THE UNIVERSITY OF SCRANTON
A JESUIT UNIVERSITY

HamSCI: Space Weather Operational Resources and Needs of the Amateur Radio Community

Nathaniel A. Frissell[1], Philip J. Erickson[2], Ethan S. Miller[3], William Liles[4], H. Ward Silver[4], R. Carl Luetzelschwab[4], Tamitha Skov[5]

[1]The University of Scranton
[2]MIT Haystack Observatory
[3]Systems & Technology Research
[4]HamSCI Community
[5]Aerospace Corporation

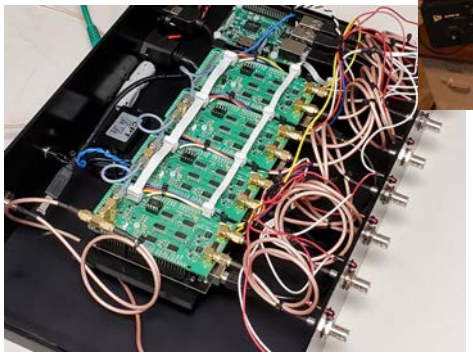
nathaniel.frissell@scranton.edu

What is Ham Radio?

- **Hobby for Radio Enthusiasts**
  - Communicators
  - Builders
  - Experimenters
- **Wide-reaching Demographic**
  - All ages & walks of life
  - Over 760,000 US hams; ~3 million World Wide
- **Licensed by the Federal Government**
  - Basic RF Electrical Engineering Knowledge
  - Provides a path to learning
  - Licensing ensures a basic interest and knowledge level from each participant

KD2JAO & WB2JSV at NJIT Station K2MFF

AB4EJ Home Station



N8UR multi-TICC: Precision Time Interval Counter

nathaniel.frissell@scranton.edu

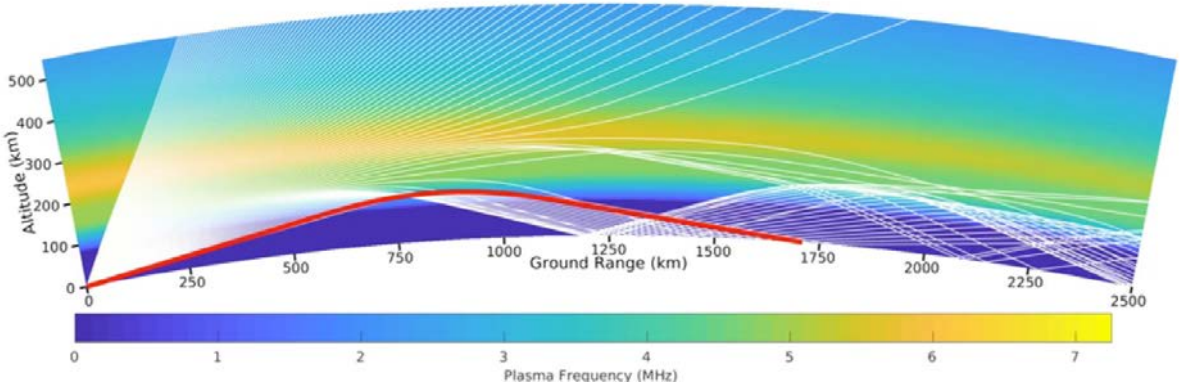
Ham Radio Frequencies and Modes

	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…	

PHaRLAP Raytrace

1600 UT 21 Aug 2017 14.03 MHz - Eclipsed SAMI3

TX: AA2MF (Florida) RX: WE9V (Wisconsin)



- Hams routinely use HF-VHF transionospheric links.
- Often ~100 W into dipole antennas.
- Common HF Modes
  - Digital: FT8, PSK31, WSPRNet, RTTY
  - Morse Code / Continuous Wave (CW)
  - Phone: Single Side Band (SSB)

nathaniel.frissell@scranton.edu

Examples of Ham Radio Communications

- **Emergency & Public Service**
- **Contesting / Radio Sport**
- **DXing / Distance Awards**

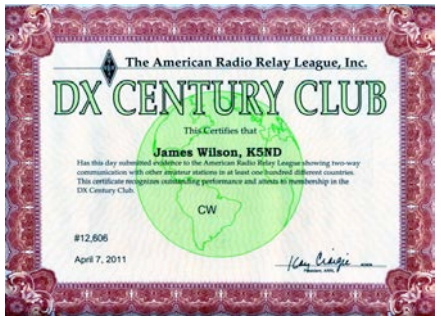

Field Day
Emergency Preparedness


K3LR Contest Super Station


CANDAC/PEARL, Eureka, Canada
Photo: Pierre Fogal VE3KTB


K2BSA Scout Jamboree

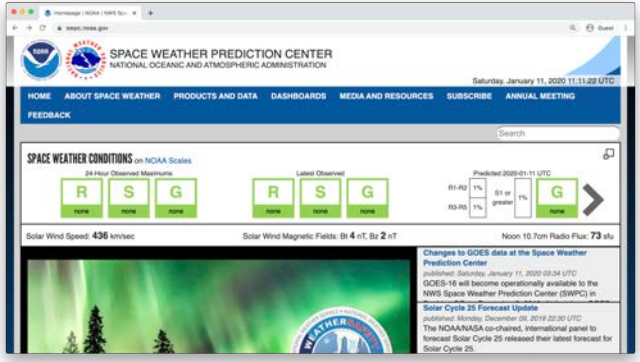

K3LR Contest Super Station



Need: Forecast between any 2 points as a function of frequency, power level/mode, time.

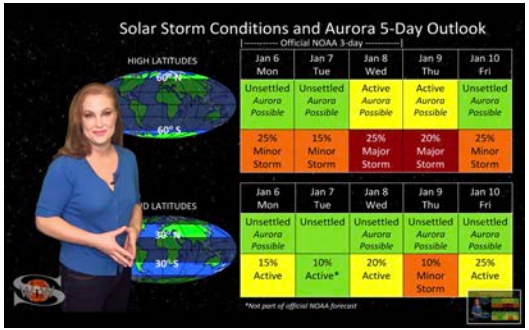
Where do hams look for space weather?

NOAA SWPC



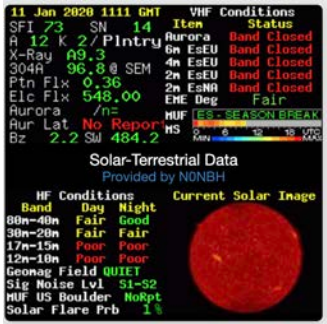
Tamitha Skov WX6SWW

spaceweatherwoman.com

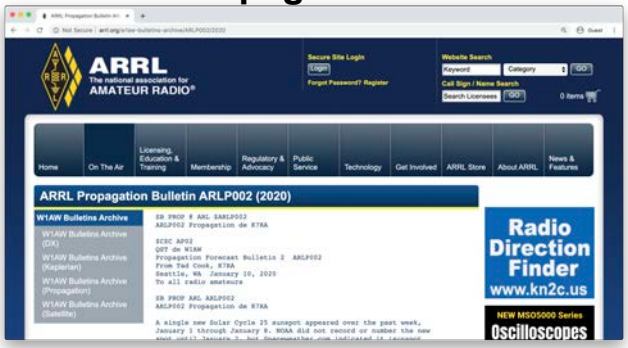


Paul Herrman N0NBH

www.hamqsl.com/solar.html



ARRL Propagation Bulletins



Spaceweather.com

And many others can be found around the web…

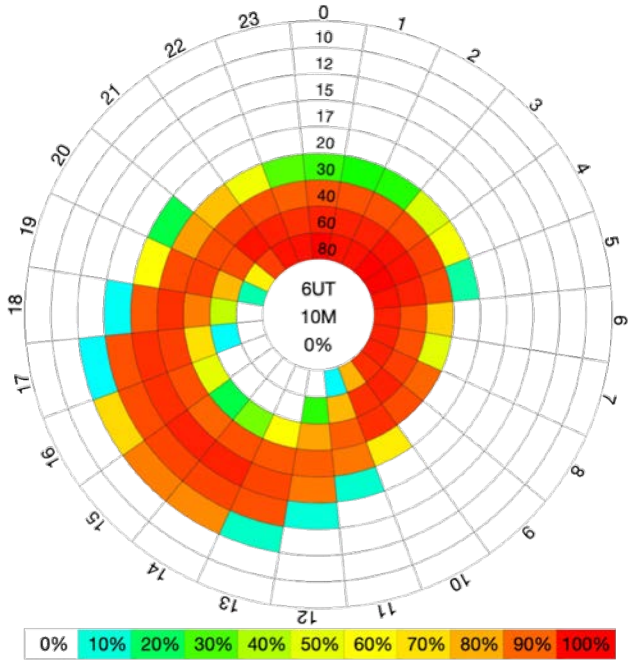
nathaniel.frissell@scranton.edu

Propagation Tools

Full HF Propagation Prediction	**Fully Empirical** • Voice of America Coverage Analysis Program (VOACAP/IONCAP/ICEPAK) • ITURHFProp • Advanced Stand Alone Prediction System (ASAPS) **Raytracing-Based** • PropLab Pro with IRI2007 • PHaRLAP with IRI2016
Ionospheric Models	• International Reference Ionosphere (IRI) • Ionosphere Real-Time Assimilative Model (IRTAM) • Global Assimilative Ionospheric Model (GAIM)
Specialty Models	• D-Region Absorption Model (DRAP - NOAA SWPC) • Ovation Prime (Auroral Oval Model)

VOACAP Prediction

Boston to London – January 2020



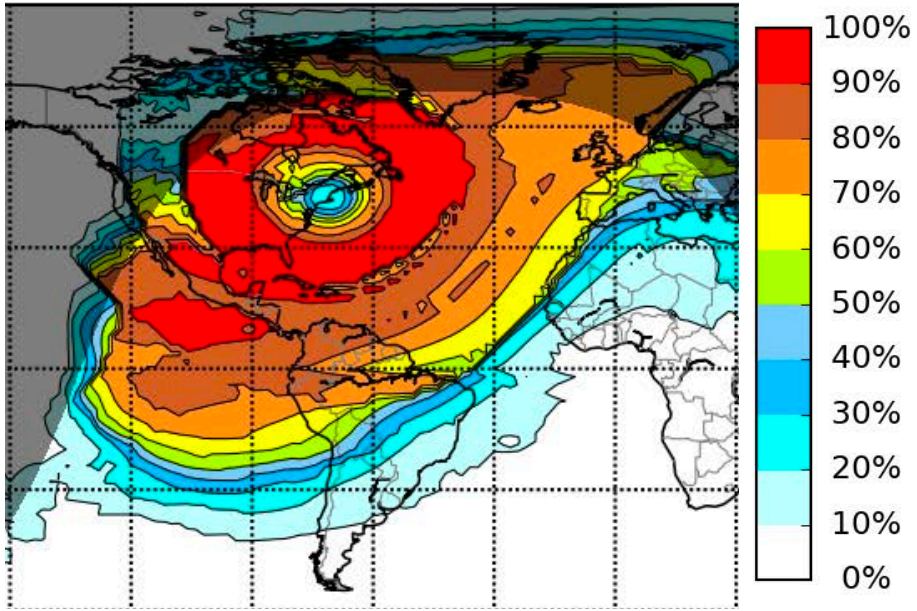
http://voacap.com/hf

nathaniel.frissell@scranton.edu

Analysis Tools – Current State

- Good tools, provide needed forecast between locations as function of frequency, power level/mode, time.
- BUT these are correct in only the monthly median sense.
- Also, they are very smoothed geospatially.
- **Need higher resolution forecasts spatially and temporally**
  - **Regional/Local Forecasts**
  - **3, 7, 10 Day? Hourly?**
- Some are working toward this
  - ASAPS, GAIM, IRTAM

ITURHFProp Prediction
Boston to World on 14 MHz
January 2020 – 1500 UT



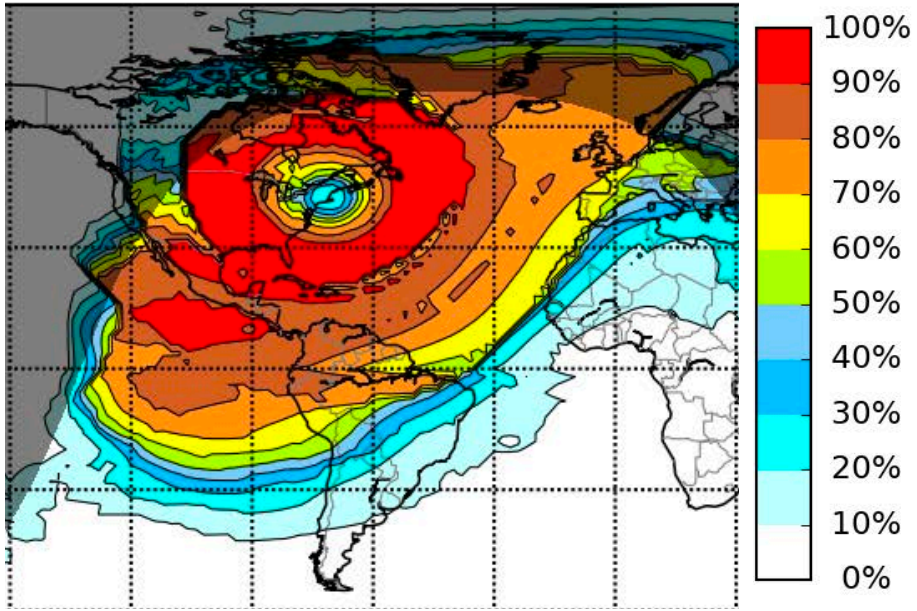
http://www.predtest.uk/area.html

nathaniel.frissell@scranton.edu

Improving the Models

- **Need better understanding of**
  - Small-scale spatial structures
  - Short time-scale variability
  - Lower Atmospheric Coupling
  - Response to Space Weather Inputs
- **Path to model improvement**
  - Analyze Observations
  - Search for coherence at new spatiotemporal resolutions
  - Produce usable, high-level forecast products
  - Validate with real observations

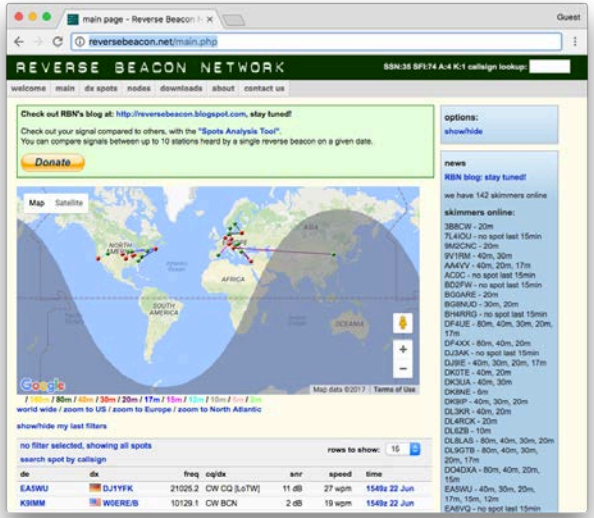
ITURHFProp Prediction
Boston to World on 14 MHz
January 2020 – 1500 UT



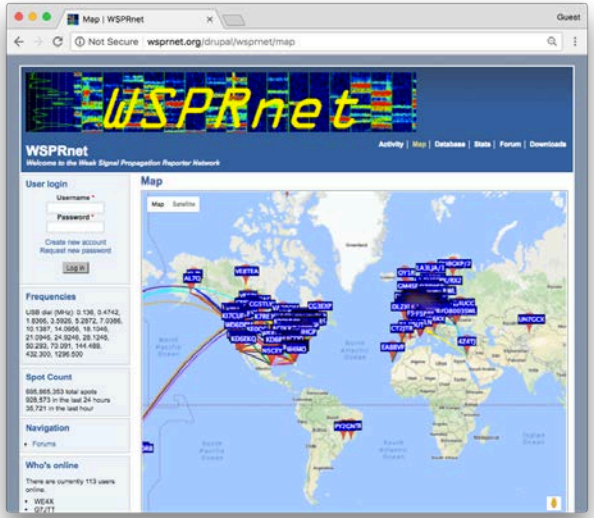
http://www.predtest.uk/area.html

nathaniel.frissell@scranton.edu

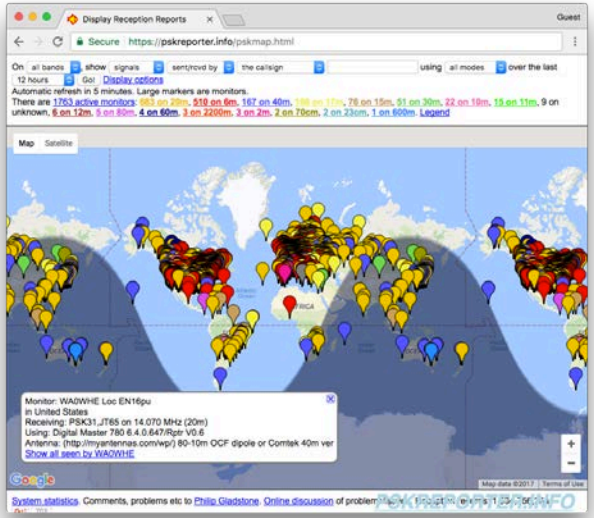
Ham Radio Observation Networks



Reverse Beacon Network (RBN)
reversebeacon.net



WSPRNet
wsprnet.org



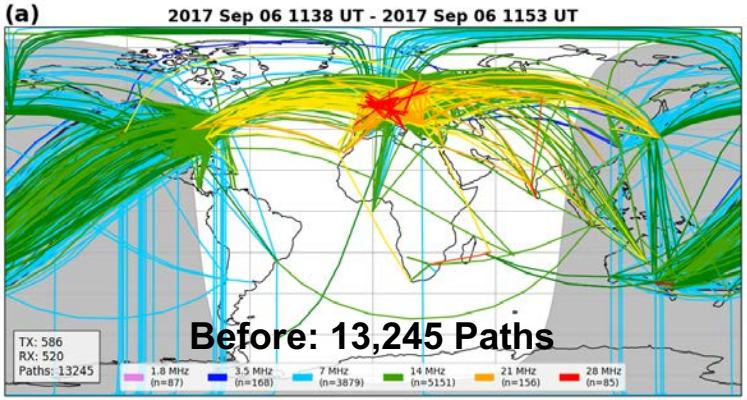
PSKReporter
pskreporter.info

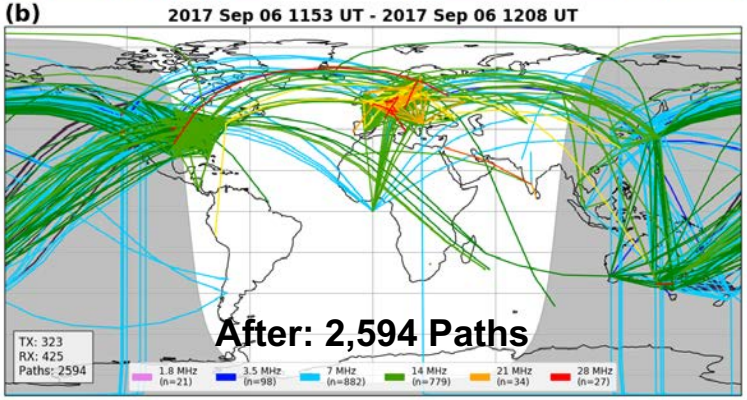
- Quasi-Global
- Organic/Community Run
- Unique & Quasi-random geospatial sampling

- Data back to 2008 (A whole Solar Cycle!)
- Available in real-time!

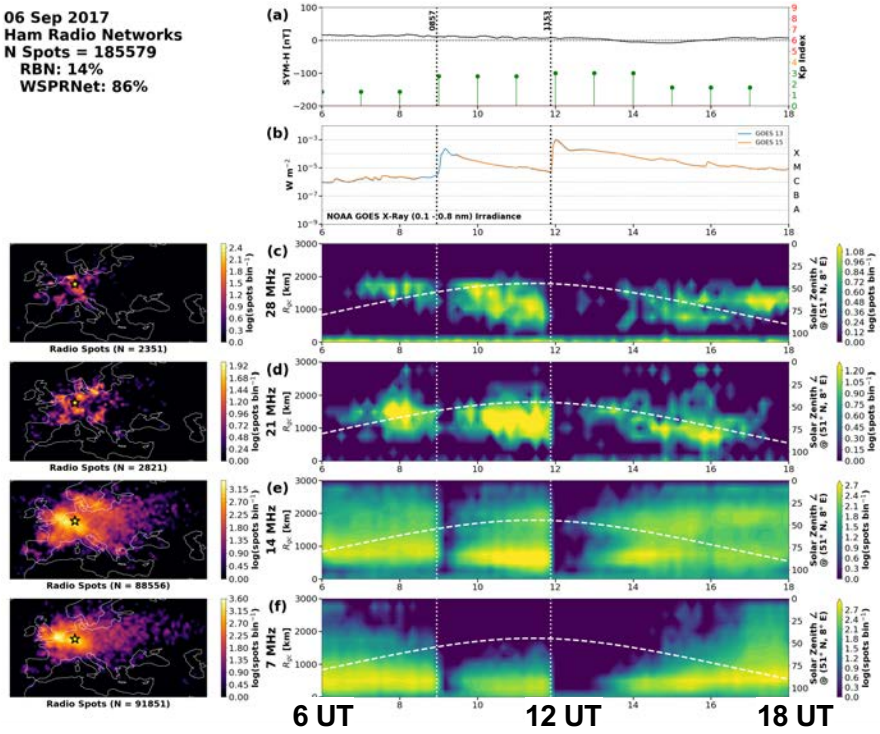
nathaniel.frissell@scranton.edu

Ham Radio HF Response to Solar Flares





6 Sept 2017 1153 UT X9.3 Flare



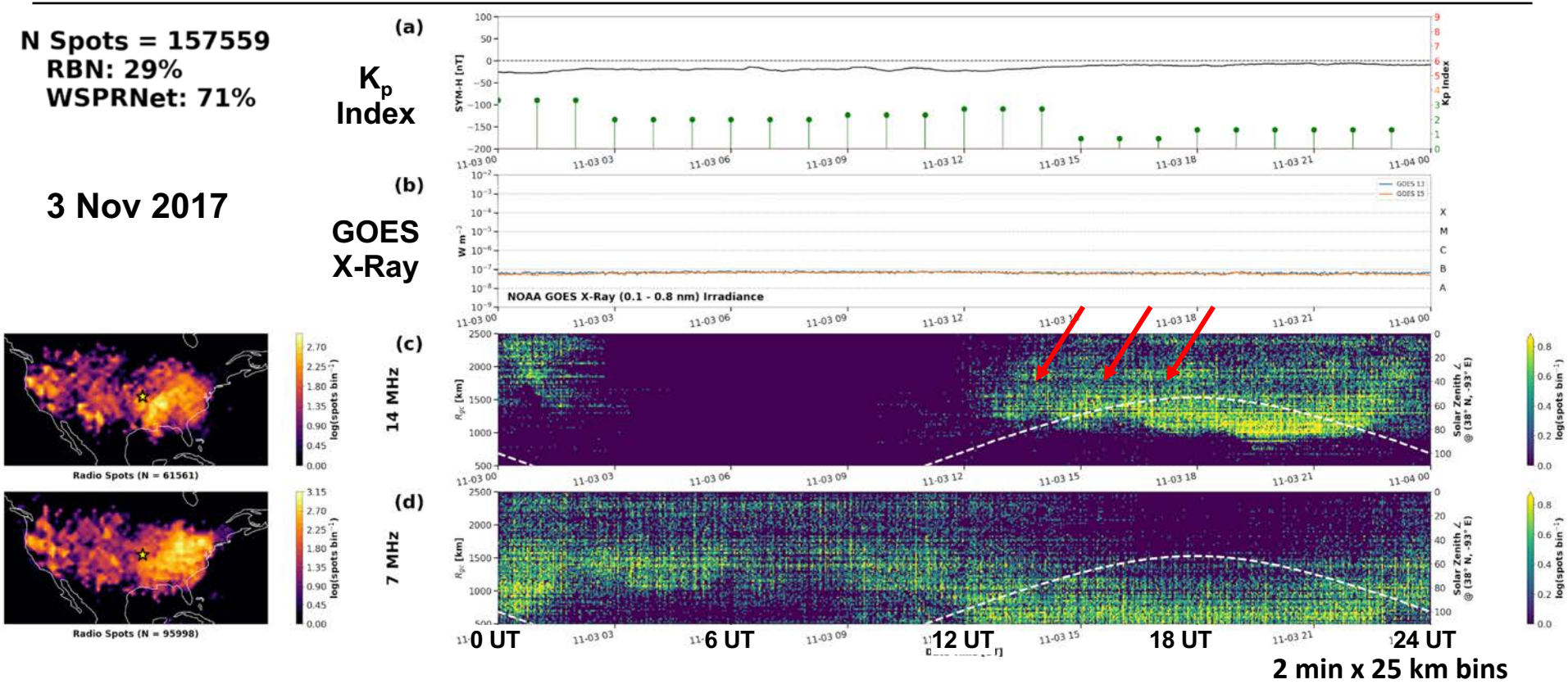
(*Frissell et al.*, 2019, https://doi.org/10.1029/2018SW002008)

nathaniel.frissell@scranton.edu

Ham Radio View of Traveling Ionospheric Disturbances

N Spots = 157559
RBN: 29%
WSPRNet: 71%

3 Nov 2017

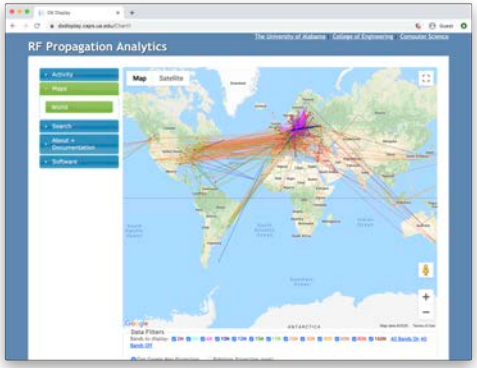


2 min x 25 km bins

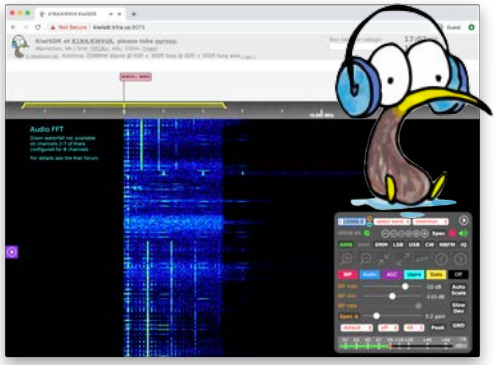
nathaniel.frissell@scranton.edu

Other Ham Radio Capabilities

- So many propagation sites!
- Lots of interesting hardware available
- Low-cost, capable, software-centric instruments (e.g. KiwiSDRs)
- The amateur radio Community itself



https://dxdisplay.caps.ua.edu/



KiwiSDR & https://sdr.hu/

ARRL The national association for AMATEUR RADIO

CQ

HamSCI

TAPR

Dayton Hamvention® Sponsored by Dayton Amateur Radio Association Since 1952

RSGB

nathaniel.frissell@scranton.edu

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 community and the general public.

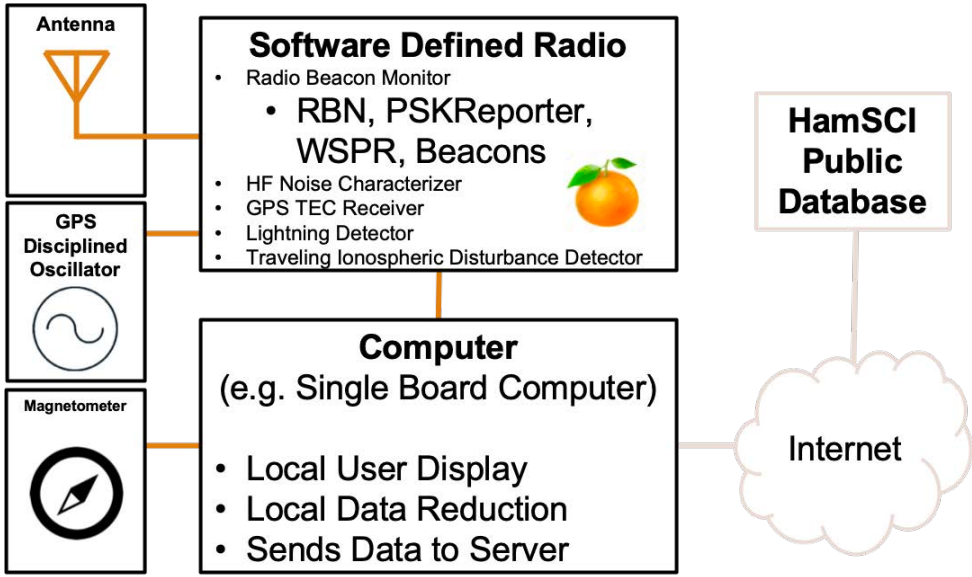
2020 HamSCI Workshop @ University of Scranton

March 20-21, 2020

nathaniel.frissell@scranton.edu

Personal Space Weather Station

- **Useful to ham radio, space science, and space weather communities.**
- **Modular Instrument Design**
  - Easy ability to add or remove instruments, especially in software architecture
- **Small footprint**
- **Nice User Interface/Local Display**
- **Standard format to send data back to a central repository**
- **Open community-driven design**



http://hamsci.org/psws

nathaniel.frissell@scranton.edu

Summary

Needs

- The **Holy Grail** of space weather prediction for the amateur radio community is a forecast of communications reliability between any two points on Earth as a function of frequency, power, mode, and time.
- We have the these tools now, but they are only good in a monthly median sense and are very geospatially smoothed. We need high time and spatial resolution versions of these models for both nowcasting and forecasting.

Resources

- The ham radio community currently has the ability to provide a global view of communications over a range of frequencies in real-time and archives to ~2008. These datasets can be used to validate and improve models.
- The HamSCI collective enables the collaboration between the ham radio and professional research communities.
- HamSCI Personal Space Weather Station Project seeks to create a new citizen science space weather monitoring network designed with science in mind from the start.

nathaniel.frissell@scranton.edu

Thank You

nathaniel.frissell@scranton.edu

Acknowledgements

- We gratefully acknowledge the support of NSF Grant AGS-2002278.
- 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.

Backup Slides

nathaniel.frissell@scranton.edu

Session Description

Session 6: R2O2R: User Needs and Priorities. Part I
Tuesday, January 14, 2020 10:30 AM - 12:00 PM
Boston Convention and Exhibition Center - 205A
Larisa Goncharenko, Patrick Dandenault, Chairs

Synopsis
The potential impacts of extreme space weather are gaining visibility worldwide and next-generation operational systems are being developed. As our understanding of the physics of near-Earth space (Geospace) events improves, that knowledge will be incorporated into the new systems. This session will address Standards, Metrics, and User needs for next-generational operational space weather, Research-to-Operations and Operations-to-Research (R2O2R) programs. Topics may include: next-generation hardware and software architectures; standards and metrics for comparing models, and for comparing data-assimilation algorithms; User needs and requirements for improved operational products.

Session Agenda

10:30 AM – 6.1	**Applying NASA SPoRT's R2O/O2R Paradigm to Space Weather: MAG4 Applications and Assessment at SWPC** A. LeRoy, Univ. of Alabama in Huntsville, Huntsville, AL; and S. Dahl, D. A. Falconer, R. E. Allen, and C. D. Fry
10:45 AM – 6.2	**Federal Aviation Administration User Needs: Space Weather R2O2R (Invited Presentation)** William H. Bauman III, FAA, Washington, DC
11:00 AM – 6.3	**Transition of WAM-IPE to NOAA Operations: Current Capabilities and Future Potential (Invited Presentation)** Tim Fuller-Rowell, NOAA, Boulder, CO; and N. Maruyama, H. Wang, Z. Li, T. W. Fang, G. Millward, A. Kubaryk, M. Fedrizzi, V. A. Yudin, M. Codrescu, D. Fuller-Rowell, P. Richards, and A. D. Richmond
11:15 AM – 6.4	**The Challenge of O2R and R2O for Space Weather and What We Are Doing about It (Invited Presentation)** James Spann, NASA, Washington, DC; and C. Wallace, M. Wiltberger, and J. V. Jenniges
11:30 AM – 6.5	**U.S. Air Force Space Weather O2R Priorities (Invited Presentation)** Janelle V. Jenniges, U.S. Air Force, Washington, DC; and M. Farrar
11:45 AM – 6.6	**HamSCI: Space Weather Operational Resources and Needs of the Amateur Radio Community (Invited Presentation)** Nathaniel A. Frissell, Univ. of Scranton, Scranton, PA; and P. J. Erickson, E. S. Miller, W. Liles, H. W. Silver, R. C. Luetzelschwab, and T. Skov

Abstract

https://ams.confex.com/ams/2020Annual/meetingapp.cgi/Paper/370904

The amateur (ham) radio community is a global community of over 3 million people who use and build radio equipment for communications, experimentation, and science. By definition, amateur radio is a volunteer service, with the operators required to hold government-issued licenses that are typically earned by passing knowledge tests covering radio regulations and practices, radio theory, and electromagnetic theory. In the United States, there are about 750,000 licensed hams, ranging in age from very young to very old, and ranging in experience from neophyte to people with advanced degrees in radio engineering and science. Amateur radio operators are licensed to transmit on bands spread across the radio frequency (RF) spectrum, from very low frequency (VLF) up to hundreds of gigahertz. The purpose of these communications range from mission-critical emergency and public service communications to social contacts to highly competitive contests and achievement award programs. Many of these communications rely on trans-ionospheric paths, and therefore are heavily influenced by conditions in near-Earth space, or space weather.

Amateurs today obtain space weather and propagation prediction information from sources such as the NOAA Space Weather Prediction Center (SWPC), spaceweather.com, the Voice of America Coverage Analysis Program (VOACAP), amateur radio propagation columnists (ARRL, RSGB, and CQ Magazine), and spaceweatherwoman.com (Dr. Tamitha Skov). In order to predict success for their communications efforts, hams often use parameters such as smoothed sunspot number, 10.7 cm wavelength solar flux proxy, and the planetary Kp and Ap indices as inputs to predict radio propagation performance. Traditionally, these predictions focus on the driving influence of space conditions and the sun's output. However, frontier research in the space sciences community has revealed that for improved predictive success, much more information needs to be provided on neutral atmosphere dynamics from the lower atmosphere and its coupled effects on the ionosphere, and predictions need to be available at higher temporal and spatial resolution. Lower atmospheric influences include atmospheric gravity waves that can couple to traveling ionospheric disturbances that can dramatically alter radio propagation paths. Tropospheric phenomena such as temperature inversions and wind shear also affect VHF and UHF propagation. To be most useful, the ham community needs operational products that provide real time nowcasts and multi-day forecasts which predict how space weather through the whole atmosphere affects radio wave propagation on global scale and at all operational wavelengths.

To help with this effort, hams can provide data with unique spatial and temporal coverage back to the research and forecast community. The amateur radio community has already started this process with the creation of multiple global-scale, real-time propagation reporting systems such as the Weak Signal Propagation Reporting Network (WSPRNet), PSKReporter, and the Reverse Beacon Network (RBN). Studies by the Ham radio Science Citizen Investigation (HamSCI) have shown that data from these systems, if applied correctly, can effectively be used to study ionospheric space weather events. Experienced amateurs keep detailed records of verified point-to-point contacts and have extensive experience operating under a wide variety of geophysical conditions and locations, both of which can provide unique insights when shared with the professional research community. In this presentation, we will describe efforts led by the HamSCI collective to provide this research community feedback through active HamSCI community email lists and annual HamSCI workshops. We will also describe strategies with good initial success at amateur-professional collaboration, including a HamSCI-led amateur radio community - professional research community partnership to create a network of HamSCI Personal Space Weather Stations (PSWS), which will allow citizen scientists to make science-grade space weather observations from their own backyards.

nathaniel.frissell@scranton.edu

Questions from Ward Silver N0AX

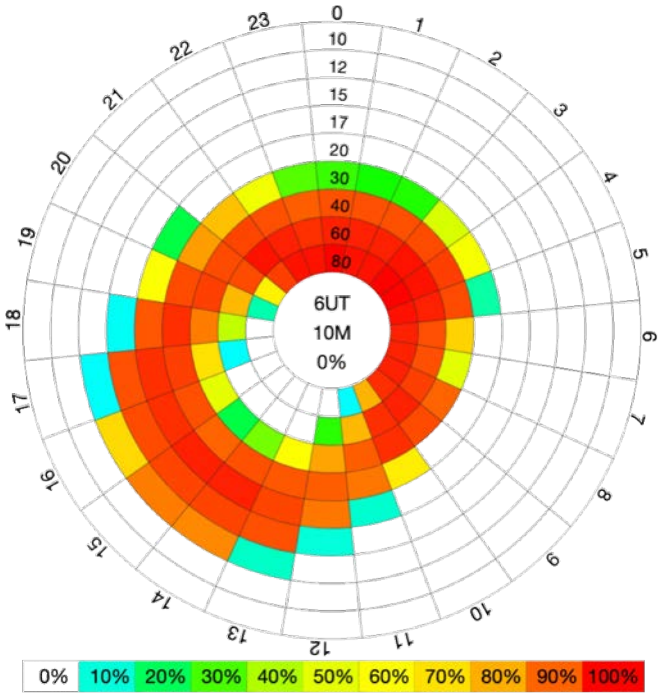
- For advanced station capability photos and descriptions, I suggest you check with K5CM and the Time Nuts group - some of them have atomic clocks in their basements!

- What I'd like to know more about space weather research is:
  - what parameters beyond those we've considered would be useful and within the ability of amateurs to measure
  - requirements for amateur-based measurements, realizing these might be looser than professional-quality but there would be more data
  - can we get better real-time assessments of various point-to-point modes, such as path-specific F2 MUF, sporadic-E, chordal or ducted propagation

Current Propagation Tools

- Voice of America Coverage Analysis Program (VOACAP/IONCAP/ICEPAK)
- ITURHFProp
- Advanced Stand Alone Prediction System (ASAPS)
- PropLab Pro with IRI2007
- PHaRLAP with IRI2016
- Global Assimilative Ionospheric Model (GAIM/HFNowcast)
- DRAP (NOAA SWPC)
- Ovation Prime

Boston to London – VOACAP January 2020
voacap.com/hf



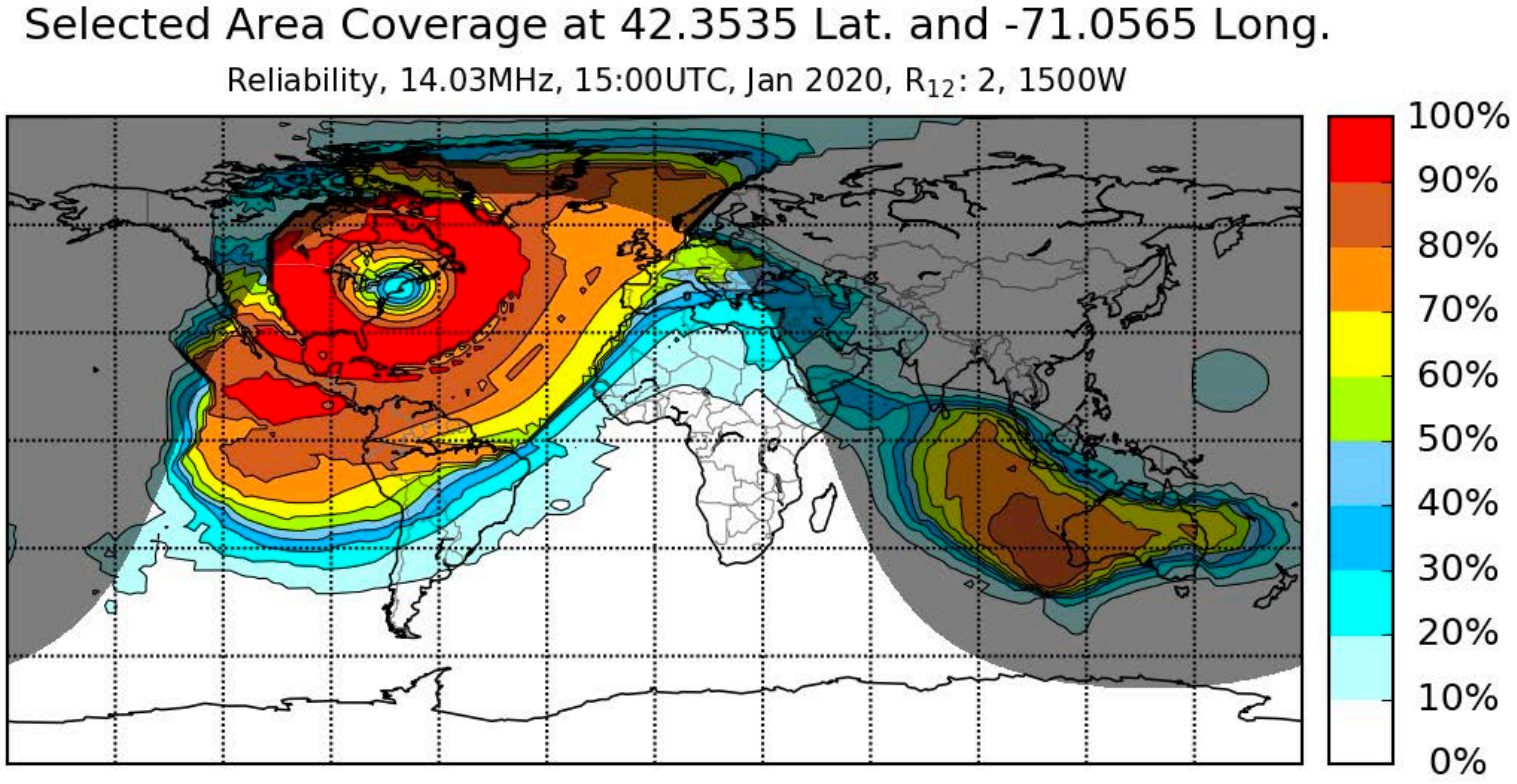
nathaniel.frissell@scranton.edu

Propagation Tools

- **Full HF Propagation Packages**
  - High-level, easy to interpret for the operator
  - Example Output Parameters
    - Circuit reliability
    - Received Signal Strength
    - SNR
  - Purely Empirical
    - VOACAP/IONCAP/ICEPAK
    - ITUHFProp
    - ASAPS
  - Ray-Tracing Based
    - PropLab Pro (uses empirical IRI)
- **Ionosphere Models**
  - Models Physical State of the Ionosphere
  - Example Output Parameters
    - Densities
    - Temperatures
    - Velocities
  - Purely Empirical
    - IRI
  - Assimilative - Empirical
    - IRTAM
    - GAIM-GM
  - Assimilative – Physics-Based
    - GAIM-FP

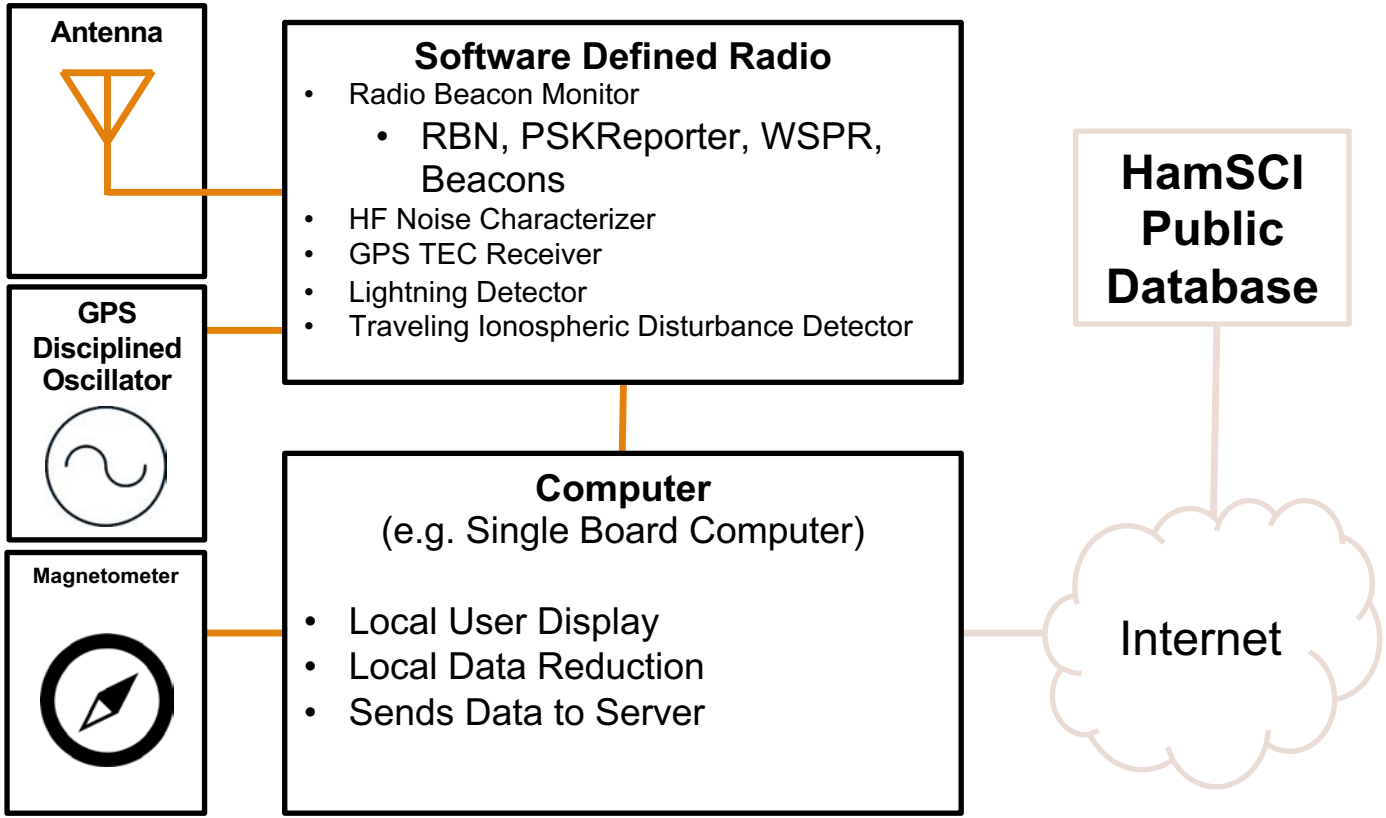
nathaniel.frissell@scranton.edu

Analysis Tools – Current State



nathaniel.frissell@scranton.edu

Personal Space Weather Station



nathaniel.frissell@scranton.edu