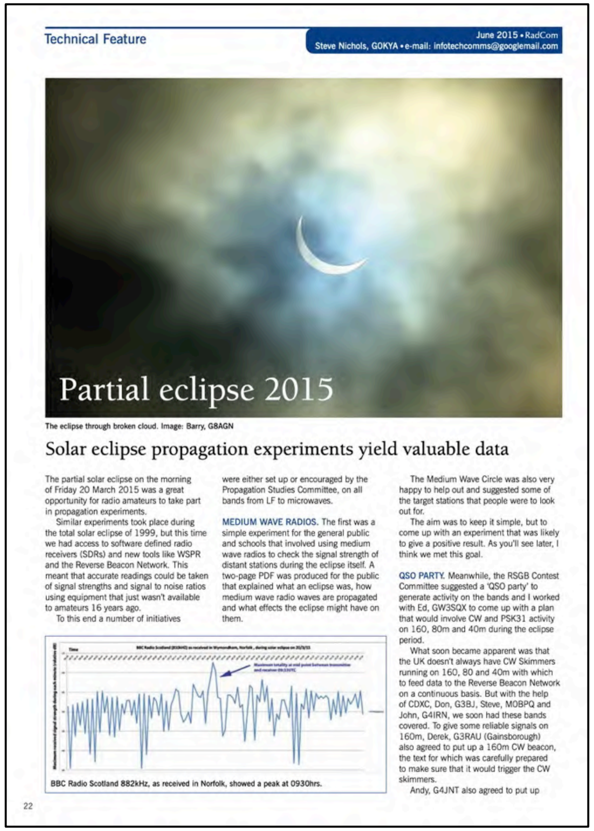
October 2023 Eclipse: Effects on HF Propagation

As seen using WSJT-X mode FST4W

Gwyn Griffiths G3ZIL

The 2015 partial eclipse over the UK



Technical Feature

June 2015 • RadCom
Steve Nichols, G0KYA • e-mail: infotechcomms@googlemail.com

Partial eclipse 2015

The eclipse through broken cloud. Image: Barry, G8AGN

Solar eclipse propagation experiments yield valuable data

The partial solar eclipse on the morning of Friday 20 March 2015 was a great opportunity for radio amateurs to take part in propagation experiments.

Similar experiments took place during the total solar eclipse of 1999, but this time we had access to software defined radio receivers (SDRs) and new tools like WSPR and the Reverse Beacon Network. This meant that accurate readings could be taken of signal strengths and signal to noise ratios using equipment that just wasn't available to amateurs 16 years ago.

To this end a number of initiatives were either set up or encouraged by the Propagation Studies Committee, on all bands from LF to microwaves.

MEDIUM WAVE RADIOS. The first was a simple experiment for the general public and schools that involved using medium wave radios to check the signal strength of distant stations during the eclipse itself. A two-page PDF was produced for the public that explained what an eclipse was, how medium wave radio waves are propagated and what effects the eclipse might have on them.

The Medium Wave Circle was also very happy to help out and suggested some of the target stations that people were to look out for.

The aim was to keep it simple, but to come up with an experiment that was likely to give a positive result. As you'll see later, I think we met this goal.

QSO PARTY. Meanwhile, the RSGB Contest Committee suggested a 'QSO party' to generate activity on the bands and I worked with Ed, GW3SQX to come up with a plan that would involve CW and PSK31 activity on 160, 80m and 40m during the eclipse period.

What soon became apparent was that the UK doesn't always have CW Skimmers running on 160, 80 and 40m with which to feed data to the Reverse Beacon Network on a continuous basis. But with the help of CDXC, Don, G3BJ, Steve, M0BPQ and John, G4IRN, we soon had these bands covered. To give some reliable signals on 160m, Derek, G3RAU (Gainsborough) also agreed to put up a 160m CW beacon, the text for which was carefully prepared to make sure that it would trigger the CW skimmers.

Andy, G4JNT also agreed to put up

BBC Radio Scotland 882kHz, as received in Norfolk, showed a peak at 0930hrs.

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Steve Nichols, RadCom, June 2015.

Steve Nichols G0KYA's June 2015 RadCom article highlighted use of new technologies since the 1999 eclipse, e.g. WSPR, RBN, SDRs.

This talk will explore the use of new technologies and methods since Steve's article. In particular, to study propagation during the October 2023 annular eclipse over North America.

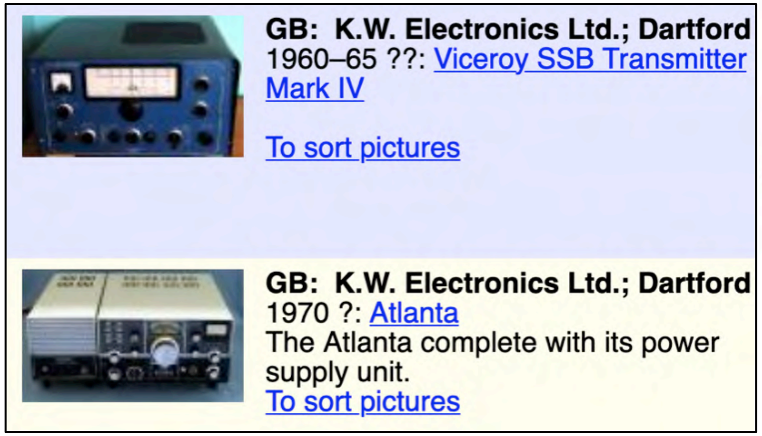
Outline

- About me, and my early steps with WSPR.
- What's FST4W? Why use it over WSPR? What hardware?
- The October 2023 Annular Eclipse.
- Effects on propagation: Enhancements, loss, changes of modes, changes in 'height of the ionosphere'.
- 8 April 2024 total eclipse, a role for UK amateurs?

1970: GW3ZIL on Anglesey

Licenced aged 15. School project on surface to undersea sea diver communication using conduction current signalling.

Image: Holyhead and Anglesey Mail



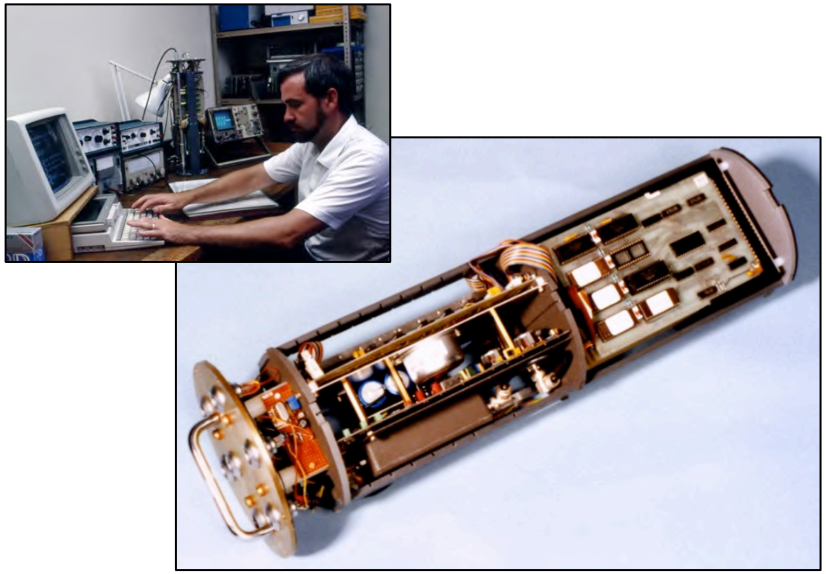
GB: K.W. Electronics Ltd.; Dartford
1960–65 ??: Viceroy SSB Transmitter Mark IV

To sort pictures

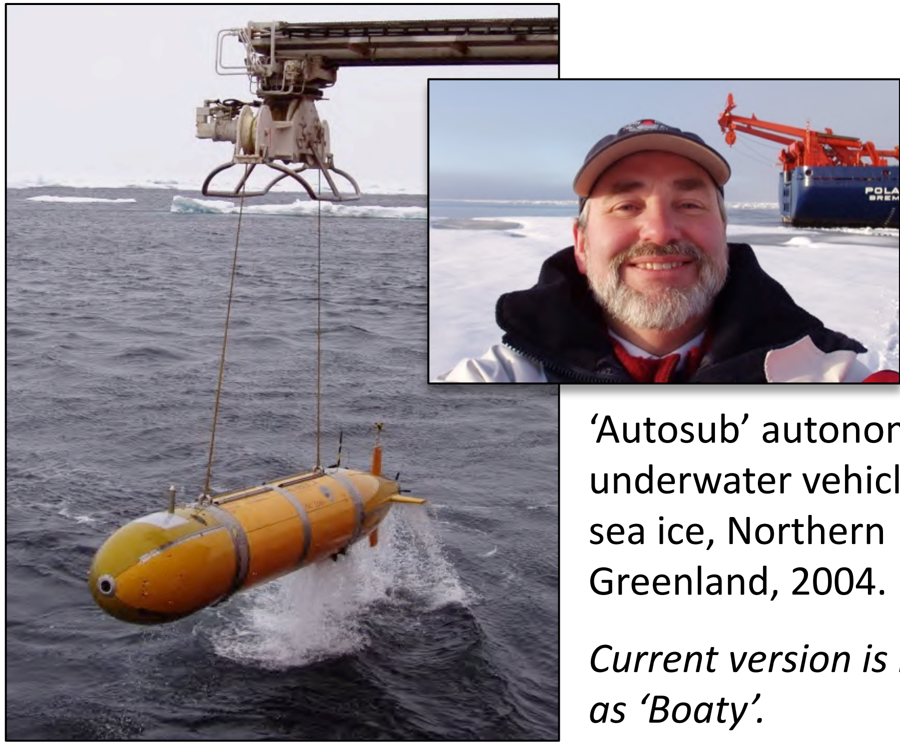
GB: K.W. Electronics Ltd.; Dartford
1970 ?: Atlanta
The Atlanta complete with its power supply unit.
To sort pictures

https://www.radiomuseum.org/collection/gwyn_griffiths.html

Oceanography: Instruments to Submersibles



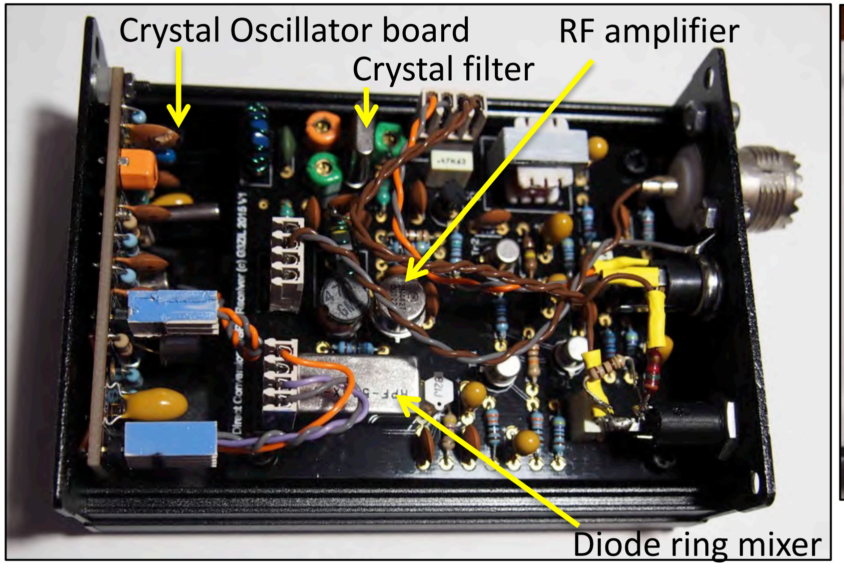
Battery powered (3 months), self-contained Doppler Sonar, 1987. Direct conversion 1 MHz receiver, in-phase and quadrature outputs. RCA CDP1802 CPU, 12 bit ADC and hardware multipliers for frequency analysis.

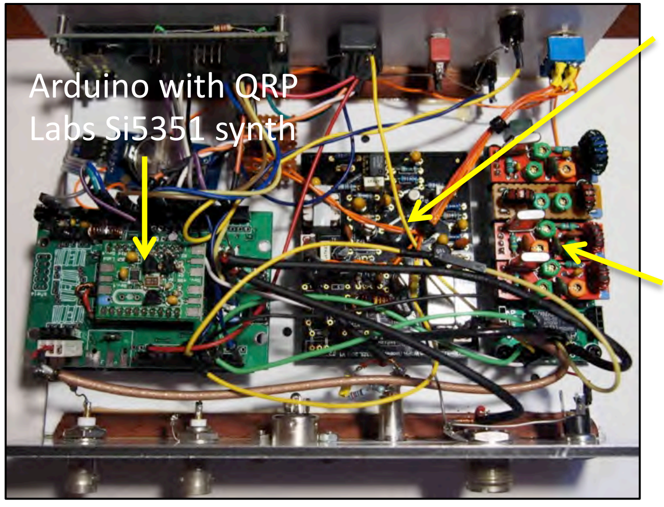


‘Autosub’ autonomous underwater vehicle under sea ice, Northern Greenland, 2004.

Current version is known as ‘Boaty’.

Return to Amateur Radio: WSPR HF band sets

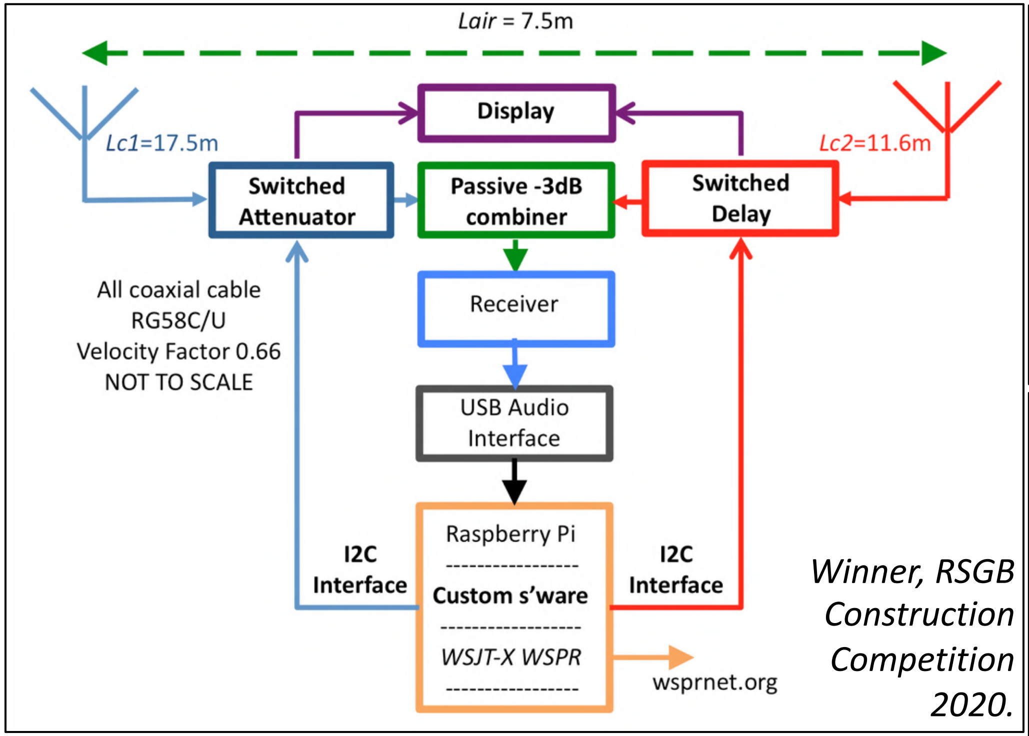


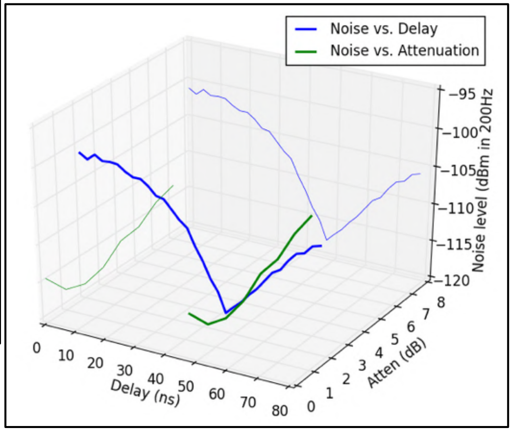


- Single-band direct-conversion receiver, inspired by W3PM design.
- Crystal oscillator. Single-crystal front end selectivity, passes USB, null at LSB. Practical Wireless April 2016

- WSPR multiband transceiver: Arduino controller and transmitter using Si5351 synthesizer. 1 W output.
- Direct conversion receiver: four switched crystal filters.
- Nice exercise, but my implementation too noisy.

WSPR reception: Noise measurement & reduction



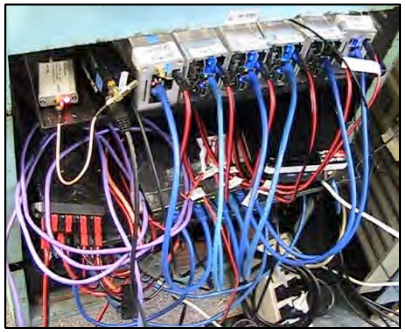


Automated phasing method of noise cancellation. Measures noise at attenuator and delay settings during gap in WSPR transmissions.

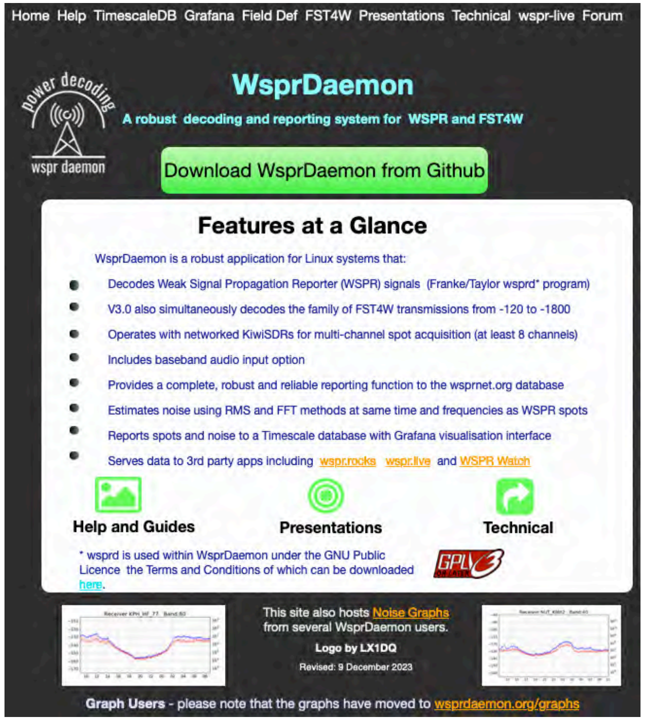
The 2023 eclipse: How I became involved…

Coffee Catz, Sebastopol, Sonoma County, Northern California.

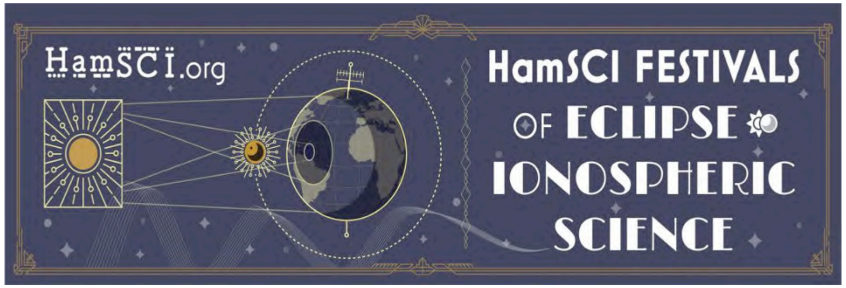
N6GN, AI6VN, K6PZB, K6RFT, KJ6MKI, KK6EEW, KP4MD/W6, N3AGE, W6SB, WA6UAT, WB6CXC, WB6YRW, WW6D, WA7ABP, W7WKR



Rack of KiwiSDRs at KPH, courtesy Maritime Radio Historical Society, installed and maintained by Rob Robinett AI6VN *et al*. KPH images courtesy KP4MD/W6.



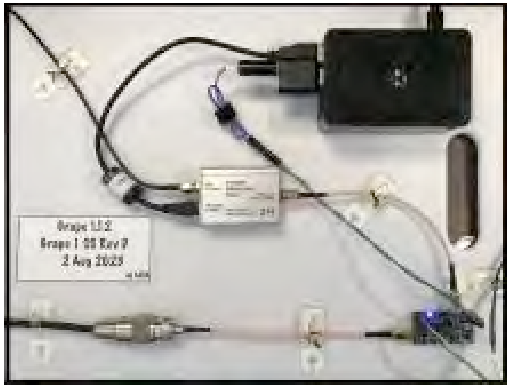
The 14 October 2023 Annular Eclipse: HamSci Ham Radio Citizen Science Investigation



Below, the 'Grape' 1 kHz IF receiver for use with standard frequency transmissions, e.g. WWV 5 and 10 MHz, CHU, with station map for October 2023.

A platform to promote projects with following objectives:

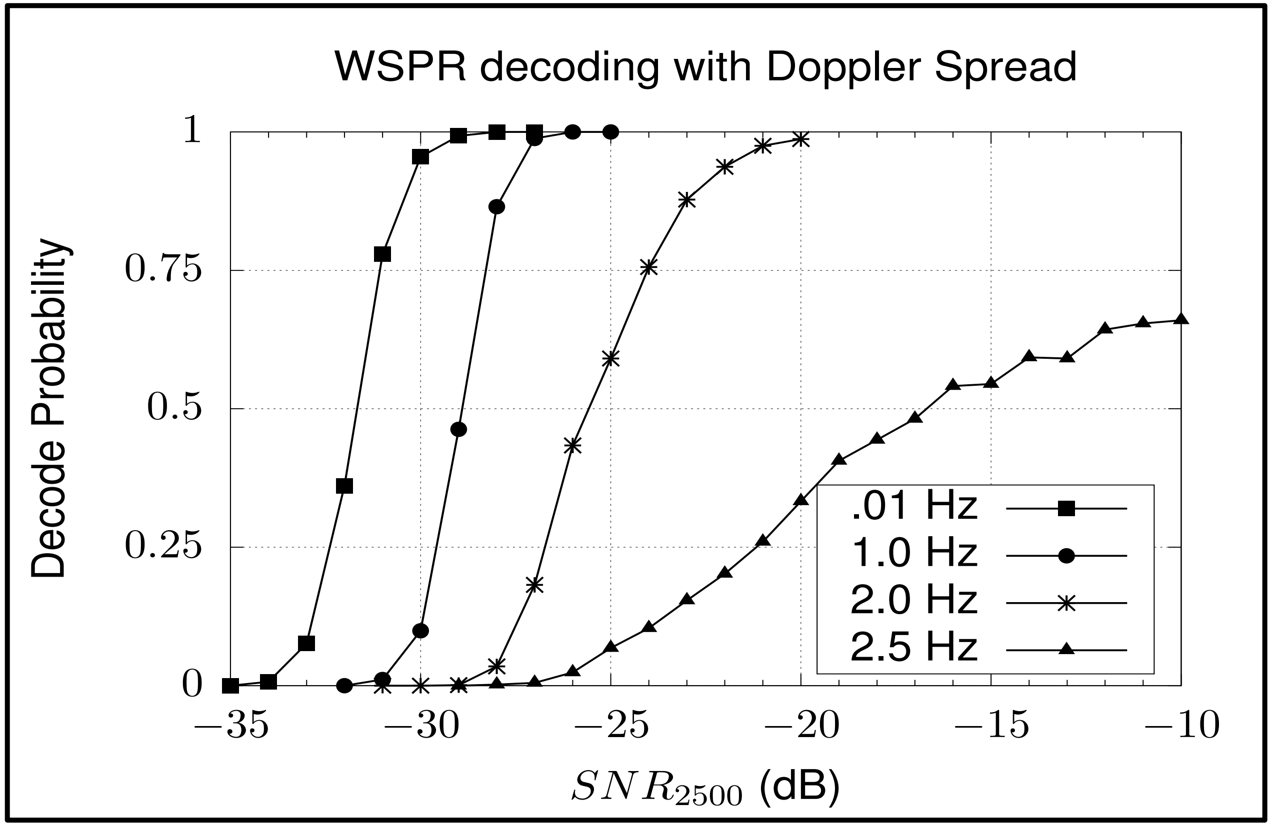
- Advance scientific research and understanding through amateur radio.
- Encourage development of new technologies.
- Provide educational opportunities for amateur community and the public.



https://hamsci.org

http://wsprdaemon.org/technical

WSPR: Limited by SNR *and* frequency spread



Courtesy Steve Franke K9AN

Here, 'Doppler spread' is the span between upper and lower -10 dB points of the signal's spectrum.

Another measure is *w50*, spanning 50% of total power, that is between -3 dB points.

So… how could we measure frequency spread?

Use FST4W. It measures frequency spread

FST4W, a WSJT-X mode, can measure frequency spread (*w50, width between -3dB points*) *if* an empty file *plotspec* present in the directory wsjt-x is started.

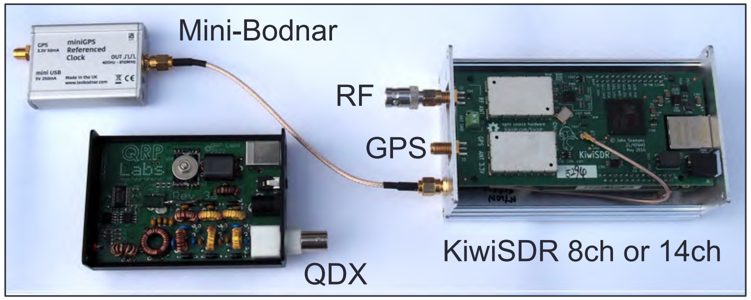
Knowing frequency spread:

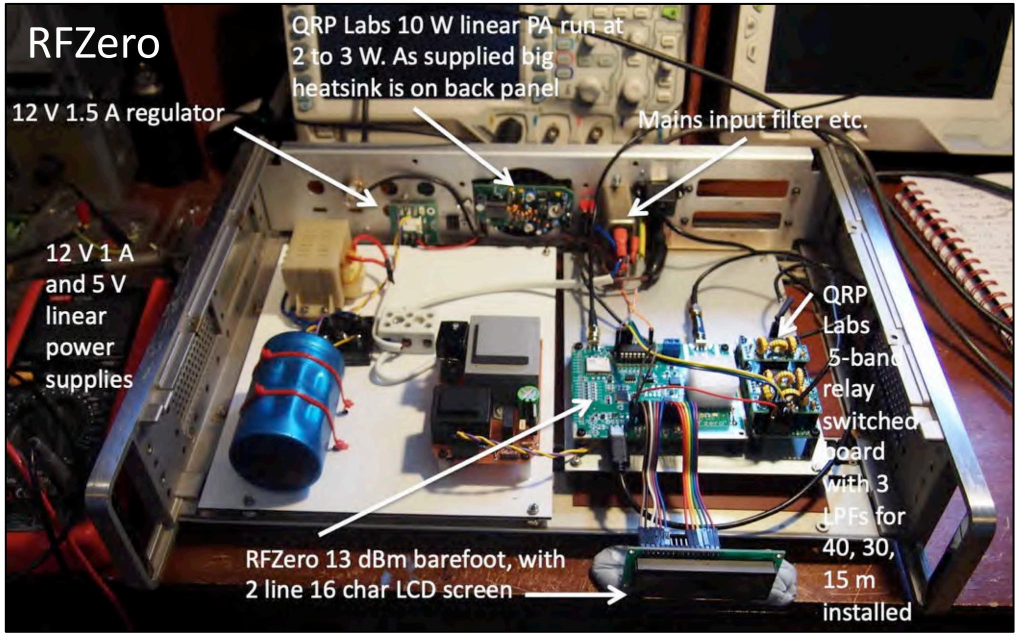
- Has led to reduced receiver and transmitter jitter and drift.
- Has proven to be a useful measurement for ionospheric propagation studies.

However. . .

- WSJT-X sub-optimum for receive, one length at a time:
  Use WsprDaemon – handles all lengths, and reports frequency spread
- No drift compensation, tighter equipment requirements: Use analogue TCXO or GPSDO
- Ionospheric Doppler spread for longer sequences: Use 120 second variant.
- Few people transmitting and receiving at present: Need to Publicise.

Equipment for FST4W

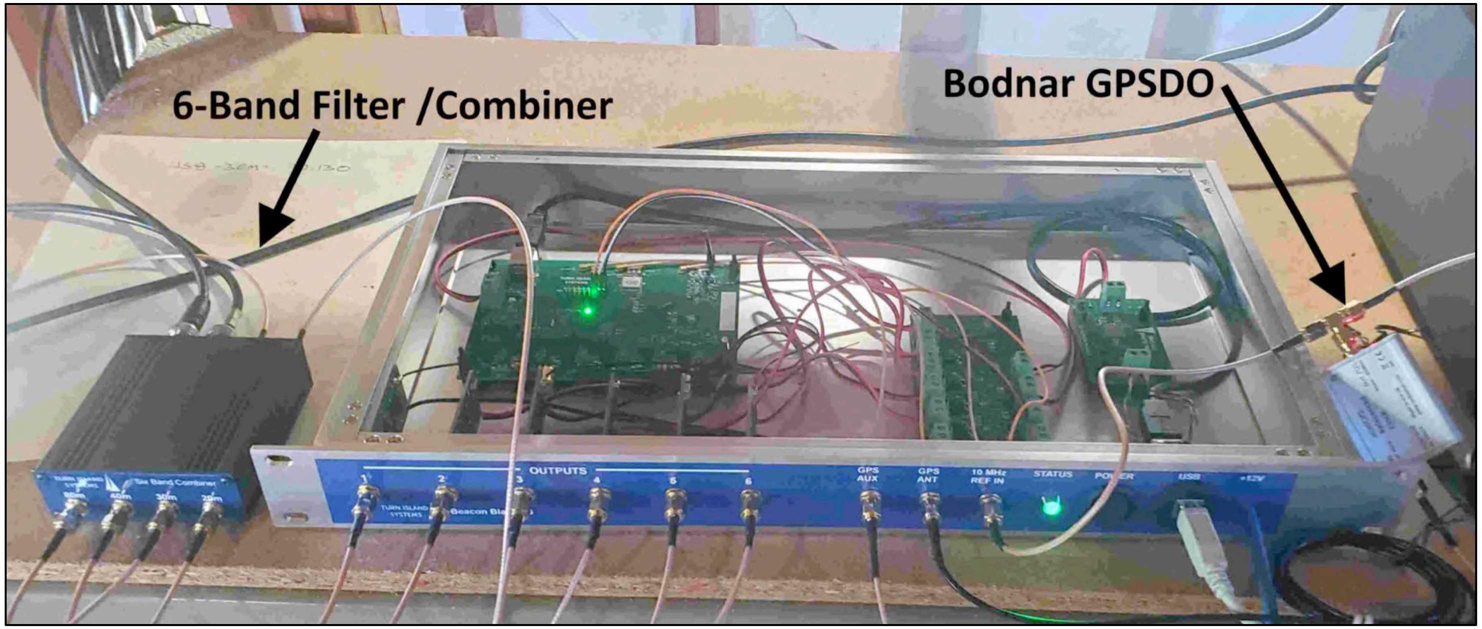




If at all possible use equipment with GPS-aided, or even better, phase-locked GPS disciplined Master Oscillator or an OCXO. Why? Ionosphere frequency spread can be as low as few 10s of milliHertz at 14 MHz. https://rfzero.net/ https://qrp-labs.com/

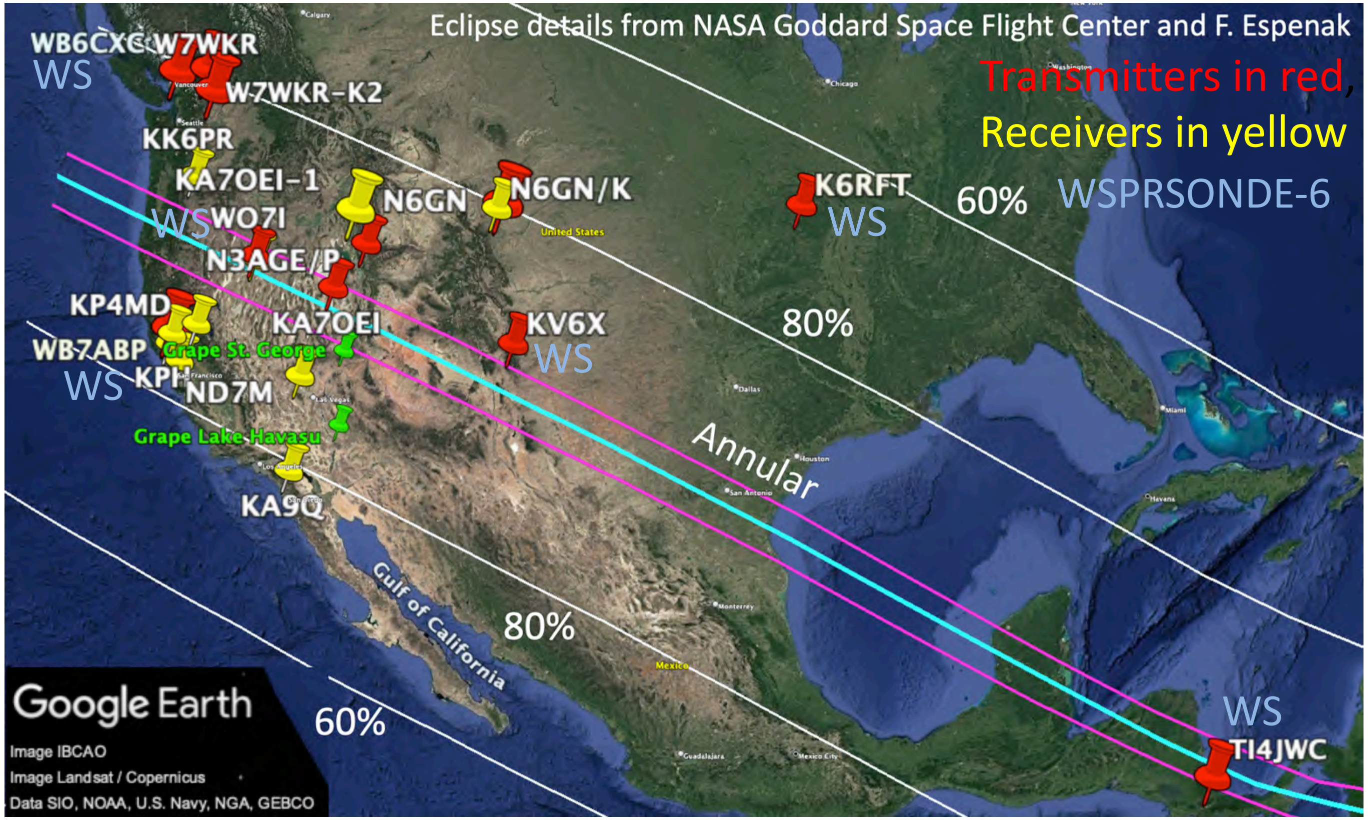
Equipment for FST4W: The WSPRSONDE

Image: Paul Elliott WB6CXC



Designed specifically for FST4W operation during the October 2023 eclipse the WSPRSONDE-6 from Turn Island Systems can transmit on six HF bands simultaneously with 100% duty cycle. https://turnislandsystems.com

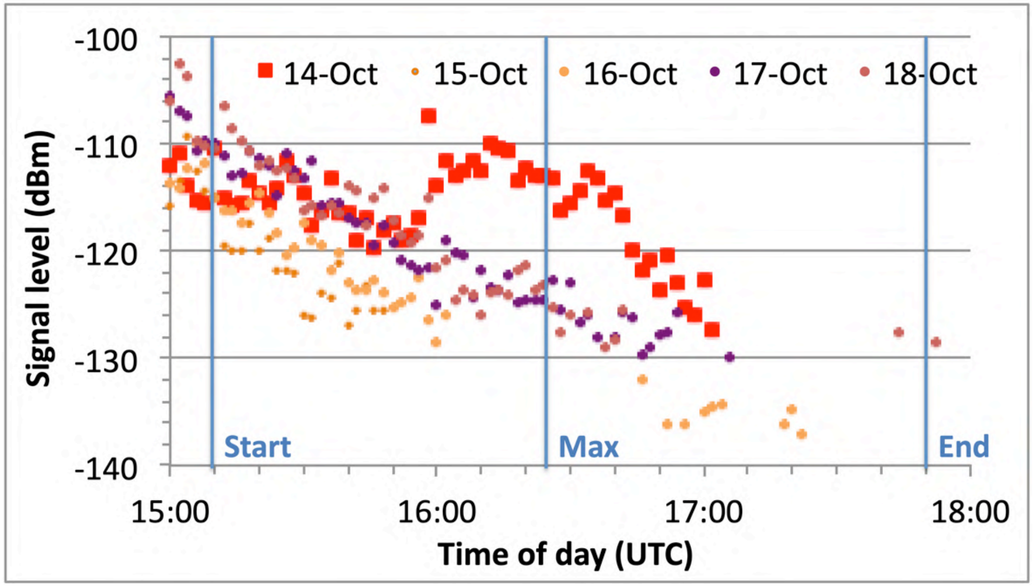
The 14 October 2023 Annular Eclipse: FST4W



80 m: Higher signal level from reduced D-region absorption

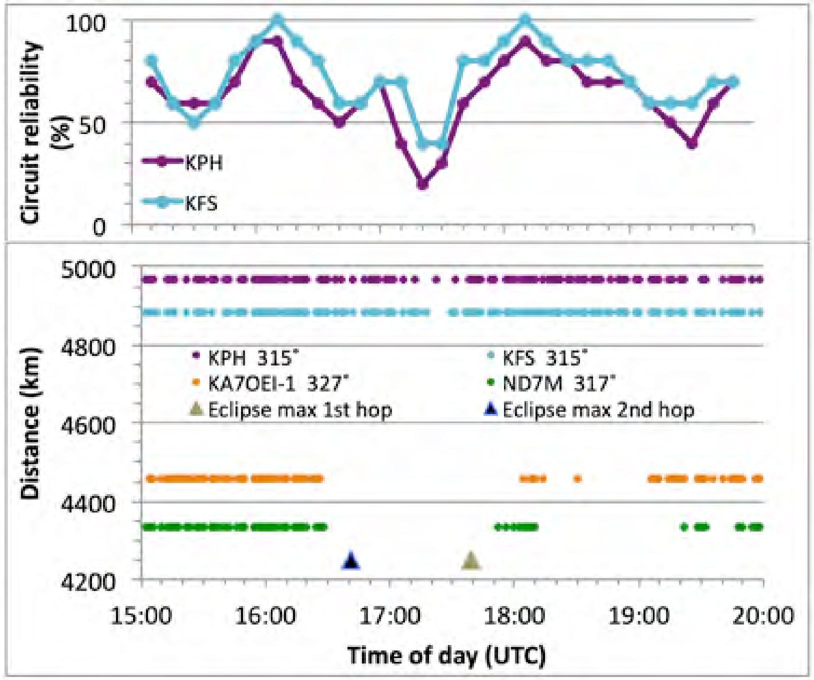
Lowest frequency in this FST4W study:

- 466 km path from 89% obscured to 85% obscured.
- Band was closing at time of eclipse.
- Clear rise of 12-15 dB in signal level compared with non-eclipse days.
- Effect not seen in first half of build-up to maximum obscured.
- Usefulness of continuous measurements from KiwiSDR. Quantify change, not just a narrative.

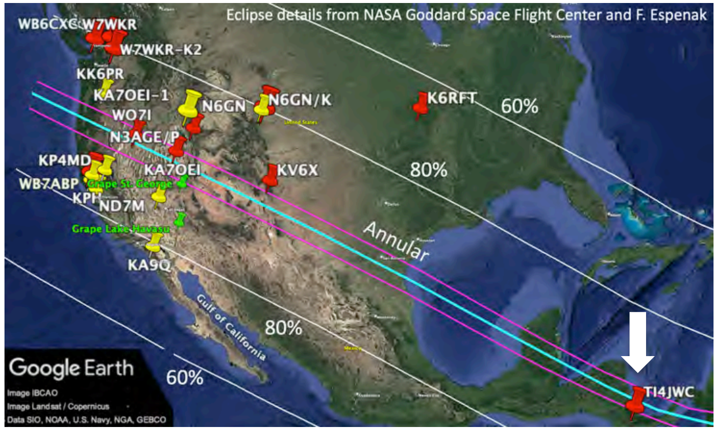


Signal levels on 14-18 October 2023 at KA7OEI-1, Northern Utah for FST4W transmissions from WO7I, Nevada on 3.57 MHz.

10 m: Effect of lower F2 critical frequency



Circuit reliability (top) and presence/absence (bottom) at four stations for FST4W from TI4JWC on 10 m.



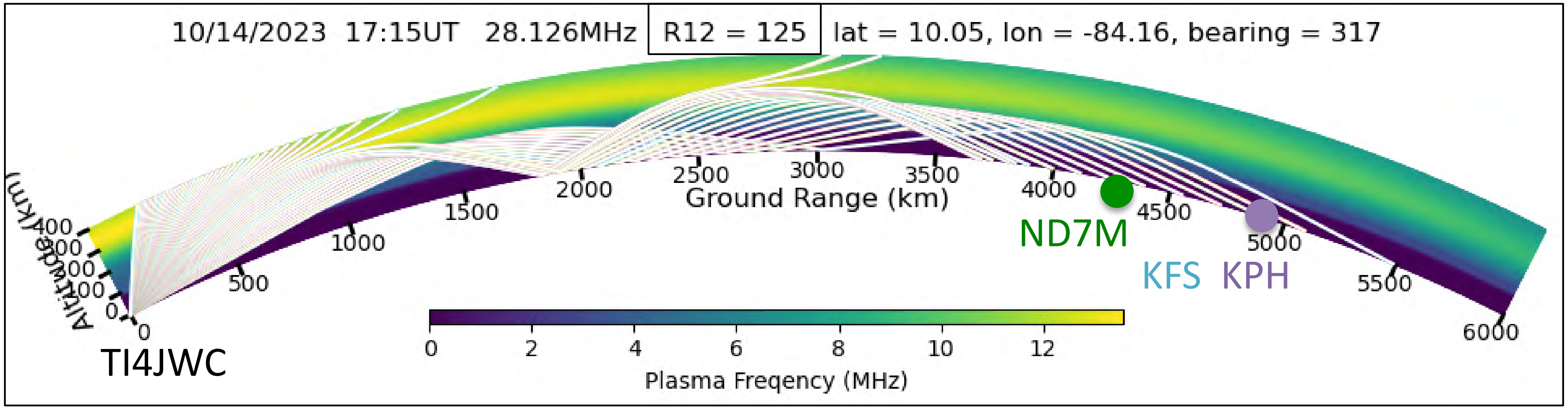
Two gaps at ~4400 km range – was this when eclipse affected each of the two hops?

- WSPRSONDE-6 simultaneous transmissions every two minutes on 80-10 m.
- Critical frequency high enough to not have complete gaps at ~5000 km range KFS and KPH.
- *'Sticky-Note' for UK and April 2024 eclipse.*

10 m: Effect of lower F2 critical frequency

Two gaps at ~4400 km range – was this when eclipse affected each of the two hops?

R_{12} is effective sunspot number, the 12 month running average



Ray trace using PyLap

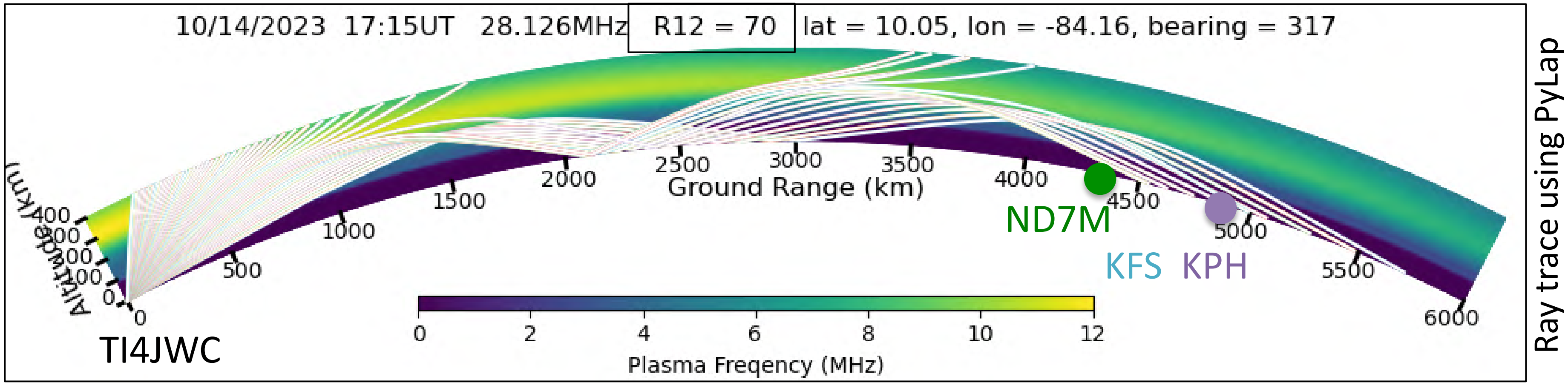
- What drop in R_{12}, the effective sunspot number, does it take to push minimum range of second hop to beyond 4300 km?

PyLap ray tracing package from: https://github.com/HamSCI/PyLap

Effective sunspot number from https://spawx.nwra.com/spawx/ssne24.html

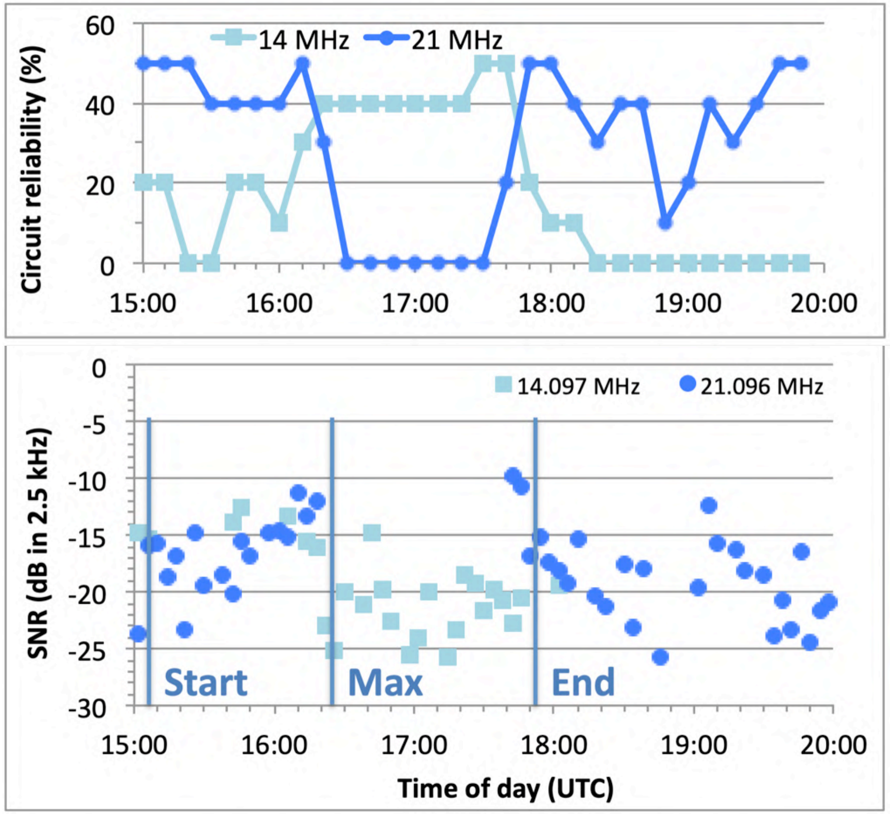
10 m: Effect of lower F2 critical frequency

Two gaps at ~4400 km range − was this
when eclipse affected each of the two hops?



- What drop in 'Sunspot Number' does it take to push minimum range of second hop to beyond 4300 km? **Answer: 70**
- Not a high fidelity test, as we are affecting both ionosphere refractions to equal extent, more complex changes in an eclipse.

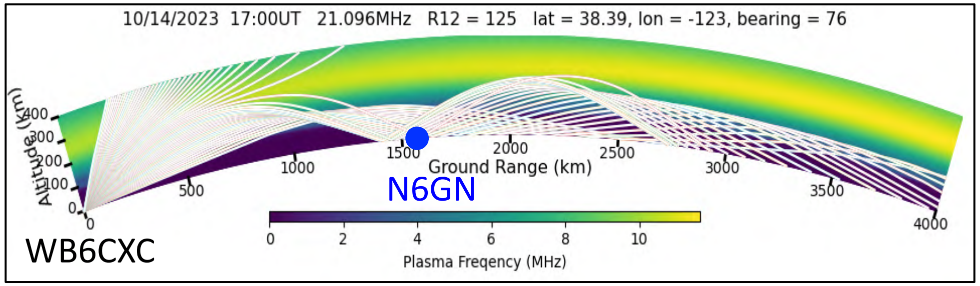
20 & 15 m: Effect of lower F2 critical frequency

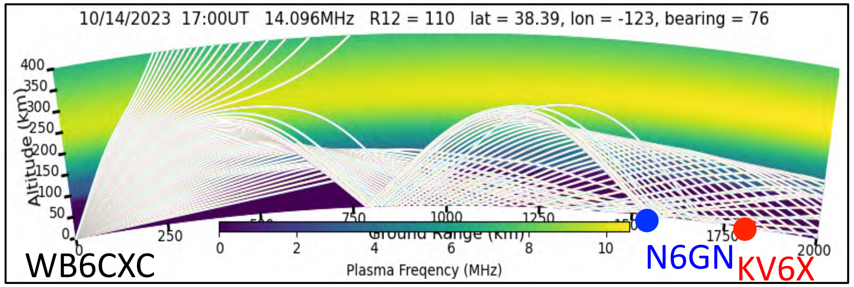


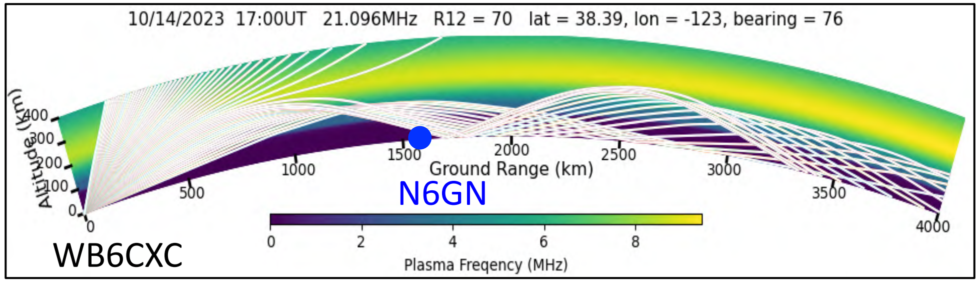
Circuit reliability (top) and SNR (bottom) at N6GN, N. Colorado for FST4W transmissions from WB6CXC, N. California on 20 m and 15 m.

- 1566 km path from 84% obscured to 83% obscured across path of eclipse.
- WSPRSONDE-6 simultaneous transmissions every two minutes on 80-10 m.
- Real-world − not all decoded.
- Clear gap on 15 m from just prior maximum eclipse to its end.
- 20 m remained open, critical frequency high enough, but…

20 & 15 m: Confirmation from ray tracing







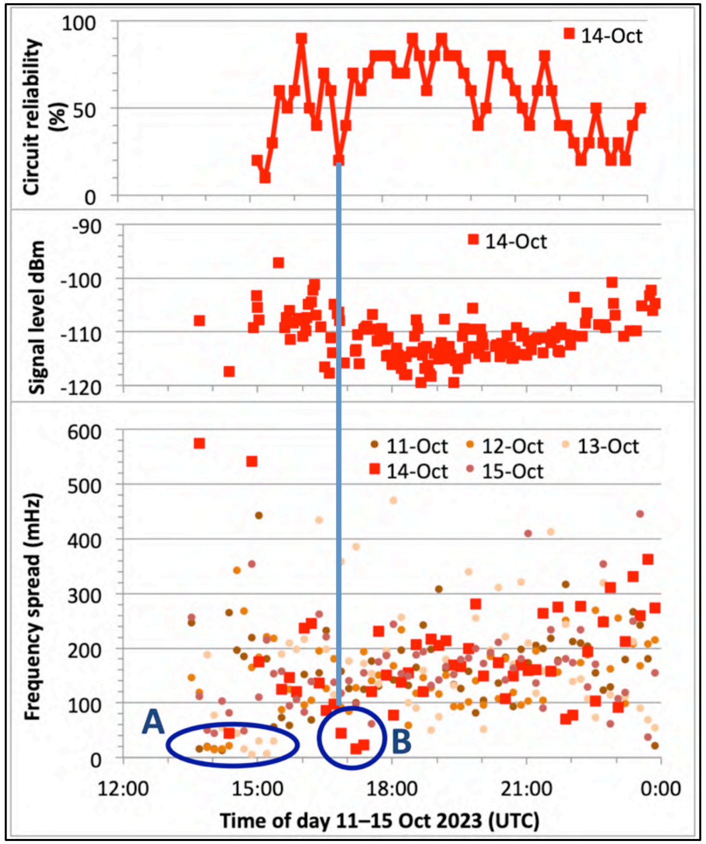
20 m A *possible* explanation: When unaffected by eclipse N6GN at furthest one-hop range, dependent on low take-off angles (<10˚) at Tx and Rx.

Also, just shy of two-hop minimum distance.

With lower sunspot number, within one-hop region for higher take-off angles.

15 m Consistent picture: One-hop when unaffected by eclipse, and within skip zone if sunspot number dropped to 70, as for the TI4JWC-ND7M path.

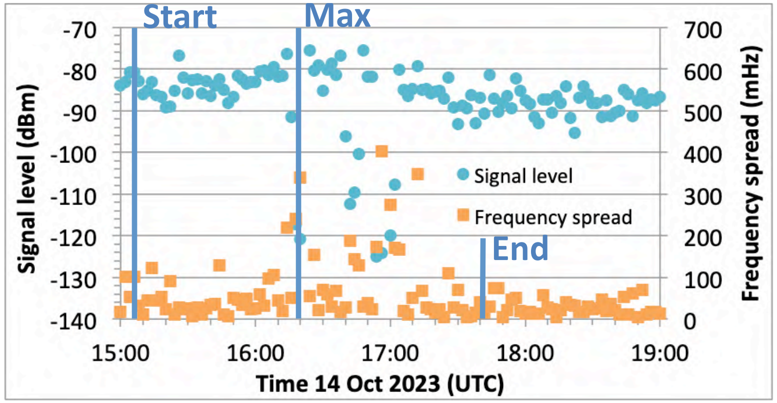
20 m: Two-hop becomes One-hop



How can we see this happening? FST4W and its frequency spread measurement.

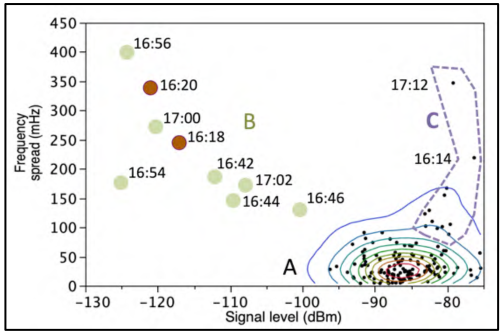
- 1808 km path from W7WKR, WA to KV6X, NM
- As 20 m path opens, one-hop propagation prevails, period ‘A’ on graph, sub-100 mHz frequency spread.
- As critical frequency increases, path becomes two-hop, with >100 mHz frequency spread and much variation.
- But, for a short time, period ‘B’, the path reverted to one-hop with lower frequency spread.

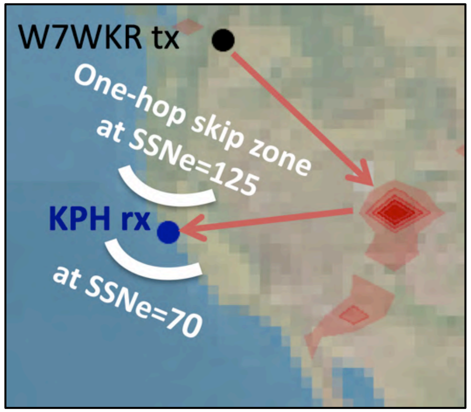
20 m: One-hop becomes two-hop sidescatter



How can we see this happening? FST4W and its frequency spread measurement.

- 1055 km path from W7WKR, WA to KPH, CA
- One-hop propagation either side of eclipse, tight cluster 'A' of signal level and spread values.
- As critical frequency drops during eclipse, path changes to two-hop sidescatter, as in map.





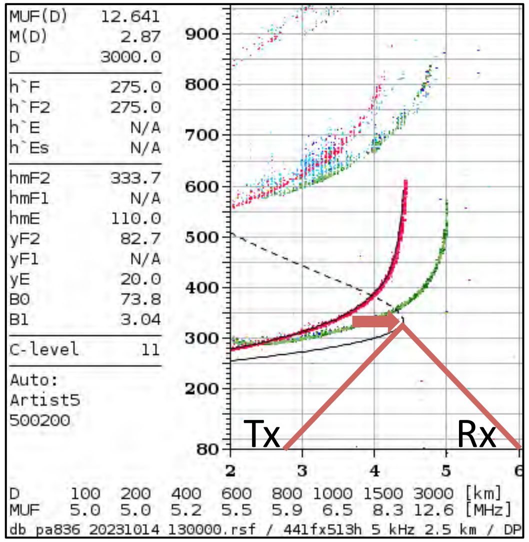
What's two-hop side-scatter?

How did I arrive at this map?

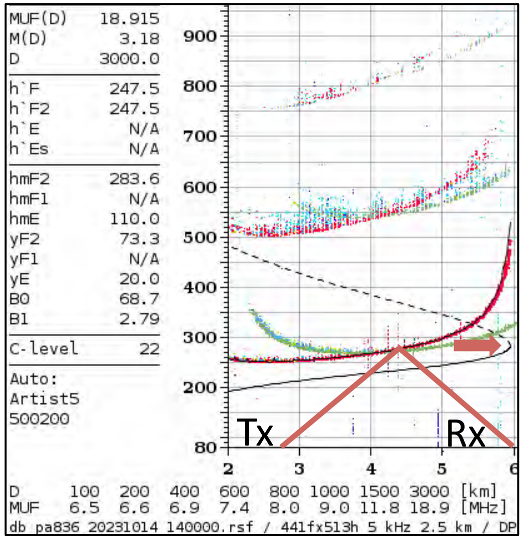
Subject of RSGB Tonight @ 8 on 5 Feb.

Change of tack: Measuring precise frequency

13:00



14:00



Why? To measure the changes in height at which signals refract in the ionosphere as a response to the eclipse.

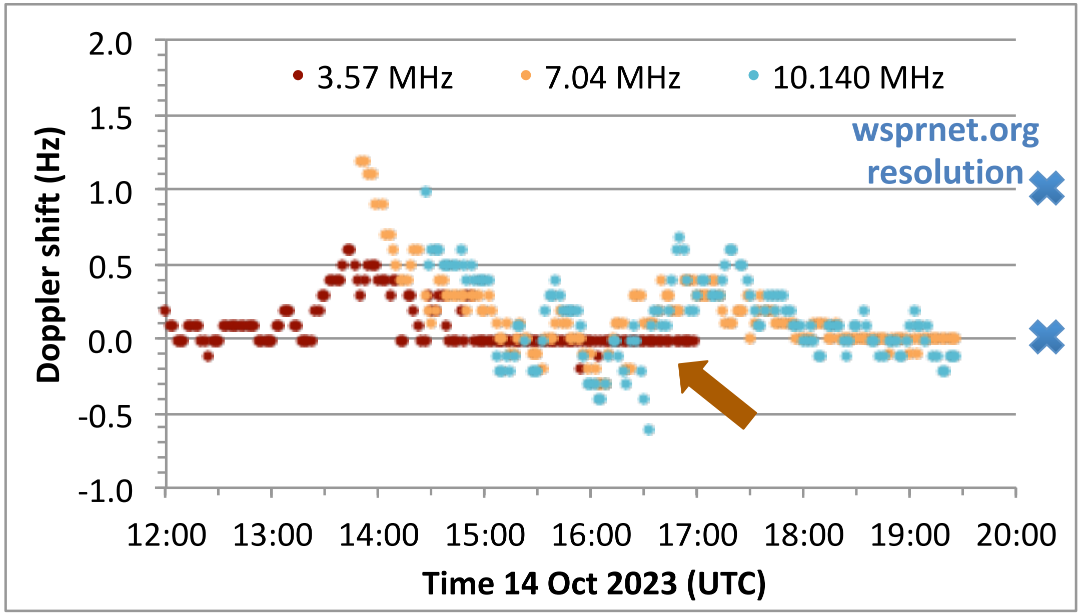
- Needs GPS aided or disciplined master oscillators at transmitter and receiver.
- Ideally, multiband to capture the full picture as bands open and close.
- Morning: Positive Doppler shift, which we can measure, as path shortens as refraction height drops.

Ionosonde data courtesy GIRO data centre lgdc.uml.edu under C-BY-NC-SA 4.0 license and the Pt. Arguello, Van den Berg Air Base, California team.

Height (km) F2 max electron density (solid & dashed black line) at UTC

13:00	13:30	14:00	14:30	15:00
334	328	284	260	238

Measuring Doppler shift

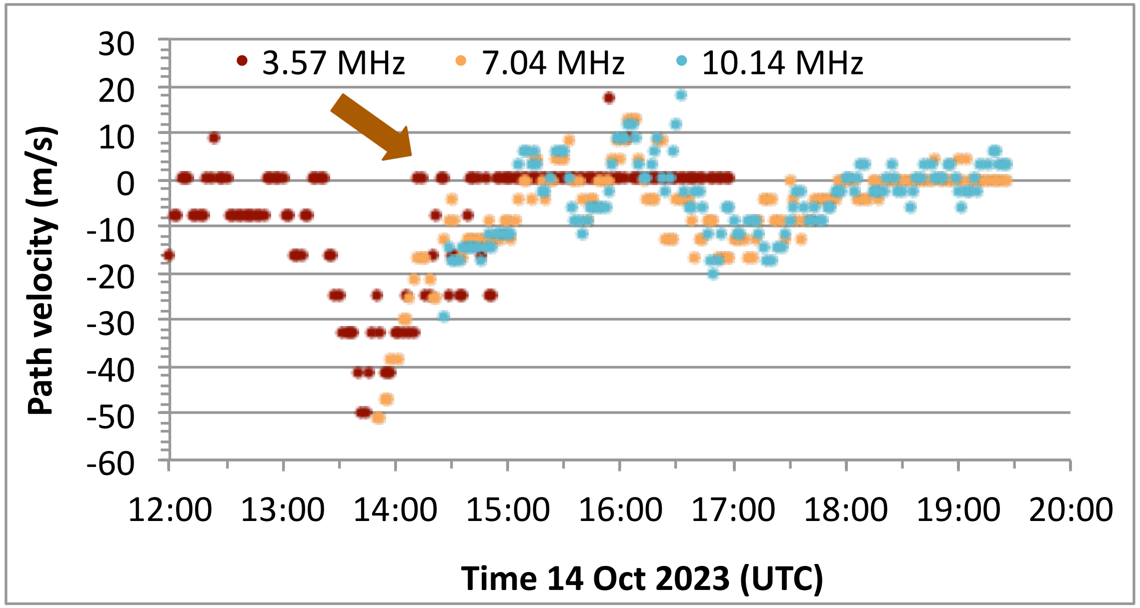


- WSPRSONDE-6 phase-locked GPS phase locked transmitter at WO7I (89% obscured), to GPS-aided KiwiSDR at ND7M (87% obscured), both in Nevada, on a 545 km path.
- WsprDaemon reports FST4W (and WSPR) frequencies to 0.1 Hz.
- **80 m** open during the night − we capture positive Doppler shift right from the start of the descent.
- **40 m** and **30 m** open in turn, continue to give data after **80 m** has closed.

Doppler shift is proportional to frequency: $\Delta f = -\frac{f}{c}.\frac{dP}{dt}$

Δf is Doppler shift, *f* frequency, *c* velocity of light, $\frac{dP}{dt}$ is rate of change path length *P*

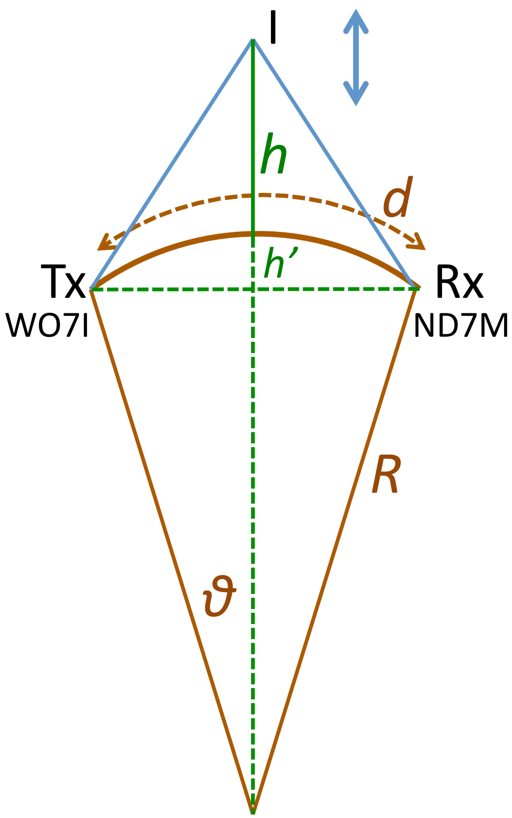
From Doppler shift to path velocity



- With frequency-dependence of Doppler shift compensated, this is a remarkable agreement for path velocity on three bands.
- Except for **80 m** reading zero from about 14:30 UTC. Why?
- Most likely, the 'always there' E layer critical frequency had risen sufficiently for **80 m** to refract from the E layer. And the E layer was not changing height.

Rate of change of path length, i.e. path velocity: $\frac{dP}{dt} = -\frac{c.\Delta f}{f}$

From path velocity to height of refraction



We know distance *d* and radius of the earth *R*

Calculate the half angle $\vartheta = d/2R$

Path P is distance from Tx –> I –> Rx

Get one value of h from ionosonde at one time

$$P_0 = 2.\sqrt{(R.\sin(\theta))^2 + (h + R.(1-\cos(\theta)))^2}$$

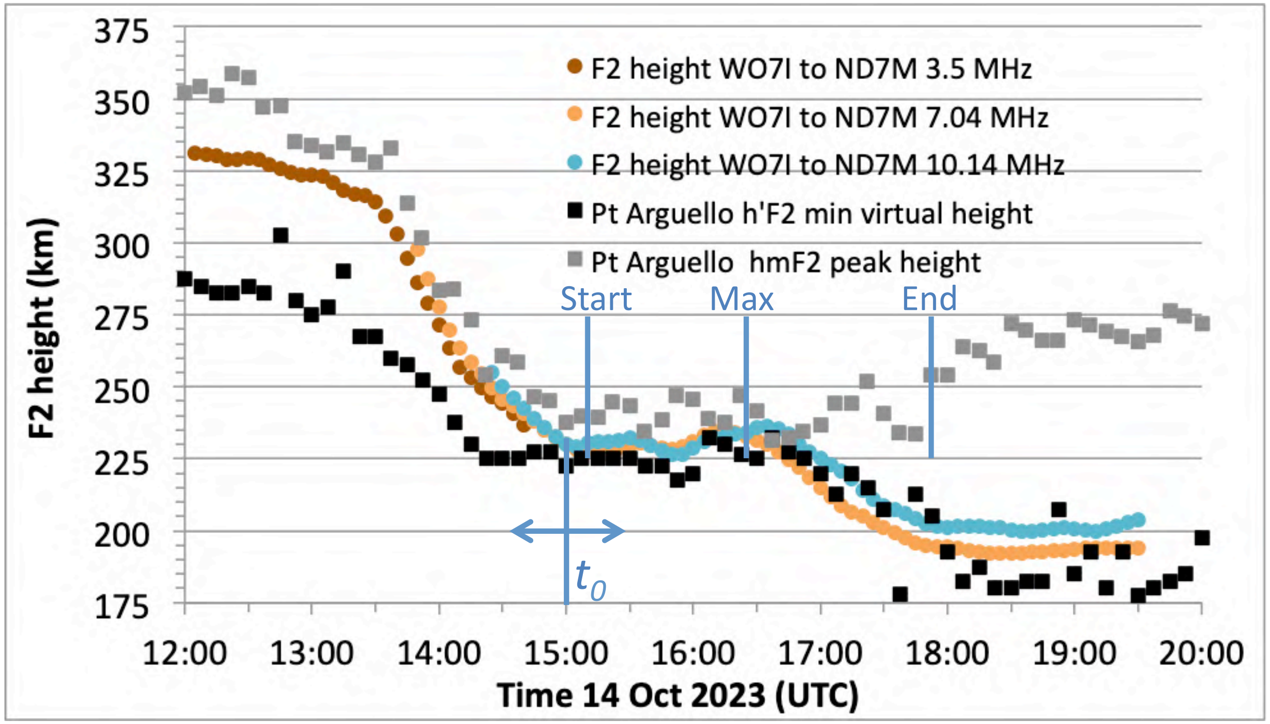
We now have a path length at a reference time t_0

We take path velocity *v* (in metres per second) at the next two-minute interval, multiply by 120 (seconds) to get path length change (metres) during that two minutes then add to reference path length P_0 to give P_t. Then calculate *h* at this time:

$$h_t = \frac{1}{2}\sqrt{P_t^2 - (2.R\sin(\theta))^2} - R.(1-\cos(\theta))$$

http://wsprdaemon.org/technical

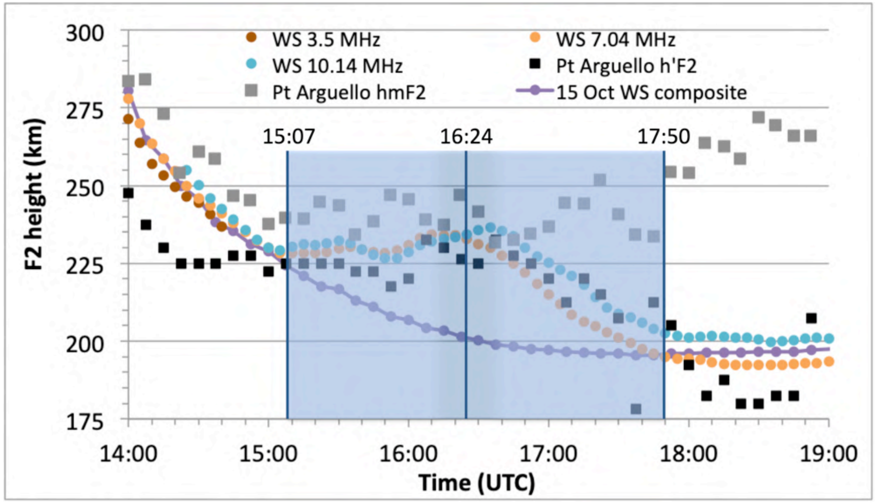
Height of refraction measurement

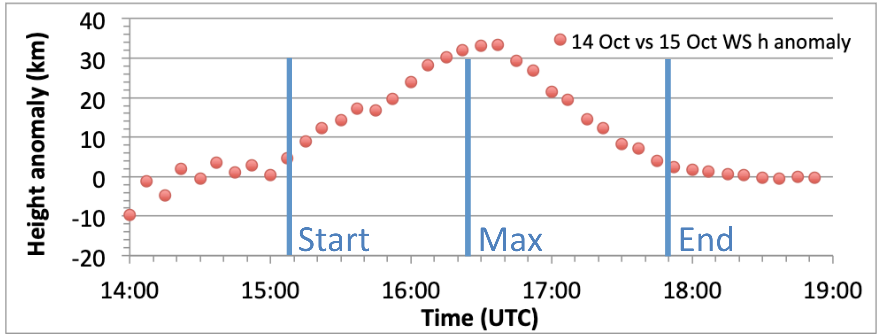


- 15:00 UTC - reference time for height *h* from ionosonde.
- Add incremental path length measurements every two minutes before and after this time.
- Measurements track **peak height** early in the day, then the **minimum virtual height** h'F2 as the two measures diverge.
- FST4W measurements more often and smoother.

Encouraging match for morning descent, what about eclipse effect?

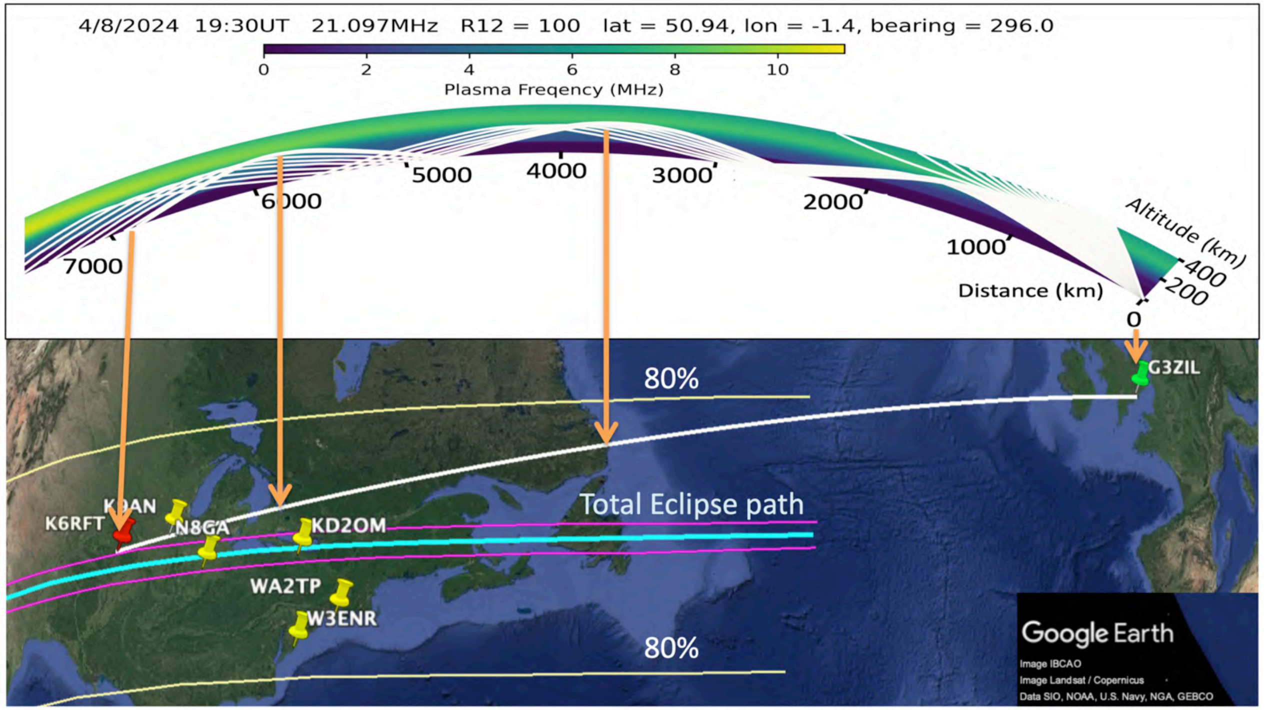
Eclipse-induced change in height of refraction





- Zoom-in version of height graph with next day, 15 October, average FST4W-derived height.
- Calculate height anomaly for the eclipse day, that is height on 14th minus height on 15th
- Maximum height anomaly of 32 km 10 min after maximum occlusion (91% at path mid point).
- This is a far smoother record than from the difference of ionosonde heights:*"...hmF2 from these ionosondes is very 'noisy' ... a calculation that critically depends on small details..."* Terry Bullett W0ASP, *"...my day job, I collect ... ionospheric sounding data ..."*

April 2024 eclipse: Role for UK amateurs?



- Eclipse ends at sunset mid-Atlantic. However…
- Ray trace model for 8 April 2024 19:30 UTC shows example three-hop path to K6RFT on 21 MHz.
- Second and third hops within eclipse region, third hop affected first then second.
- Just a model … here sunspot number is 100 … but worth trying WSPR on 21, 24, 28 MHz from 17:00 – 21:00 UTC 7–9 April?

Summary

- True delight to return to Amateur Radio after a long absence.
- Able to find, mould, create a field of interest – such a diverse world.
- Digital modes within WSJT-X can provide so much more information than basic automated report of Signal to Noise Ratio.
- Eclipses provide a ‘natural experiment’ to study, first hand, propagation modes we’ve learnt about in books.
- Join in! Any time is a good time, and bookmark 8 April 2024 eclipse.

Acknowledgment

My thanks to the WSJT-X development team for FST4W, Rob Robinett AI6VN for WsprDaemon, its decoding logging and amazing database and the KPH and KFS installations, the Monday ‘Catz’ group for fellowship and insights, and, for facilitating data for this study: Clint KA7OEI, Dan KV6X, Glenn N6GN, Dennis ND7M, Dick W7WKR, John TI4JWC, Paul WB6CXC, Tom WO7I, Maritime Radio Historical Society for KPH, and Craig W6DRZ and KFS Radio Club for KFS.

Find out more…

More on this work: http://wsprdaemon.org/technical http://wsprdaemon.org/presentations

HamSci Eclipse Festival: https://hamsci.org/eclipse

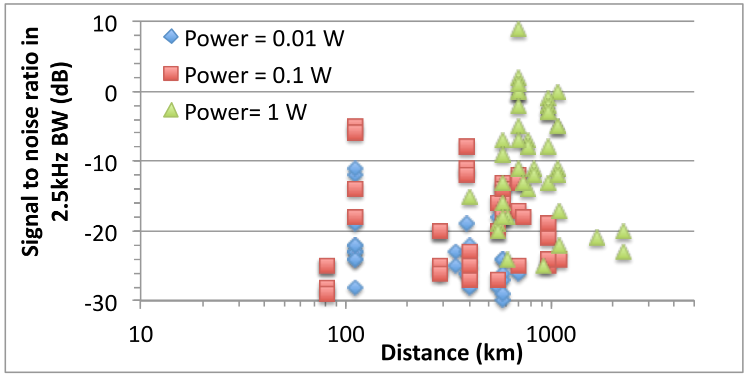
Propagation books from RSGB:
https://www.rsgbshop.org/acatalog/Online_Catalogue_Propagation_45.html

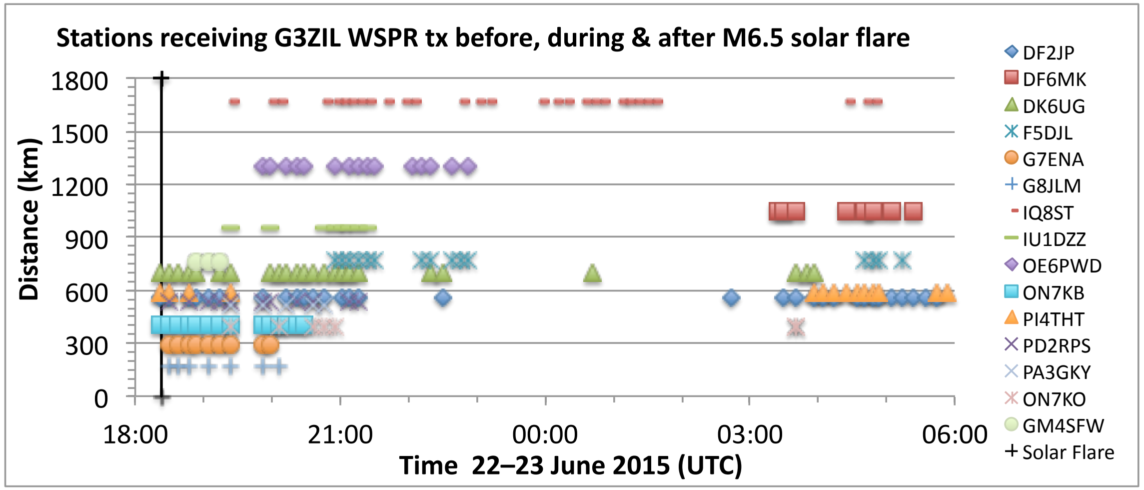
Chen-Pang Yeang, 'Probing the Sky with Radio Waves – From Wireless Technology to the Development of Atmospheric Science'. University of Chicago Press. *Scholarly and brilliantly readable.*

Tools: https://github.com/rrobinett/wsprdaemon https://github.com/HamSCI/PyLap

Contact me: gwyn@autonomousanalytics.com

WSPR interests: Technical and propagation





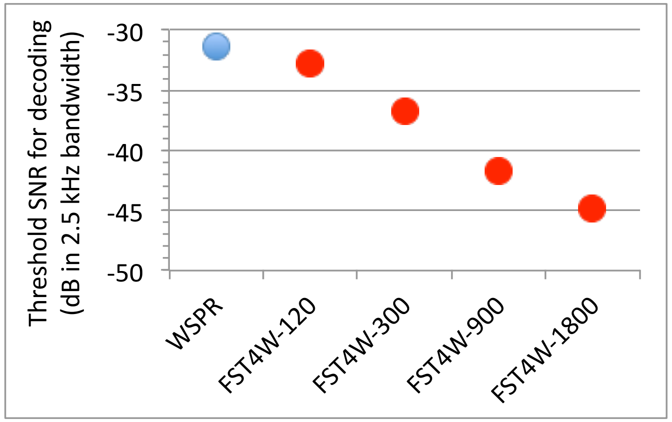
- Definitely hooked on what could be achieved with a 1 W or less transmitter using WSPR
- From my notes, *“On the evening of 22 June 2015 I noticed there was a short period in the evening with no reports of my signal. I checked power out and all was well…”*

Why FST4W? The Nice to Haves

Option of four sequence lengths: 120 (same as WSPR-2), 300, 900 and 1800 seconds.

FST4W-120, very usable at HF, has:

- Lower decode threshold, by about 1.4 dB, than WSPR
- Higher tolerance to Doppler spread. At 2 Hz spread WSPR needs -17 dB SNR, FST4W-120 decodes at -24 dB SNR.



Defined at 50% probability of decode with Doppler spread of no more than 0.01 Hz

Downsides

WSJT-X sub-optimum for receive, one length at a time : Use WsprDaemon – handles all lengths

No drift compensation, tighter equipment requirements: Use analogue TCXO or GPSDO

Ionospheric Doppler spread for longer sequences: Use 120 second variant.

Very few people transmitting and receiving at present: Need to Publicise.