Example Doppler Measurements

WWV 10 MHz Carrier Frequency, 8/20/17 (Control Day)
Received Near Milwaukee, WI. Mean=10,000,000.0022 Hz

Measurements by Steven Reyer
WA9VNJ (SK)
Example Doppler Measurements

WWV 10 MHz Carrier Frequency, 8/21/17 (Eclipse Day)
Received Near Milwaukee, WI. Mean=10,000,000.0096 Hz

Solar Eclipse Shadow and WWV Signal Crossing Northeast of North Platte, NE:
Start Partial
Maximum
End Partial

Time (Hours, UTC)
Example Doppler Measurements

Envelope estimation with 7.5 minute timing markers superimposed over data record to allow manual digitization for computer analysis.

Analysis by Steve Cerwin WA5FRF
Estimated Doppler Frequency Envelope Imported to Excel Spreadsheet and Calculated Velocity of Path Length Change

WA9VNJ 08/21/17 Eclipse Data
Digitized Representation of Estimated Doppler Shift Envelope

Velocity of path length change = \(- \frac{c}{f_0} \times \text{Doppler Shift}\)
= \(-30 \times \text{Doppler Shift at 10 MHz}\)

Note sign and scale change. Positive velocity values indicate increasing path length from ascending ionization layer.

Analysis by
Steve Cerwin
WA5FRF
Relative path length obtained from a cumulative sum of path length increments computed from:

\[ \Delta P = \Delta v \cdot \Delta t, \]

where

- \( \Delta P \) = Incremental change in path length
- \( \Delta v \) = Path velocity increment from velocity envelope
- \( \Delta t \) = Time increment = 7.5 min = 450 sec

\[ P = \Delta P_1, \Delta P_1 + \Delta P_2, \Delta P_1 + \Delta P_2 + \Delta P_3, \ldots \]
KD8OXT SAMI3 Simulation Shows an F-layer Height Increase of 31 km From the Eclipse but No Change in E-layer Height

Control Day
F-layer Height = 201 km

Eclipse Day
F-layer Height = 232 km

SAMI3 simulation generated by Kristina Collins KD8OXT using:
Eclipse Study – Initial Observations

- The eclipse-induced increase in layer height inferred from WA9VNJ Doppler data was 40 km. The SAMI3 simulations performed by KD8OXT showed the increase to be 32 km.

Possible causes for the difference include:
- Error in the manually drawn Doppler envelope estimation.
- Inaccuracies in the actual Doppler data reported by the FLDIGI frequency measuring program.
- Error in the “flat earth” ray trace model used to calculate layer height from path length. This model does not take into account the curvature of the earth and assumes straight line propagation paths with geometric reflection from a virtual reflection height instead of curved ray paths and a rounded refraction in the ionization layer.
- The F layer depictions in the SAMI3 simulations were not continuous in the video from which they were captured. It is possible the frame captures were not taken at the right time and did not reflect the actual minimum height on the control day or the maximum height during the eclipse day. Also the maximum height on the simulations was 250 km and it is possible higher layer predictions were there but not displayed.
- The solar-terrestrial forecasts used for the simulation may not have been the actual numbers present during the eclipse.

- The data presented here assumes the measured frequency shift data resulted only from Doppler shift caused by the ascending-then-descending refraction layer. It is possible that the extra frequency shift may have been caused by wave velocity modulation. The passage of the eclipse shadow over the propagation path causes both layer height changes and rapid changes in free electron density that can decelerate and accelerate wave velocity.

- The SAMI3 simulations showed an eclipse-induced increase in F-layer height but no change in the E-layer. This prediction ties in nicely with many spectral recordings that show a steady frequency track along with mode splitting into multiple higher order modes during daily dawn and dusk transitions. This suggests that the frequency swings and mode splitting occur in the F layer while the steady track comes from the E-layer.
Festival of Frequency (FoF) Measurements

• Kristina Collins KD8OXT has been leading the charge to run global campaigns to monitor HF Doppler shifts using both PSWS Grapes and Amateur gear.

• Initial results from October 1, 2019 FoF now submitted to IEEE GRSL.

• Preparing for December 4, 2021 Southern Hemisphere Eclipse.
Festival of Frequency Measurement

Frequency Deviation from 5 MHz WWV

2019 Oct 1

Submitted Frequency Data

Map

Submitted Frequency Data

Map

[Collins et al., 2020, Submitted IEEE GRSL]
WA5FRF Comparison Between Spectrogram and Single Frequency Formats During HamSCI Festival of Frequency Measurements

Spectrogram Format using Spectrum Lab

Single Frequency Detector using FLDIGI

Dusk Transition -------------- > Night ------------------------ > Dawn Transition ---------------- > Day ----------------- > Dusk Transition

Path: WWV, Ft. Collins CO to WA5FRF, near San Antonio, TX  0000z – 2359z October 1, 2019

Slide Courtesy of Steve Cerwin, WA5FRF

nathaniel.frissell@scranton.edu
Chirp Ionosonde Studies

• Science mode to take advantage of the TangerineSDR

• Make oblique ionograms using FM Chirp Ionosondes of opportunity

• Made possible by open source software and help from Dr. Juha Vierinen

• Science effort led by HamSCI/Scranton Post-Doc Dr. Dev Joshi, KC3PVE

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 site in Virginia to Spring Brook, Pennsylvania – the receiver station on Nov. 17, 2020.
KiwiSDR Capture of Chirp Ionosonde
Prototype Receive Station

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

- Implemented on Intel Core i9 with 128GB RAM Ettus USRP N200
- Receiver located in Spring Brook, PA (~10 miles from Scranton)
- Antenna: ZS6BKW @ 30 ft Altitude (Dipole-Like)
- A goal of TangerineSDR PSWS is to reduce the hardware requirements of this application substantially.

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/
GNU Chirpsounder2 by Juha Vierinen

- 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 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
Chirp Ionosonde Studies

17 Nov 2020

[Joshi et al., 2020, https://github.com/jvierine/chirpsounder2]
Monday Night TangerineSDR Telecons

- Engineering-focused telecon to support
  - TangerineSDR development
  - Magnetometer module development
  - TangerineSDR-based PSWS

- Monday nights at 9 PM Eastern
- Hosted by TAPR and The University of Scranton
- Zoom link, calendar, and archives at https://hamsci.org/get-involved
Thursday Morning Grape Telecons

- Engineering-focused telecon to support
  - Low-cost PSWS engineering and science
- Thursday mornings at 10 AM Eastern
- Hosted by Case Western Reserve University and Case ARC W8EDU
- Zoom link and calendar available at https://hamsci.org/get-involved
Thursday Bi-Weekly HamSCI Telecons

- Science-focused telecon to support HamSCI Science
- Every other Thursday 3 PM Eastern
- Hosted by The University of Scranton
- Contributed speakers are welcome!
- Zoom link, calendar, and archives at https://hamsci.org/get-involved
We welcome papers related to:

- Development of the PSWS
- Ionospheric Science
- Atmospheric Science
- Radio Science
- Space Weather
- Radio Astronomy

Theme: Midlatitude Ionospheric Science

Abstracts are due February 15, 2021.

Visit [hamsci.org/hamsci2021](http://hamsci.org/hamsci2021) for details.
## Virtual HamSCI Workshop (March 19-20, 2021)

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<th>Saturday AM 1</th>
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<td>Invited Tutorials</td>
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<td>Lunch Discussion</td>
<td>Saturday AM 2</td>
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<td>Experiment Co-Design</td>
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<tr>
<td>Friday PM</td>
<td>Lunch Discussion</td>
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<tr>
<td>Science Orals</td>
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<tr>
<td>Friday 2200z (6 PM EST)</td>
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<tr>
<td>Keynote: “History of Radio”</td>
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</tr>
<tr>
<td></td>
<td>Saturday PM</td>
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<td>iPosters and Breakout Rooms</td>
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</tbody>
</table>
The midlatitudes are where the bulk of humanity live and radio amateurs operate, however this region has traditionally been considered “quiet” compared to the auroral zone and equatorial region and therefore has received less scientific attention.

In this tutorial, Dr. Ruohoniemi will present a review of the physics of the midlatitude ionosphere, discuss recent advancements and open questions at the frontiers of research, and consider means by which the amateur radio community can contribute to advancing scientific understanding and technical capabilities.

Dr. J. Michael Ruohoniemi is a professor of electrical engineering at Virginia Tech and Principal Investigator of the Virginia Tech SuperDARN Laboratory.
Amateur Radio Observations and The Science of Midlatitude Sporadic E

Joseph Dzekevich K1YOW

Amateurs may ask, “How are sporadic-E transatlantic VHF communications possible between North America and Europe?”

In his tutorial, Joe K1YOW will explain what Sporadic E is, how amateur operators use Sporadic E to enable long-distance VHF communications, current theories of Sporadic E formation, and how we might be able to better understand Es formation by examining amateur radio propagation logs.

Joe’s studies of Sporadic E using amateur radio have been published both in QST (2017) and CQ Magazine (2020).
This talk will explore developments in the history, science, technology, and licensing of radio amateur communities from the early 1900s through to the present day, exploring how individuals and communities contributed to “citizen science” long before the term entered popular usage in the 1990s.

Dr. Brunton will also explore how these community-led developments can inspire the next generation’s interest in science, technology, engineering, and mathematics (STEM), citizen science, and amateur radio.

Dr. Bruton is Curator of Technology and Engineering at the Science Museum, London, specializing in the history of communications. Her PhD dissertation is entitled Beyond Marconi: the roles of the Admiralty, the Post Office, and the Institution of Electrical Engineers in the invention and development of wireless communication up to 1908.
Acknowledgments

The authors gratefully acknowledge the support of NSF Grants AGS-2002278, AGS-1932997, and AGS-1932972. We are especially grateful to the amateur radio community who voluntarily produced and provided the HF radio observations used in this presentation, especially the operators of the Reverse Beacon Network (RBN, reversebeacon.net), the Weak Signal Propagation Reporting Network (WSPRNet, wsprnet.org), PSKReporter (http://pskreporter.info), qrz.com, and hamcall.net. The Kp index was accessed through the OMNI database at the NASA Space Physics Data Facility (https://omniweb.gsfc.nasa.gov/). The SYM-H index was obtained from the Kyoto World Data Center for Geomagnetism (http://wdc.kugi.kyoto-u.ac.jp/). GOES data are provided by NOAA NCEI (https://satdat.ngdc.noaa.gov/). GPS-based total electron content observations and the Madrigal distributed data system are provided to the community as part of the Millstone Hill Geospace Facility by MIT Haystack Observatory under NSF grant AGS-1762141 to the Massachusetts Institute of Technology. We acknowledge the use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python, matplotlib, NumPy, SciPy, pandas, xarray, iPython, and others.
Thank You!
## Acronym Glossary

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>Auroral Electrojet Index</td>
</tr>
<tr>
<td>BKS</td>
<td>Blackstone, VA SuperDARN Radar</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
</tr>
<tr>
<td>HF</td>
<td>High Frequency (3-30 MHz)</td>
</tr>
<tr>
<td>LSTID</td>
<td>Large Scale Traveling Ionospheric Disturbance</td>
</tr>
<tr>
<td>MSTID</td>
<td>Medium Scale Traveling Ionospheric Disturbance</td>
</tr>
<tr>
<td>RBN</td>
<td>Reverse Beacon Network</td>
</tr>
<tr>
<td>SAMI3</td>
<td>SAMI3 is Another Model Ionosphere</td>
</tr>
<tr>
<td>SuperDARN</td>
<td>Super Dual Auroral Radar Network</td>
</tr>
<tr>
<td>Sym-H</td>
<td>Symmetric-H Index (For measuring geomagnetic storms)</td>
</tr>
<tr>
<td>TEC</td>
<td>Total Electron Content</td>
</tr>
<tr>
<td>TID</td>
<td>Traveling Ionospheric Disturbance</td>
</tr>
<tr>
<td>WSPRNet</td>
<td>Weak Signal Propagation Reporting Network</td>
</tr>
</tbody>
</table>
Abstract

The Ham Radio Science Citizen Investigation (HamSCI) is a platform to foster collaborations between the amateur (ham) radio and professional space science and space weather communities. Its mission is to (1) advance scientific research and understanding through amateur radio activities, (2) encourage the development of new technologies to support this research, and (3) provide educational opportunities for the amateur radio community and the general public. Similar to amateur astronomy, amateur radio allows individuals new to the avocation a path for learning, and those with years of experience a place to apply their advanced skills. This is accomplished through collaborative projects, coordinated experiments, workshops, telecons, and e-mail groups. In this presentation, we describe current HamSCI activities, available datasets, recent results, and future plans. This includes the HamSCI Personal Space Weather Station (PSWS) project, analysis of near-global communications monitoring networks such as the Reverse Beacon Network (RBN) and Weak Signal Propagation Reporting Network (WSPRNet), and analysis of observed Doppler shifts for high frequency signals of opportunity.
References


Backup Slides
What is Amateur (Ham) Radio?

- **Hobby for Radio Enthusiasts**
  - Communicators
  - Builders
  - Experimenters

- **Wide-reaching Demographic**
  - All ages & walks of life
  - Over 760,000 US amateurs; ~3 million Worldwide

- **Licensed by the Federal Government**
  - Basic RF electrical engineering knowledge
  - Licensing provides a path to learning and ensures a basic interest and knowledge level from each participant
  - Each amateur radio station has a government-issued “call sign”

- **Ideal Community for Citizen Science**

  Note: A license is not required to operate a PSWS because it is receive only!

KD2JAO & WB2JSV at NJIT Station K2MFF

AB4EJ Home Station

N8UR multi-TICC: Precision Time Interval Counter

nathaniel.frissell@scranton.edu
The Ionosphere

https://commons.wikimedia.org/wiki/File:IonosphereLayers-NPS.gif
TIDs in Blackstone SuperDARN
Periods get longer...

<table>
<thead>
<tr>
<th>Range</th>
<th>Est. Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>min</td>
<td>13:30</td>
</tr>
<tr>
<td>max</td>
<td>14:00</td>
</tr>
<tr>
<td>min</td>
<td>15:00</td>
</tr>
<tr>
<td>max</td>
<td>16:15</td>
</tr>
<tr>
<td>min</td>
<td>17:00</td>
</tr>
<tr>
<td>max</td>
<td>18:30</td>
</tr>
<tr>
<td>min</td>
<td>19:15</td>
</tr>
</tbody>
</table>
PSWS Control Software and Database

Developed by University of Alabama

Primary objective
- Local Control Software for Tangerine SDR
- Central Control System for PSWS Network
- Central Database to collect observations

Current Status
- Prototype of local control software exists
- Runs on Odroid N2 Single Board Computer
- Uses data from a TangerineSDR Simulator
- Can monitor up to 16 band segments at a time
- 4 types of data collection
  - **Snapshotter**: wideband high frequency spectrograms at a 1 second cadence.
  - **Ring Buffer**: Continuous local storage of IQ samples for 24 hours, then upload on request from Central Control (with throttling)
  - **Firehose**: Continuous transfer IQ samples to a local computer
  - **Propagation Monitoring**: Decoding of FT8 and WSPR amateur radio digital modes on up to 8 bands at a 1 minute cadence

Bill Engelke AB4EJ demonstrates early versions of the TangerineSDR Local Control Software and Simulator at 2020 HamCation in Orlando, FL.
Scientific SDR (TangerineSDR)

Developed as “TangerineSDR” by TAPR

Data Engine Specifications
• Altera/Intel 10M50DAF672C6G FPGA 50K LEs
• 512MByte (256Mx16) DDR3L SDRAM
• 4Mbit (512K x 8) QSPI serial flash memory
• 512Kbit (64K x 8) serial EEPROM
• μSDXC memory card up to 2TByte

Data Engine Features
• 11-15V wide input, low noise SMPS
• 3-port GbESwitch (Dual GbEdata interfaces)
• Cryptographic processor with key storage
• Temperature sensors (FPGA, ambient)
• Power-on reset monitor, fan header

RF Module
• AD9648 125 dual 14 bit 122.88Msps ADC
• 0dB/10dB/20dB/30dB remotely switchable attenuator
• LTC6420 20 20dB LNA
• Fixed 55MHz Low Pass Filter
• Optional user defined plug in filter
• On-board 50Ω calibration noise source
• On-board low noise power supplies
• Dual SMA antenna connectors

GNSS/Timing Module
• Precision timestamping (10 to 100 ns accuracy)
• Frequency reference (Parts in $10^{13}$ over 24 hr)

Current Status
• Prototypes expected by Fall 2020
• More information at tangerinesdr.com
Ground Magnetometer

Developed by TAPR and NJIT

Purpose
• To establish a densely-spaced magnetic field sensor network to observe Earth’s magnetic field variations in three vector components.

Target performance level
• ~10 nT field resolution
• 1-sec sample rate (note: Earth’s magnetic field ranges from 25,000 to 65,000 nT)

Sensors
• PNI RM3100 magnetometer module
  • 3 axis magneto-inductive measurement module
  • Low cost (≤ $20) allows widespread deployment
  • Very small (25.4 x 25.4 x 8 mm)
• MCP9808 temperature sensor

Prototypes have been made

Software driver development
• Current low-level software is rudimentary
• Both low-level and user facing software must be created to support further characterization and optimization of the sensors.

Planned Testing
• Testing at established quiet sites.
• Comparison with calibrated sensors of established quality.

Magnetometer prototype designed by David Witten KD0EAG at the 2020 HamCation conference in Orlando, FL
Low-Cost PSWS Status

- Developed as the “Grape” Receiver by Case Western Reserve University and Case Amateur Radio Club W8EDU.
- **Primary objective** is to measure Doppler Shift of HF standards stations such as WWV and CHU.
- **Cost target is ~$100.**
- **Four stations** are currently deployed, some with prototype receivers and some with amateur transceivers. Preparations are also underway to set up stations with several aspiring data collectors.
- Doppler shift data is collected via spectrographs and frequency estimation algorithms.
- The low-cost PSWS team is currently fine-tuning metadata formats and automatic data upload.
What is Total Electron Content (TEC)?

\[ I_s = \frac{1}{40.3} \frac{f_1^2 f_2^2}{f_1^2 - f_2^2} [(L_1 - L_2) - (\lambda_1 n_1 - \lambda_2 n_2) + b_r + b_s] \]

Slant TEC | Frequency Terms | Recorded carrier phases of the signal (converted to distance units) | Integer cycle ambiguities | Instrument (satellite and receiver) bias terms

- \( f_1 = 1575.42 \text{ MHz (GPS L1)} \)
- \( f_2 = 1227.60 \text{ MHz (GPS L2)} \)
- 1 TECU = \(10^{16} \) Electrons m\(^{-2}\)