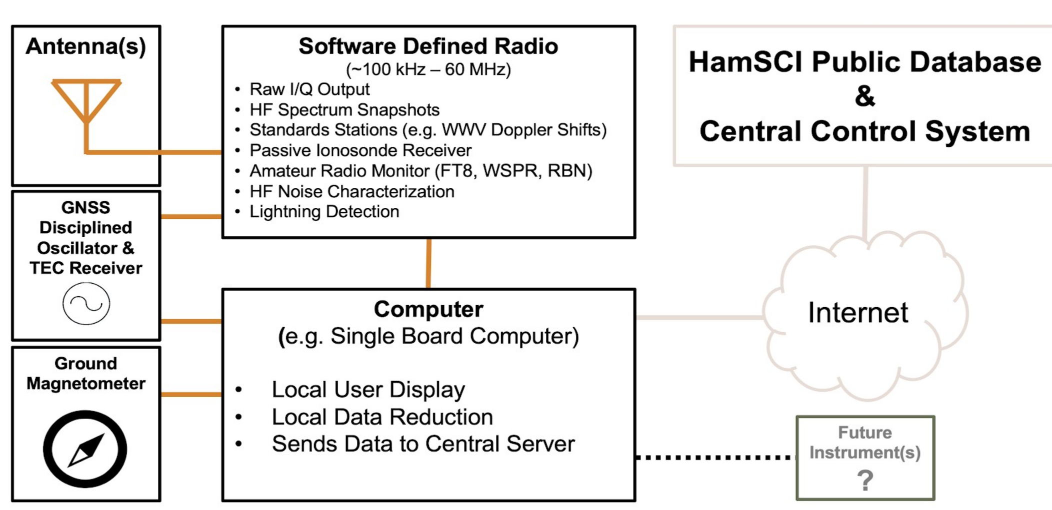
Abstract

The spread in the echoes of high-frequency (HF, 3-30 MHz) radio waves from the F-region of the ionosphere has been the earliest indication of plasma density irregularities in the mid-latitude F region ionosphere. Although mid-latitude spread F has been widely studied, the plasma instability mechanisms for these irregularities are still largely unknown. This phenomenon can cause radio wave scintillation effects that degrade the performance of man-made technologies such as satellite communications and global navigation satellite systems (GNSS). 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.

Introduction



The image above shows 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.

HamSCI is a collective that allows university researchers to collaborate with the amateur radio community in scientific investigations.

Objectives:

- Advance scientific research and understanding through amateur radio activities.
- Encourage the development of new technologies to support this research.
- Provide educational opportunities for the amateur radio community and the general public.

What is the **HamSCI PSWS** ?

The **HamSCI Personal Space Weather Station** (PSWS) is a multi-instrument, ground-based device designed to observe space weather effects both as a single-point measurement and as part of a larger, distributed network.

The PSWS 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, 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).

Method/Experiment

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.

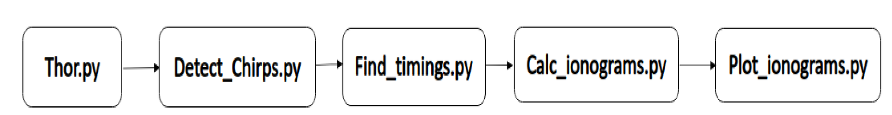
This is a new implementation of the GNU Chirp Sounder. This new version allows to automatically find chirps without knowledge of what the timing and the chirp-rate is.

The process starts with a data capture with **THOR** (comes with DigitalRF), a USRP N2x0, a GPSDO, and a broadband HF antenna. The Ettus N200 will be eventually be replaced by the tangerine software defined radio receiver as it is still under development.

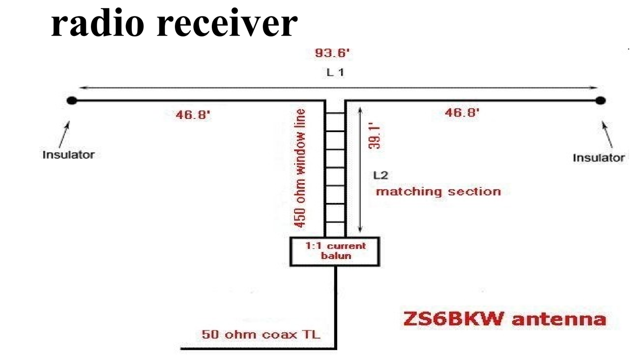
The following parts of the **chirpsounder2** software are then implemented to plot the ionograms from the collected data:

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

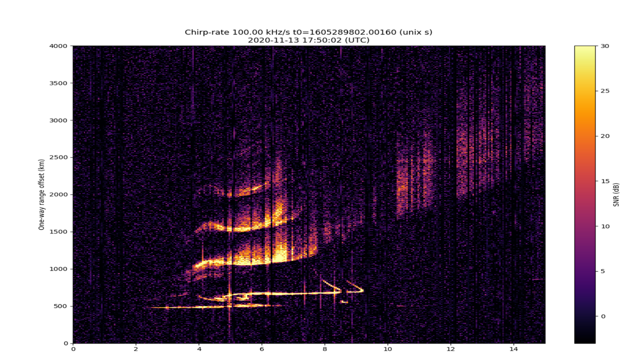


USRP N200 software-defined radio receiver



Receiver Location

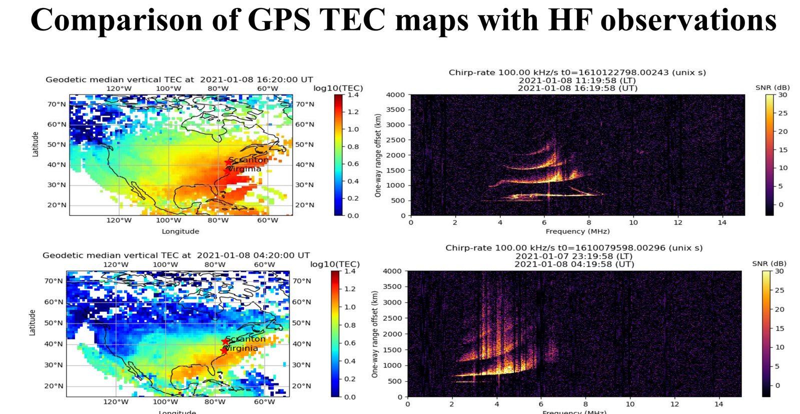
Data and Analysis



An ionogram showing the reception of chirp-signals transmitted from the ROTHR site in Virginia and received at the receiver location in Spring Brook, PA on Nov. 13, 2020.

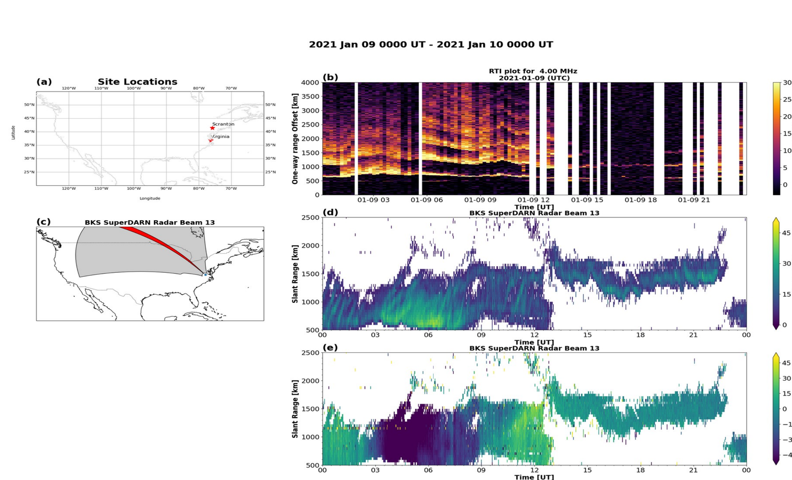
The receiver located in Spring Brook, PA received chirp-signals and the chirpsounder2 software was used to process the received data to calculate and plot ionograms. In above image, signals transmitted from the ROTHR chirp-transmitter in Virginia have been received after single-hop and multi-hop propagations from the F-layer of the ionosphere.

Comparison of GPS TEC maps with HF observations



The ionograms are compared with Global Positioning System (GPS) Total Electron Content (TEC) maps to see the (dis)-similarities in the observations made from both the HF receiver at Scranton and GPS TEC observations. The top panel shows 'anti-correlation' between the enhanced TEC values in the GPS TEC map and clean 1st hop F-region trace in the ionogram; whereas the bottom panel shows the 'correlation' between enhanced TEC values in the GPS-TEC map and spread 1st hop F-region trace in the ionogram.

We construct a Range-Time-Intensity plot, also known as keogram, for a chosen frequency from the ionograms. The spread-F signatures in the RTI plot (panel b in the image in the right) of the ionosonde receiver on Jan 9, 2021 compare well with enhanced ionospheric scatter observations between 0 – 12 UT along beam 13 of the Blackstone SuperDARN Radar.



Conclusions

Discussion:

In this research work, we presented early results of chirp-ionosonde observations made by a module of HamSCI Personal Space Weather Station (PSWS) located at Springbrook, Pennsylvania. In particular, we showed the high-frequency radio-wave transmitted from the ROTHR station in Virginia as received by the PSWS and processed using chirpsounder2 software.

In our preliminary analysis, we find both the cases of correlation and anti-correlation between the mid-latitude irregularities as detected in the HF observations and increased TEC activity as seen in the GPS TEC maps. As of the case of comparison between SuperDARN and HF chirp-sounder observations, we find good correlation during days with spread F and non-spread F. In our future work, we aim to further study these irregularities and the underlying reasons for the correlation and the anti-correlation with the GPS TEC and SuperDARN radar observations.

Future Work:

- Better characterize mid-latitude Spread-F and irregularity signatures observed in oblique HF ionograms.
- Optimize processing chain for lower-cost computers.
- Develop techniques for triangulating ionosounder transmitter locations using PSWS network.
- Implement Chirpsounder2 on TangerineSDR/HamSCI PSWS Hardware.
- Analyze chirp-sounder observations to understand the short term and small spatial scale ionospheric variabilities in the ionosphere-thermosphere system.
- Establish a network of oblique receivers around chirp transmitters to analyze mesoscale ionospheric structure

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 bv Juha Vierinen.
- The GPS TEC based observations both correlate and anti-correlate with the HF receiver observations in our preliminary investigation.
- The SuperDARN observations correlate well with the HF receiver observations on both spread-F and non-spread F days in the ionosphere in our preliminary analysis.

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