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

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Slide 1

It's my great pleasure to attend this HamSci Workshop in person. I'm grateful to Nathaniel and his grants for supporting my participation. I also acknowledge these individuals and organisations for the tools and the data collection that have enabled this study.

Slide 2

SPR metadata - the existence of a path of known length between a transmitter and receiver on a particular band at a particular time - has been used to study previous eclipses. My motivation was to test whether the extended *measurement* capabilities of WSPR, and its stable-mate FST4W, could provide *additional* information. Specifically, I used Rob Robinett's WsprDaemon system, to draw on noise, signal level, Doppler shift and frequency spread measurements alongside the usual SNR.

The measurements do *indeed* show promise. Today I'll summarise examples showing reduced total absorption, lowered F2 region critical frequency and a change in height of refraction at multiple frequencies.

Slide 3

Starting in the early morning over radio station KPH, Point Reyes, California, the eclipse coincided with the regular diurnal change in propagated-in noise level on 3.5 and 7 MHz. The average daily pattern of high level at night and a minimum around local noon is in black, with three individual days in cyan showing the typical day-to-day variation. The eclipse results in clear anomalies at both frequencies. The noise rose as the absorption due to reduction in solar extreme UV fell. Onset was almost immediate. The maximum noise anomaly occurred 10 minutes after maximum obscuration at 3.5 MHz and 3 minutes earlier on 7 MHz. On 7 MHz the noise returned to its nighttime level, but on 3.5 MHz peaked 11 dB below.

Slide 4

I found a chasm between the relatively straightforward *observations* of the impact of solar obscuration on noise and the *multi-layered complexity* of the physics that would be needed to produce a reasonable fidelity model. Nevertheless, I made a start by modelling, using PyLap 3D ray tracing, locations of noise sources with one-hop propagation paths to KPH on 7 MHz, shown in magenta. Areas where rays would transit the D region are in black. By now it was crystal clear to me that I had no knowledge of the actual spatial distribution of noise over the ocean, countryside, desert, or cities within this area. The chasm became wider as I considered what would be the next steps of adding ionospheric physics.

Slide 5

Having seen the eclipse's effect on noise level, let's turn to its effect on signal to noise ratio on a single path at 3.5 MHz. In the SNR time series for the 14th and 15th at left there is a clear rise during the eclipse. But hold on. There are two factors in SNR, S, the signal level, and N, the noise. As we have measured noise we can determine the signal level, centre. Both graphs have 10 dB major increments on the Y-axis - this immediately shows the greater dynamic range for signal level change over SNR change. Here is a note of caution - SNR can be a compromised proxy for signal level where the noise, propagated in or local, varies.

Looking at the anomalies, right, that is, values on the eclipse day minus those on the following day at the same time shows that the peak SNR anomaly was 6 dB below the signal level anomaly.

Slide 6

To look at the signal level anomaly in more detail we can compare the 14th October data with the product of one minus the obscuration factor for the eclipse, and cosine of the solar zenith angle representing the regular diurnal change in signal level due to absorption. What I take away from the plot at left is better agreement *after* the eclipse maximum than before.

Calculating the signal level anomaly for the eclipse day by subtracting signal level at the same time on the 15th we have no need to include diurnal variation due to solar zenith angle. But we do add noise from subtracting two measurements. Nevertheless, this plot also shows a delayed response before eclipse maximum, with little increase for the first 40 minutes.

Slide 7

Moving on to look at some effects of lowered F2 critical frequency, here are some results on 28 MHz on 4300 to 4900 km paths along the eclipse from TI4JWC Costa Rica to California, Utah and Nevada. Top left we have Circuit Reliability for California stations KPH and KFS, the percentage of transmissions received in 20-minute intervals, about 4900 km distant. Both showed double dips, first around 16:40 UTC and second, deeper dips, around 17:20.

In the plot lower left received transmissions are shown as spots for the four stations, with distance from TI4JWC on the Y-axis. It's clear that for KA7OEI and ND7M, some 4400 km distant, the pattern was quite different to that at KPH and KFS – in that there were prolonged gaps. Also shown are time bars for the start, maximum and end of the eclipse at indicative locations for where the first and second hops from Costa Rica refracted from the F2 region.

There was no significant effect on circuit reliability until about 20 minutes before eclipse maximum at the location of the second refraction, after which no signals were received in Utah and Nevada until a brief reappearance around 1800 UTC. This reappearance was followed by a gap ending around when the eclipse ended at the location of the first refraction.

Slide 8

This double-dip response on a two-hop path might be useful as a test for a model. I can only make a rudimentary test using PyLap ray tracing as I can only reduce R twelve, the smoothed sunspot number, for the whole path. The upper trace shows the model output for a non-eclipse day - all four stations were within the second hop grounding zone. By reducing R twelve to 70 I could bring the Utah and Nevada stations into the second skip zone. And here, of course, may be an explanation for why the gap at Utah and Nevada did not start until 20 minutes before eclipse maximum at the second hop - R twelve had not decreased enough to stretch the second skip zone beyond their locations. I'm keen to know if the work on integrating SAMI3 with PyLap will enable a higher fidelity simulation on this interesting path.

Slide 9

Results on that two-hop path led me to look again at the path of the 8 April eclipse. Great circle paths and ray tracing suggest that the second and third hops at 21 MHz and above originating from the UK and Europe may be affected by reduced F2 region critical frequency. The geometry and spatial distribution of transmitters from Europe and receivers in North America are most favourable. I've encouraged UK stations to transmit WSPR via talks and a news item in this month’s Radio Society of Great Britain magazine, RadCom.

Slide 10

One of the benefits of having used the FST4W mode is that we also have frequency spread data. I've shown previously how propagation modes can be identified using frequency spread. On this 1808 km path example at 14 MHz, as the band opens each day, the spread is generally low, below 100 milliHz, consistent with one-hop propagation. As critical frequency rises two-hop is also supported, and we have a mix of modes with much scatter in frequency spread. But on the eclipse day, just after maximum obscuration at path mid point propagation reverted to one hop only, period B, identified by low frequency spread - a direct consequence of reduction in critical frequency.

Slide 11

As the critical frequency dropped sufficiently to transiently suppress two-hop propagation, what happens on a marginal one-hop path? Frequency spread measurements from FST4W provide an answer. Simultaneous decreases in signal level, cyan, and increases in frequency spread orange suggest the propagation mode swapped from one-hop, the tight cluster 'A', to two-hop sidescatter around and after the time of maximum obscuration at mid path. The arc 'B' suggests we observed transients to and from fully developed two-hop sidescatter. The most likely location of the sidescatter was the area in red in Utah over 1100 km from both transmitter and receiver. If you're intrigued by two-hop sidescatter call by my poster. Points in area ‘C’ are not outliers – my work in progress suggests these points, with high SNR and high spread, are from the first 40 km of the one-hop landing zone where high elevation and low elevation ray landing spots overlap.

Slide 12

Simultaneous observations from multiband GPS-aided or phase-locked transmitters and receivers, and 0.1 Hz frequency resolution from WsprDaemon, provided useful Doppler data on several paths. On this one-hop 545 km path in Nevada from one of Paul Elliott's WSPRSONDES to a KiwiSDR we have useful data at three frequencies. 3.5 MHz captured the morning descent of the refracting layer before swapping to E layer refraction with zero Doppler. 7 MHz and 10 MHz opened in turn, with Doppler, hence path velocity data, during the eclipse. Both frequencies show a similar pattern of path length variation during the eclipse.

Slide 13

Estimating refraction height starts with assuming simple geometry and a triangular total path P_0 from transmitter to receiver. Second, we estimate path length P_0 using a single height measurement from the ionosonde at Pt. Arguello, California. This gives us an initial value to which we add path length increments derived from path velocity. From updated path length estimates we derive updated refraction heights h_t.

Slide 14

This rather busy graph shows Doppler-derived refraction heights from FST4W on the 545 km pass across Nevada and the St George, Utah, Grape receiver tuned to WWV 10 MHz. Having used the average of the minimum and maximum heights of the F2 layer at 15:00 UTC from the Pt. Arguello ionosonde as our reference, FST4W Doppler-derived height is shown in green for 15th October. During the eclipse we have the FST4W 7 MHz data in orange and the 10.14 MHz data in cyan. The magenta trace is the Grape 10 MHz data. The agreement is encouraging.

Slide 15

Calculating the height anomaly during the eclipse compared with 15th October the FST4W and Grape estimates agree to within 1.5 km in height and to within nine minutes in time. The height anomaly from the ionosonde is lower, at perhaps 25 km, rather than 31.5 to 33 km from the Doppler measurements. In part, this may because of the ionosonde’s location further to the west. Missing data and significant scatter from the ionosonde makes it difficult to estimate time of maximum height anomaly.

Slide 16

The results I’ve shown today are just a small sample of possible singe-path analyses from the WsprDaemon stations in this map. The extended data is all in the public domain. Guides are available at wsprdaemon.org. The observations were the straightforward part – I’m looking forward to conversations at this Workshop on how to progress from these initial analyses.

Thank you.