New Jersey Institute of Technology

HamSCI

HamSCI and the 2017 Total Solar Eclipse

Nathaniel A. Frissell, W2NAF[1]
and the HamSCI Community

[1]New Jersey Institute of Technology, K2MFF

Total Solar Eclipse

https://github.com/HamSCI/eclipse_calculator

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300 km – 0 km Altitude

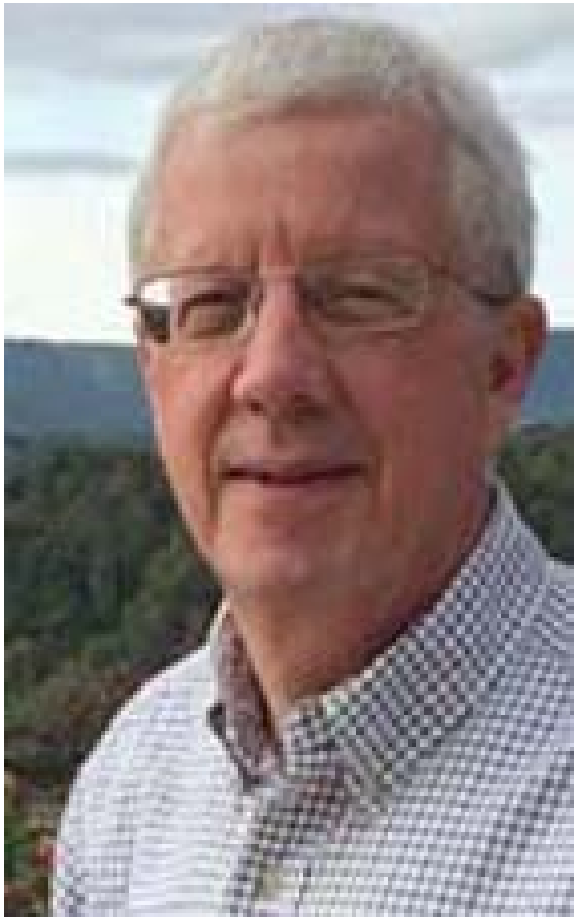
BLUE: More Eclipsed @ 300 km Alt **RED: More Eclipsed on Ground**

https://github.com/HamSCI/eclipse_calculator

HamSCI Eclipse Experiments

- **HF Frequency Measurement Experiment**
  - Measure changes in WWV, CHU frequency due to eclipse
- **Solar Eclipse QSO Party (SEQP)**
  - Ham Radio Contest-Like Event
  - Generate a quasi-random dataset
  - Data from RBN, PSKRepoter, WSPRNet, Logs
- **HF Wideband Recording**
  - Use SDRs to record large amounts of HF Spectrum

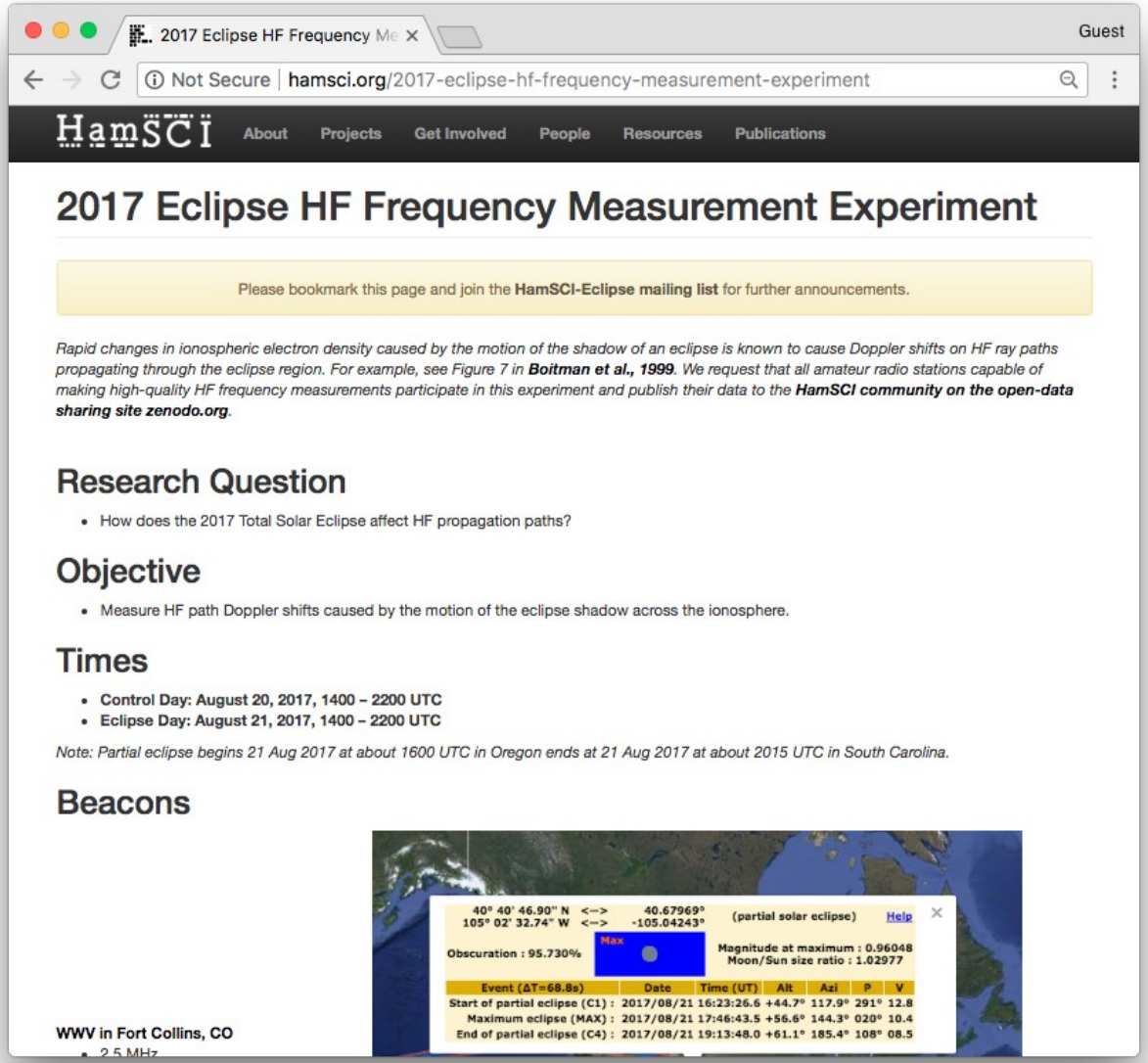
Steve Reyer, PhD, WA9VJ (SK)



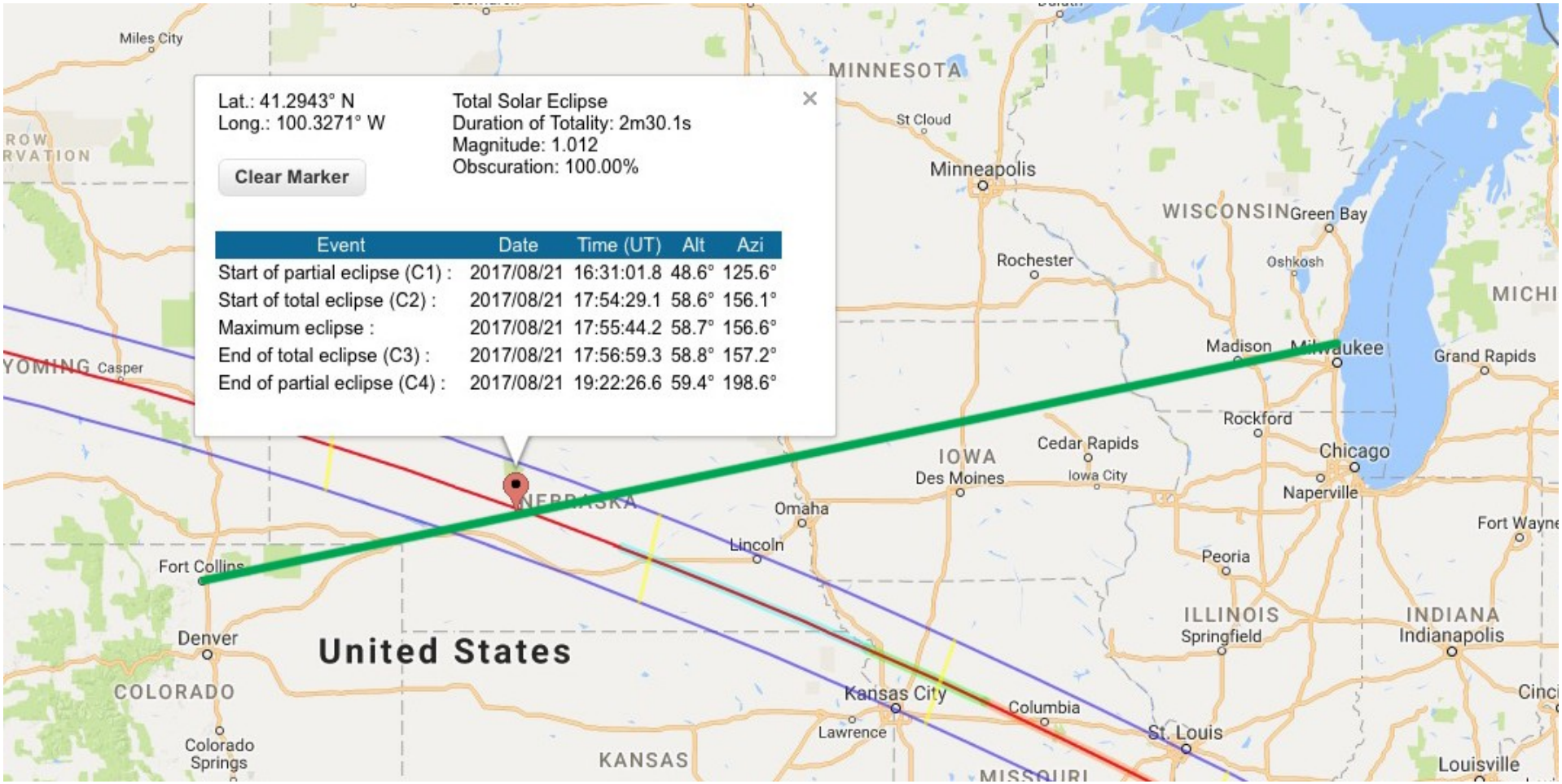
Steve Reyer
1950-2018

- Professor Emeritus of Electrical Engineering at the Milwaukee School of Engineering
- Teacher and Industry Consultant
  - digital signal processing
  - communications
  - microprocessors
  - circuits
  - Senior Design
- Active in FMT Community
- Very important for HamSCI Eclipse Frequency Measurement Experiment

HF Frequency Measurement Experiment



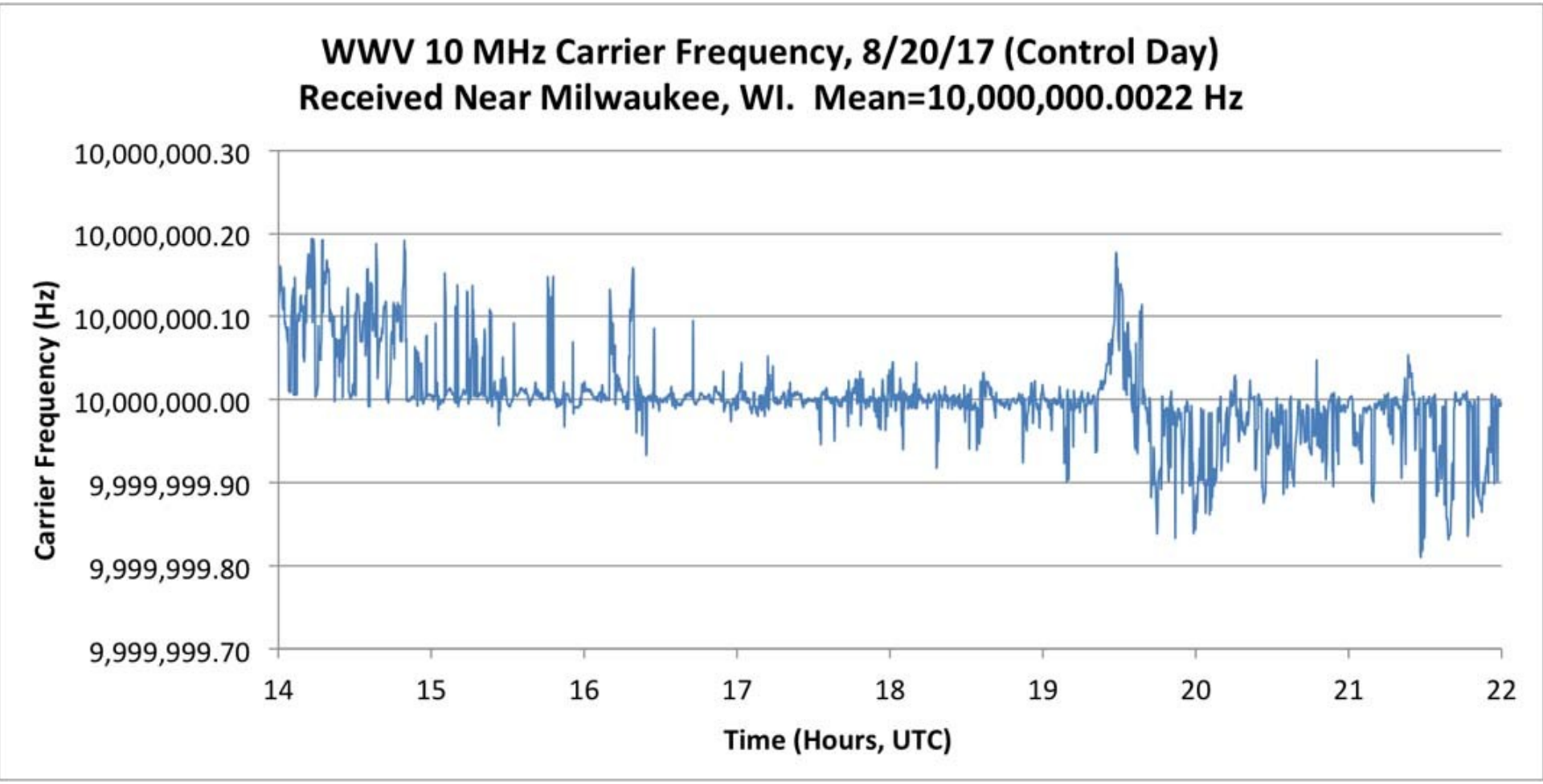
WA9VNJ 10MHz WWV Observations



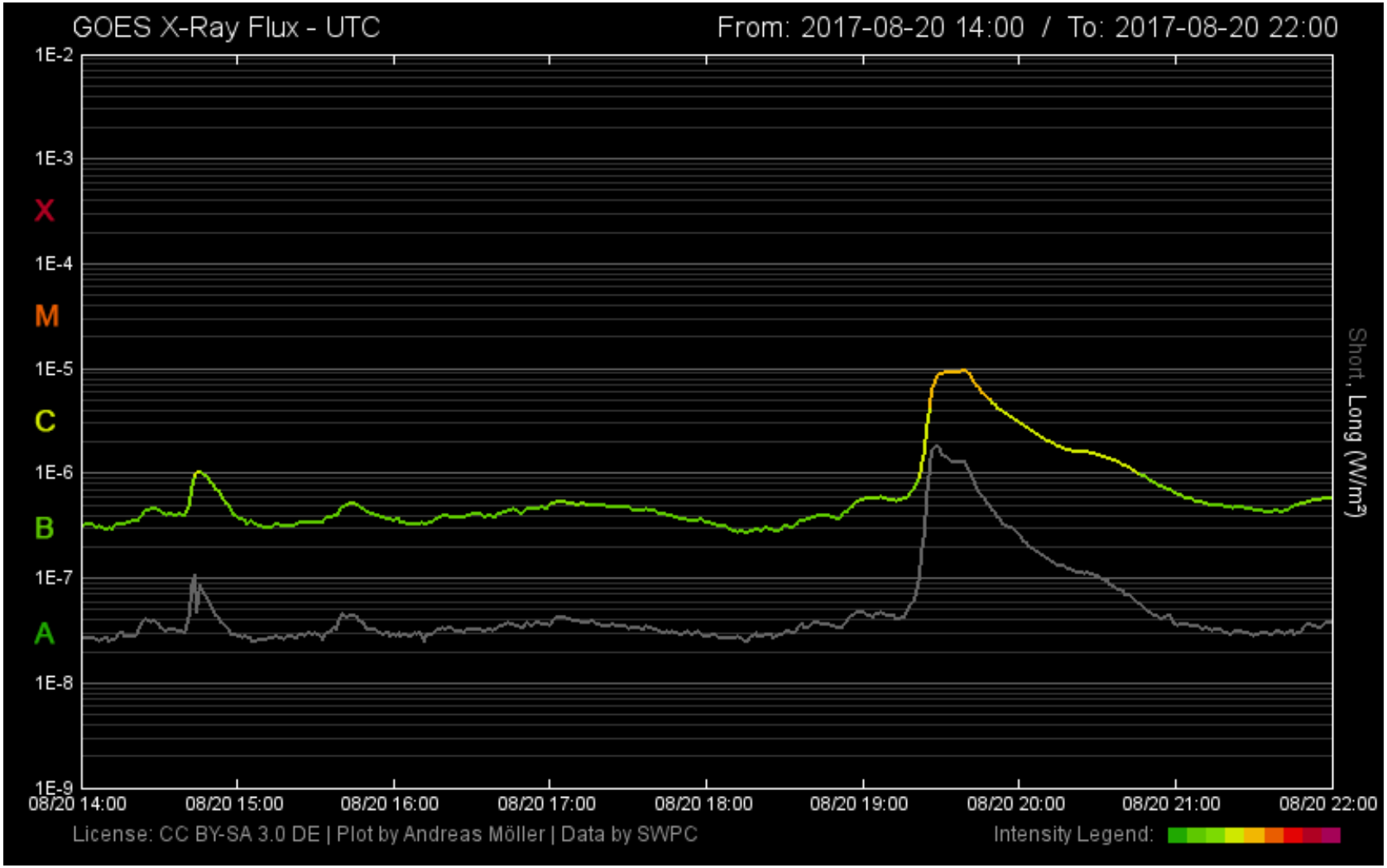
WA9VNJ Instrumentation

- **Radio:** Yaesu FT-857D with XRef-FT oscillator interface driven by a Trimble Thunderbolt GPSDO
- **Calibration:** Rigol DG1022Z signal generator locked to a second TBolt for reference signals.
- **Antenna:** DX Engineering RF-PRO-1B aimed N-S
- **Software:** Spectrum Lab (SL) and custom DSP software.

WA9VNJ 10MHz WWV Observations

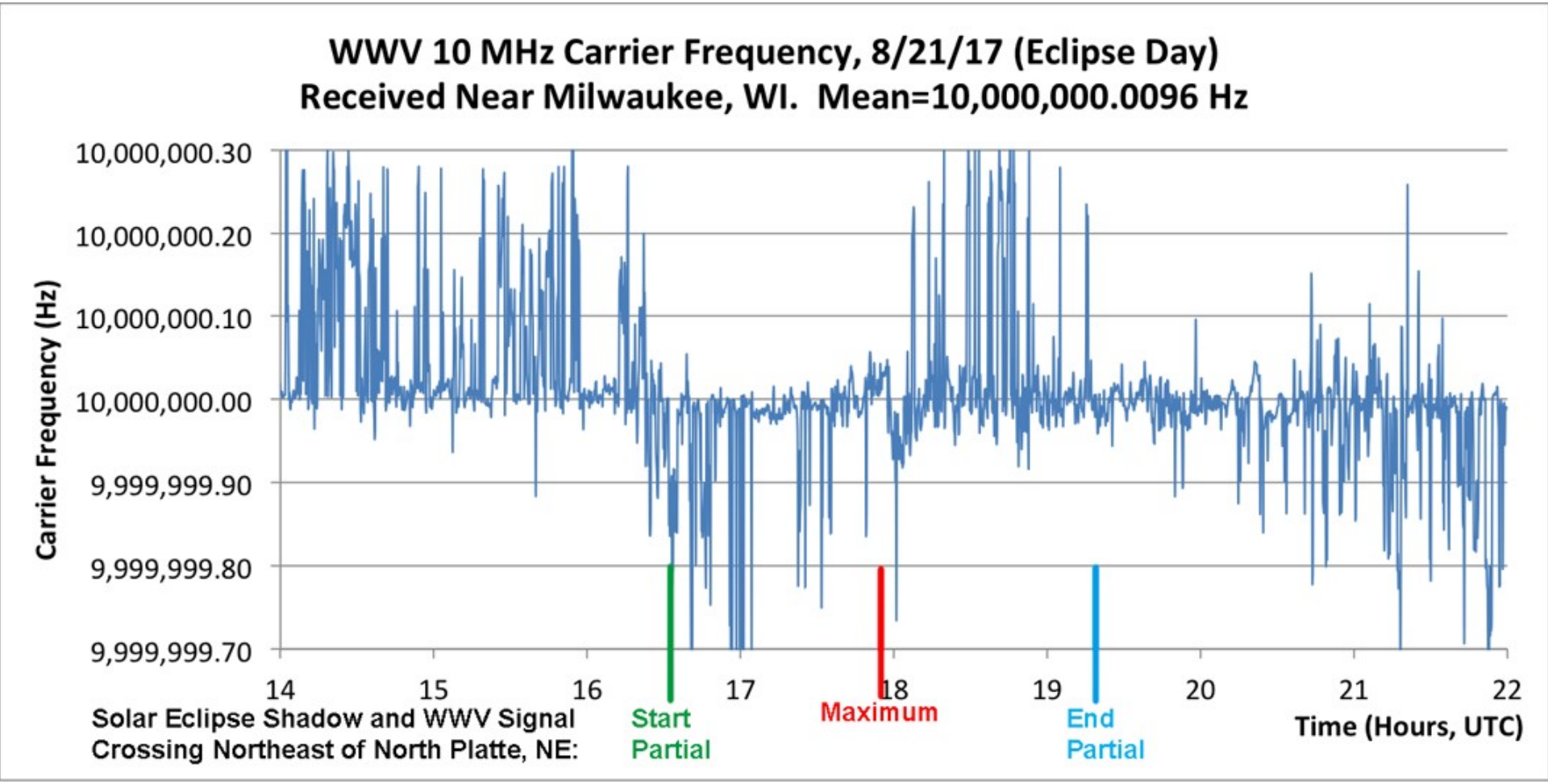


GOES X-Ray Flux – Control Day

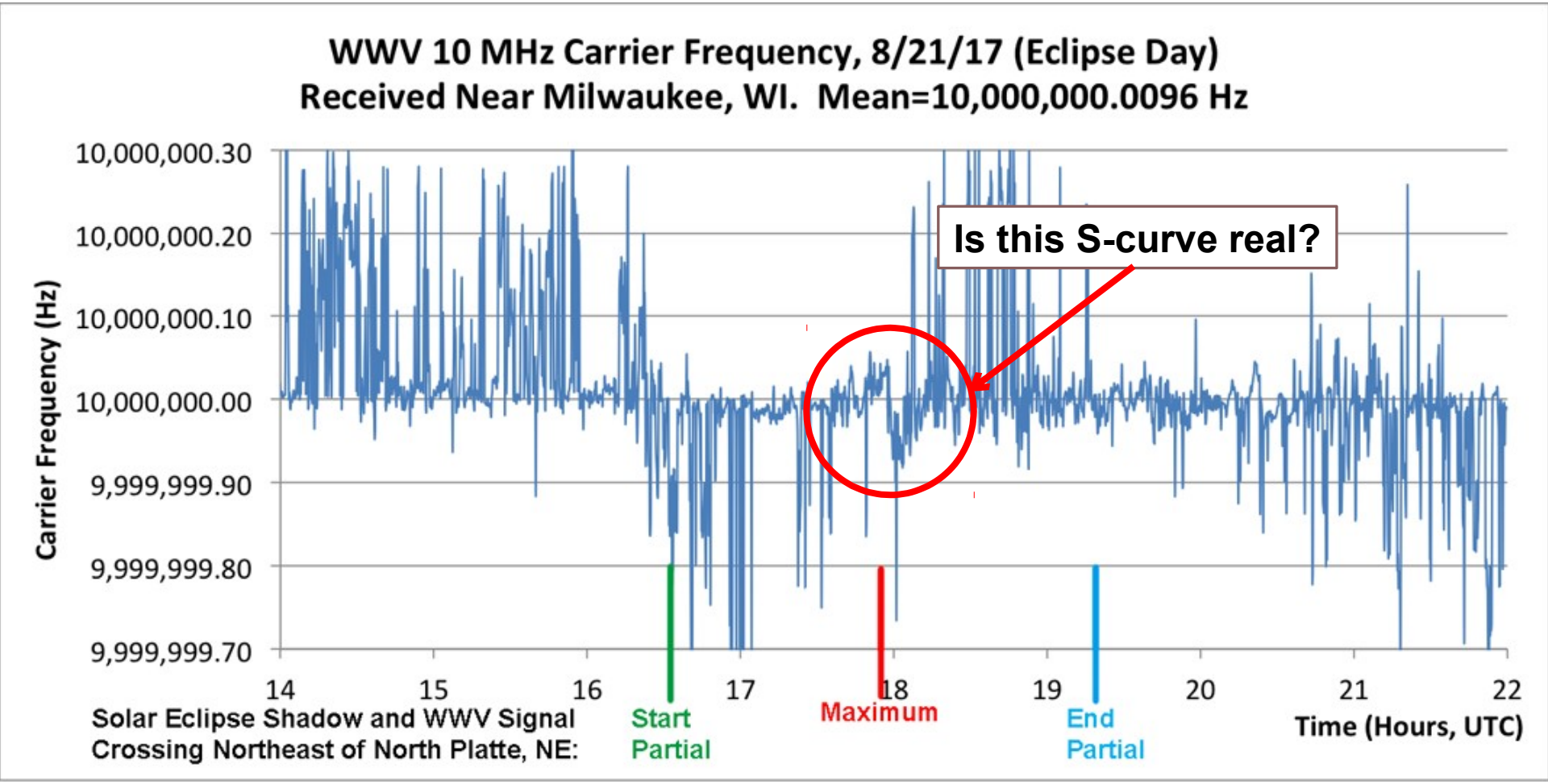


http://www.polarlicht-vorhersage.de/goes_archive

WA9VNJ 10MHz WWV Observations



WA9VNJ 10MHz WWV Observations



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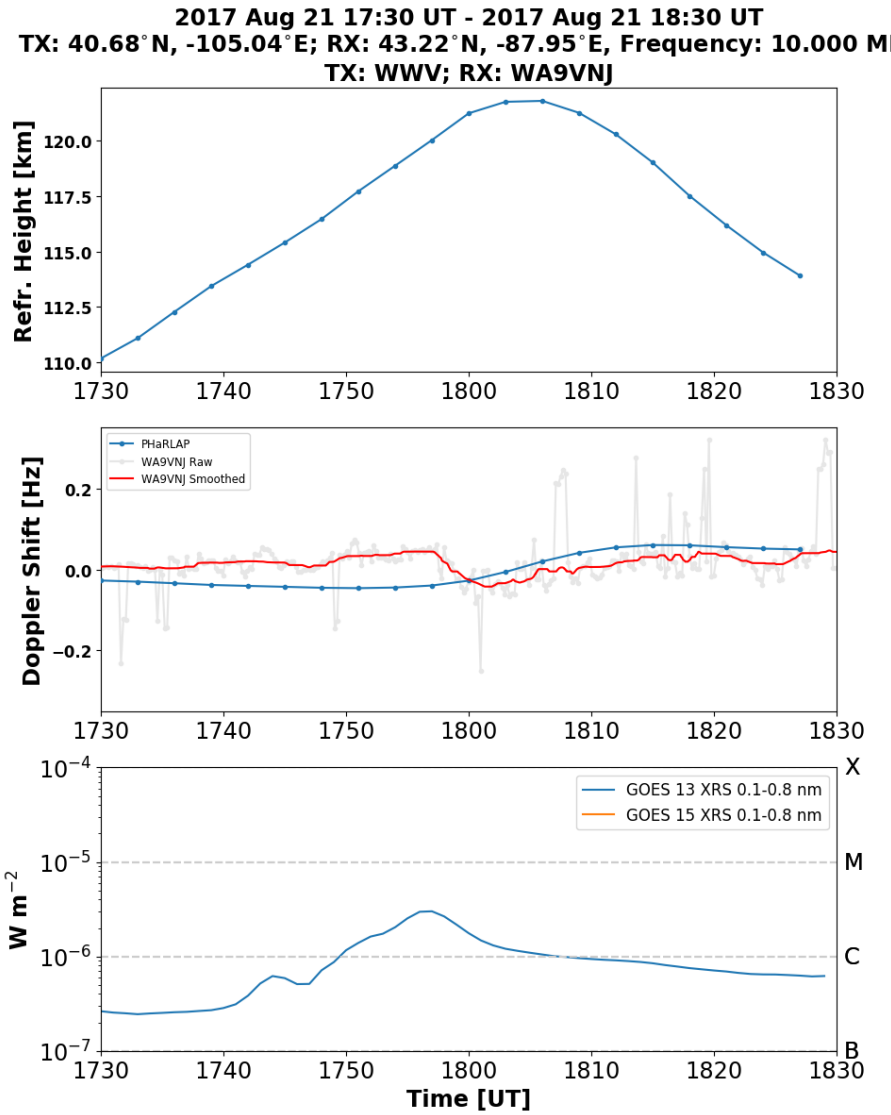
WA9VNJ/PHaRLAP/GOES



PHaRLAP/SAMI3

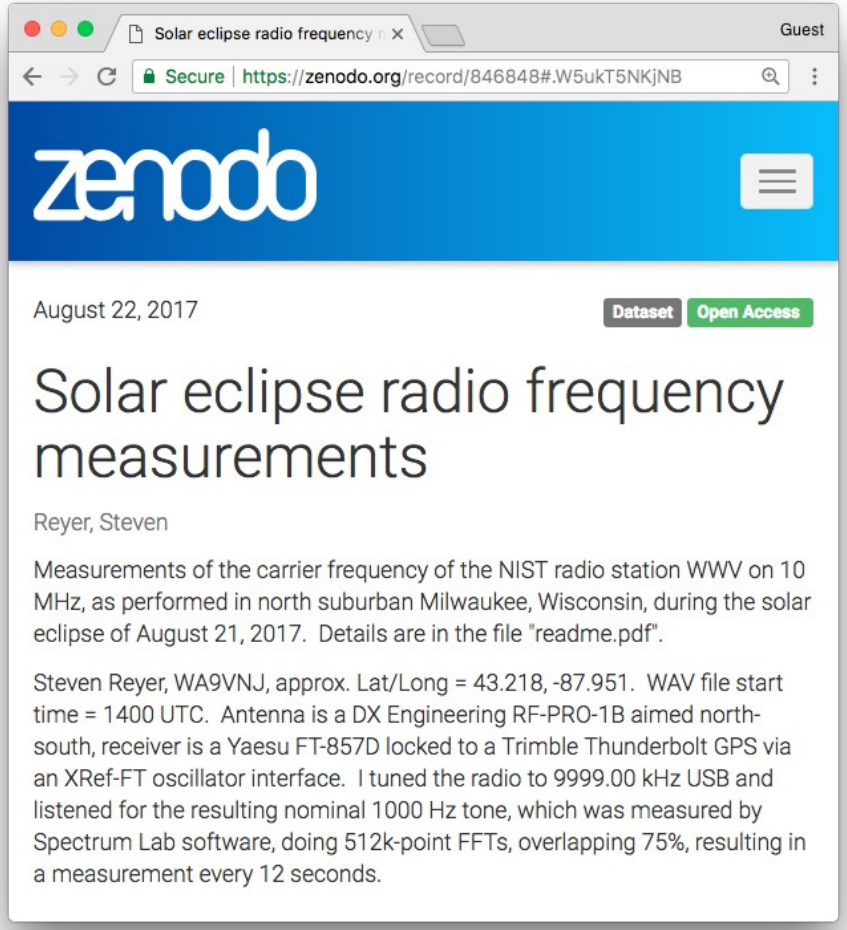
WA9VNJ

PHaRLAP/SAMI3

GOES X-RAY

WA9VNJ Conclusions

- Doppler shifts observed for
  - Dawn and Dusk
  - Eclipse Onset and Recovery
  - Solar Flares
- Small solar flares can have a pronounced effect
  - C2-Class flare caused 0.05 Hz shift!
- We don't understand the short-term variability.



https://zenodo.org/communities/hamsci

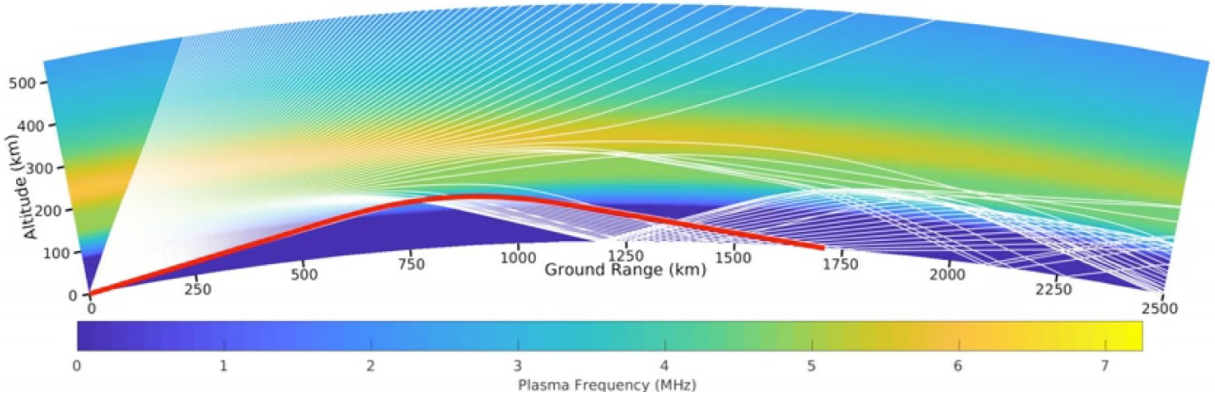
HamSCI Eclipse Research Questions

- Can we use HF ham radio communications to observe eclipse effects on the ionosphere?
- Can we use data-model comparisons to:
  - Better understand the ham radio data?
  - Constrain or calibrate the model?

Amateur Radio and the HF Bands

Frequency	Wavelength
1.8 MHz	160 m
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
50 MHz	6 m

K2MFF, The NJIT Ham Radio Station



1600 UT 21 Aug 2017 14.03 MHz - Eclipsed SAMI3
TX: AA2MF (Florida) RX: WE9V (Wisconsin)

- Hobbyists routinely use HF-VHF transionospheric links.
- Often ~100 W into dipole antennas.

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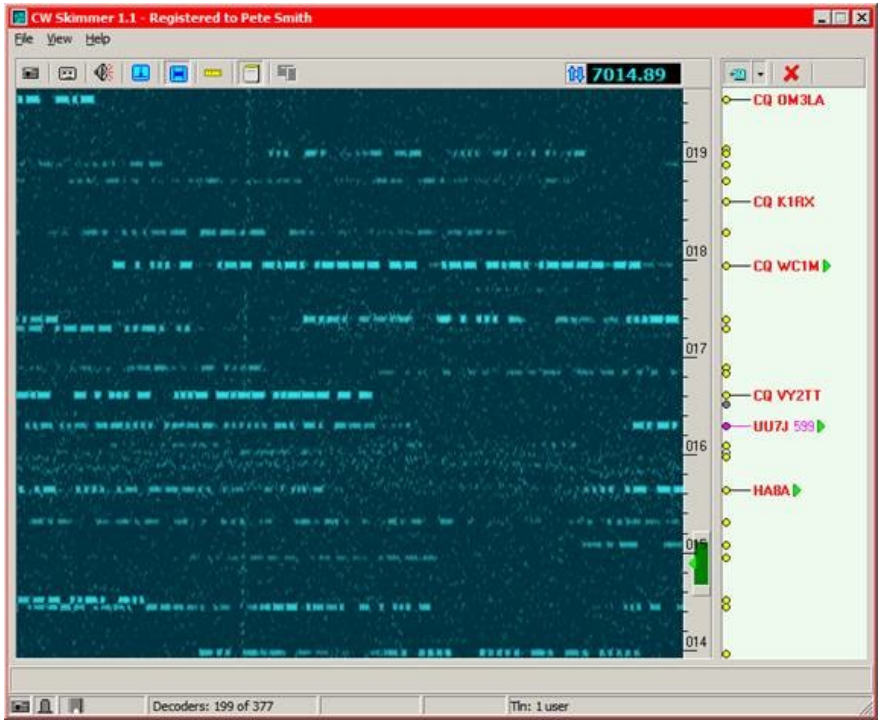
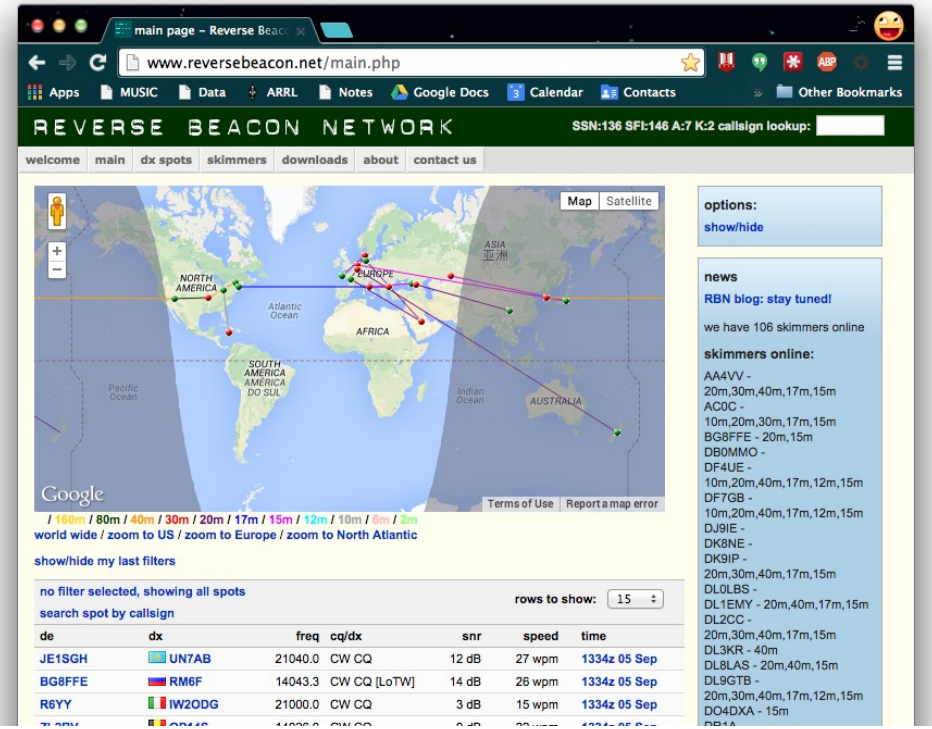
CW Skimmer and RBN





Solar Eclipse QSO Party (SEQP)

- **August 21, 2017 from 1400 – 2200 UT**
- **Contest-like (I really wanted this!)**
  - 2 Points CW or Digital
  - 1 Point for Phone
  - Multiply Score by # of Grids
- **Exchange**
  - RST + 6 Character Grid Square
- **Data sources**
  - Reverse Beacon Network
  - PSKReporter
  - WSPRNet
  - Participant-submitted logs

http://hamsci.org/seqp

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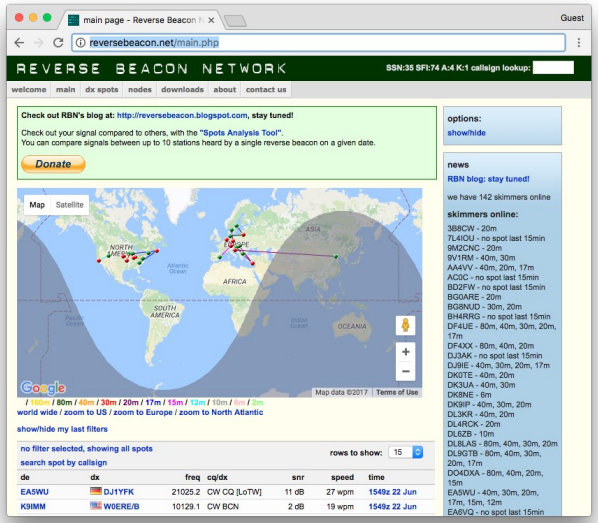
Solar Eclipse QSO Party

- 570 parsed logs
- 29,809 QSOs
- 4,929 unique callsigns
- 649 4-char grid squares
- 80 DX Entities

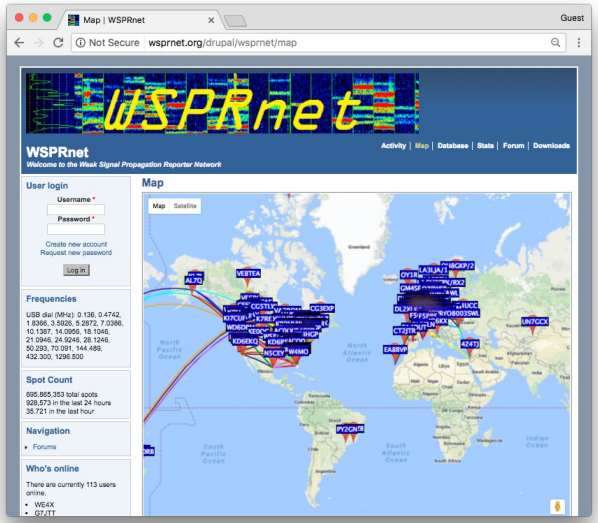
(from logs submitted to hamsci.org)

SEQP Observations



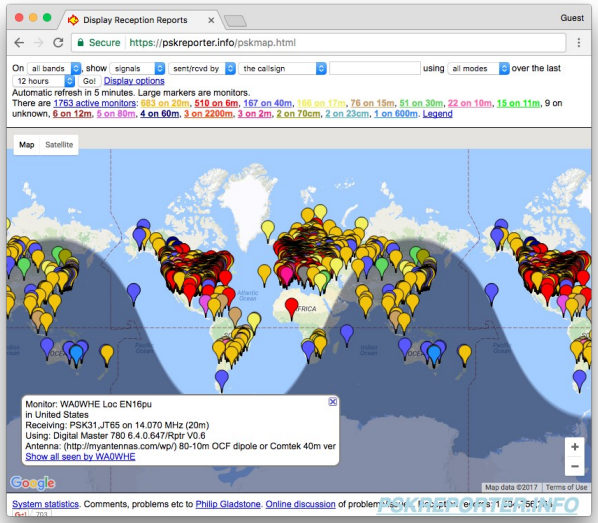
RBN

reversebeacon.net



WSPRNet

wsprnet.org



PSKReporter

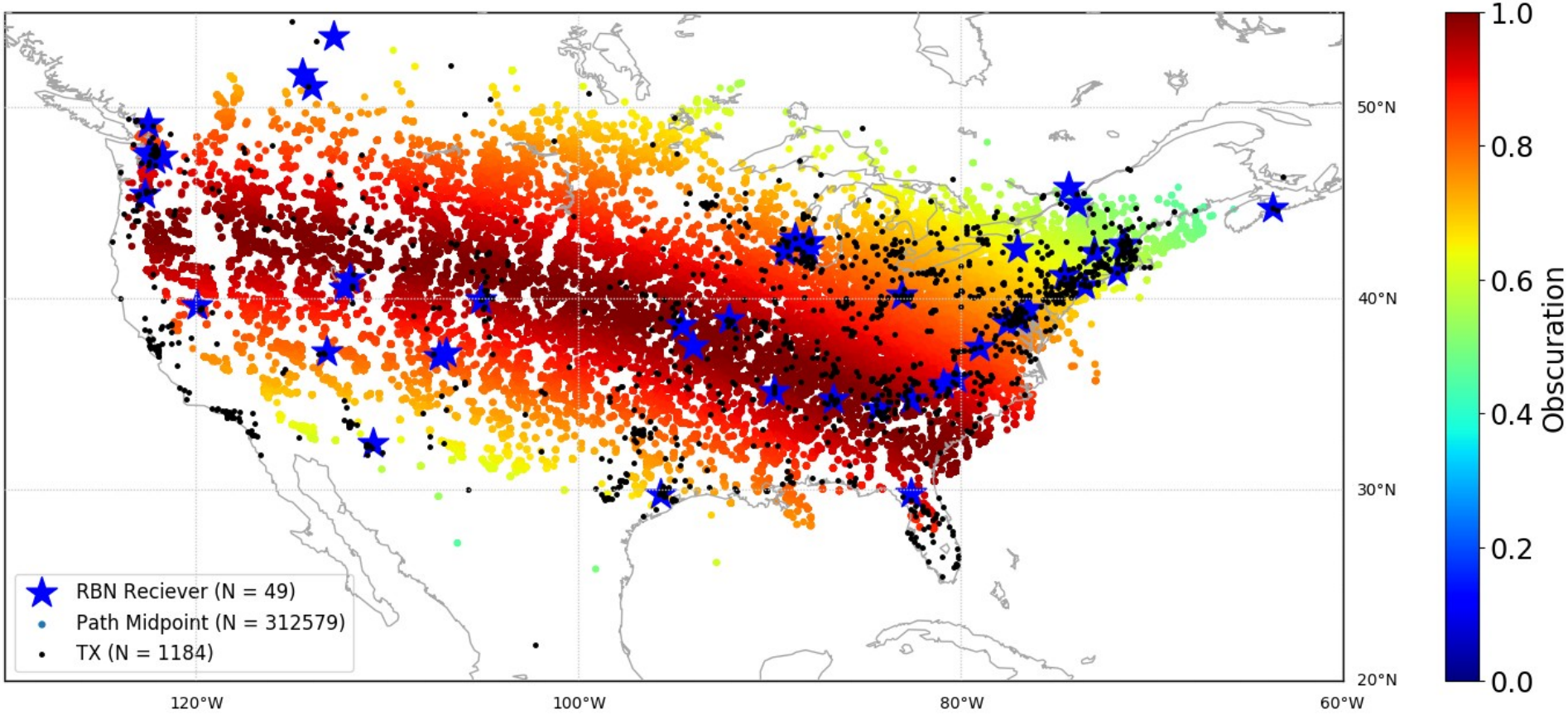
pskreporter.info

Observations from 21 August 2017 1400 – 2200 UT

Network	# Spots / QSOs
RBN	618,623
WSPRNet	630,132
PSKReporter	1,287,962
Participant Logs	29,809

Ham Radio Eclipse Data

SEQP RBN Observations



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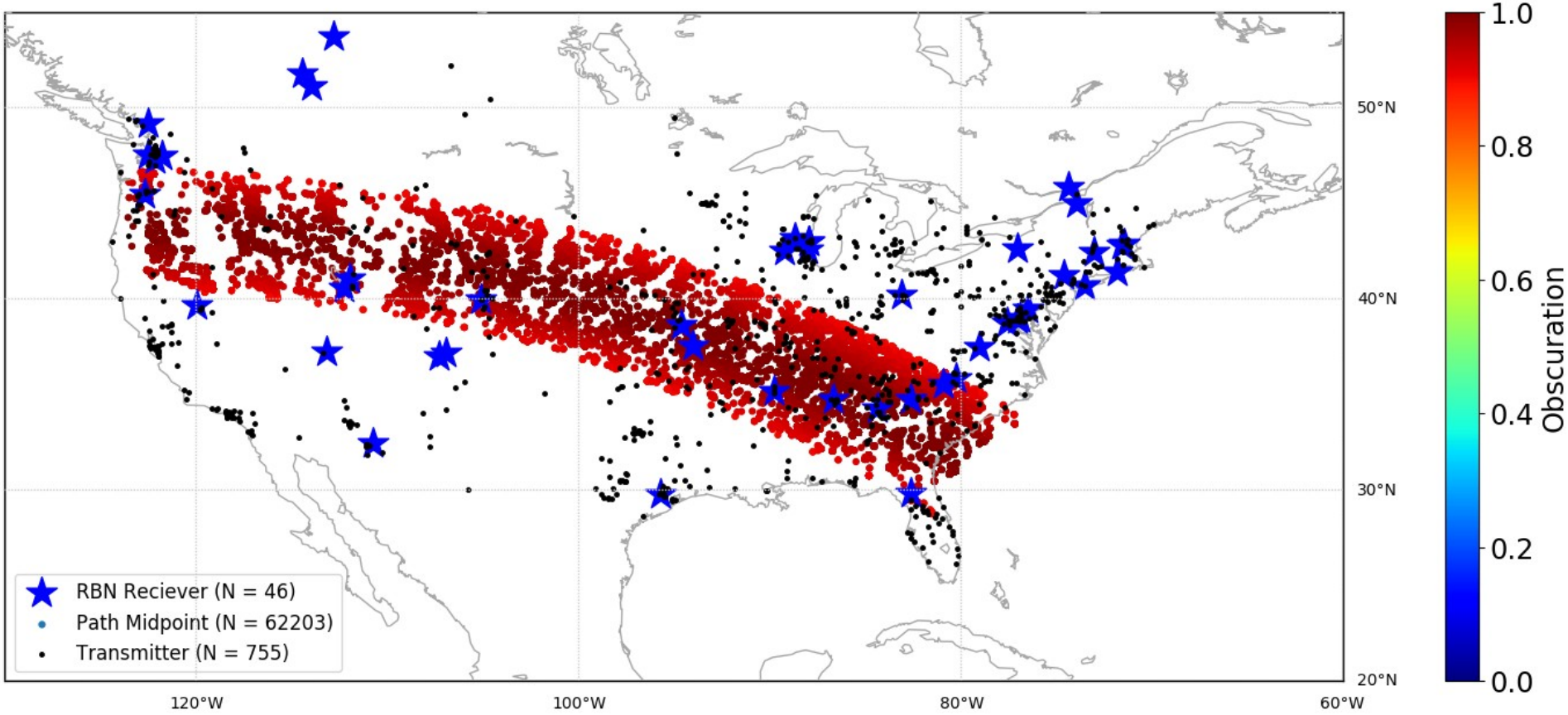
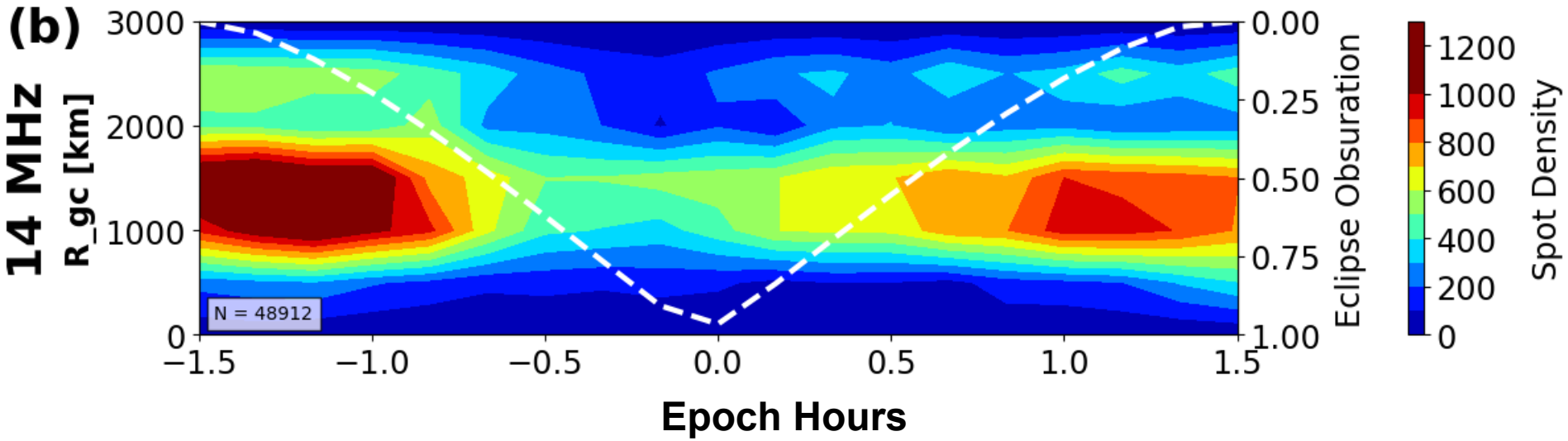
SEQP RBN ($O_{300} \geq 0.9$)



14 MHz SEQP RBN ($O_{300} \geq 0.9$)



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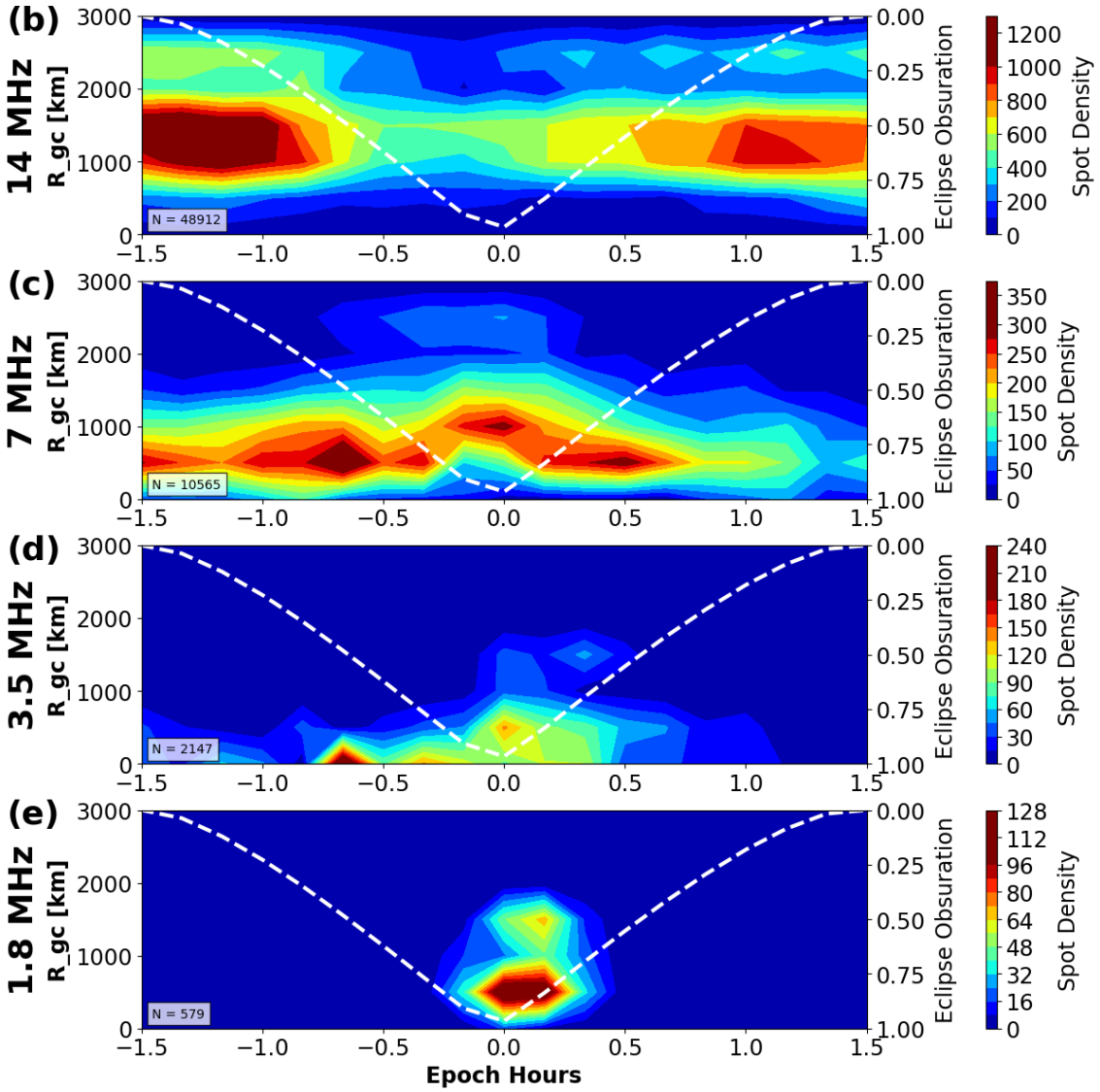
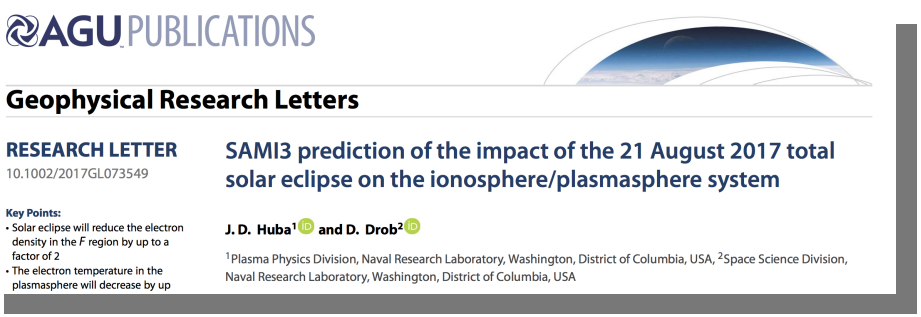
SEQP RBN ($O_{300} \geq 0.9$)



SAMI3 Eclipsed Model Ionosphere



AGU PUBLICATIONS

Geophysical Research Letters

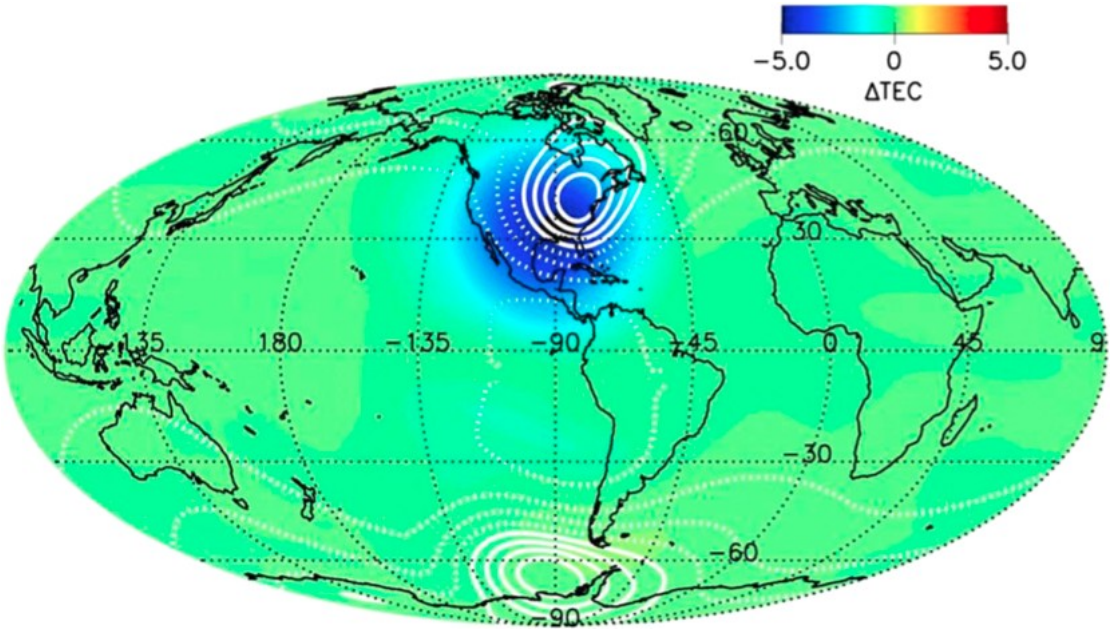
RESEARCH LETTER
10.1002/2017GL073549

SAMI3 prediction of the impact of the 21 August 2017 total solar eclipse on the ionosphere/plasmasphere system

Key Points:
- Solar eclipse will reduce the electron density in the *F* region by up to a factor of 2
- The electron temperature in the plasmasphere will decrease by up

J. D. Huba[1] and D. Drob[2]

[1]Plasma Physics Division, Naval Research Laboratory, Washington, District of Columbia, USA, [2]Space Science Division, Naval Research Laboratory, Washington, District of Columbia, USA



Huba and Drob [2017]

- SAMI3 is a first-principles ionosphere/plasmasphere model.
- A modified version of SAMI3 was made to predict the ionospheric response to the eclipse.
- SEQP results were simulated by using the PHaRLAP HF raytracing toolkit [*Cervera and Harris,* 2014] in conjunction with the eclipsed SAMI3 model.

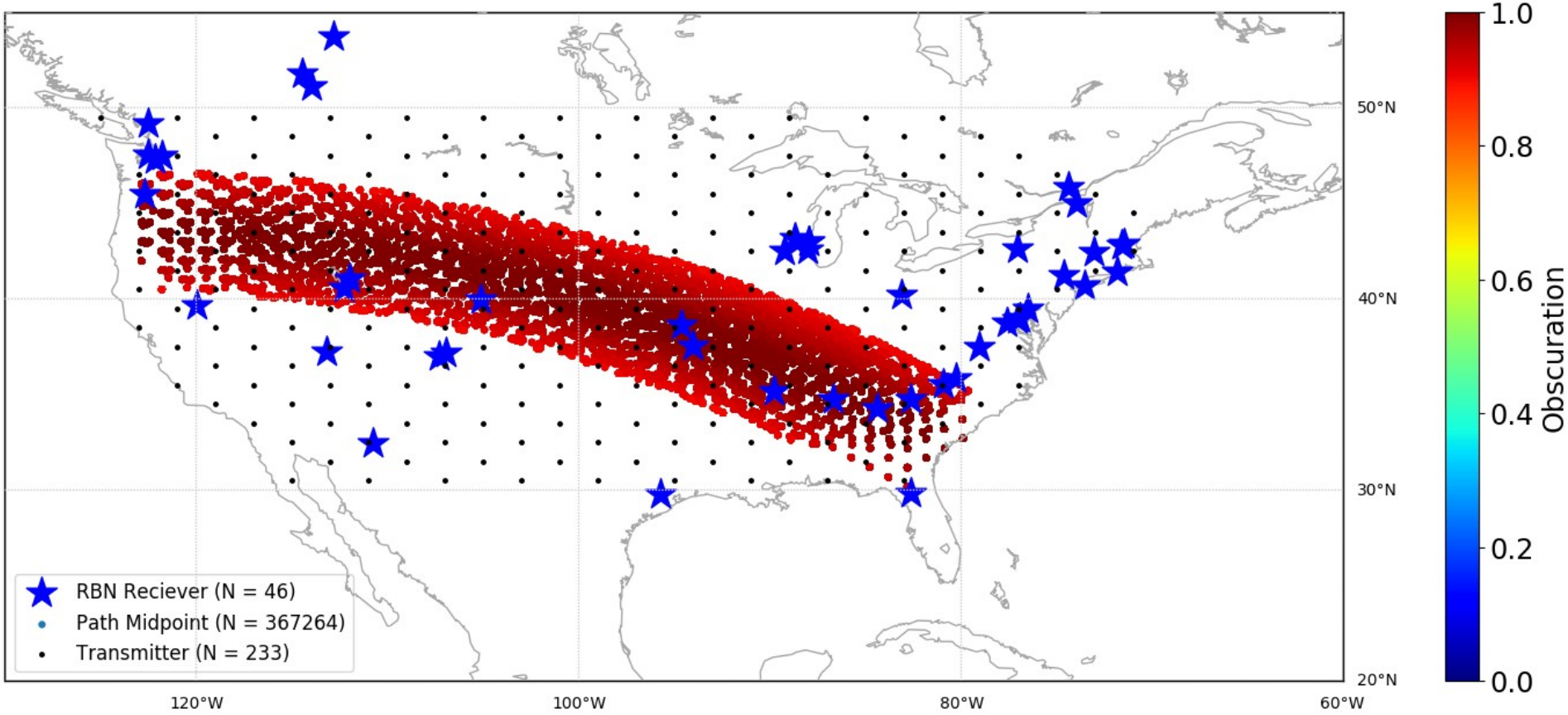
SAMI3-PHaRLAP Raytrace

1600 – 2200 UT 14.03 MHz
TX: AA2MF (Florida) RX: WE9V (Wisconsin)

Non-Eclipsed

Eclipsed

SAMI3-PHaRLAP ($O_{300} \geq 0.9$)



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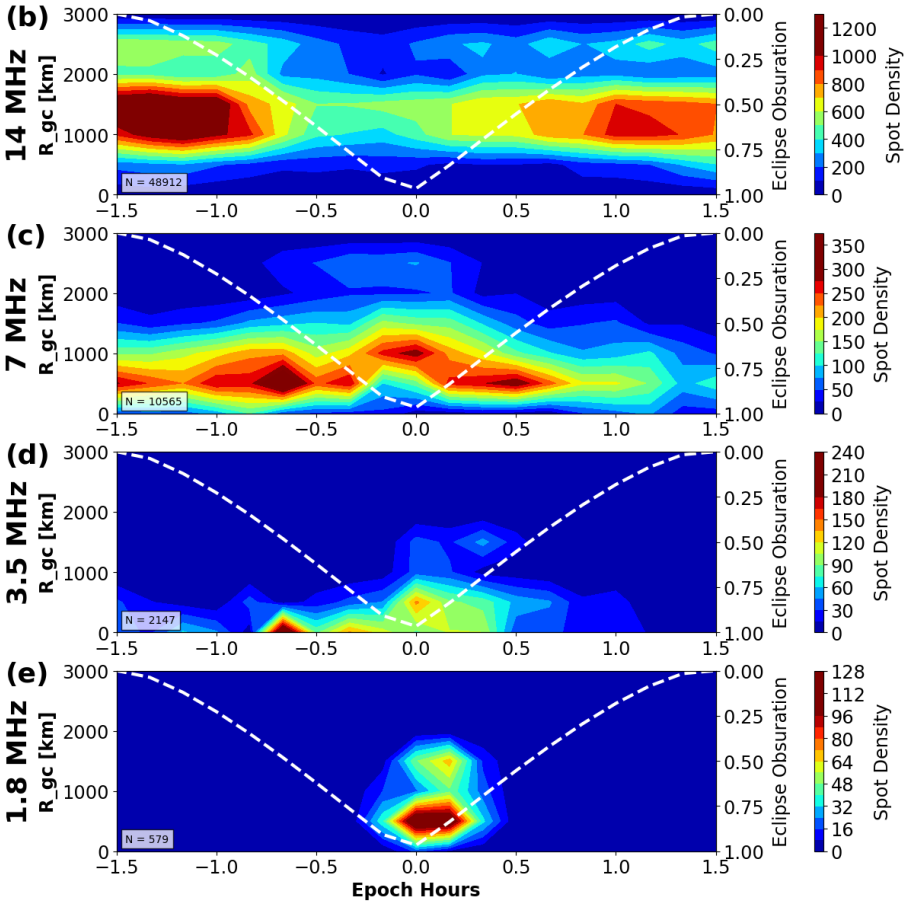
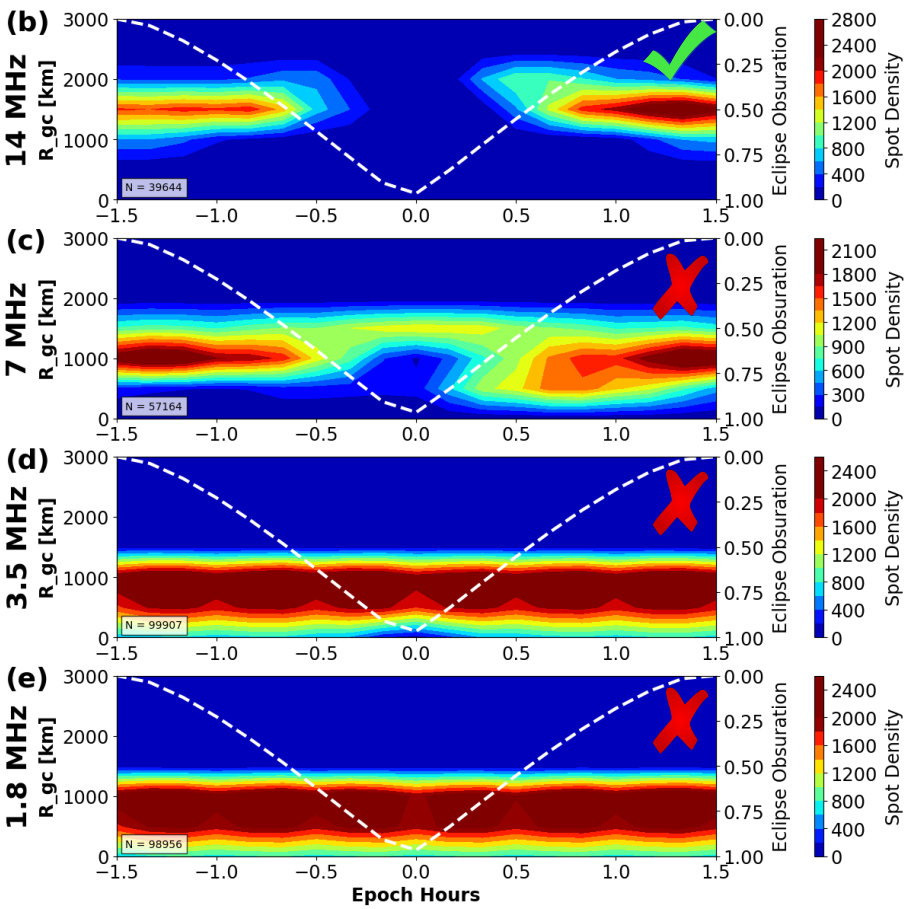
SAMI3 < 125 km alt

RBN Observations



SAMI3 < 125 km Altitude



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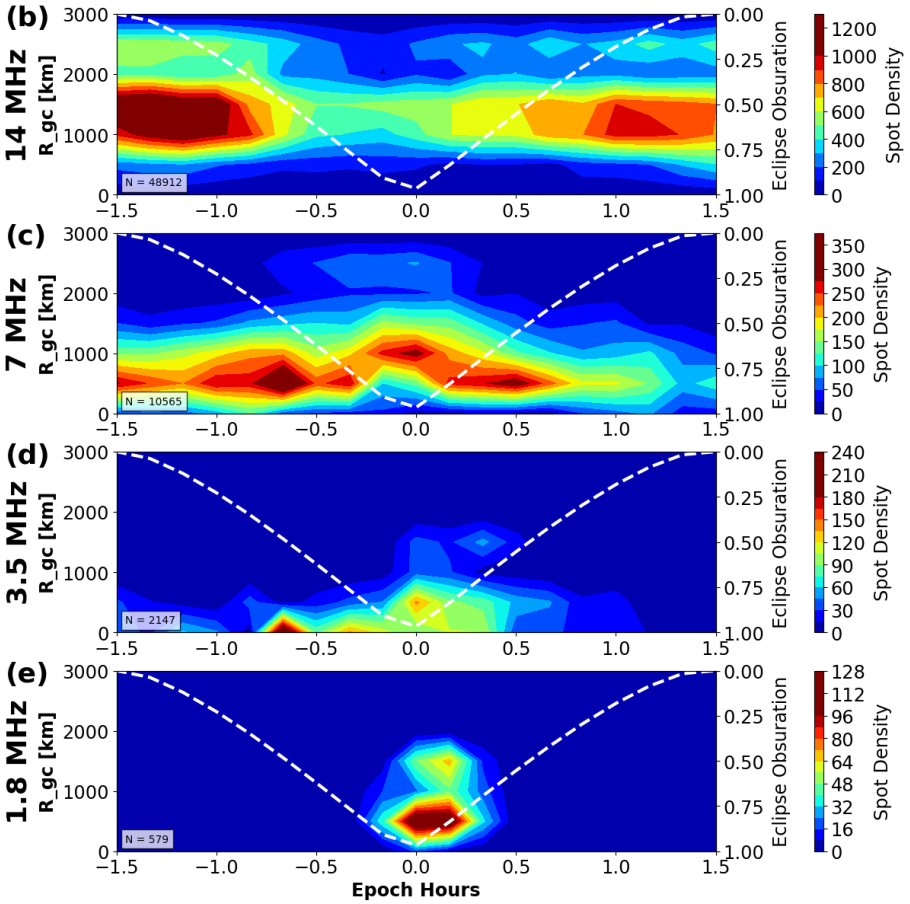
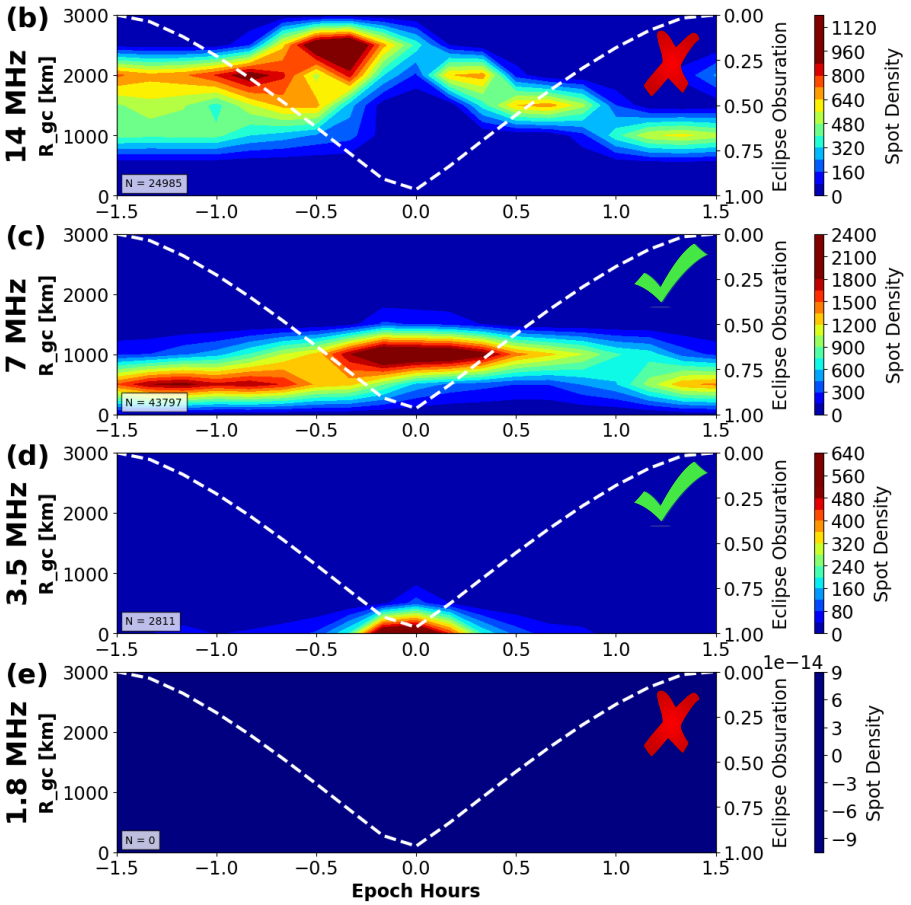
SAMI3 ≥ 125 km alt

RBN Observations



SAMI3 ≥ 125 km Altitude



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Conclusions

- SEQP generated over 2.5 million link soundings.
- Eclipse effects are observed:
  - ±0.3 hr on 1.8 MHz
  - ±0.75 hr on 3.5 and 7 MHz
  - ±1 hr on 14 MHz
- Raytracing suggests:
  - 14 MHz signals refracted at $h < 125$ km
  - 1.8 - 7 MHz refracted at $h \geq 125$ km altitude
  - Background SAMI3 density slightly too high

Published in Geophysical Research Letters!

https://doi.org/10.1029/2018GL077324

Single Operator (Preliminary)

	Call Sign	Phone QSOs	CW/Dig QSOs	Grids	Bonus	Total
1	**AA3B** Bud Trench Boyertown, PA	0	680	296	1,415	403,975
2	**K4BAI** John Laney, III Columbus, GA	0	451	248	806	224,502
3	**W1SJ** Mitchell Stern Essex Junction, VT	163	313	228	990	180,882

Multi Operator (Preliminary)

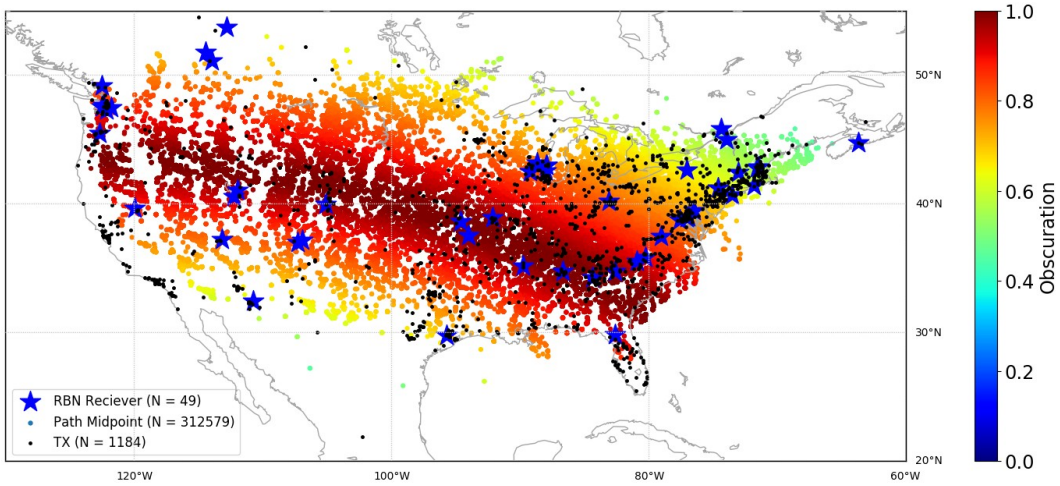
	Call Sign	Phone QSOs	CW/Dig QSOs	Grids	Bonus	Total
1	**W0ECC** Elayer Contest Club St. Charles, MO (N0AX, N5OT, & KD0YJN)	409	50	220	665	191,625
2	**W0D** DeSoto, MO (WB0SND & WB0TUA)	352	26	153	863	112,553
3	**W5GAD** Jefferson Amateur Radio Club Metairie, LA (N5LIT, KG5GJT, N5HZ, & NO5W)	256	45	167	632	93,651

SEQP RBN 10,000+ Club

RBN Call	# Spots	Operator	QTH
WE9V	54,874	Chad Kurszewski	Bristol, WI
AA4VV	40,574	Thomas Berry	Lexington, NC
KU7T	31,762	Andreas Hofmann	North Bend, WA
N4ZR-3	28,692	Pete Smith	Phoenix, MD
NC7J	28,564	Utah Contest Club	Layton, UT
W3OA	28,057	Dick Williams	Mooresville, NC
N2GZ	18,623	Greg Zenger	North Stonington, CT
N0TA	14,751	John Reilly	Loisville, CO

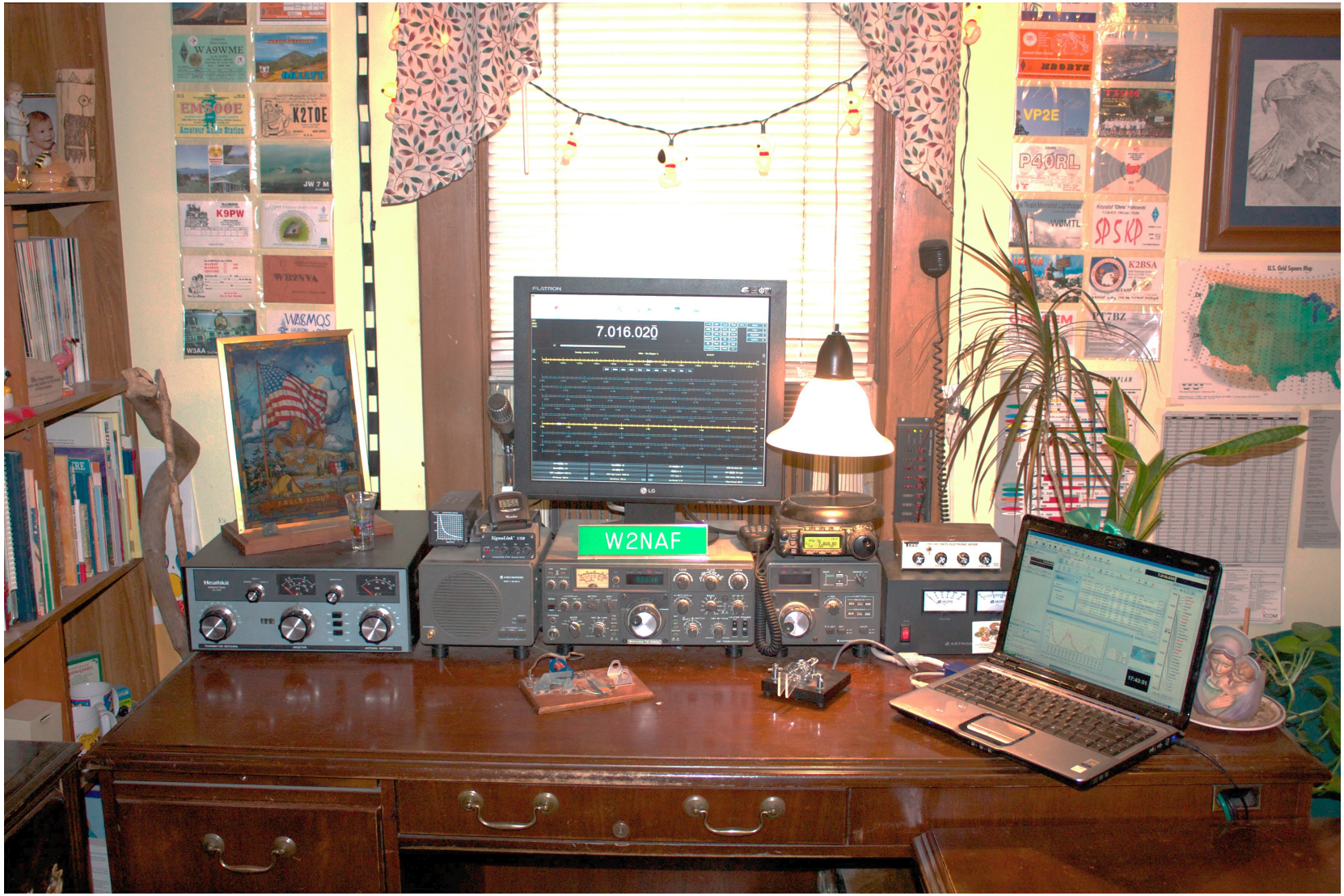
Special Thanks

- John Ackermann, N8UR
- David Bern, W2LNX
- Terry Bullett, W0ASP
- Felipe Ceglia, PY1NB
- Greg Earle, W4GDE
- Bill Engelke, AB4EJ[2]
- Phil Erickson, W1PJE
- Rachel Frissell, W2RUF
- Andy Gerrard, KD2MCQ
- Bob Gerzoff, WK2Y
- Spencer W. Gunning, K2AEM
- Michael Hirsch, N2NRL
- Steve Kaeppler, AD0AE
- Joshua D. Katz, KD2JAO
- John Magliacane, KD2BD
- Bob McGwier, N4HY
- Ethan Miller, K8GU
- Magda Moses, KM4EGE
- Carl Luetzelschwab, K9LA
- Steve Reyer, WA9VNJ
- Sam Rose, KC2LRC
- Alex Shovkoplyas, VE3NEA
- Ward Silver, N0AX
- Pete Smith, N4ZR
- Pete Teklinski, WW2I
- Joshua S. Vega, WB2JSV
- Mary Lou West, KC2NMC
- Dick Williams, W3OA
- *The ARRL*
- *All hams who have participated in HamSCI projects.*


RBN Reciever (N = 49)
Path Midpoint (N = 312579)
TX (N = 1184)
120°W
100°W
80°W
60°W
50°N
40°N
30°N
20°N
1.0
0.8
0.6
0.4
0.2
0.0
Obscuration

Thank you!

Amateur/Ham Radio



Total Solar Eclipse

21 August 2017

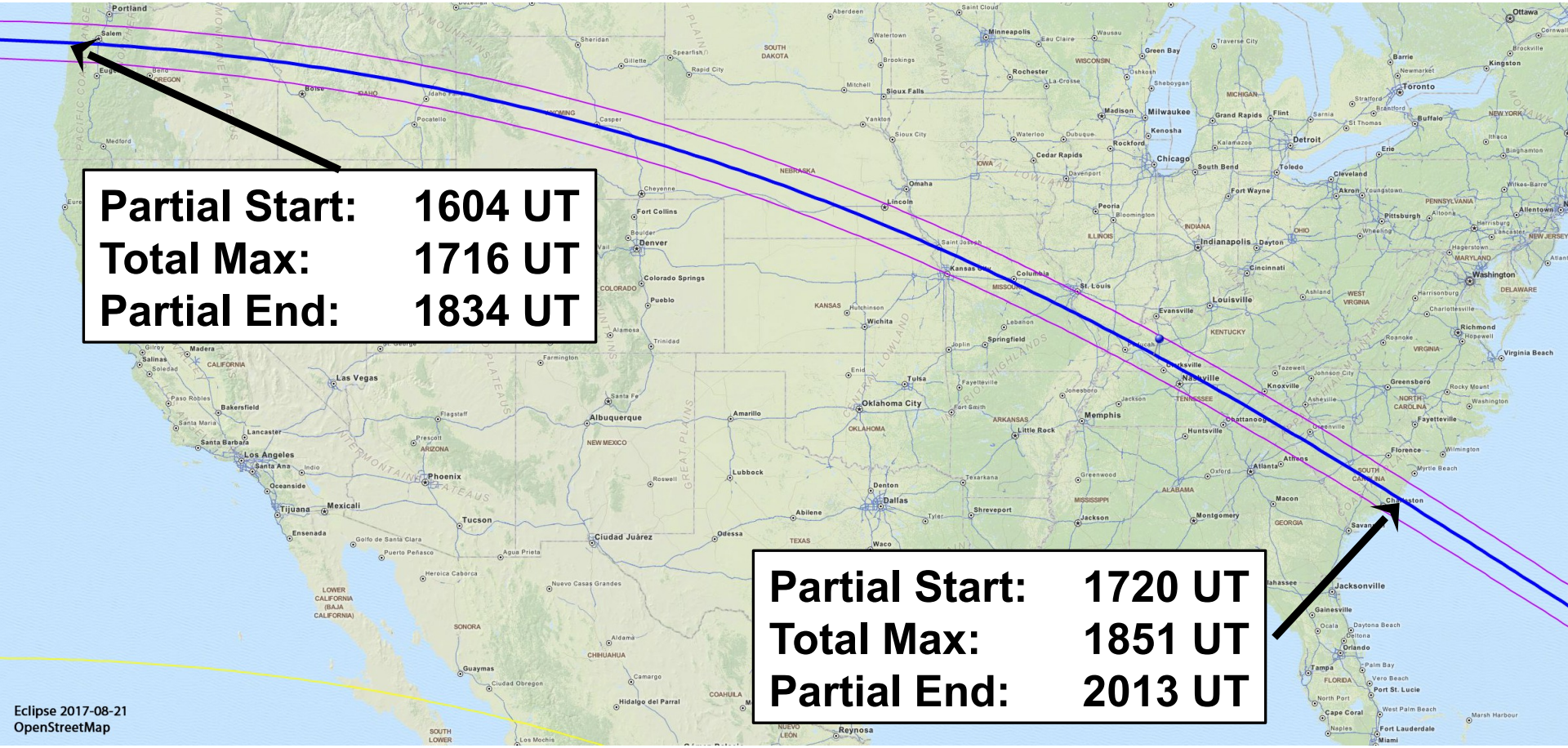
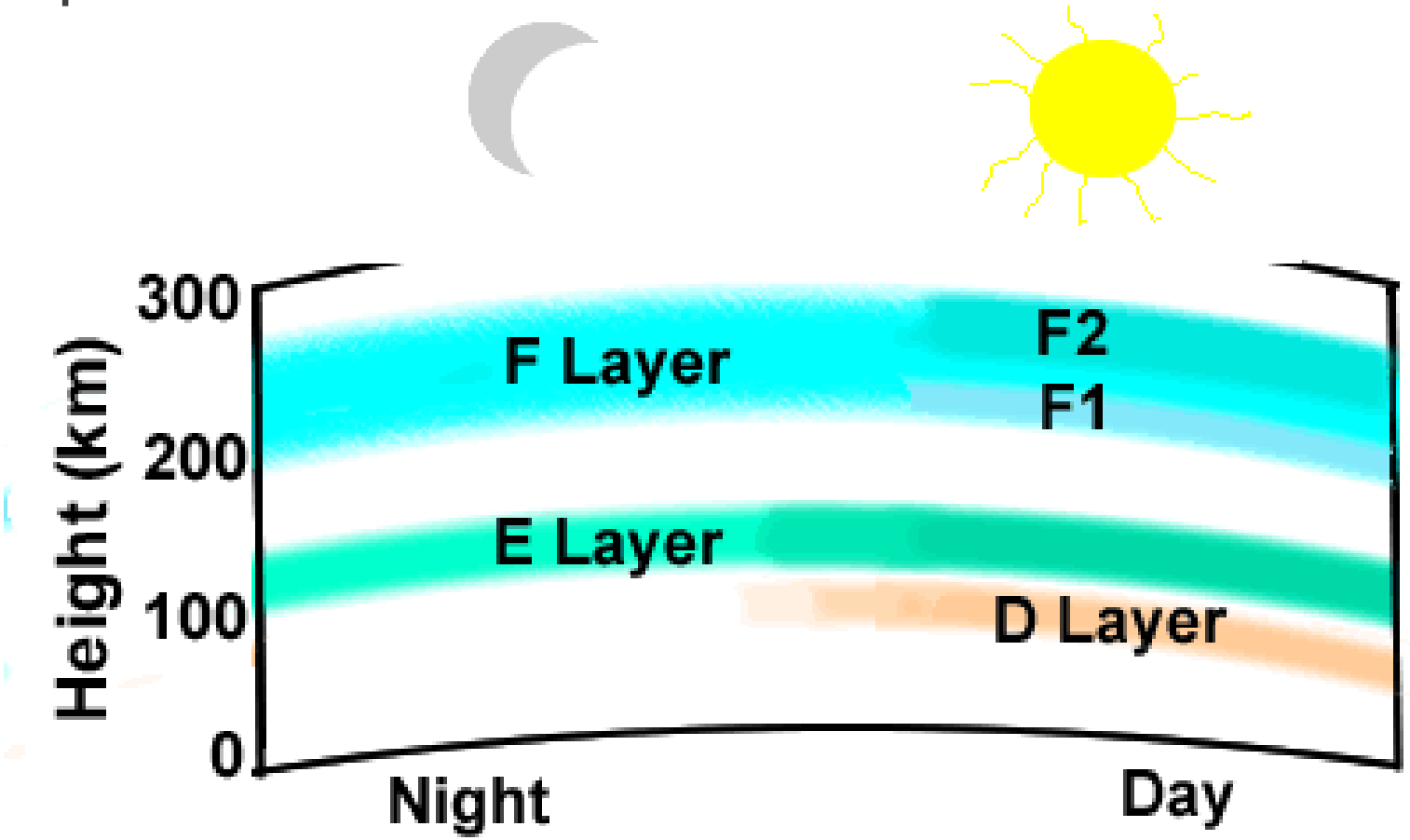


Figure: W. Strickling, Wikipedia

What is the Ionosphere?

- Primarily created by ionization of the neutral atmosphere by solar UV radiation



https://commons.wikimedia.org/wiki/File:IonosphereLayers-NPS.gif

Ionospheric Effects?

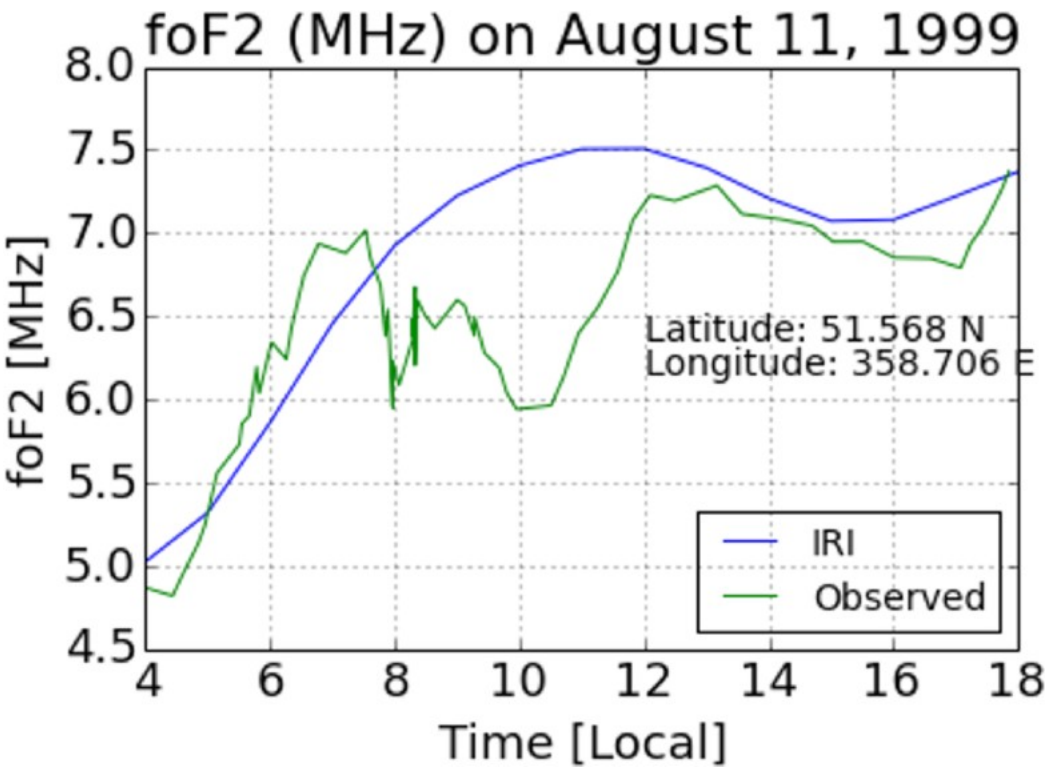
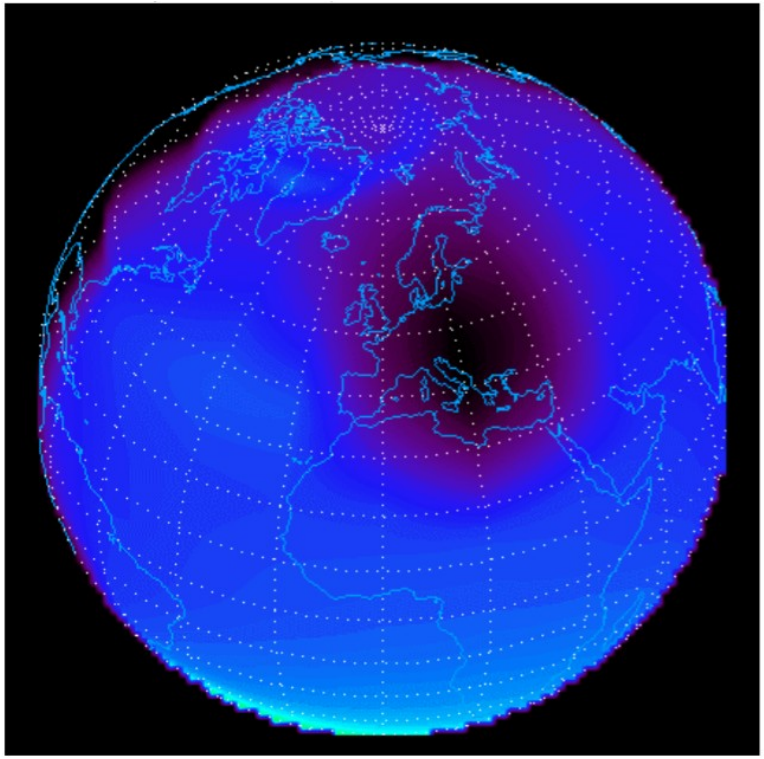
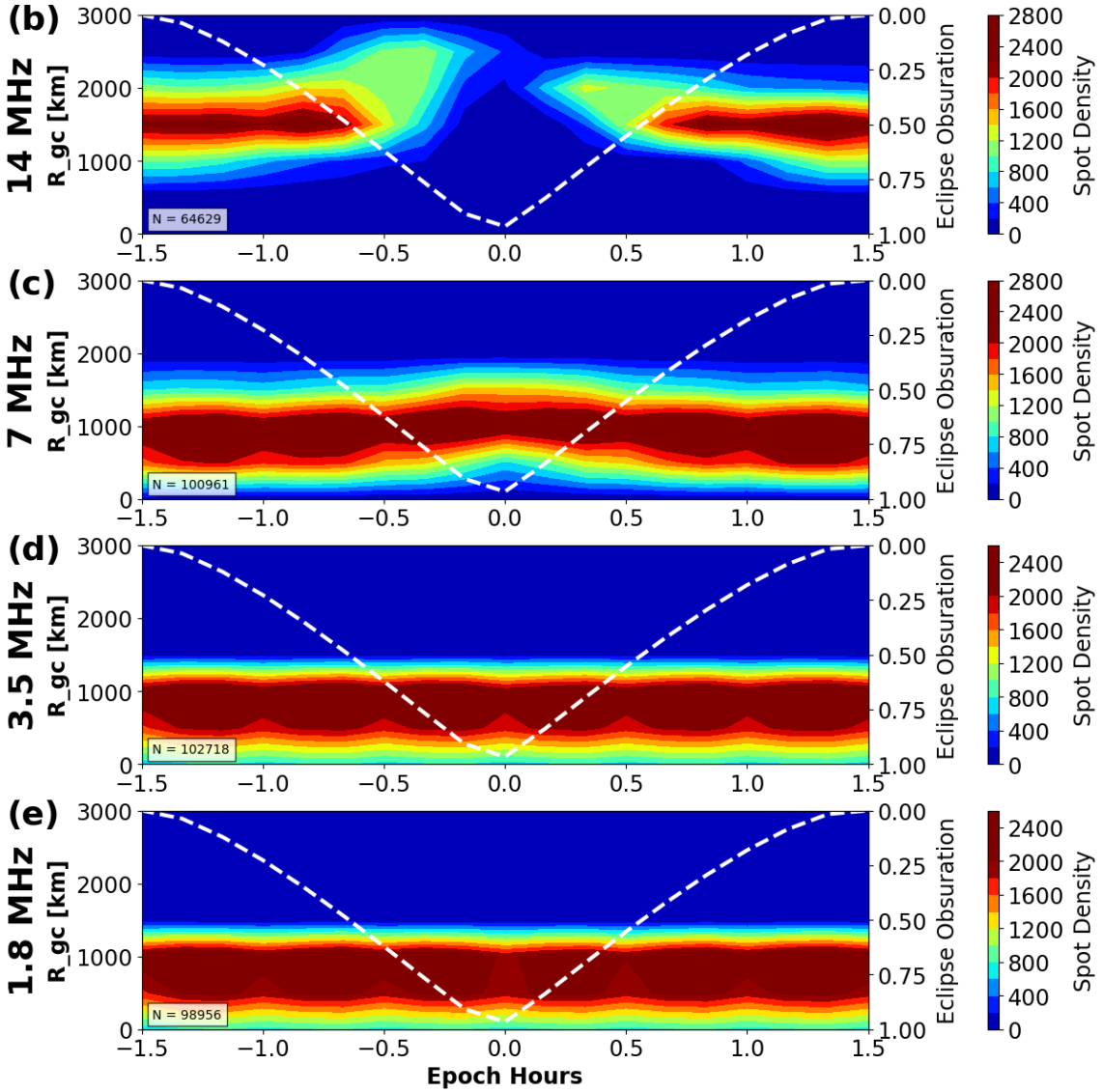


Figure: M. Moses



Model Electron Density at ~280 km alt. during 1999 Eclipse
M. Harris from *Bamford* 2000.

Eclipsed SAMI3 - PHaRLAP



What does this mean? (14 MHz)

- **Poor agreement with h ≥ 125 km altitude**
  - Ionosphere is always too weak to support 14 MHz high-angle signals.
- **Good agreement with h < 125 km altitude.**
  - Before eclipse, low angle 14 MHz signals were below the critical angle for E Region ionosphere and would refract back to earth.
  - 14 MHz signals are relatively unaffected by D region absorption.
  - At high obscuration values, ionospheric densities drop such that neither the E nor the F region can support 14 MHz.

SAMI3-PHaRLAP Raytrace

1600 – 2200 UT 14.03 MHz
TX: AA2MF (Florida) RX: WE9V (Wisconsin)
Eclipsed SAMI3

What does this mean? (1.8 – 7 MHz)

- **Poor agreement with h < 125 km altitude**
  - Low angle signals spend more time in the D region
  - D region absorbs 1.8 – 7 MHz signals
  - All low-angle signals get absorbed.
- **Good agreement with h ≥ 125 km altitude.**
  - Higher angle rays suffer less D region absorption.
  - 1.8 & 3.5 MHz signals only appear near maximum eclipse, when D region absorption is minimal.
  - 7 MHz signals are always present, but extend in range as ionospheric densities and associated refraction decreases

References

Afraimovich, E.L., E.A. Kosogorov, O.S. Lesyuta (2002), Effects of the August 11, 1999 total solar eclipse as deduced from total electron content measurements at the GPS network, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 64, Issue 18, Pages 1933-1941, ISSN 1364-6826, http://dx.doi.org/10.1016/S1364-6826(02)00221-3.

Bamford, R. (2000), Radio and the 1999 UK Total Solar Eclipse, Rutherford Appleton Laboratory, Chilton, Didcot, UK.

Calibrate the model?

- Data-model comparison suggests critical frequency of the model is too high, due to incorrect predictions of:
  - High-angle 14 MHz returns
  - Low-angle 1.8 MHz returns
- It may be possible to calibrate the model by scaling SAMI3 electron densities to best fit the observed data.

Outline

I. **Ham Radio and HamSCI**

II. **Solar Eclipse QSO Party**
   I. Ham Radio Observations
   II. Modeling Results
   III. Discussion
   IV. Conclusions

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Amateur/Ham Radio

- Hobby for Radio Enthusiasts
  - Communicators
  - Builders
  - Experimenters
- Wide-reaching Demographic
  - All ages & walks of life
  - Over 730,000 US hams; ~3 million World Wide

[http://www.arrl.org/arrl-fact-sheet]

Partnership with ARRL

August 2016 *QST*

American Radio Relay League

- National Organization for Ham Radio
- Over 170,000 members (Jan. 2016)
- Monthly magazine
- Publishes over 160 books
- Strong web/social media presence
- Education/Outreach Program

- **Promoted HamSCI and 2017 Eclipse QSO Party**

Conclusions

- A ham radio experiment known as the Solar Eclipse QSO Party (SEQP) was conducted on August 21, 2017 to monitor changes in the ionosphere due to a total solar eclipse occurring over the continental United States.
- The SEQP sounded the ionosphere using ham radio contest-style operating and generated over 2.5 million link soundings. This constitutes perhaps the largest ionospheric citizen science dataset ever created.
- Observations on the 160 - 20 m (1.8 - 14 MHz) amateur radio bands show evidence of eclipse-induced ionospheric density reductions up to ±1 hour maximum eclipse.
- Observations were simulated using the PHaRLAP raytracing toolkit in conjunction with the eclipsed SAMI3 ionospheric model.
  - 14 MHz signals refracted at $h < 125$ km.
  - 1.8 - 7 MHz refracted at $h \geq 125$ km altitude.
  - Data-model comparison can be beneficial for the calibration of ionospheric models and the physical interpretation of amateur radio data.

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Eclipse HF Doppler Measurements

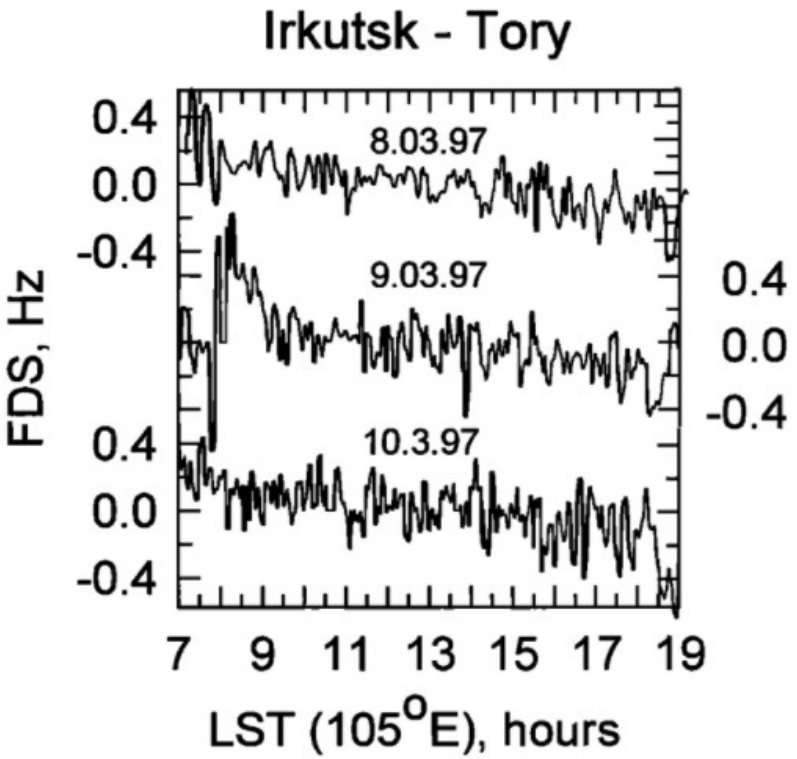


Figure 6. Temporary variations of frequency Doppler shift (FDS) recorded on the HF ray path Irkutsk – Tory during the daytime for March 8, 9, and 10, 1997.

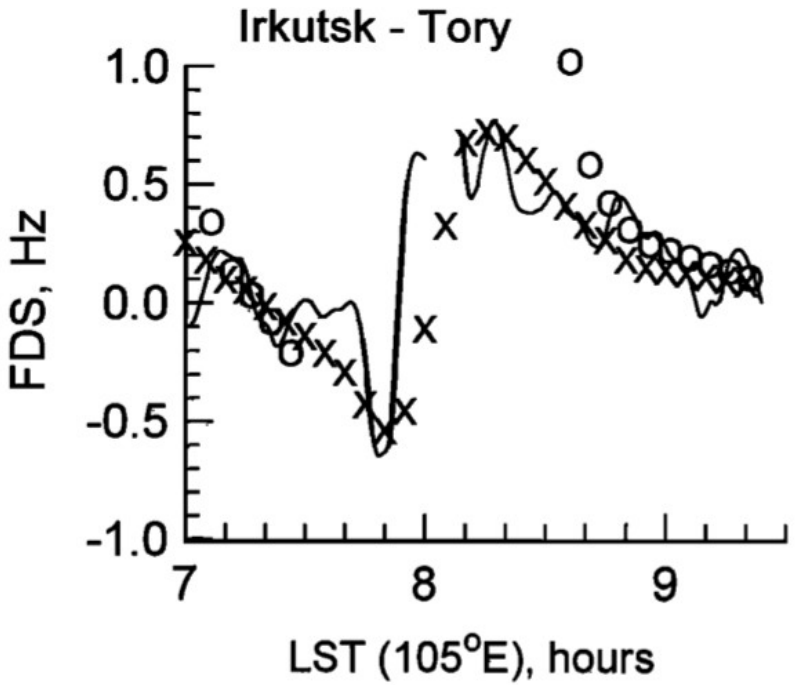
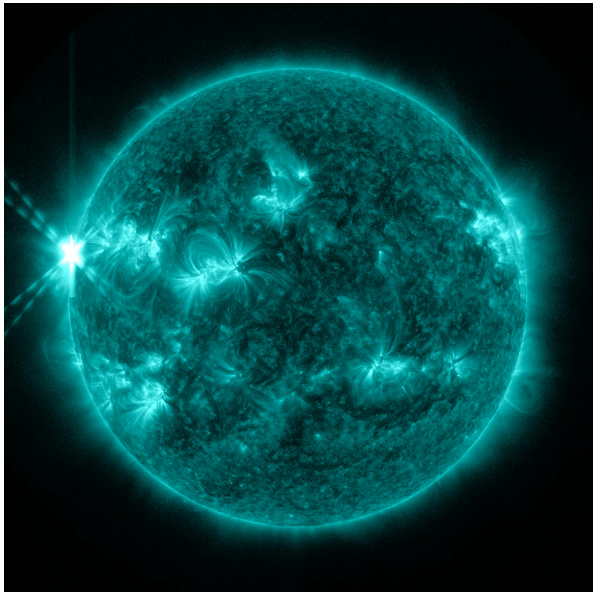


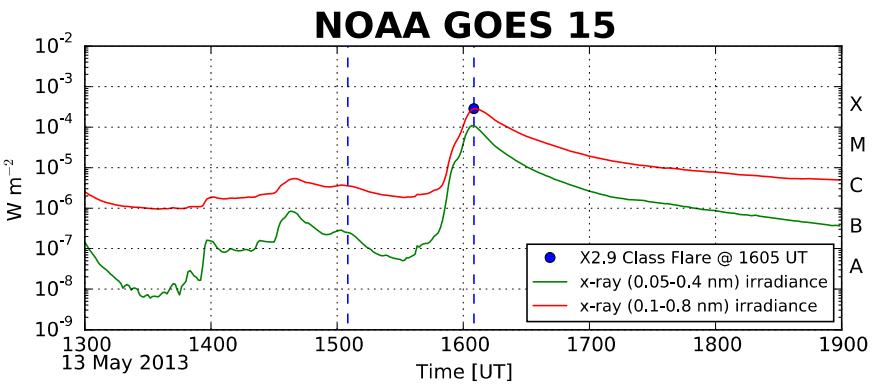
Figure 7. Comparison of measured (solid lines) and calculated temporary variations of frequency Doppler shift (FDS) during the eclipse on the HF ray path Irkutsk – Tory. Circles, calculation for the ordinary mode; crosses, calculation for the extraordinary mode.

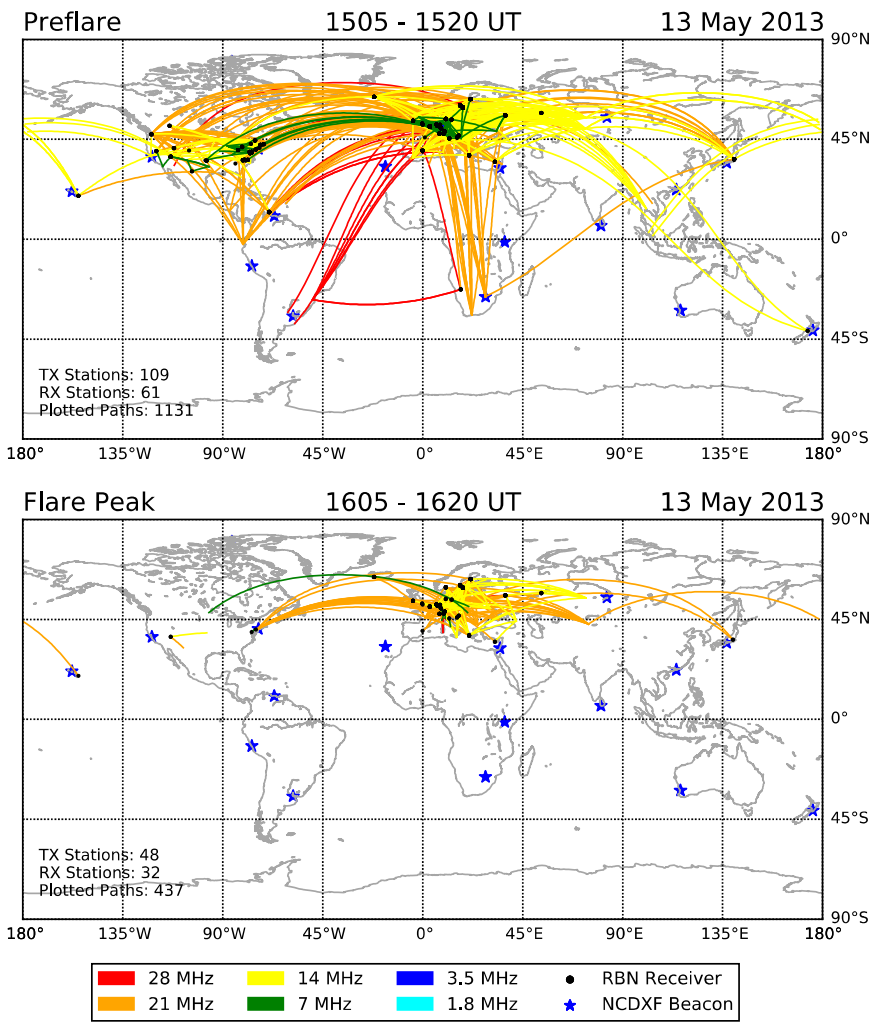
[*Boitman et al.,* 1999]

Ham Radio and Space Weather



[NASA SDO]





[*Frissell et al.*, 2014, *Space Weather*]

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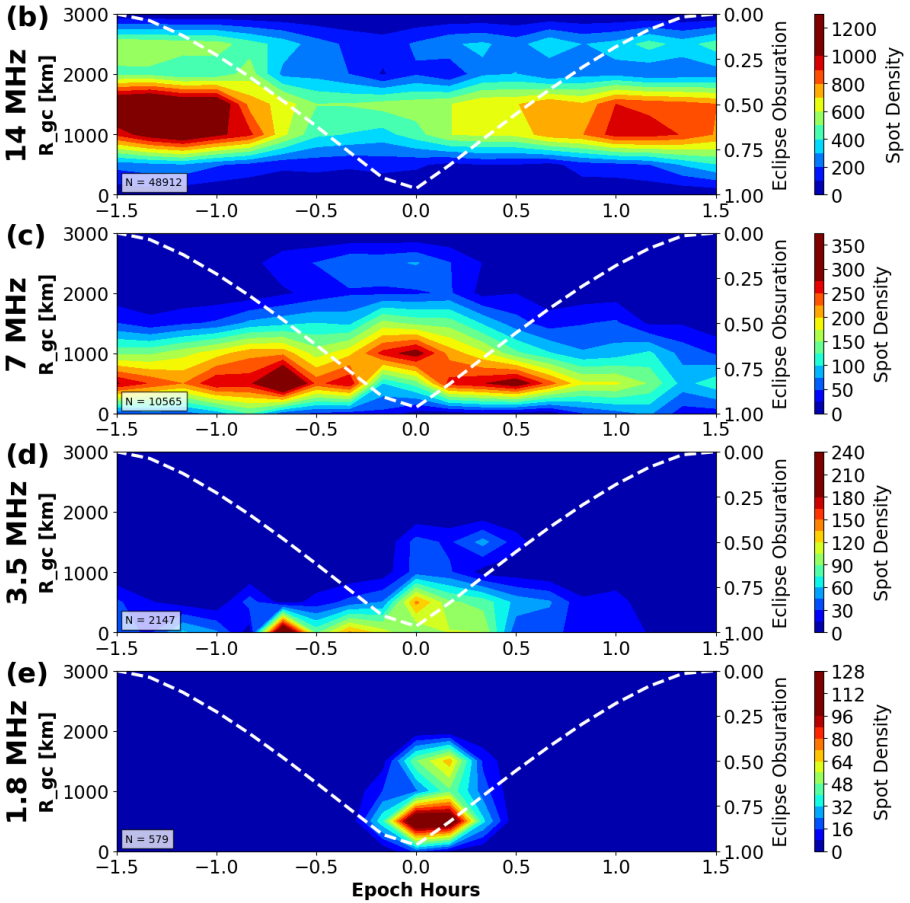
Future Work

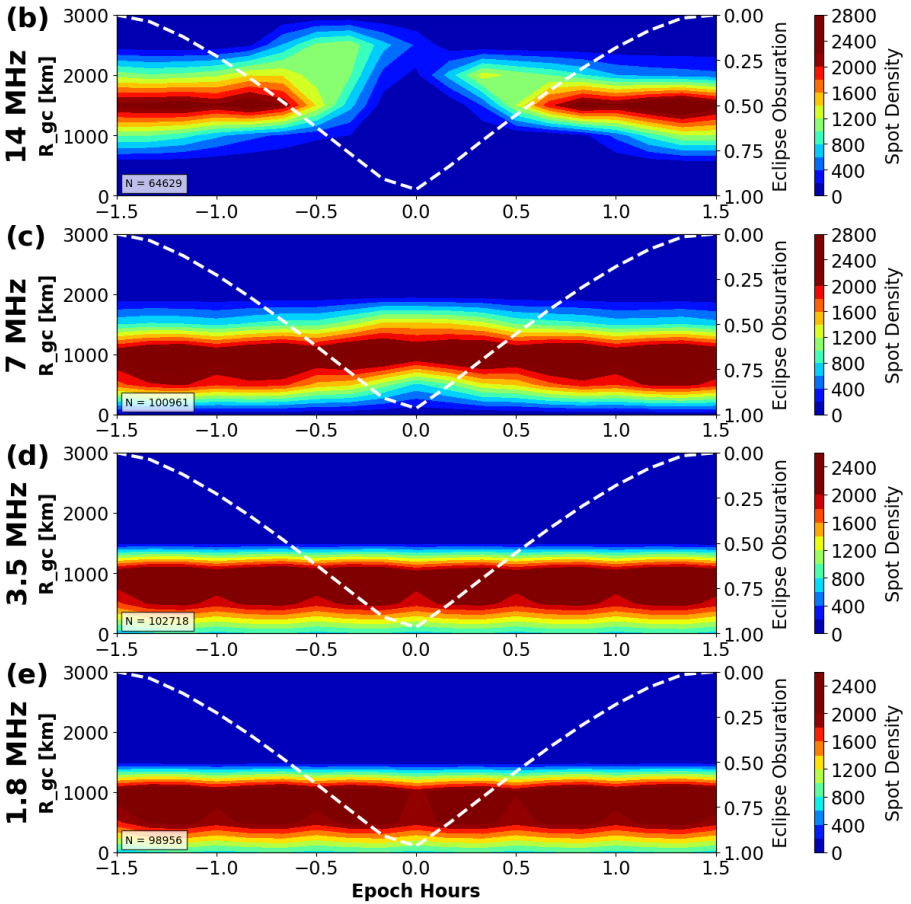
- Testing and validation of
  - Ray Trace Models
  - Ionospheric Models
- Development of new techniques for using ham radio data to characterize the ionosphere.
- Look for more localized eclipse effects?
  - Can we learn something new from the ionosphere?

RBN Observations – SAMI3 Simulation

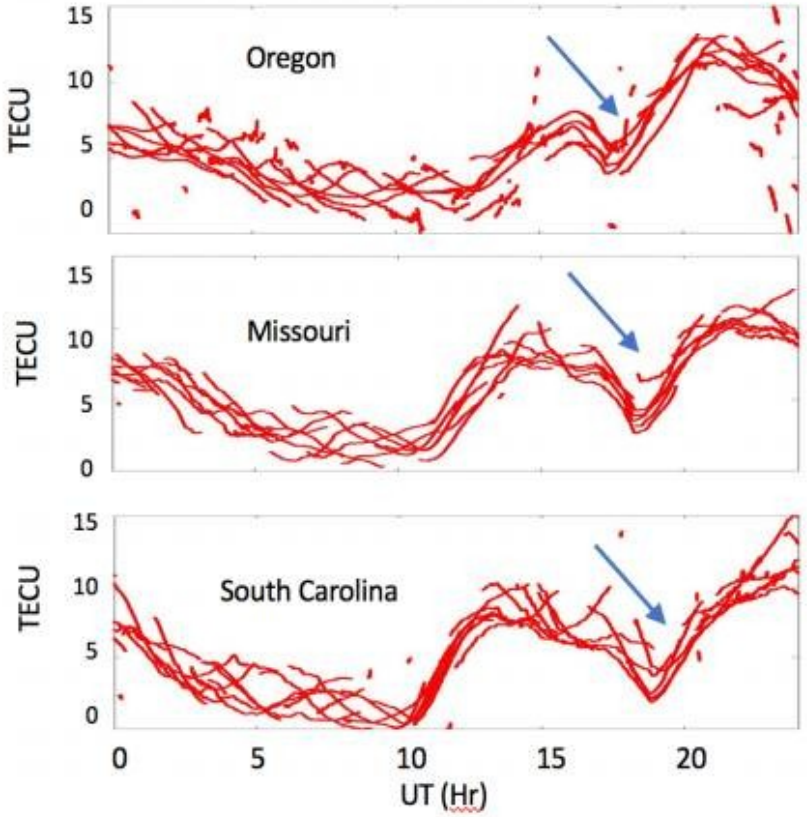
RBN Observations



Eclipsed SAMI3 - PHaRLAP

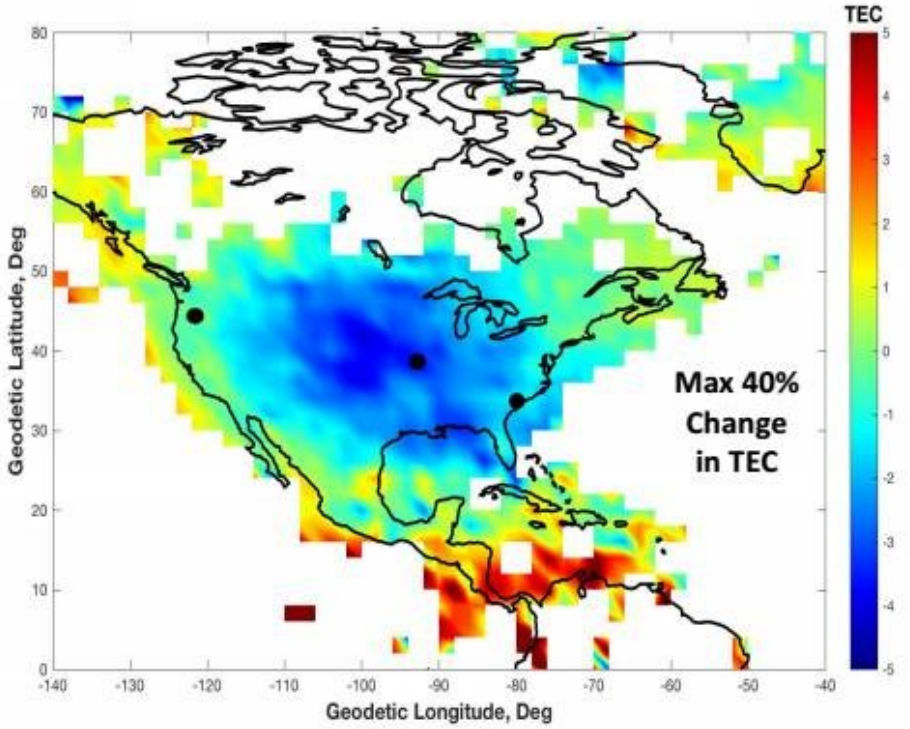


GPS-TEC Observations



Solar Eclipse
GNSS Vertical Total Electron Content
21 August 2017

Difference in TEC at 18:15 UT from start of solar eclipse at 16:45 UT



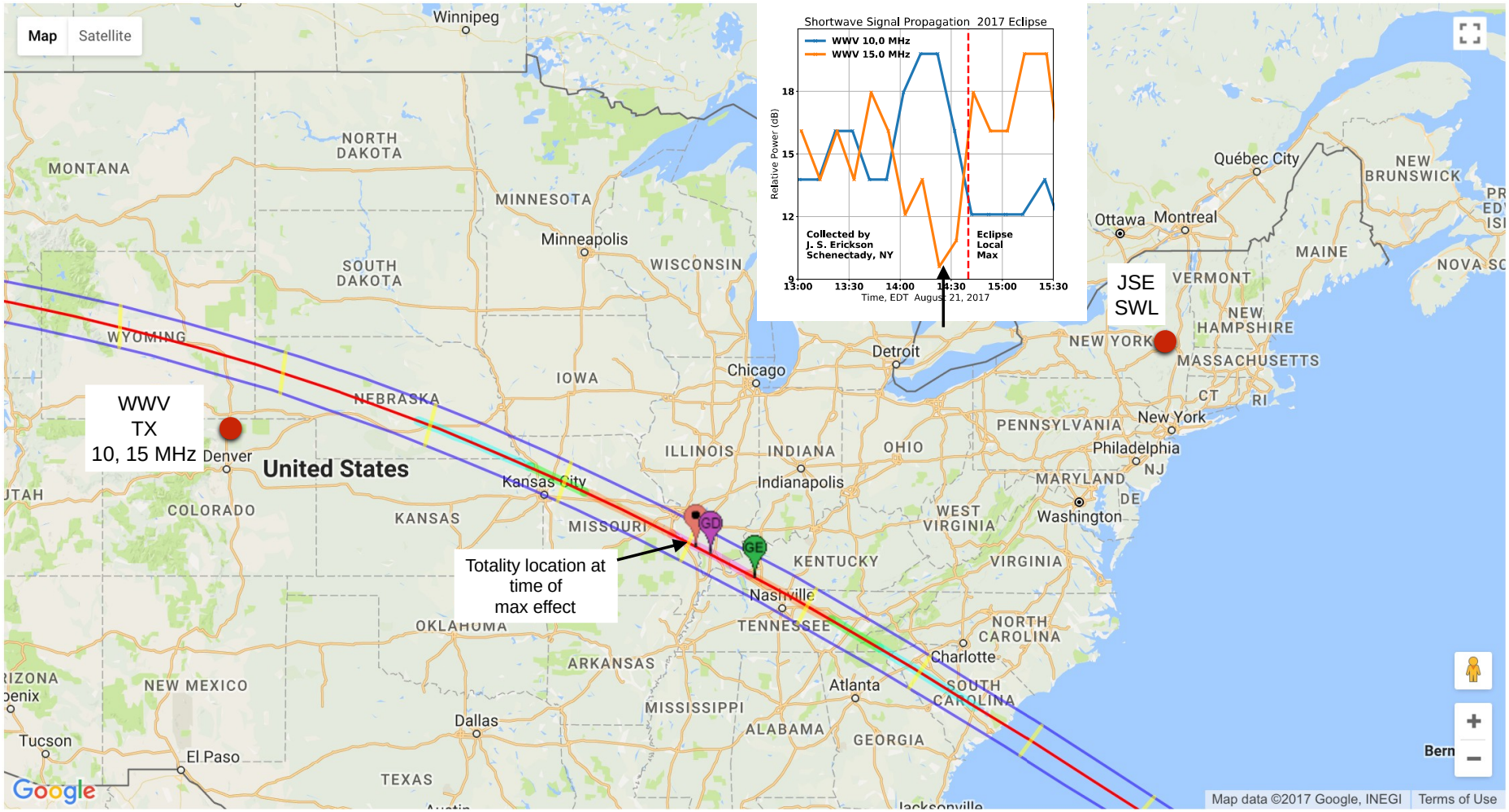
Support: NSF AGS-1242204, NASA NNX17AH71G

Courtesy of Anthea Coster

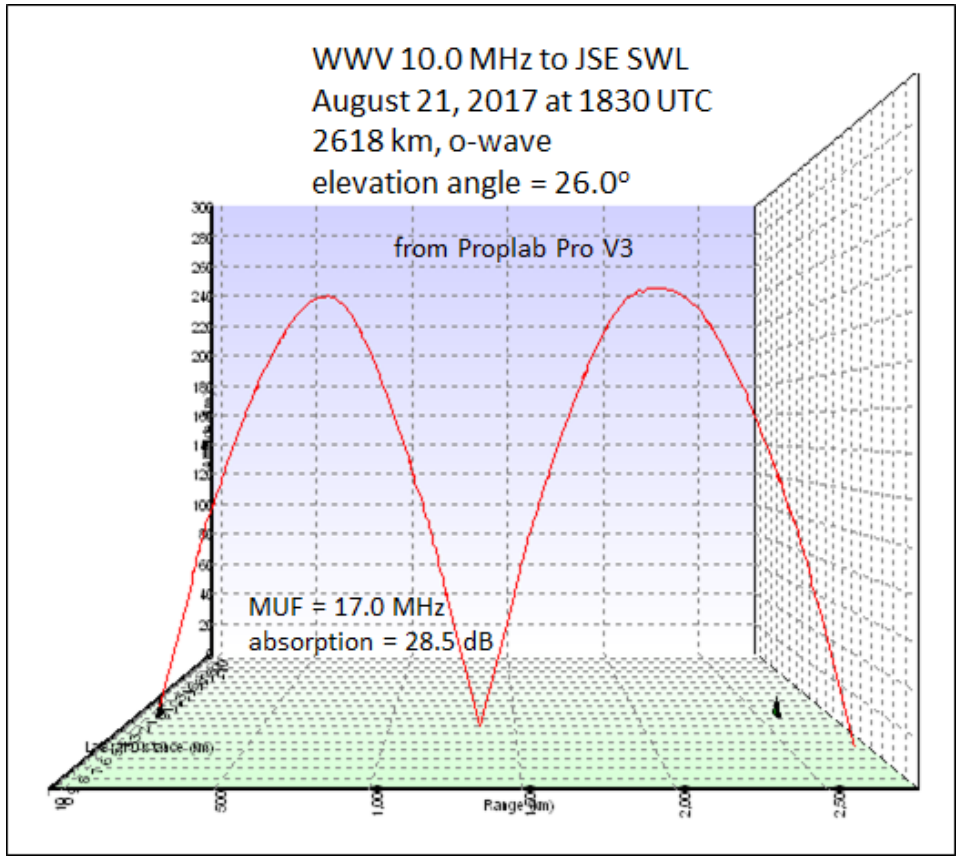
GPS-TEC Observations

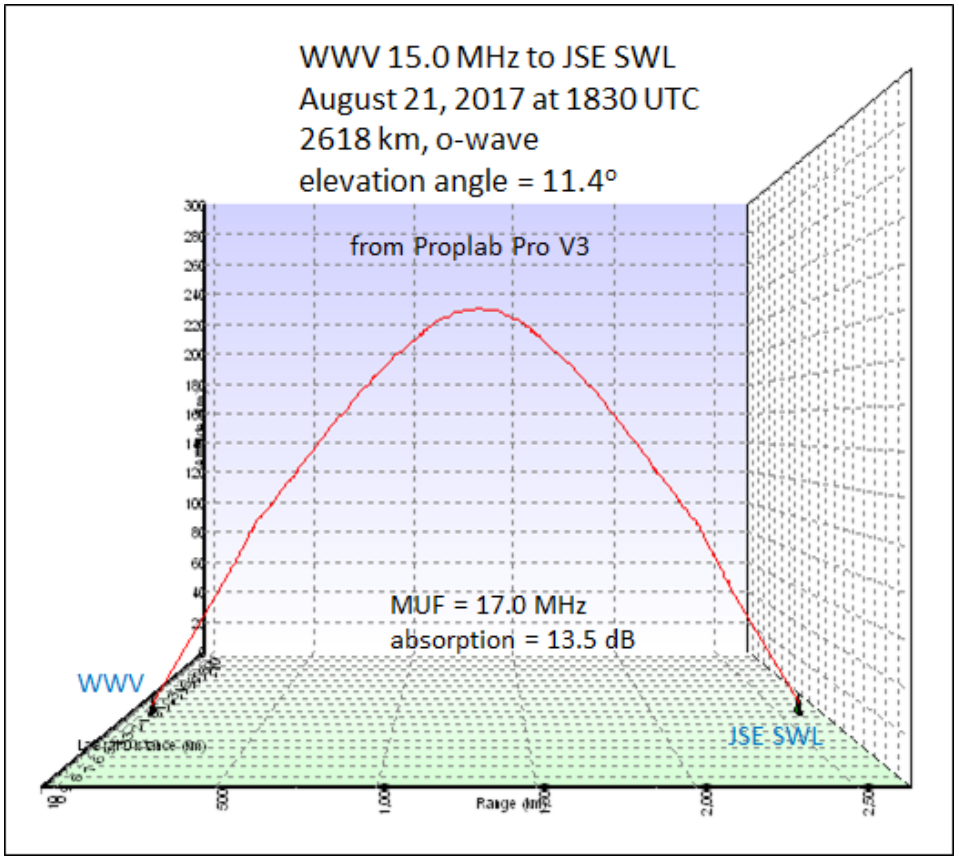
Preliminary Results Courtesy of Anthea Coster, MIT Haystack

10 & 15 MHz WWV (Schenectady, NY)

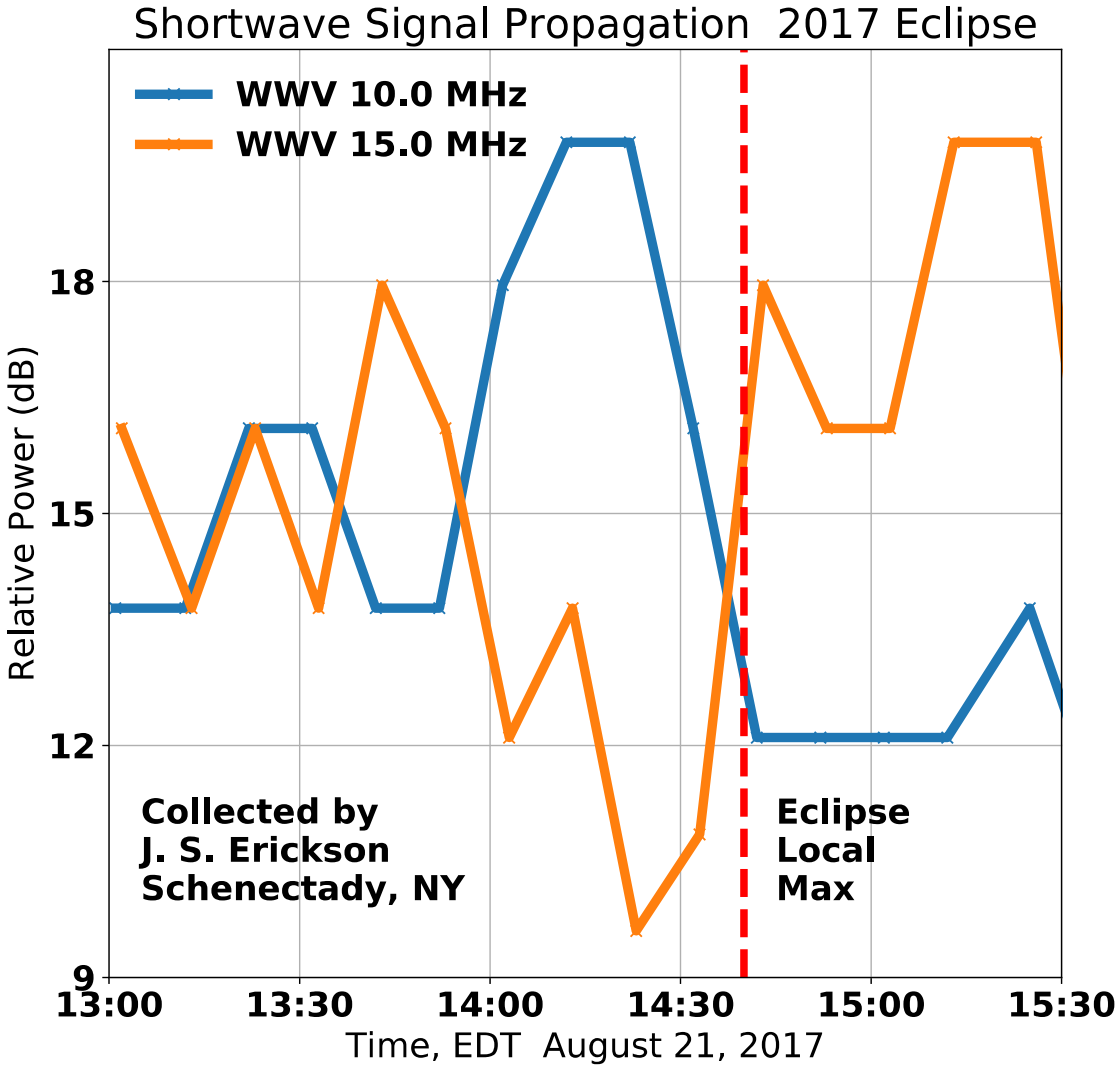


10 & 15 MHz WWV (Schenectady, NY)



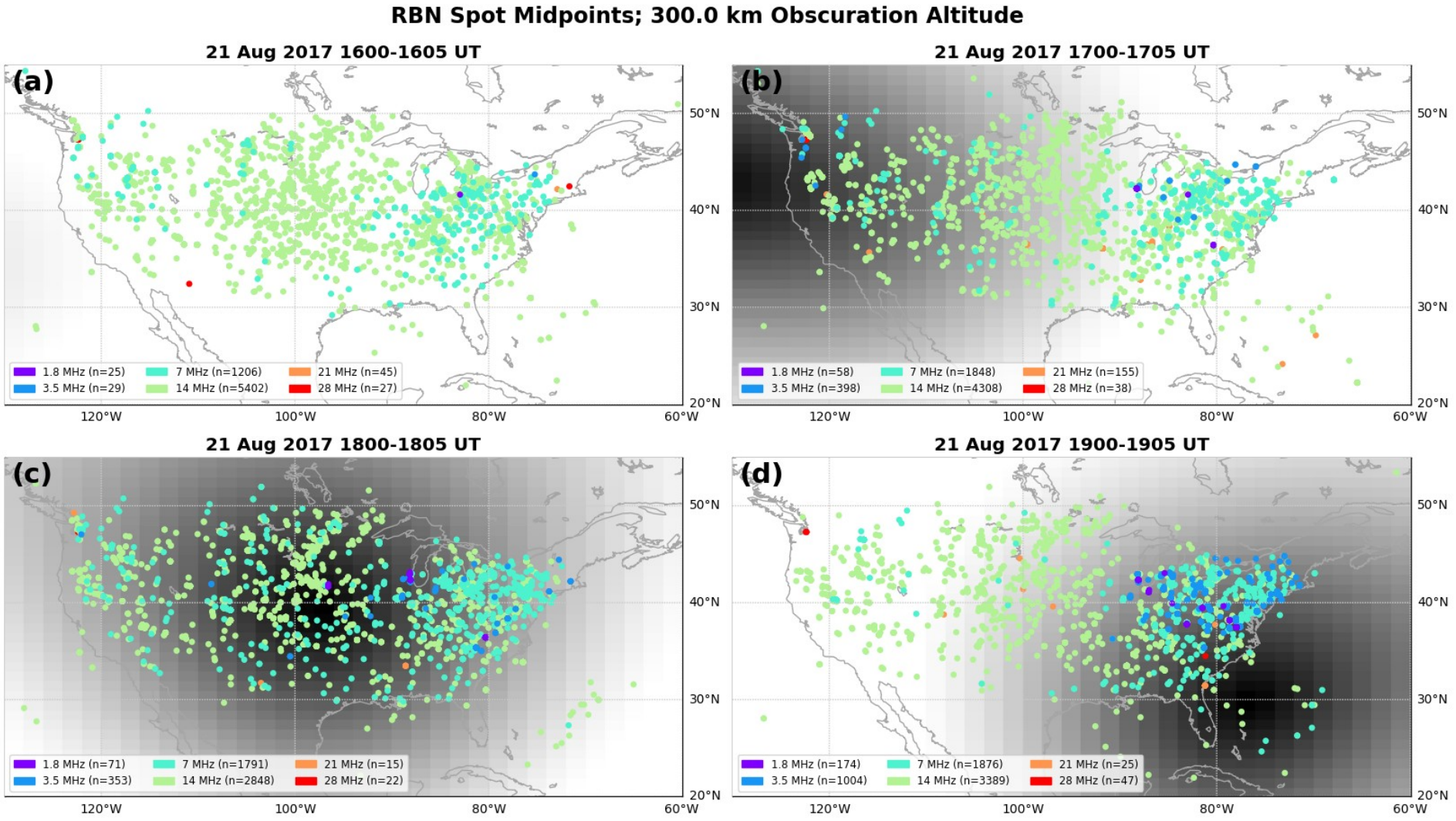


10 & 15 MHz WWV (Schenectady, NY)

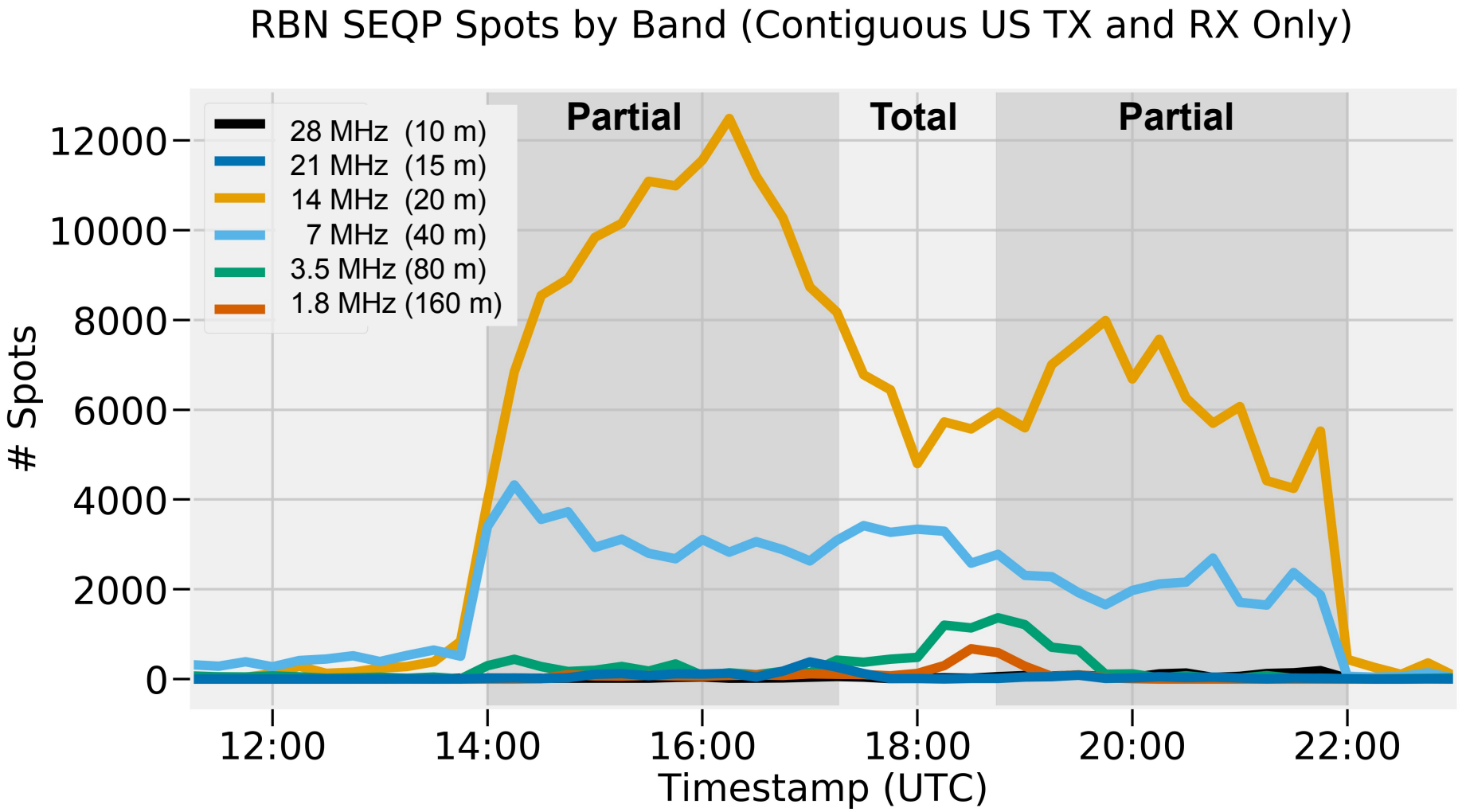


Even shortwave listeners got into the act. Using the S meter on his Panasonic RF-4900 shortwave receiver, 88 year old John S. Erickson of Schenectady, NY (father of Extra class licensee and professional ionospheric researcher Phil Erickson W1PJE) recorded the signal strength he heard from time signals WWV at 10 and 15 MHz every 10 minutes during eclipse passage.

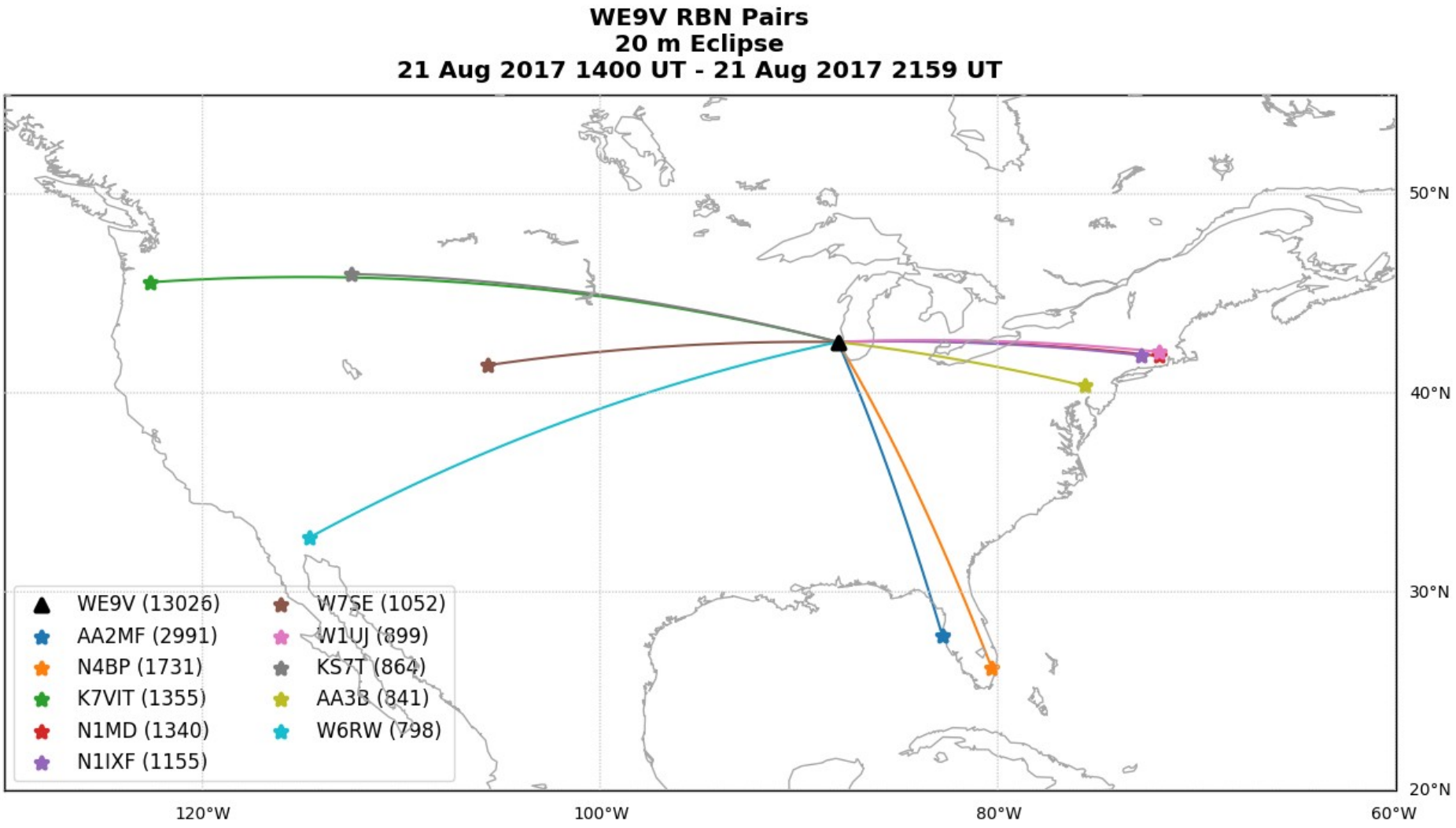
RBN - SEQP


RBN Spot Midpoints; 300.0 km Obscuration Altitude
21 Aug 2017 1600-1605 UT
(a)
1.8 MHz (n=25)
3.5 MHz (n=29)
7 MHz (n=1206)
14 MHz (n=5402)
21 MHz (n=45)
28 MHz (n=27)
21 Aug 2017 1700-1705 UT
(b)
1.8 MHz (n=58)
3.5 MHz (n=398)
7 MHz (n=1848)
14 MHz (n=4308)
21 MHz (n=155)
28 MHz (n=38)
21 Aug 2017 1800-1805 UT
(c)
1.8 MHz (n=71)
3.5 MHz (n=353)
7 MHz (n=1791)
14 MHz (n=2848)
21 MHz (n=15)
28 MHz (n=22)
21 Aug 2017 1900-1905 UT
(d)
1.8 MHz (n=174)
3.5 MHz (n=1004)
7 MHz (n=1876)
14 MHz (n=3389)
21 MHz (n=25)
28 MHz (n=47)
50°N
40°N
30°N
20°N
120°W
100°W
80°W
60°W

SEQP RBN Spots



WE9V 14 MHz RBN Rx, Wisconsin

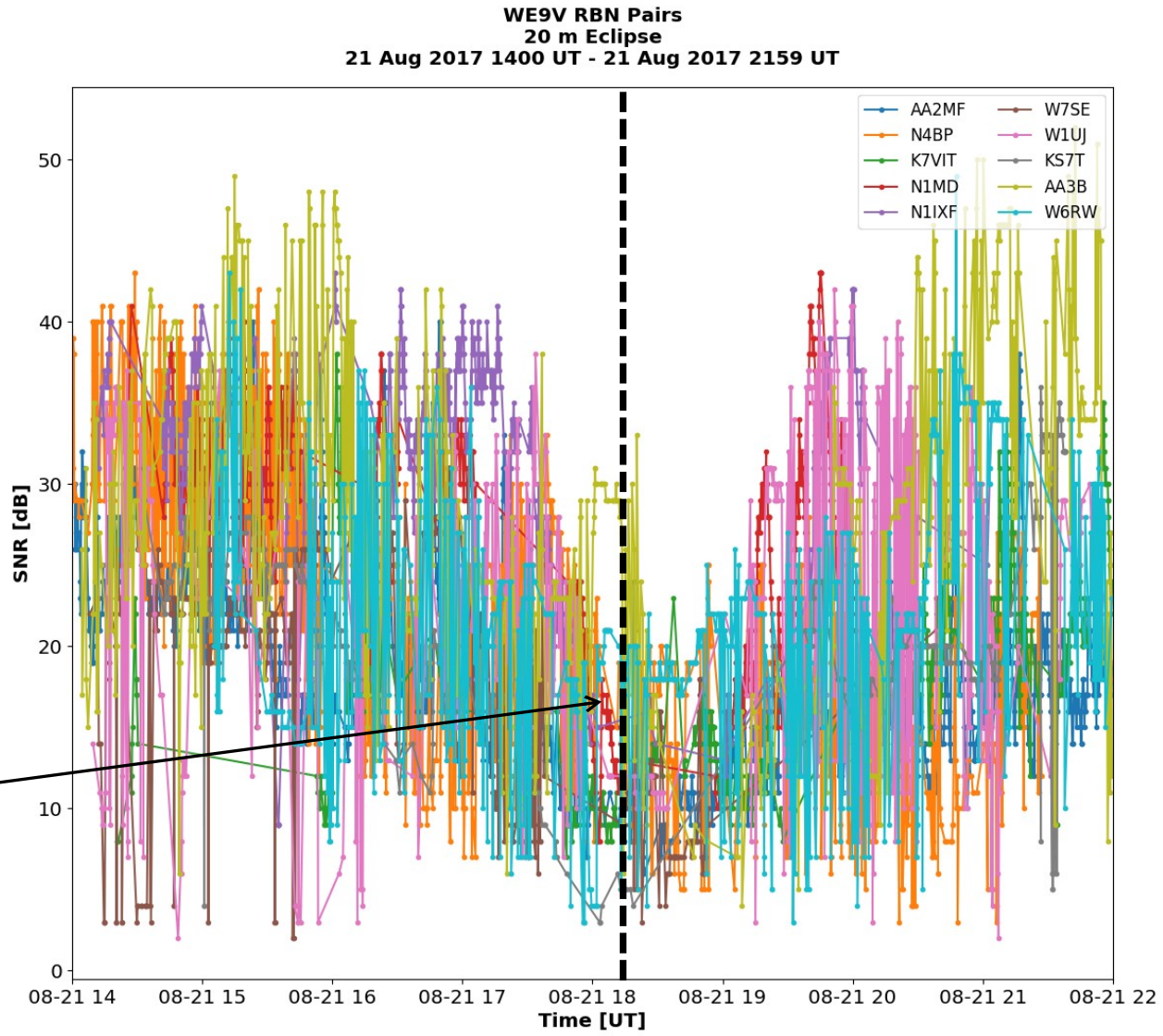


WE9V 14 MHz RBN Rx, Wisconsin

Ground Eclipse Times
Bristol, WI:

- Start partial: 1653 UT
- Max: 1818 UT
- End partial: 1940 UT

Clear drop in 20 meter propagation during temporary 'nighttime' conditions



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HamSCI Workshop at NJIT

Friday, Feb. 23 – Saturday, Feb. 24, 2018

New Jersey Institute of Technology

Newark, NJ

HamSCI

NJIT New Jersey Institute of Technology

We welcome papers and presentations on

2017 Eclipse Ionospheric Effects using

Amateur Radio and related data.

Watch hamsci.org and ARRL news for details.

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HamSCI

The **H**am radio **S**cience **C**itizen **I**nvestigation is:

hamsci.org/dayton2017

An organization 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.

NJIT New Jersey Institute of Technology

Founder/Lead HamSCI Organizer:
Dr. Nathaniel A. Frissell, W2NAF
NJIT Center for Solar-Terrestrial Research