ISWAT G2B-07 HamSCI: Ham Radio Science Citizen Investigation

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HamSCI Ham radio Science Citizen Investigation

hamsci.org/dayton2017

Founder/Lead HamSCI Organizer:
Dr. Nathaniel A. Frissell, W2NAF
The University of Scranton

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

Objectives:

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

What is Amateur (Ham) Radio?

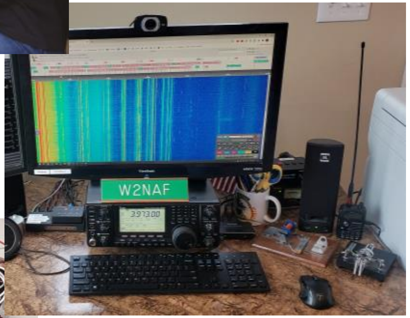
- **Hobby for Radio Enthusiasts**
  - Communicators
  - Builders
  - Experimenters
- **Wide-reaching Demographic**
  - All ages & walks of life
  - Over 760,000 US amateurs; ~3 million Worldwide

(http://www.arrl.org/arrl-fact-sheet)

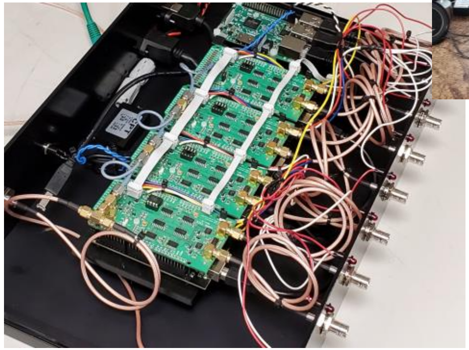
- **Licensed by the Federal Government**
  - Basic RF electrical engineering knowledge
  - Licensing provides a path to learning and ensures a basic interest and knowledge level from each participant
  - Each amateur radio station has a government-issued “call sign”
- **Ideal Community for Citizen Science**

University of Scranton Students at W3USR

Photo by Byron Maldonado



W2NAF Home Station

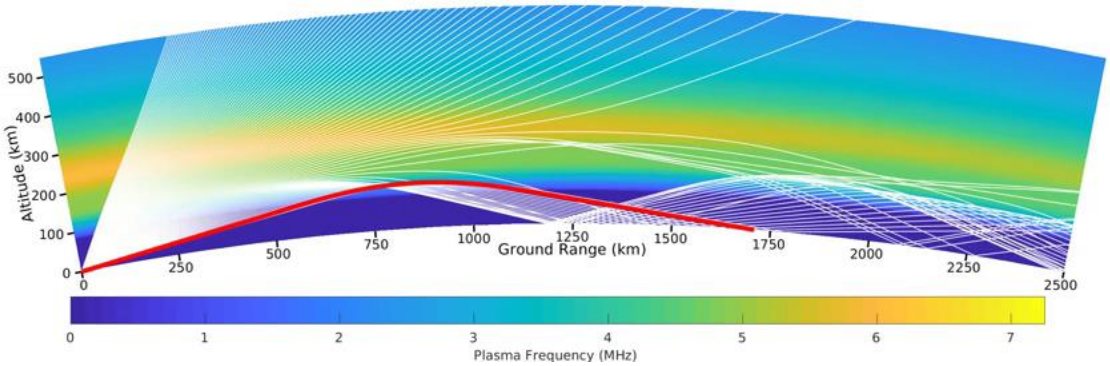


N8UR multi-TICC: Precision Time Interval Counter

Amateur Radio Frequencies and Modes

Eclipsed SAMI3 - PHaRLAP Raytrace

1600 UT 21 Aug 2017 • 14.03 MHz • TX: AA2MF (Florida) • RX: WE9V (Wisconsin)



PHaRLAP: Cervera & Harris (2014), https://doi.org/10.1002/2013JA019247
SAMI3: Huba & Drob (2017), https://doi.org/10.1002/2017GL073549
Amateur Radio and the Eclipse: Frissell et al. (2018), https://doi.org/10.1029/2018GL077324

- **Amateurs routinely use HF-VHF transionospheric links.**
- **Often ~100 W into dipole, vertical, or small beam antennas.**
- **Common HF Modes**
  - Data: FT8, PSK31, WSPR, RTTY
  - Morse Code / Continuous Wave (CW)
  - Voice: Single Sideband (SSB)

	Frequency	Wavelength
LF	135 kHz	2,200 m
MF	473 kHz	630 m
	1.8 MHz	160 m
HF	3.5 MHz	80 m
	7 MHz	40 m
	10 MHz	30 m
	14 MHz	20 m
	18 MHz	17 m
	21 MHz	15 m
	24 MHz	12 m
	28 MHz	10 m
VHF+	50 MHz	6 m
	And more…	

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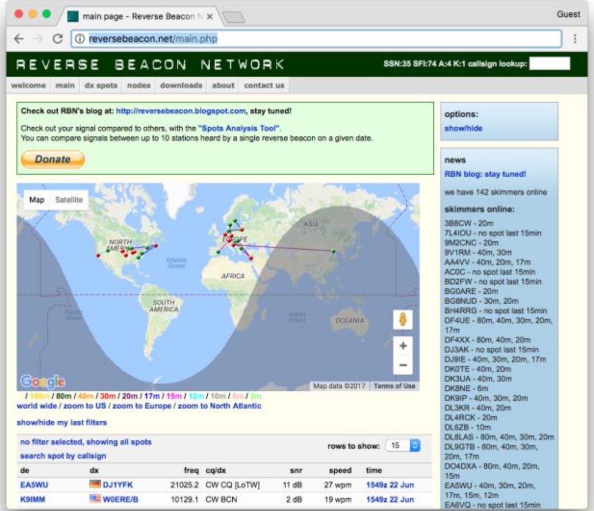
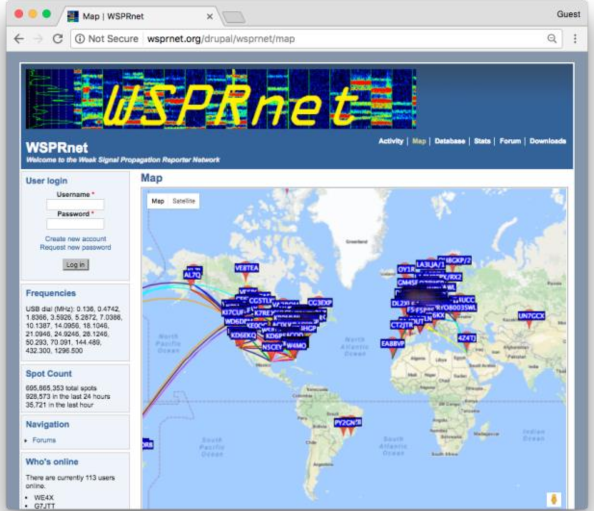
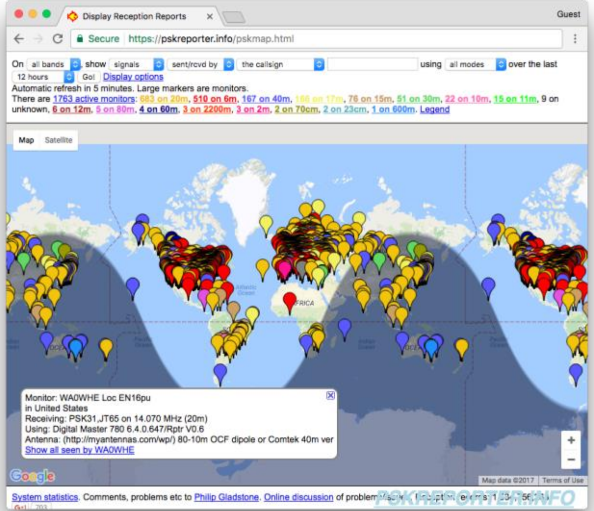
Amateur Radio Observation Networks



Reverse Beacon Network (RBN)
reversebeacon.net



WSPRNet
wsprnet.org



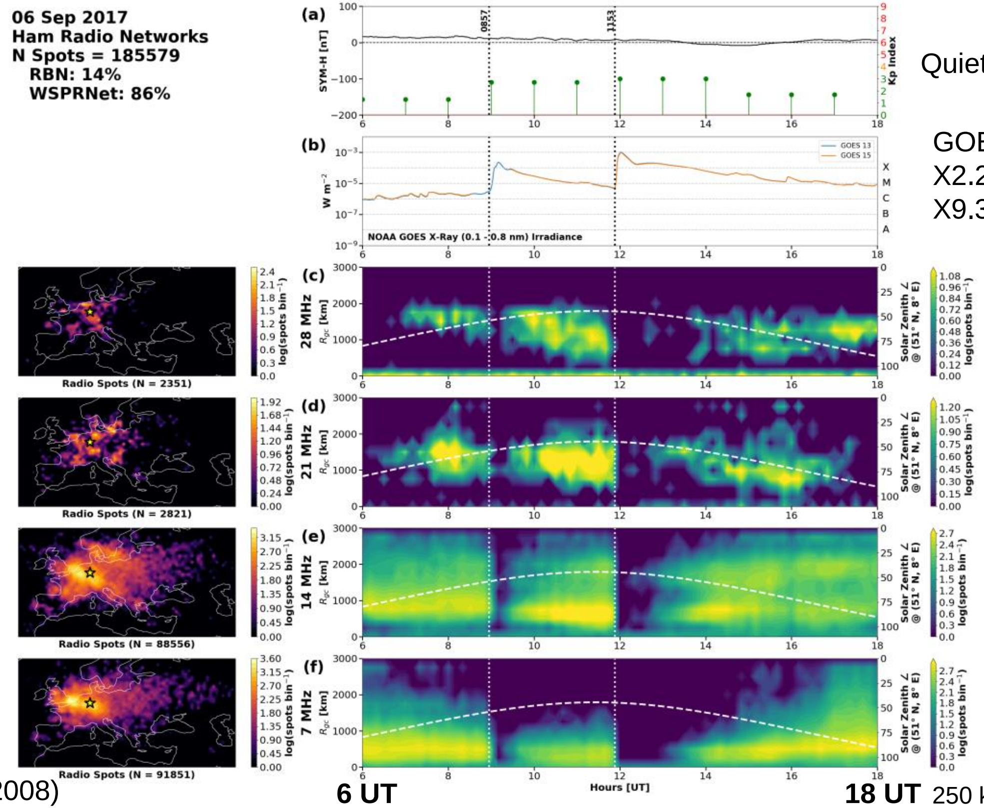
PSKReporter
pskreporter.info

- Quasi-Global
- Organic/Community Run
- Unique & Quasi-random geospatial sampling

- Data back to 2008 (A whole solar cycle!)
- Available in real-time!

EU Response to Solar Flares

- Europe in daylight.
- Both flares cause deep blackouts.



Quiet Kp/Sym-H

GOES Flares
X2.2: 0857 UT
X9.3: 1153 UT

28 MHz

21 MHz

14 MHz

7 MHz

6 UT

18 UT

250 km × 10 min bins

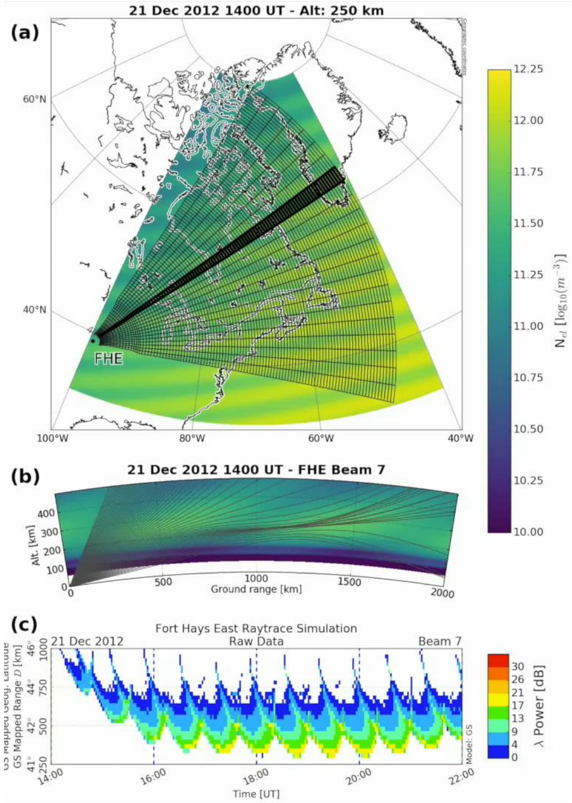
([Frissell et al., 2019](https://doi.org/10.1029/2018SW002008), https://doi.org/10.1029/2018SW002008)

Traveling Ionospheric Disturbances

- TIDs are Quasi-periodic Variations of F Region Electron Density
- Medium Scale (MSTID)
  - $T \approx 15 - 60$ min
  - $v_H \approx 100 - 250$ m/s
  - $\lambda_H \approx$ Several Hundred km (< 1000 km)
  - May be associated with meteorological or auroral sources
- Large Scale (LSTID)
  - $\lambda_h > 1000$ km
  - $30 < T$ [min] <180
  - Sources are typically attributed to Auroral Electrojet Enhancement, Particle Precipitation
- Both may be associated with Atmospheric Gravity Waves
- Identifying the actual source can be difficult

[Francis, 1975; Hunsucker 1982; Ogawa et al., 1967; Ding et al., 2012; Frissell et al., 2014; 2016]

Traveling Ionospheric Disturbances



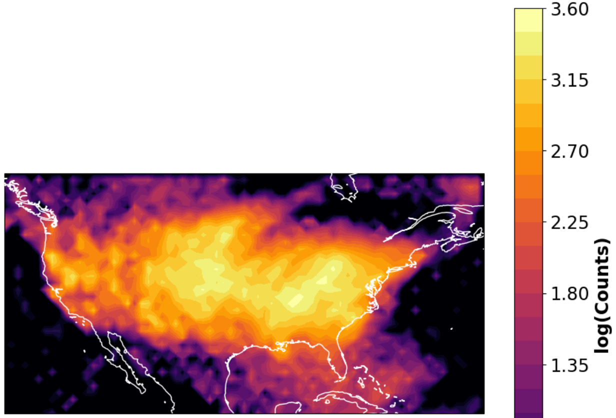
Ray trace simulation illustrating how SuperDARN HF radars observe MSTIDs.

(a) Fort Hays East (FHE) radar field of view superimposed on a 250 km altitude cut of a perturbed IRI. FHE Beam 7 is outlined in bold.
(b) Vertical profile of 14.5 MHz ray trace along FHE Beam 7. Background colors represent perturbed IRI electron densities. The areas where rays reach the ground are potential sources of backscatter.
(c) Simulated FHE Beam 7 radar data, color coded by radar backscatter power strength. Periodic, slanted traces with negative slopes are the signatures of MSTIDs moving toward the radar.

[Frissell et al., 2016]

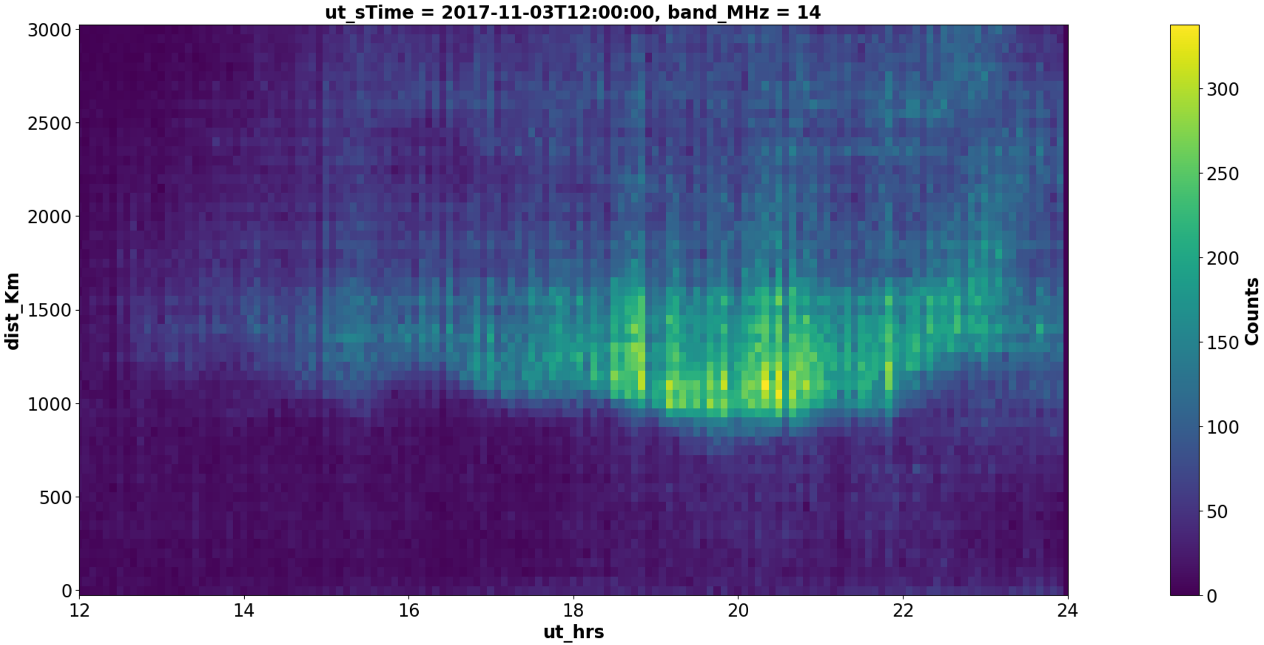
November 3, 2017

20171103.1200-20171104.0000_timeseries.png



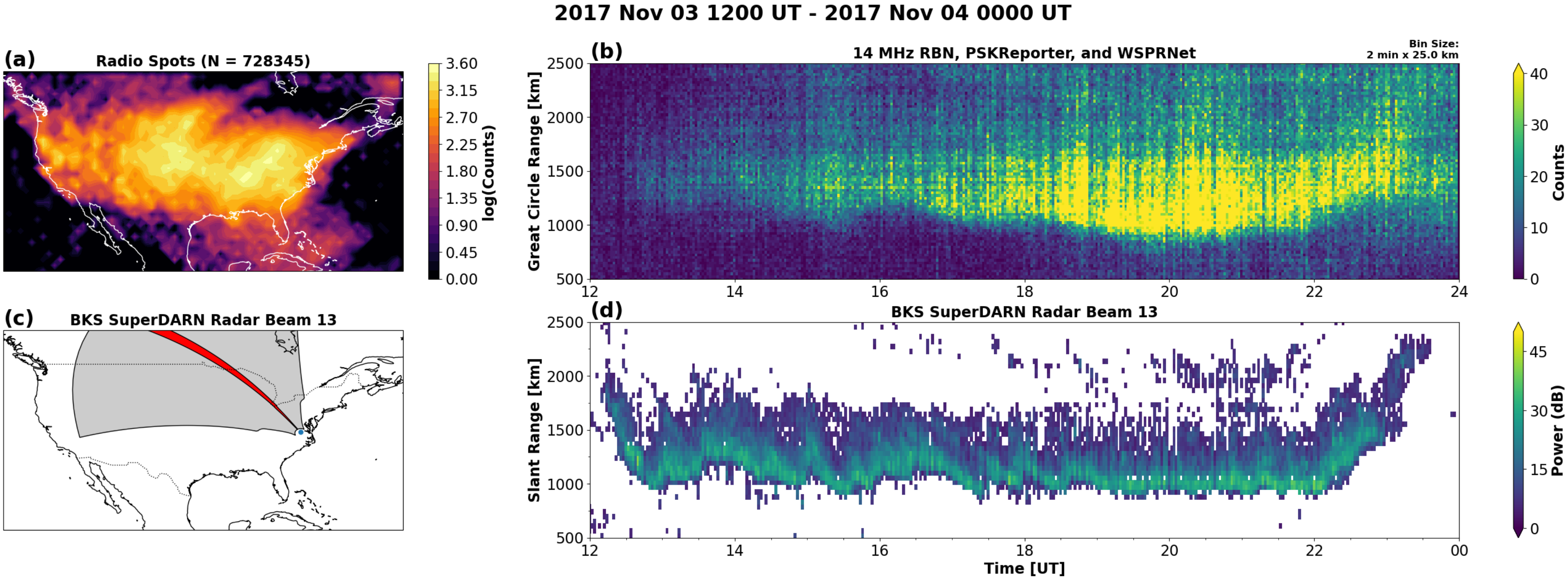
Radio Spots (N = 728345)

(1°x1° bins)



(5 min x 50 km bins)

November 3, 2017



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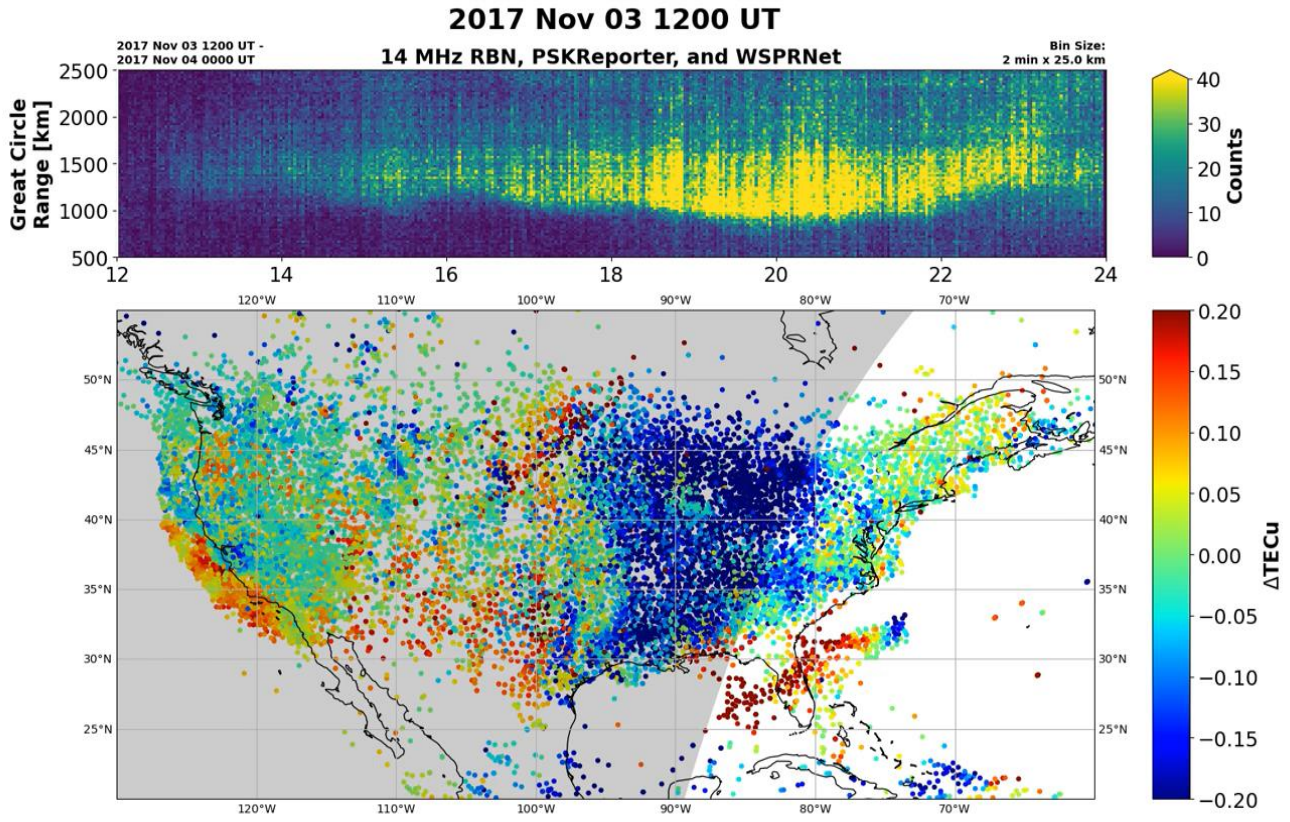
Amateur Radio Compared with GNSS dTEC



- Radio range is shortest when TEC is red (higher TEC)
- Higher electron densities → More HF refraction, communication range decreases

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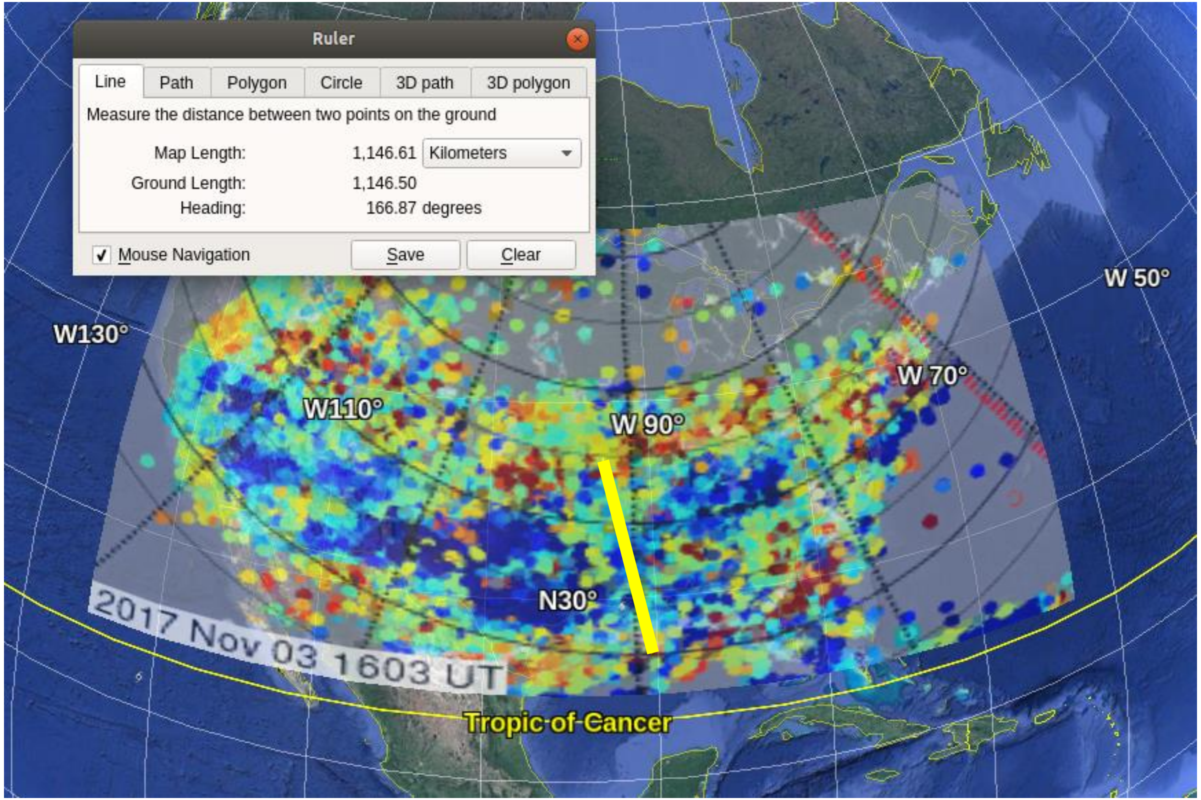
Estimated GNSS TEC LSTID Parameters

$\lambda_h \approx 1{,}136$ km

$v_p \approx 1280$ km/hr

$T \approx 53$ min

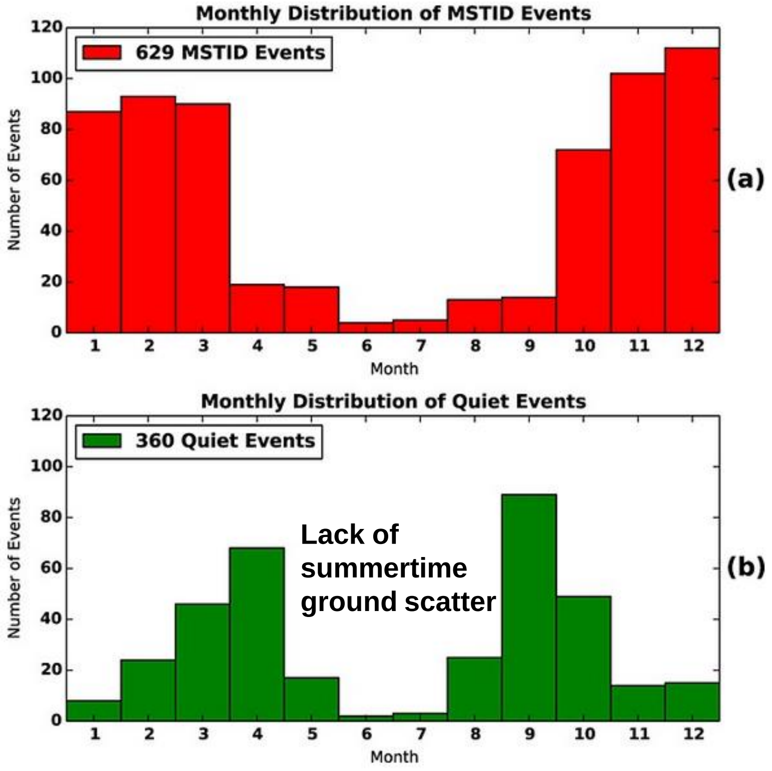
$\Phi_{Azm} \approx 167°$



TEC MUSIC Analysis by E. G. Thomas.
For algorithm description, see
[Bristow et al. (1994)] and
[Frissell et al. (2014)].

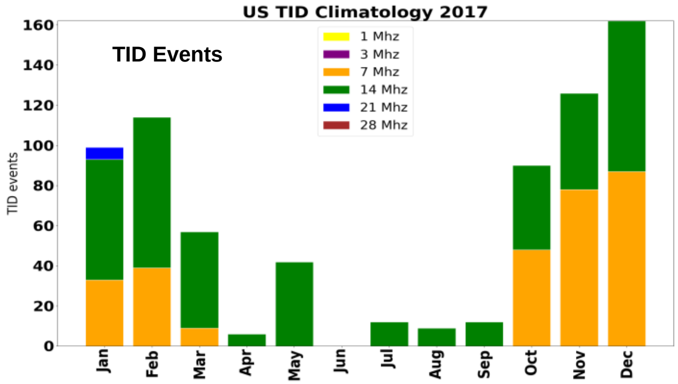
SuperDARN Climatology Comparison

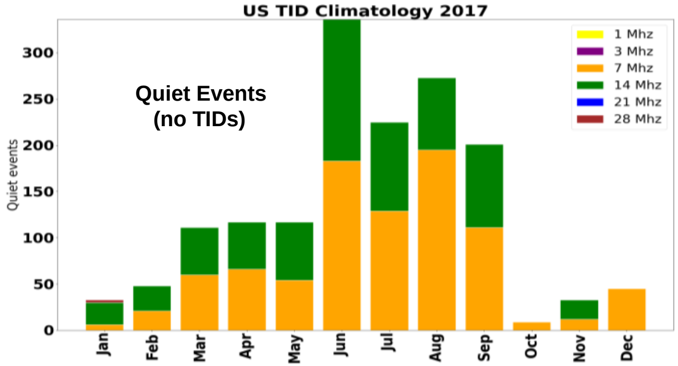
SuperDARN



(*Frissell et al.*, 2014, https://doi.org/10.1002/2014JA019870)

Amateur Ham Radio





(*Diego Sanchez et al., 2021*)

TID Studies: NASA SWO2R & NSF CAREER

NASA SWO2R *(2 years, 2021-2023)*

Enabling Space Weather Research with Global Scale Amateur Radio Datasets

PI: N. Frissell W2NAF, Co-Is: T. Atkison, W. Engelke AB4EJ, and P. Erickson W1PJE

- Development of automated TID detection and parameter extraction algorithms.
- Develop empirical TID models that use geophysical indices as independent variables and model the probability of TID occurrence signatures in terrestrial HF communications.
- Validate models for the 7 and 14 MHz bands in the continental US and mainland Europe.
- Deposit RBN/PSKReporter/WSPRNet data into public NASA data repositories.

NASA Partner | THE UNIVERSITY OF SCRANTON A JESUIT UNIVERSITY | MIT HAYSTACK OBSERVATORY

NSF CAREER (5 years, 2021-2026)

CAREER: Amateur Radio as a Tool for Studying Traveling Ionospheric Disturbances and Atmosphere-Ionosphere Coupling

PI: N. Frissell W2NAF

- Identify the amount of TIDs observed by HF communications systems that are and are not associated with geomagnetic activity.
- Determine the ability of data from amateur radio to fill TID observational gaps and be scientifically useful.
- Establish TID longitudinal dependence on the 2D stratospheric polar vortex configuration.
- Test the multistep vertical coupling paradigm of AGWs/TIDs theorized in the latest physics-based models.

NSF | THE UNIVERSITY OF SCRANTON A JESUIT UNIVERSITY

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ISWAT Proposed Paper

Observing Large Scale Traveling Ionospheric Disturbances Using High Frequency Amateur Radio Receiving Networks: Automated Detection and the Development of Empirical Predictive Models

Abstract: Traveling Ionospheric Disturbances (TIDs) are quasi-periodic variations of F-region ionospheric electron densities that in particular affect the range and quality of High Frequency (HF, 3-30 MHz) radio communications, through motion of the ionospheric skip-focusing distance during TID passage. For a radio operator, this manifests as signal fading and enhancement with periods ranging from about 15 minutes to a few hours. In addition to their operational impacts, TIDs are of great scientific interest because they are often associated with neutral Atmospheric Gravity Waves (AGWs). Thus, TID observations can be also used to advance understanding of critically important neutral atmosphere-ionosphere coupling. In this paper, we demonstrate a forthcoming automated technique and system for the detection of TIDs, using spectral analysis applied to HF amateur (ham) radio observations observed by the Reverse Beacon Network (RBN), Weak Signal Propagation Reporting Network (WSPRNet), and PSKReporter automated amateur radio systems. Each of these systems is built, operated, and maintained by amateur radio community volunteers and has significant coverage over the North American and European continents. We will also discuss plans for further development of this automated detection technique with the goal of constructing a predictive empirical model of TIDs using geophysical drivers. Such a TID model has significant potential for global and regional space weather studies.

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Acknowledgments

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- amateur radio community who voluntarily produced and provided the HF radio observations used in this paper, especially the operators of the Reverse Beacon Network (RBN, reversebeacon.net), the Weak Signal Propagation Reporting Network (WSPRNet, wsprnet.org), PSKReporter (pskreporter.info) qrz.com, and hamcall.net.

- support of NSF AGS-200227 and NASA 19-LWS19_2-0069.

- use of SuperDARN data. SuperDARN is a collection of radars funded by national scientific funding agencies of Australia, Canada, China, France, Italy, Japan, Norway, South Africa, United Kingdom and the United States of America.

- PyDARN Analysis Toolkit made available by the SuperDARN Data Analysis Working Group, Schmidt, M.T., Billett, D.D., Martin, C.J., Huyghebaert, D., Bland, E.C., … Sterne, K.T. (2021, February 23). SuperDARN/pydarn: pyDARNio v2.0.1 (Version v2.0.1). Zenodo. http://doi.org/10.5281/zenodo.4558130.

- GNSS TEC data used is provided by the Millstone Hill Geospace Facility under NSF grant AGS-1952737.

- The use of NASA/GSFC's Space Physics Data Facility's OMNIWeb (or CDAWeb or ftp) service, and OMNI data.

- Use of SuperMAG data (Gjerloev, 2012) and the SML/SME/SMU indices (Newell and Gjerloev, 2011), including data provided by: INTERMAGNET, Alan Thomson; CARISMA, PI Ian Mann; CANMOS, Geomagnetism Unit of the Geological Survey of Canada; The S-RAMP Database, PI K. Yumoto and Dr. K. Shiokawa; The SPIDR database; AARI, PI Oleg Troshichev; The MACCS program, PI M. Engebretson; GIMA; MEASURE, UCLA IGPP and Florida Institute of Technology; SAMBA, PI Eftyhia Zesta; 210 Chain, PI K. Yumoto; SAMNET, PI Farideh Honary; IMAGE, PI Liisa Juusola; Finnish Meteorological Institute, PI Liisa Juusola; Sodankylä Geophysical Observatory, PI Tero Raita; UiT the Arctic University of Norway, Tromsø Geophysical Observatory, PI Magnar G. Johnsen; GFZ German Research Centre For Geosciences, PI Jürgen Matzka; Institute of Geophysics, Polish Academy of Sciences, PI Anne Neska and Jan Reda; Polar Geophysical Institute, PI Alexander Yahnin and Yarolav Sakharov; Geological Survey of Sweden, PI Gerhard Schwarz; Swedish Institute of Space Physics, PI Masatoshi Yamauchi; AUTUMN, PI Martin Connors; DTU Space, Thom Edwards and PI Anna Willer; South Pole and McMurdo Magnetometer, PI's Louis J. Lanzarotti and Alan T. Weatherwax; ICESTAR; RAPIDMAG; British Antarctic Survey; McMac, PI Dr. Peter Chi; BGS, PI Dr. Susan Macmillan; Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN); MFGI, PI B. Heilig; Institute of Geophysics, Polish Academy of Sciences, PI Anne Neska and Jan Reda; University of L'Aquila, PI M. Vellante; BCMT, V. Lesur and A. Chambodut; Data obtained in cooperation with Geoscience Australia, PI Andrew Lewis; AALPIP, co-PIs Bob Clauer and Michael Hartinger; MagStar, PI Jennifer Gannon; SuperMAG, PI Jesper W. Gjerloev; Data obtained in cooperation with the Australian Bureau of Meteorology, PI Richard Marshall.

- use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python (van Rossum, 1995), matplotlib (Hunter, 2007), NumPy (Oliphant, 2007), SciPy (Jones et al., 2001), pandas (McKinney, 2010), xarray (Hoyer & Hamman, 2017), iPython (Pérez & Granger, 2007), and others (e.g., Millman & Aivazis, 2011).

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Thank you!

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NASA SWO2R Motivation

- From an operational perspective, there are few (if any) TID predictive models in the unclassified domain that can be effectively used.
- From a science perspective, a properly developed empirical TID model can aid in identifying which physics drivers of TIDs are most important.
- Currently available physics-based models that can predict TIDs require detailed specification of initial conditions and are computationally intensive.
- Currently available empirical HF propagation models do not capture ionospheric variability on TID timescales and obscure the identity of the underlying physical drivers.

NASA SWO2R Model Development

- This NASA SWO2R grant will develop empirical TID models that use geophysical indices as independent variables and model the probability of TID occurrence signatures in terrestrial HF communications.
- These models will be used to conduct sensitivity studies that will identify the key geophysical drivers of TID occurrence.
- These empirical models will be developed in three phases:
    1. Development of automated TID detection and parameter extraction algorithms.
    2. Development of a regression-based Generalized Linear Model
    3. Development of a convolutional neural network model
- These models will be validated for the 7 and 14 MHz bands in the continental US and mainland Europe.

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