Analysis of Changes to Propagation and Refraction Height on Specific Paths Induced by the 14 October 2023 Eclipse

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This study could not have been performed without these **tools**: WsprDaemon from Rob Robinett AI6VN, FST4W from the WSJT-X development team, PyLap (a wrapper for PHaRLAP, created by Dr Manuel Cervera, Defence Science and Technology Group, Australia that incorporates the International Reference Ionosphere /dat/iri2016/00_iri2012-License.txt) from HamSci and the University of Scranton, ionosonde data from Pt. Arguello via GIRO released under CC-BY-NC-SA 4.0 license, PSWS Central Control System from HamSci, and the WsprSonde-6 hardware from Paul Elliott WB6CXC. I acknowledge FST4W **data collection** from KPH (Maritime Radio Historical Society), KFS Radio Club, WO7I (Tom Bunch), ND7M (Dennis Benischek), TI4JWC (John Clark), W7WKR (Dick Bingham), KV6X (Dan Beugelmans), and Grape **data collection** from KF7YRS (Lee Phebus).

Motivation and Outline

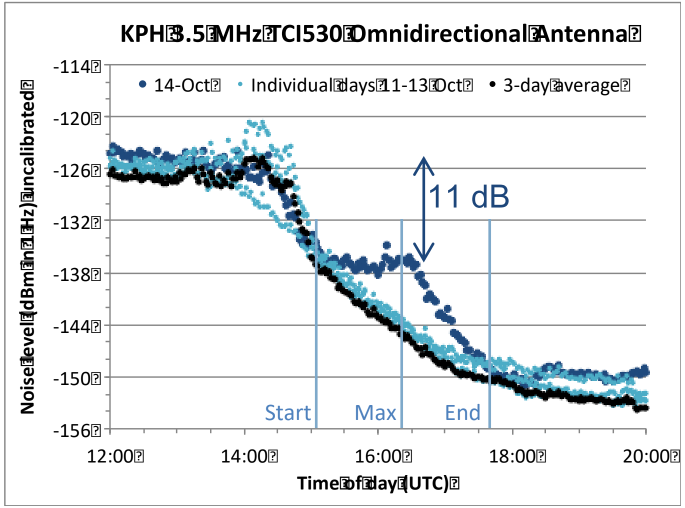
Test the capabilities of the WsprDaemon software and its user community to extract maximum information from WSJT-X modes WSPR and FST4W. Specifically:

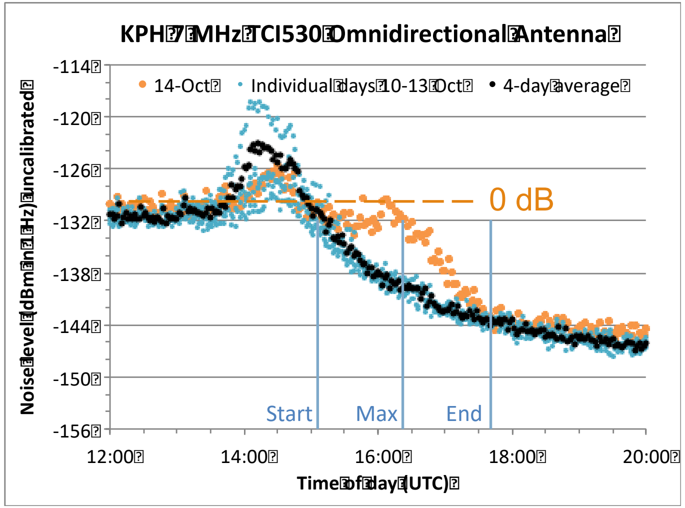
- Simultaneous noise measurement
- Calculation of signal level
- GPS-aided or GPS-disciplined equipment
- Frequency resolution of 0.1 Hz
- Doppler shift measurement
- Frequency spread measurement (FST4W)
- Simultaneous multiple frequencies
- Data publically available, several on-line tools, e.g. wspr.rocks, wspr.live

Our measurements show the eclipse:

- Reduced total absorption
    - Propagated-in noise
    - One-hop path
- Lowered F2 critical frequency
    - Effect on circuit reliability
    - Propagation mode transient changes
- Produced an anomaly in height of refraction
    - One hop path, three frequencies

Reduced Total Absorption L_t: Propagated-in Noise Increase





- WsprDaemon software records noise alongside WSPR and FST4W spots every two minutes.
- KPH, Point Reyes, California has low local noise from combination of rural site with much attention to minimizing local sources and mechanisms.
- Consequently, noise level is dominated by propagated-in noise.

Normal diurnal variation of noise at 3.5 and 7 MHz at KPH has maximum propagated-in noise at night.

Minimum noise around noon local solar time due to absorption.

3.5 MHz Peak noise during eclipse was 11 dB *below* its night-time value: -136 dBm in 1 Hz vs. -125 dBm in 1 Hz.

7 **MHz** Peak noise during the eclipse was *equal to* its night-time value: -130 dBm in 1 Hz.

Chasm between Observations, known Unknowns & Physics

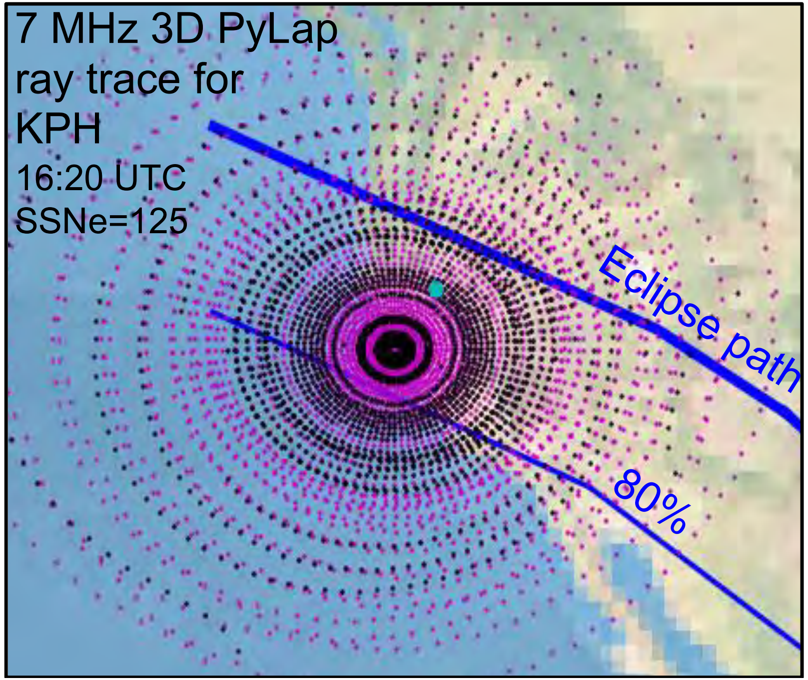
A reasonable fidelity model would include time and space variations of:

- **Locations** of one-hop propagated-in noise sources
- Noise source **transitions** of the **D** region
- Ratio of the operating frequency to the E-region critical frequency *fo*E

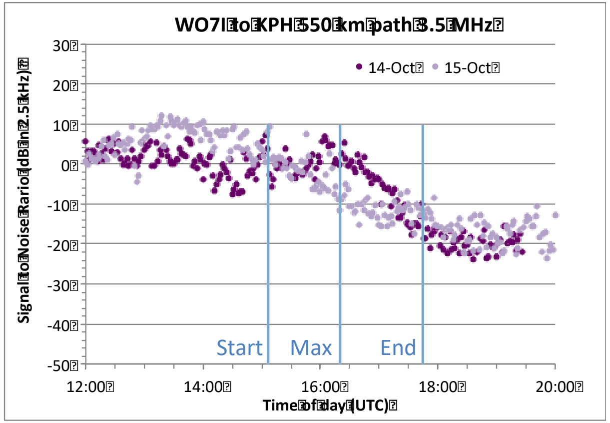
Time, space and height variations of:

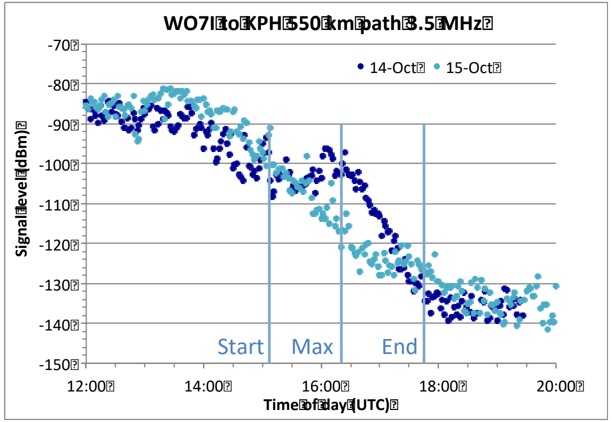
- Electron density *N*
- Collision frequency *v*
- Ion production and loss

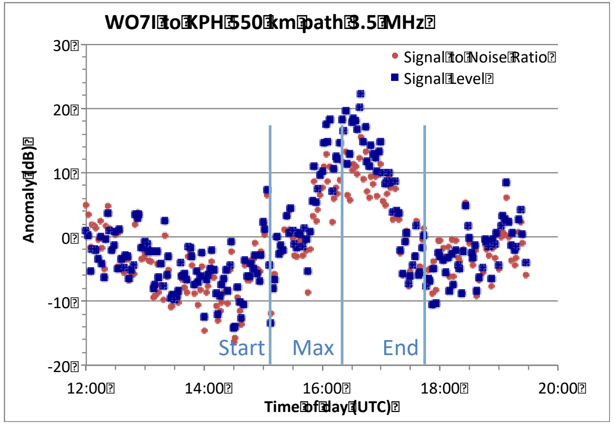
With their own complexity. Then there is the neutral atmosphere…

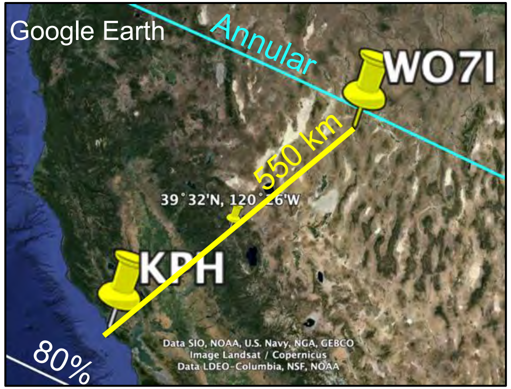


Reduced Total Absorption L_t: SNR and Signal Level 3.5 MHz



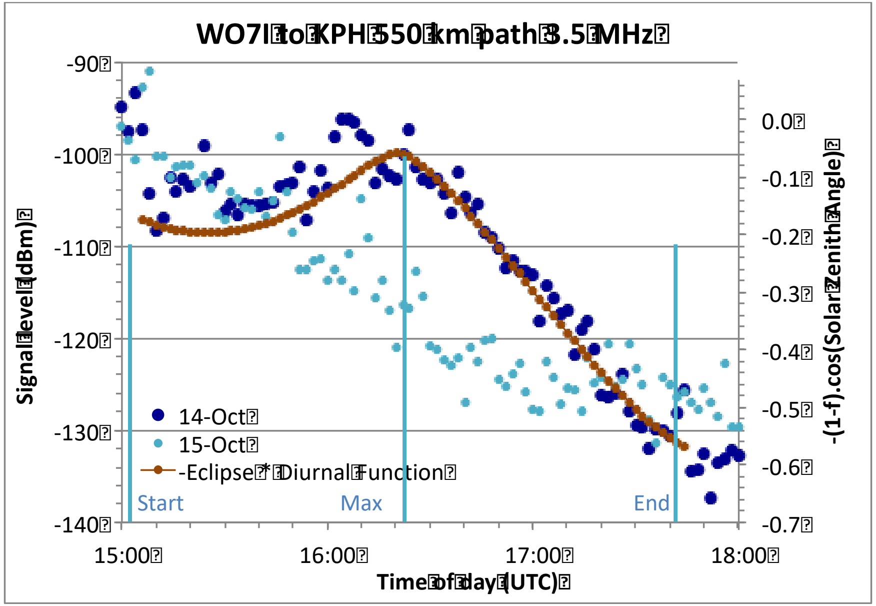


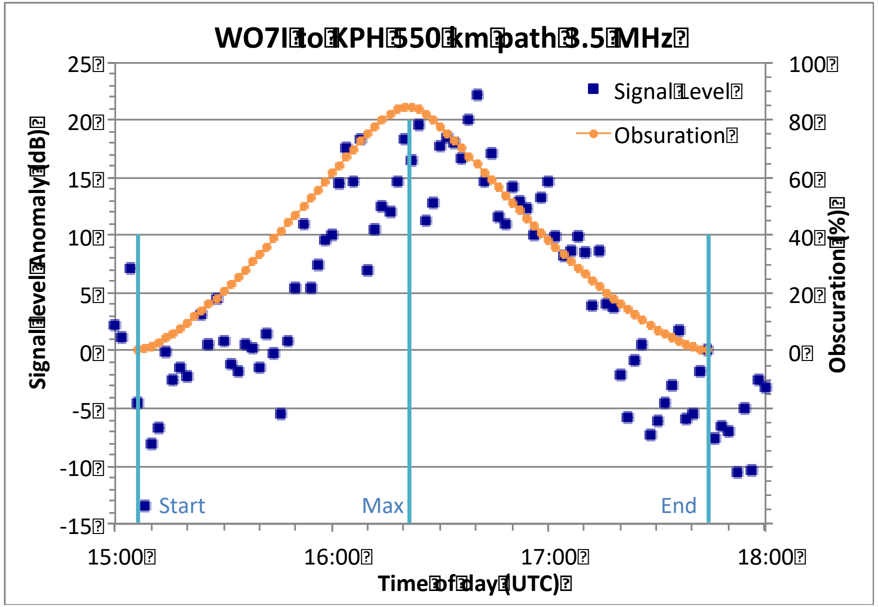




- Predominantly one-hop path: median frequency spread 67 mHz.
- SNR, the only measurements from modes WSPR, FT8 etc., can be a compromised proxy for signal level when noise level varies.
- Simultaneous noise measurement enables signal level estimate.
- Median signal level anomaly 16.5 dB, median SNR anomaly 10.4 dB over interval +/- 20 minutes of maximum obscuration.

Signal Level Variation and Obscuration Factor





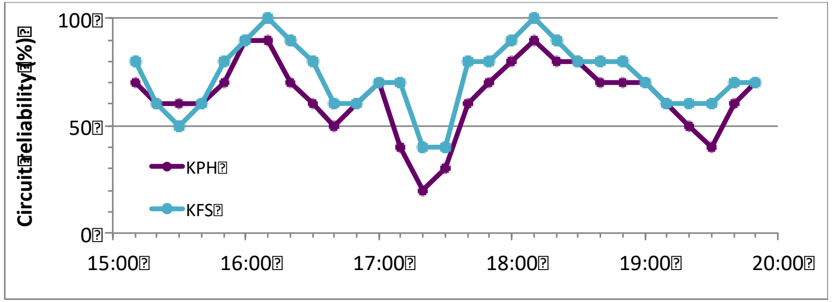
Eclipse * Diurnal Function = (1-*f*) . cos (*χ*)

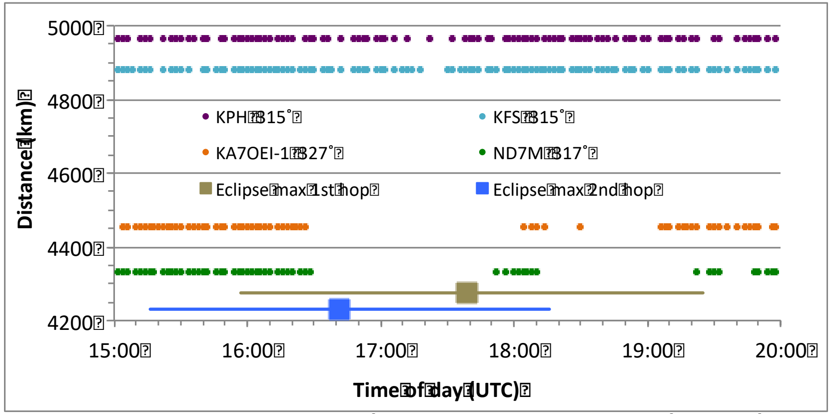
f is fraction of sun's disc obscured, *χ* is the Solar Zenith Angle. Allows comparison of results including the normal diurnal variation of total absorption with *χ*.

Only obscuration fraction ***f*** needed when comparing signal level anomaly between eclipse and non-eclipse days.

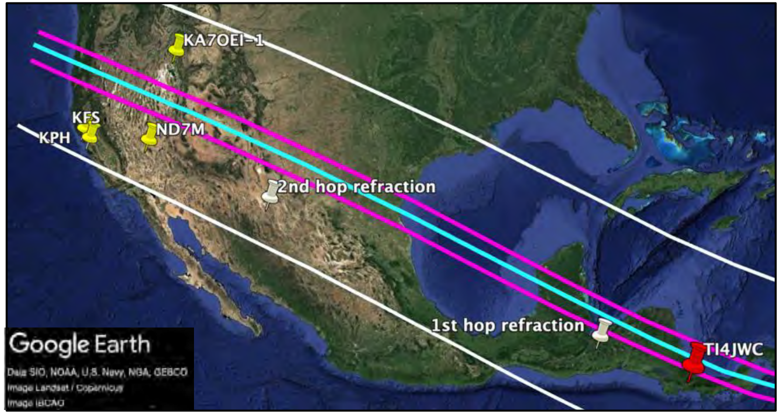
Increased scatter from subtracting values for the two days.

Lowered F2 Critical Frequency: 28 MHz on Two-hop Paths





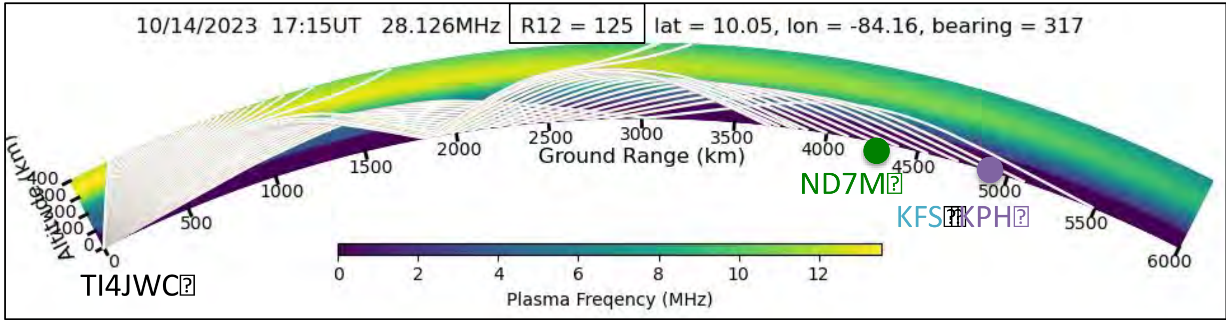
Two gaps at ~4400 km range – was this when eclipse affected each of the two hops in turn?

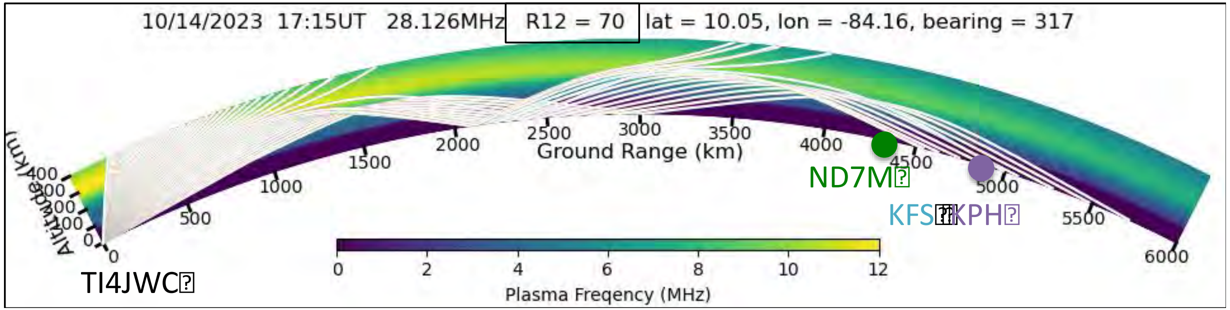


- WSPRSONDE-6 simultaneous transmissions from TI4JWC, Costa Rica, every two minutes on six bands 3.5 MHz to 28 MHz.
- Hypothesis that *foF2* was reduced such that it was:

1. High enough for 5000 km KPH/KFS range to remain within second propagation zone.
2. Low enough for ~4400 km ND7M/KA7OEI-1 range to be within second skip zone.

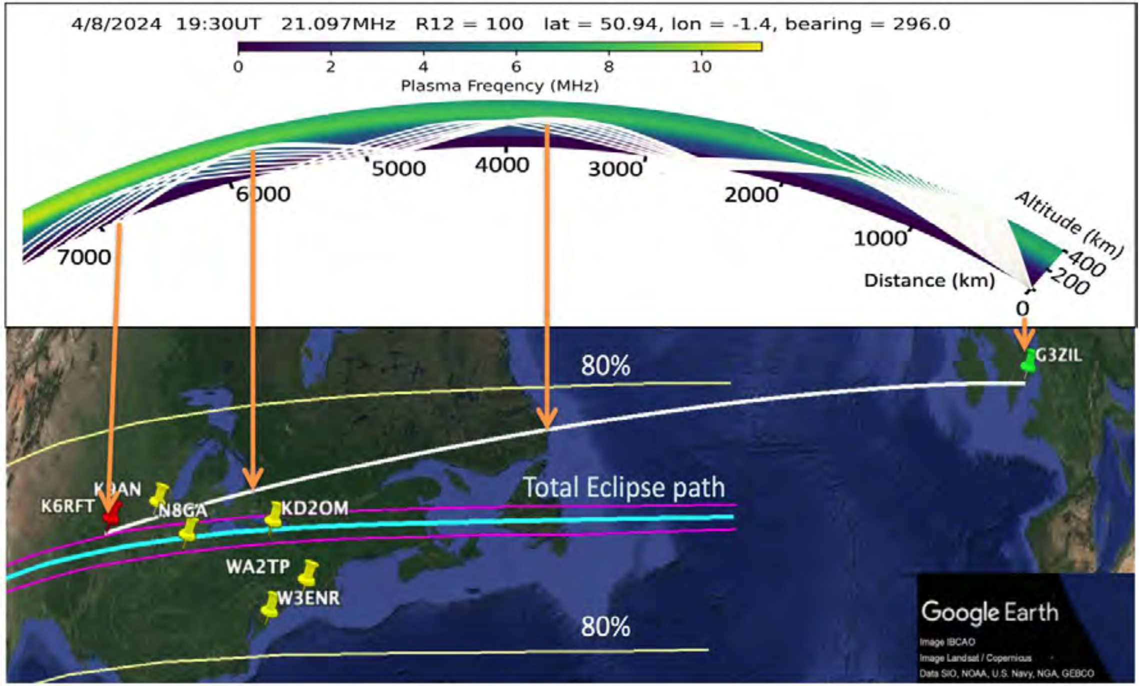
Hypothesis Test with PyLap Ray Tracing: Alter R_{12}





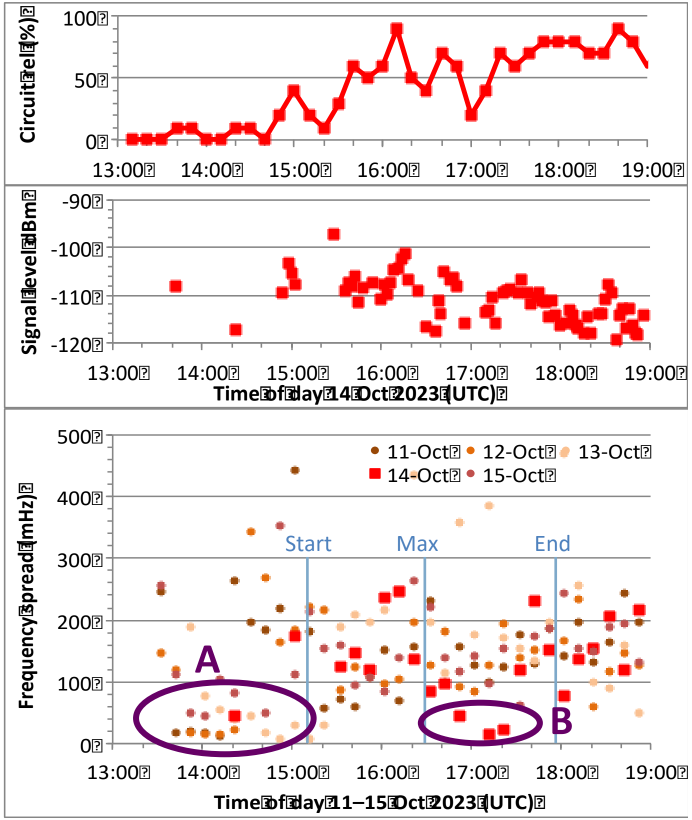
- Using PyLap ray tracing, what drop in R_{12} does it take to push minimum range of second hop to beyond 4300 km while keeping propagation to 5000 km? **Answer: 70**
- Not a high fidelity test. R12 change affects both ionospheric refractions, more complex travelling changes in an eclipse needs a more capable model.
Integrated PyLap and SAMI3?

An Equivalent during the April 2024 Eclipse?



- 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/FST4W on 21, 24, 28 MHz from 17:00 – 21:00 UTC 7–9 April?
- News item in March RSGB *RadCom*

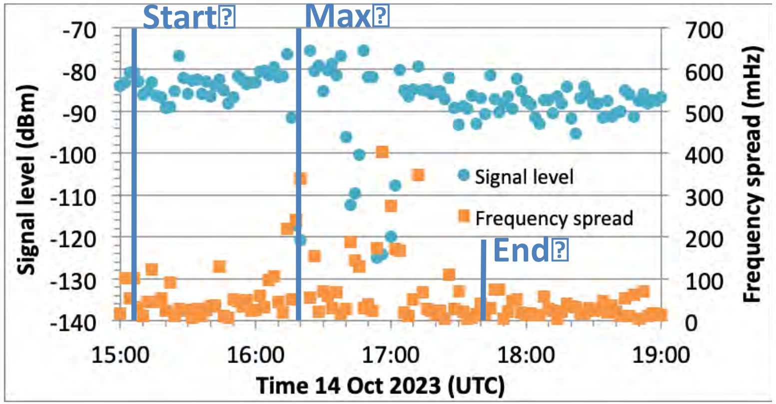
Lowered F2 Critical Frequency: Propagation Modes Change

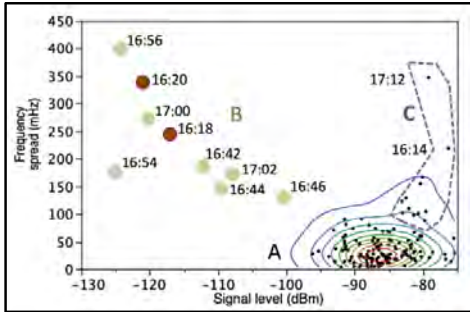


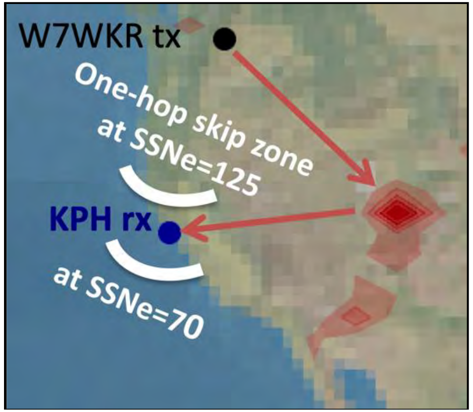
Two hop becomes one-hop

- 1808 km path on 14 MHz from W7WKR, Washington State to KV6X, New Mexico
- Daily, as the path opens, one-hop propagation prevails, period ‘A’. Identified by <100 mHz frequency spread measured using FST4W.
- Daily, as *foF2* increases, path becomes mix of one-hop and two-hop with >100 mHz frequency spread and much variation.
- But, for a short time during the eclipse, after maximum obscuration, period ‘B’, the path reverted to one-hop only marked by its lower frequency spread.

Lowered F2 critical frequency: Propagation Modes Change



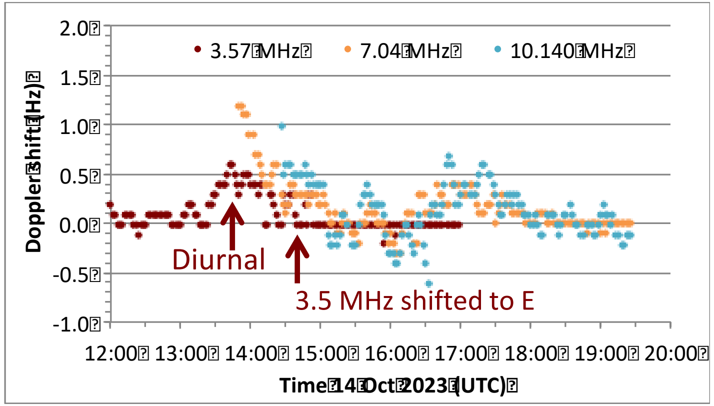


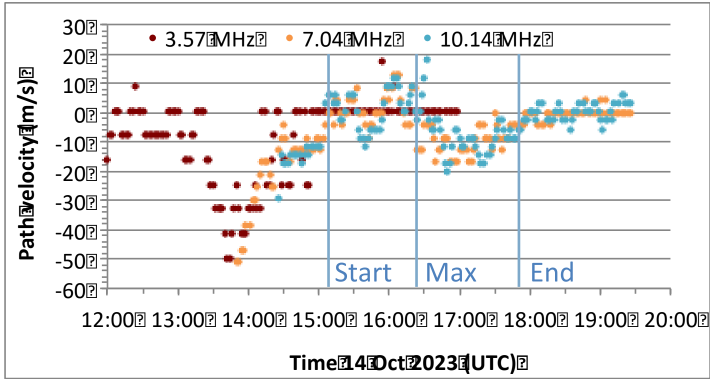


One-hop becomes two-hop sidescatter

- 1055 km 14 MHz path W7WKR to KPH.
- One-hop propagation prevails on this shorter path throughout normal days. Identified by <100 mHz frequency spread, **cluster 'A'**.
- One-hop propagation either side of eclipse.
- Spots with high frequency spread and lower SNR, area 'B', suggest propagation changed to two-hop sidescatter.
- Implication is that Maximum Usable Frequency for this 1055 km path dropped below 14 MHz. But only at, and after, maximum obscuration.

Anomaly in Height of Refraction: Doppler to Path Velocity



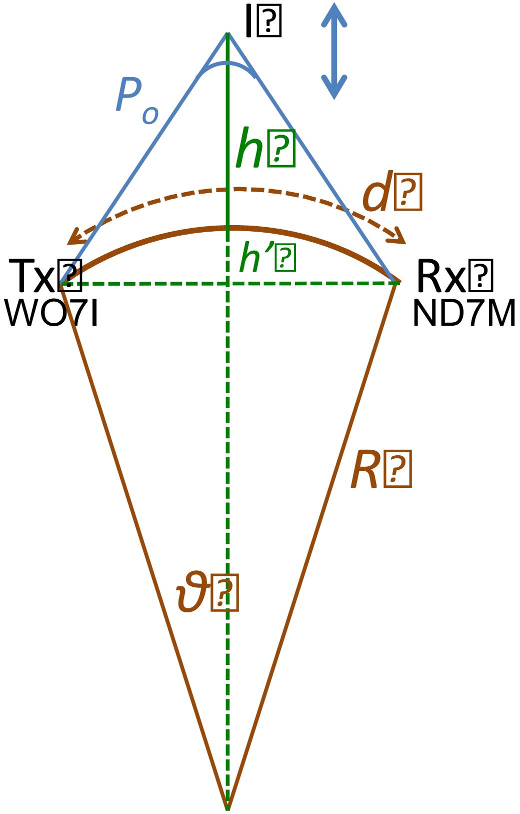


- WsprDaemon reports FST4W mean frequency to 0.1 Hz.
- WSPRSONDE-6 GPS phase locked transmitter at WO7I (89% obscured), to GPS-aided KiwiSDR at ND7M (87% obscured), both in Nevada, one-hop 545 km path.
- **3.5 MHz**, open during the night, captured positive Doppler shift from start of refracting layer descent.
- **7 MHz** and **10 MHz** open in turn, continue to give data after **3.5 MHz** propagation a) shifted from F2 to E layer refraction and b) ceased.
- Doppler shift Δf to rate of change of path length *P*, i.e. Path Velocity:

$$\frac{\Delta P}{\Delta t} = -\frac{c.\Delta f}{f}$$

where *c* is velocity of light and *f* the operating frequency

Path Velocity to Height



1. $\theta = d/2R$
2. Get <u>one</u> value of h from Pt. Arguello ionosonde at t_0 to estimate path length P_0 at t_0:

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

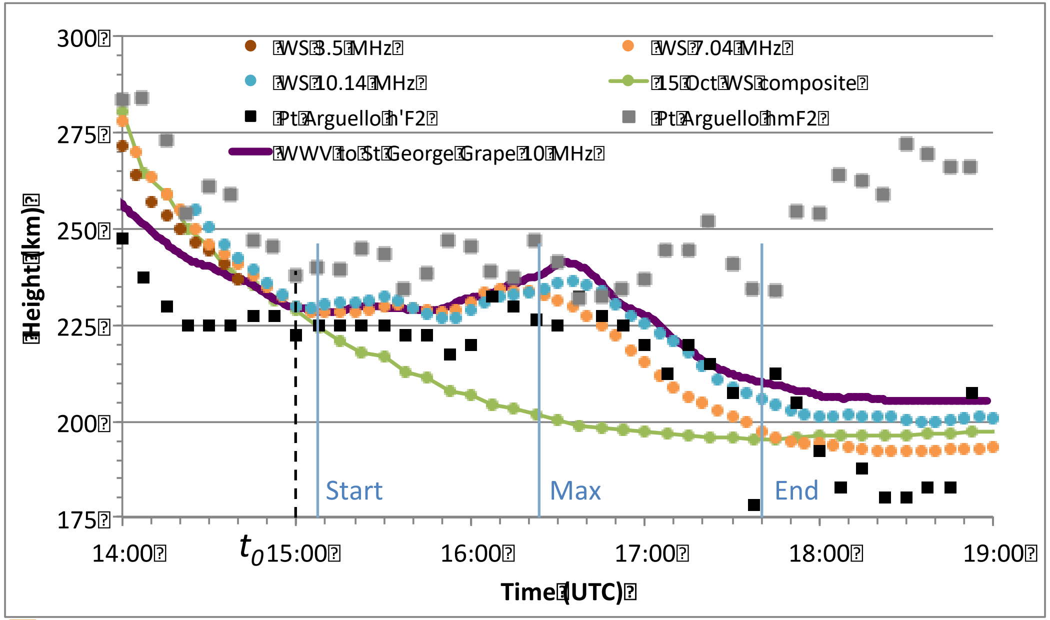
3. Calculate path length P_t at next two-minute interval:

$$P_t = P_0 + \frac{\Delta P}{\Delta t}.\Delta t$$

4. Calculate h_t for the next two-minute interval:

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

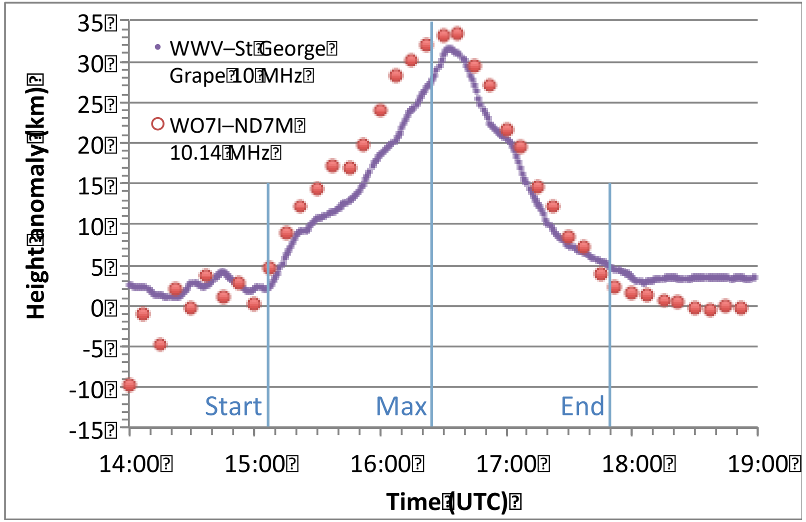
Height of Refraction: FST4W and WWV to St. George Grape

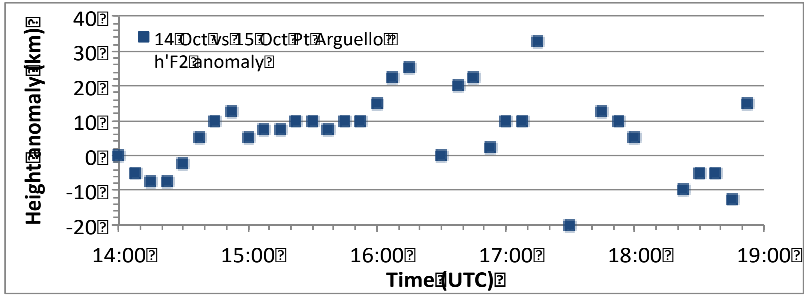


- Reference height *h* average of *h'F2* and *hmF2* from ionosonde at t_0 = 15:00 UTC
- Height for 15 Oct. non-eclipse day is composite of 3.5 MHz, 7.04 MHz and 10.14 MHz

- Doppler shift of St. George Grape (#57) calculated using complex auto-correlation at one lag.
- Sound-card induced offset at St. George Grape nulled by assuming zero Doppler 18:30–19:00 UTC.

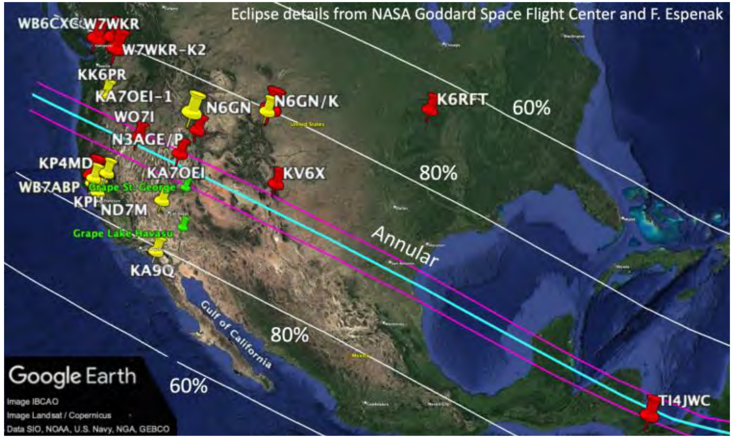
Anomaly in Height of Refraction: FST4W, Grape, Ionosonde





- Maximum height anomaly:
  WO7I – ND7M 33 km, 10 min after maximum
  WWV – St. George 31.5 km, 1 min after maximum
  Both 86% obscured at path mid point.
- Oblique FST4W and Grape Doppler gives smoother and more complete records than ionosonde h’F2 or hmF2 heights. *"...hmF2 from these ionosondes is very 'noisy' ... a calculation that critically depends on small details...”* Terry Bullett, W0ASP, HamSci online forum

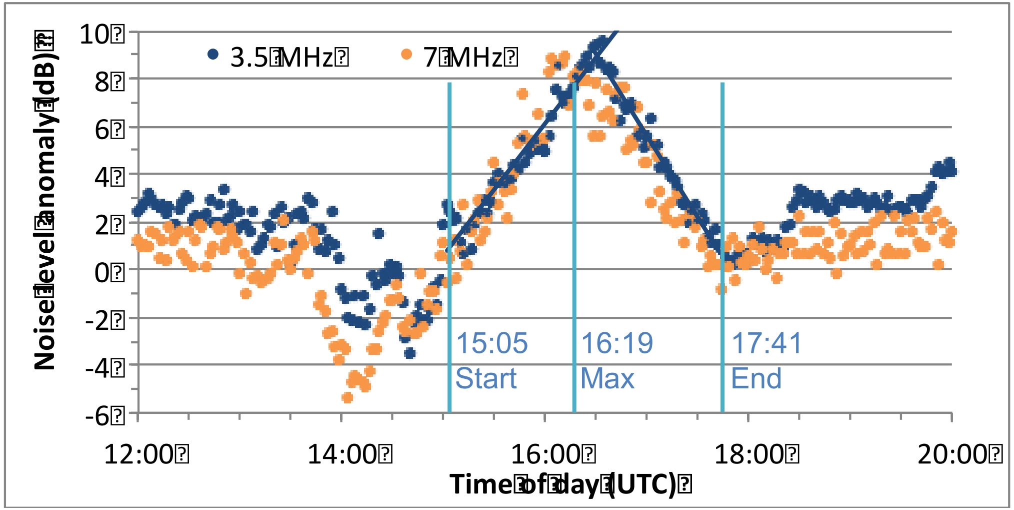
Conclusions



Map showing the subset of WsprDaemon receivers and transmitters with at least 60% obscuration for the 14 October 23 eclipse. All extended data in the public domain.

- Extended information in the WsprDaemon database on noise, signal levels, frequency spread and Doppler frequency adds considerably to digital modes metadata.
- Eclipse-induced changes to noise and signal levels were straightforward to observe, but prove challenging for this amateur to model and to partition between many contributing factors.
- Subtle propagation mode changes were observed and documented using frequency spread.
- While PyLap ray tracing is useful, a dynamic ionosphere model would be needed to simulate these propagation path transient features.

Noise Level Anomaly at 3.5 MHz and 7 MHz



- 3.5 MHz and 7 MHz noise 7–9 dB higher than normal at KPH.
- Noise anomaly start and end times tie in well with eclipse start and end times at KPH.
- Noise maximum 10.5 min *after* obscuration maximum at KPH on 3.5 MHz and 3.75 min *before* at 7 MHz
- Anomaly shape suggests convolution of noise source spatial distribution with space-time variation of eclipse obscuration.