Early Observations of Mid-latitude Ionospheric Irregularities Using GNUChirpsounder for the HamSCI Personal Space Weather Station

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Outline

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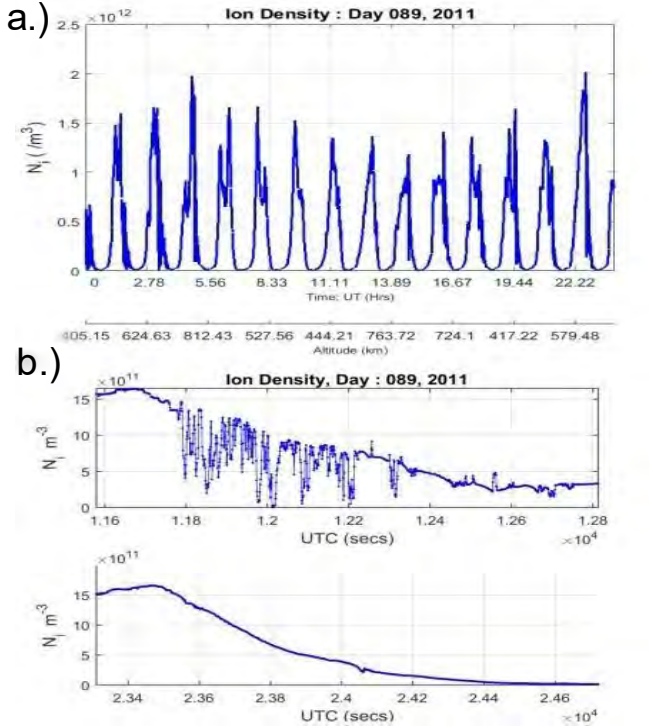
- Mid-latitude Irregularities
- HamSCI : Personal Space Weather Station
- Observations
- Discussion and Future Work
- Summary

Ionospheric Irregularities

- Ionospheric irregularities have been extensively studied over the decades of research with a host of diagnostics
- Plasma density variations occur rapidly across the geomagnetic field but slowly (or not at all) along the geomagnetic field
- Scale length can vary from meters to several kilometers across the magnetic field
- In general, the irregularities occur in the auroral and polar cap F region almost all the time , in the auroral E region in the times of geomagnetic activity, and during nights in equatorial E and F regions

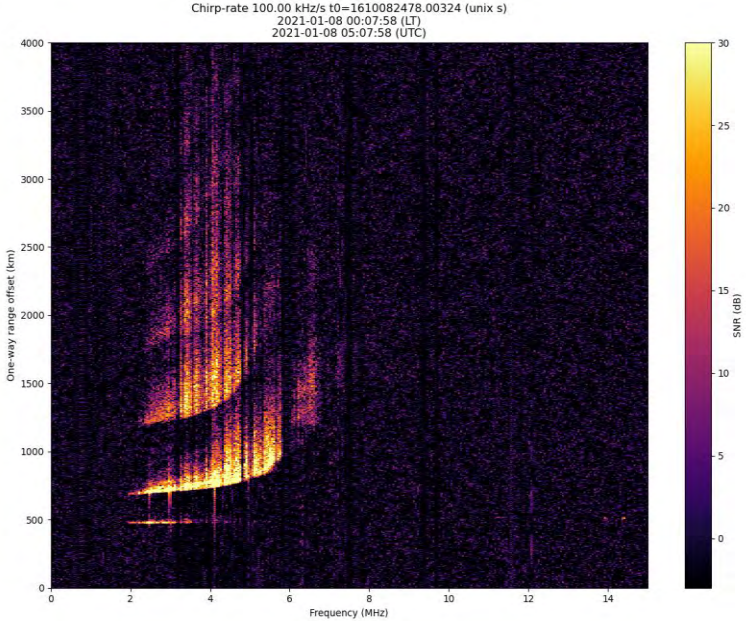


(a) An example of ion-density measurements for UTC day 089, 2011 made by C/NOFS PLP sensor (top). (b) Ionospheric Irregularities in upper subplot and smooth ion density measurements on the same day in lower subplot (below). (Joshi, 2019)

Reference: *Perkins, F. W.: Ionospheric irregularities, Rev. Geophys., 13, 884 pp., 1975.*

Mid-latitude Irregularities

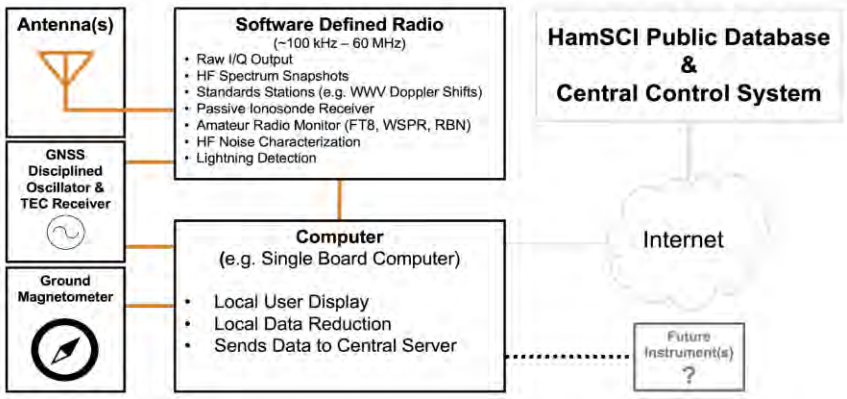
- Mid-latitude ionosphere initially thought not to be unstable
- The geophysical conditions at mid-latitude ionosphere different than those at auroral and equatorial latitudes
- Two main classes of irregularities have been observed in mid-latitudes : patchy dense Es layers (sporadic E) and mid-latitude spread F
- Meter-scale density irregularities within Es layers due to Kelvin-Helmholtz instability or/and plasma instability
- Mid-latitude spread F associated with thermospheric gravity waves, related medium-scale traveling ionospheric disturbances (MSTID) and Perkin's instability

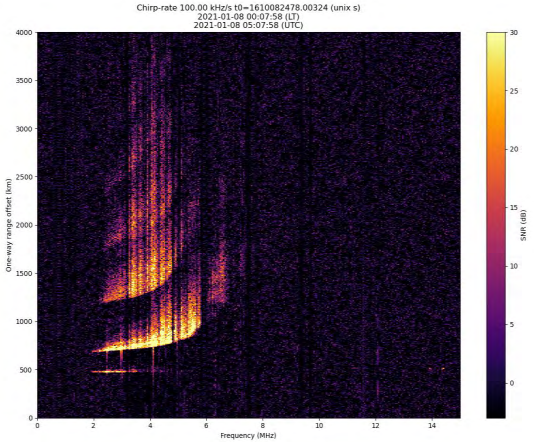


Reference: *Hysell, D., Larsen, M., Fritts, D. et al. Major upwelling and overturning in the mid-latitude F region ionosphere. Nat Commun 9, 3326 (2018). https://doi.org/10.1038/s41467-018-05809-x*

PSWS : Architecture

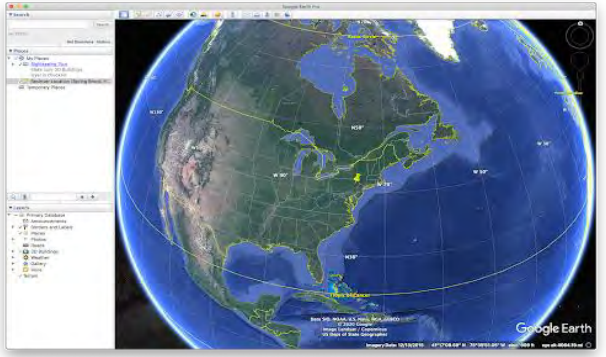
- We aim to develop an ionospheric sounding mode that will be implemented on the Performance-Driven (TangerineSDR) PSWS model.
- The mode currently being implemented is ETTUS N200 SDR using Juha Vierinen's GNU Chirpsounder2, which generates oblique ionograms from FM Chirp Ionosonde Signals of Opportunity.





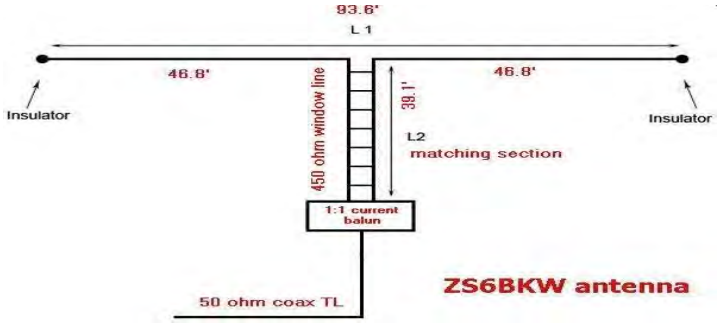
Experimental Setup

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



Receiver located near Scranton, Pennsylvania.

- Implemented on Intel Core i7 with 64GB RAM Ettus USRP N200
- Receiver located in Spring Brook, PA (~10 miles from Scranton)
- **Antenna:** ZS6BKW @ 30 ft. Altitude (Dipole-Like)



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/

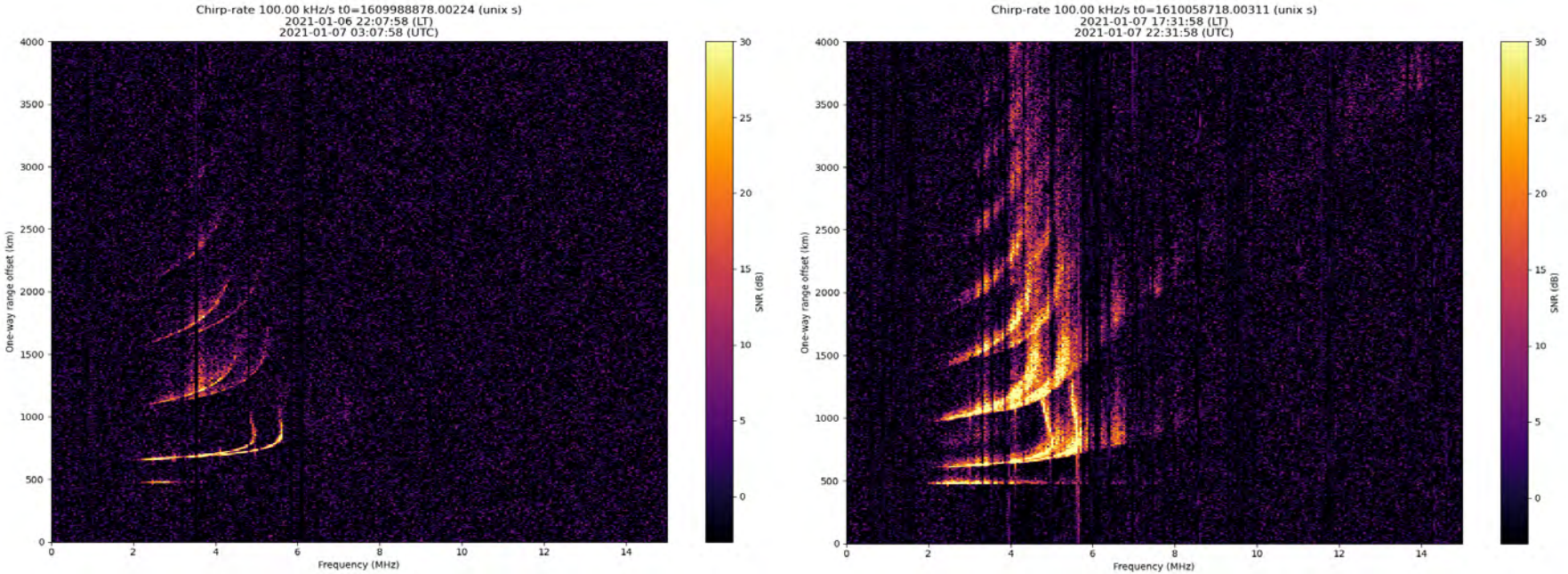
Methodology

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

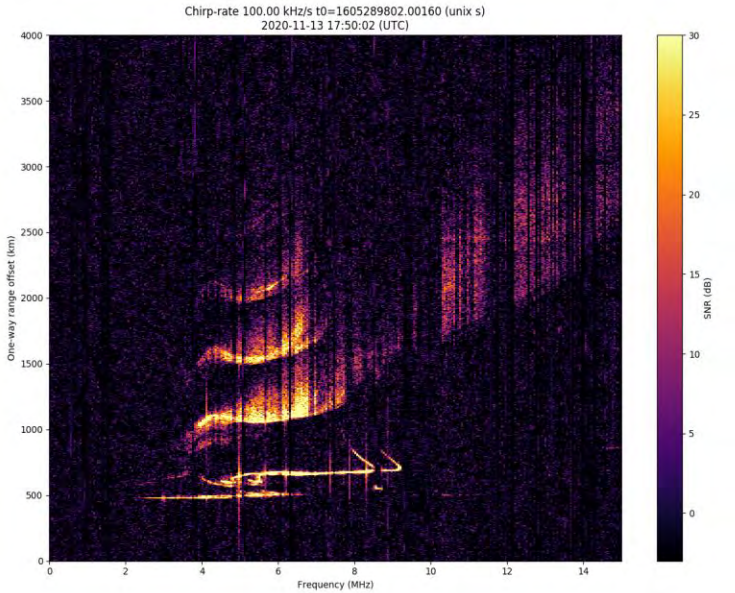
- **detect_chirps.py** # To find chirps using a chirp-rate matched filter bank
- **find_timings.py** # To cluster detections and determine what chirp timings and chirp rates exist
- **calc_ionograms.py** # To calculate ionograms based on parameters
- **plot_ionograms.py** # To plot calculated ionograms

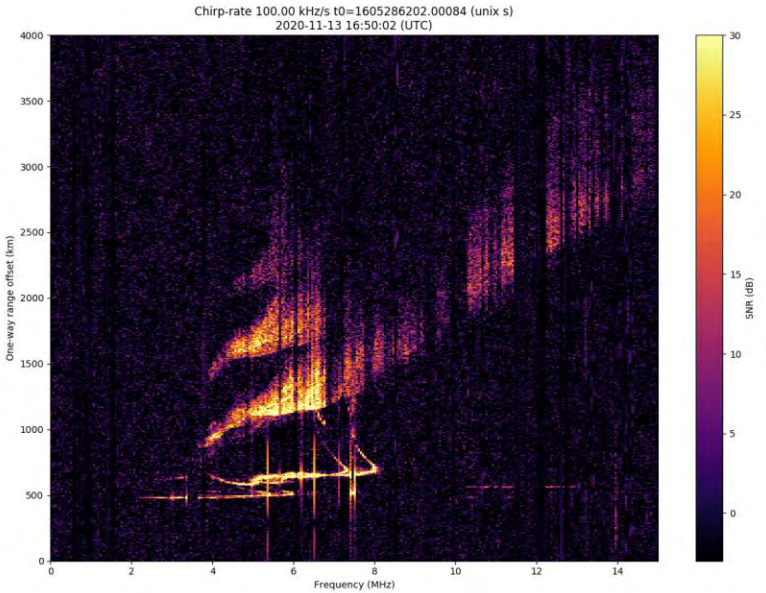
Spread-F



- Ionograms 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 site in Virginia to Spring Brook, Pennsylvania – the receiver station on Jan. 07, 2021.

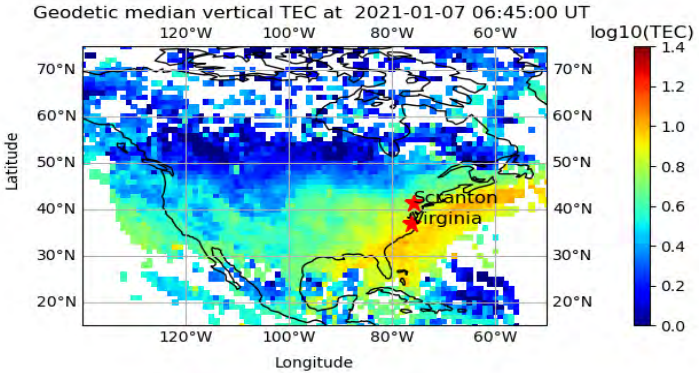
Ionograms

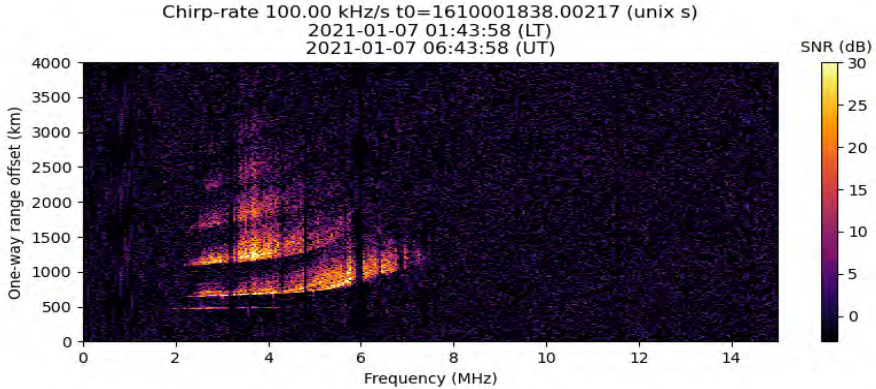


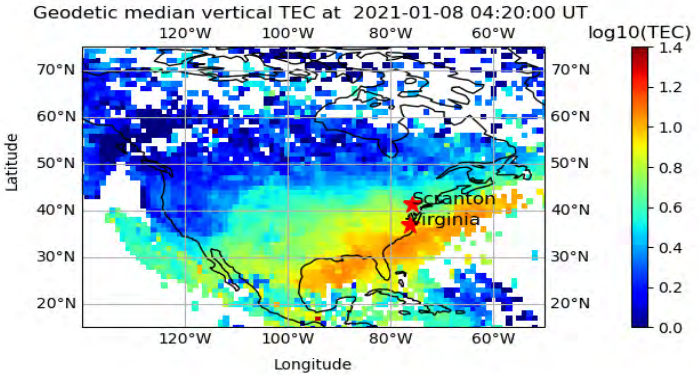


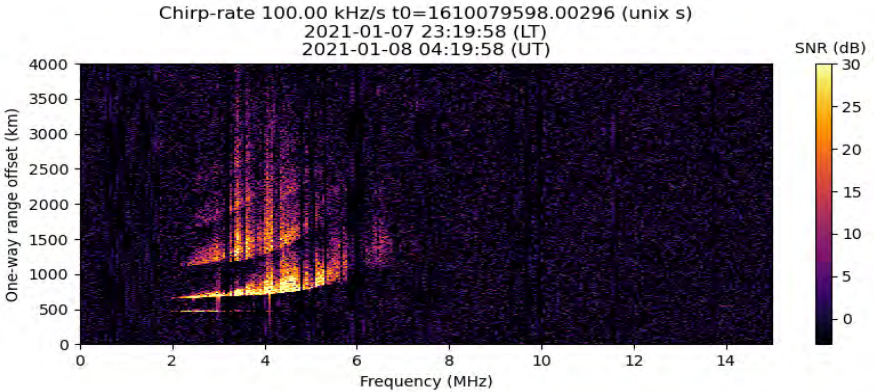
- Two ionograms showing the reception of chirp-signals transmitted from the ROTHR site in Virginia and received at the receiver location in Spring Brook, PA on Nov. 13, 2020.

Comparing GPS TEC & HF Observations









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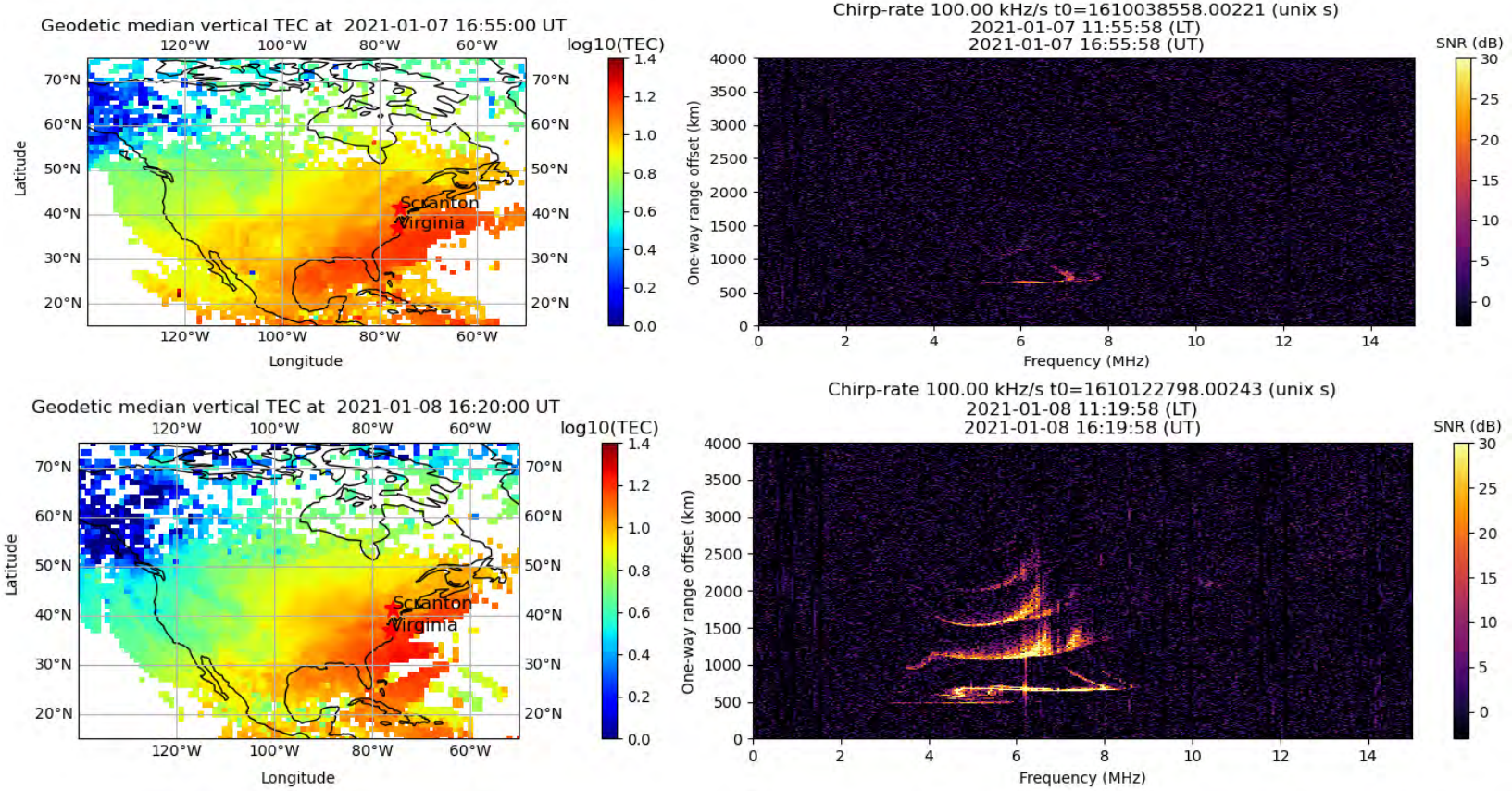
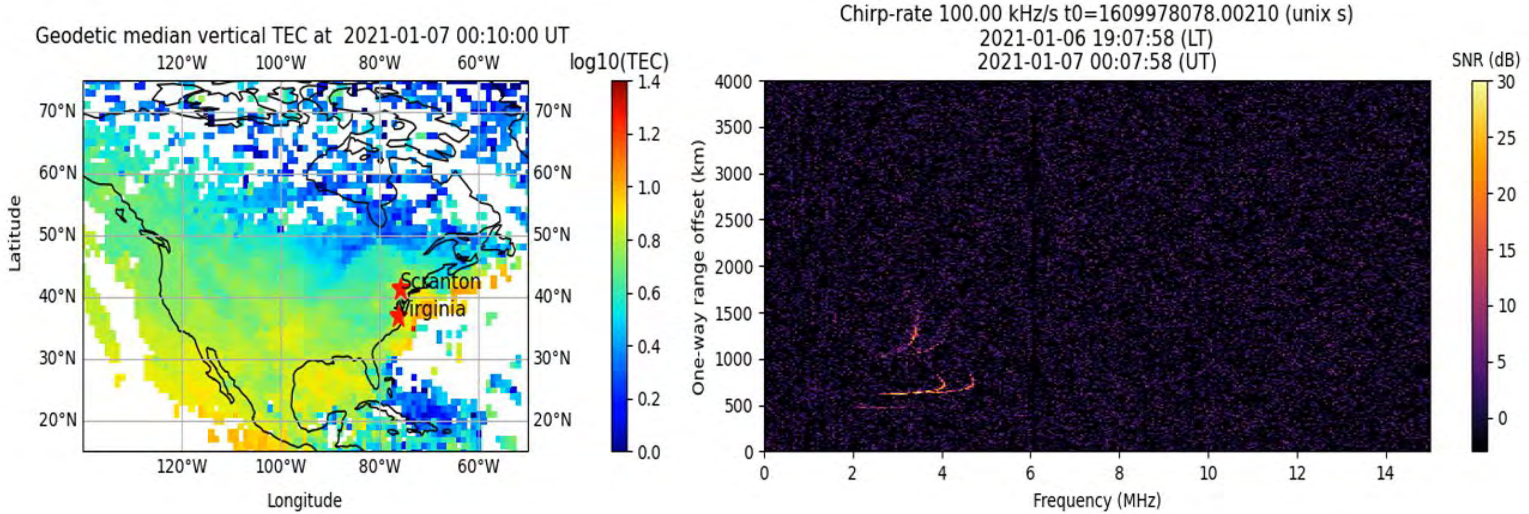
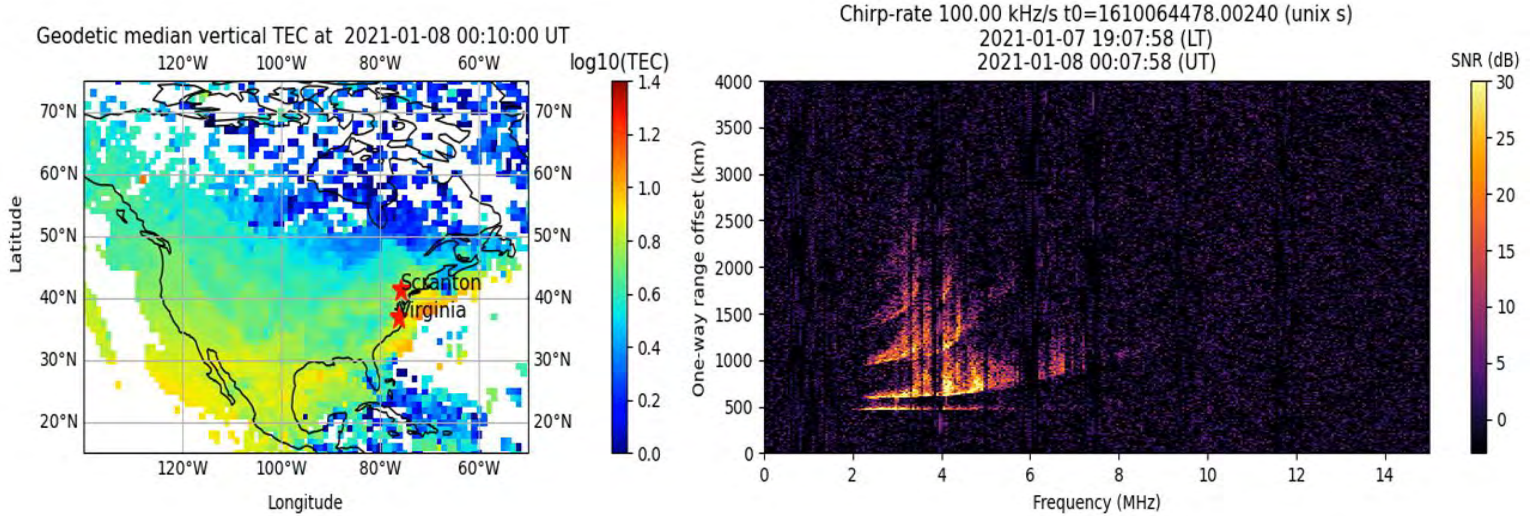


Movie: 7 Jan 2021



GPS TEC and HF chirp-sounder observations for 2021-01-07 UTC

Movie: 8 Jan 2021



GPS TEC and HF chirp-sounder observations for 2021-01-08 UTC

Discussion and Future Work

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 comparison between GPS TEC maps and HF chirp-sounder observations, we find instances of both correlation and anti-correlation between these observations.

Future Work:

- Analyze chirp-sounder observations to understand the short term and small spatial scale ionospheric variabilities in the ionosphere-thermosphere system
- Better characterize midlatitude irregularity structures to seek to understand the sources of these irregularities
- Establish a network of oblique receivers around chirp transmitters to analyze mesoscale ionospheric structure
- Develop techniques for triangulating ionosonde transmitter locations using PSWS network

Summary

- 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 GPS TEC based observations both correlate and anti-correlate with the HF receiver observations in our preliminary investigation.

Acknowledgements

- The authors gratefully acknowledge the support of NSF Grant AGS-2002278, AGS-1932997, and AGS-1932972.
- GNU Chirpsounder 2 is available from https://github.com/jvierine/chirpsounder2.
- The GNSS TEC data used in this study is provided by the Millstone Hill Geospace Facility under NSF grant AGS-1952737.

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Thank you!