Estimation of Ionospheric Layer Height by Measuring the Time Difference of Arrival (TDOA) Between 1 and 2 Hop Propagation Modes. 2023 Annular Eclipse Observations.

Steve Cerwin WA5FRF[1], Paul Bilberry N5DUP[1], Sam Blackshear AB5YO[1], Jesse T. McMahan K1FR[1], Kristina V. Collins KD8OXT[2], Nathaniel A. Frissell W2NAF[3]

[1]HamSCI, [2]Case Western Reserve University, [3]The University of Scranton

Abstract

A HamSCI science objective for the 2023 and 2024 eclipses is to use amateur radio stations to measure how the ionosphere changes with eclipse passage. Of particular interest is the change in effective ionization layer height caused by the momentary blockage of solar radiation. Layer height between two stations can be deduced from a Time of Flight (TOF) measurement but doing so requires complexity beyond the capability of most amateur radio stations. Particularly difficult requirements are precision absolute time references for both stations and calibration of the lengthy time delays incurred in modern DSP based transceivers. A simpler method that can be just as effective is to measure the Time Difference of Arrival (TDOA) between the 1- and 2- hop modes over paths and frequencies that support both modes. The 1-hop mode is shorter and arrives first, followed by the longer 2-hop mode. Geometric models based on virtual height or refractive ray tracing can be used to mathematically relate 1-2 hop TDOA to layer height. The measurement can be implemented by transmitting audio signals that are sensitive to a time delay when summed together, as happens in the receiver during simultaneous 1 and 2 hop propagation. Suitable audio waveforms include a 1-cycle audio burst, audio chirps of controlled sweep rate, and a pseudorandom noise burst. The TDOA measurement using the short pulses is performed by directly measuring the time difference between the two received pulses. The summation of a chirp waveform with a delayed copy of itself produces a beat note equal to the product of the sweep rate and the time delay that can be used to calculate TDOA. The TDOA can be extracted from both the PN bursts and chirps through an autocorrelation technique. The audio signals can simply be fed to the microphone input and recovered from the speaker output of ordinary SSB amateur radio equipment using audio .wav programs. This paper gives details of the method and of on-air experiments both before and during the 2023 Annular Eclipse.

I. Approximating F2 Layer height from Time Difference of Arrival (TDOA) between 1- and 2-hop Propagation Modes

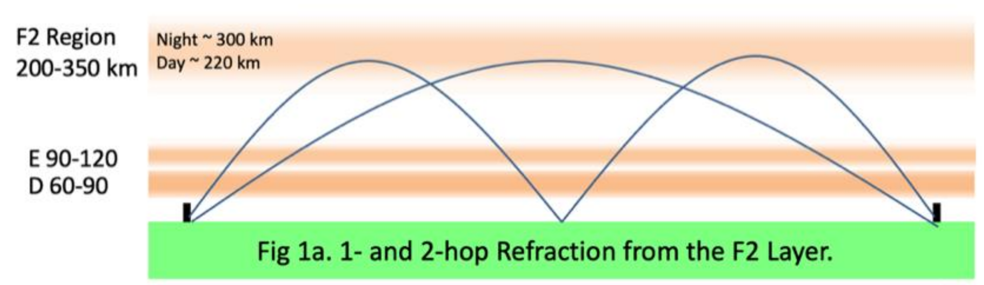

Fig 1a. 1- and 2-hop Refraction from the F2 Layer.

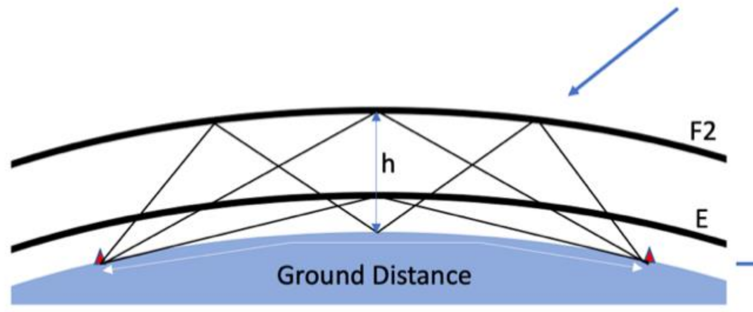

Fig 1b. Virtual Height model Used to Calculate Relationship between Virtual Height h and Path Length. Time of Flight = Path Length / c

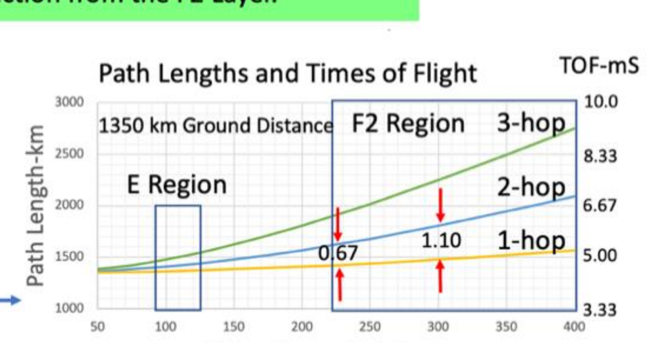

Fig 1c. TDOA Example: At 1350 km ground distance the Time Difference of Arrival between 1 and 2 hop modes is 0.67 ms at 225 km layer height and 1.10 ms at 300 km.

II. TDOA Measurement Example: Audio Frequency Chirp

The summation of a linear frequency chirp of sweep rate SR with a copy of itself delayed by time Δt produces a beat frequency at

$$f_{Beat} = SR * \Delta t.$$

The beat pattern has a period $p = 1/ f_{Beat}$. The Time Difference of Arrival (TDOA) of the two modes can be calculated from the measured beat note period or frequency by:

$$TDOA = \Delta t = 1/(p*SR) = f_{Beat} / SR$$

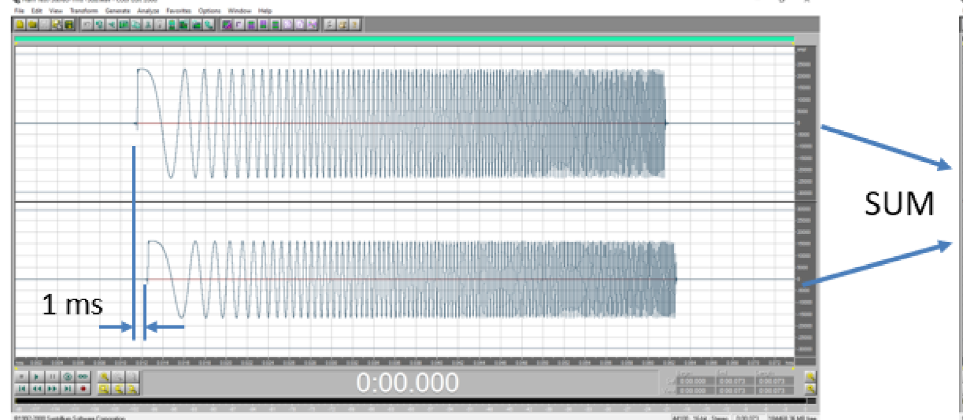

Fig 2a. Two 100 Hz/ms Chirps with 1 ms Time Delay. Delayed Chirp is 3 dB lower in Amplitude to Simulate Multipath.

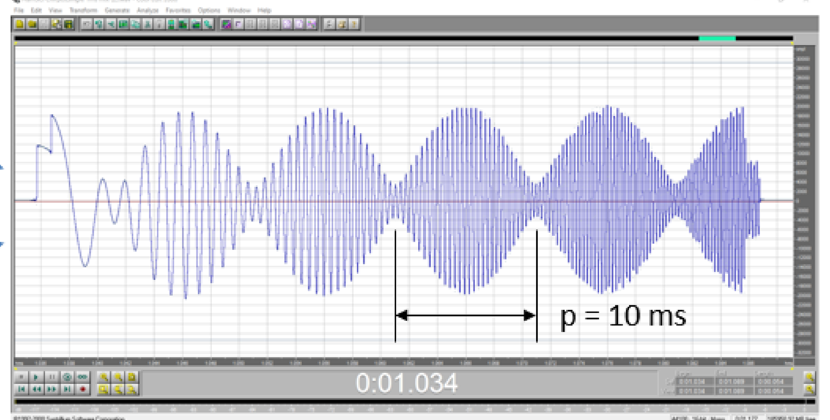

Fig 2b. Summation produces a Waveform with a Beat Note of Frequency 100 Hz and a Period of 10 ms.

$$TDOA = 1 / (10ms * 100Hz/ms) = 100Hz / 100Hz/ms = 1 ms$$

III. On-air Example: 317 km path in Texas Near Austin Ionosonde

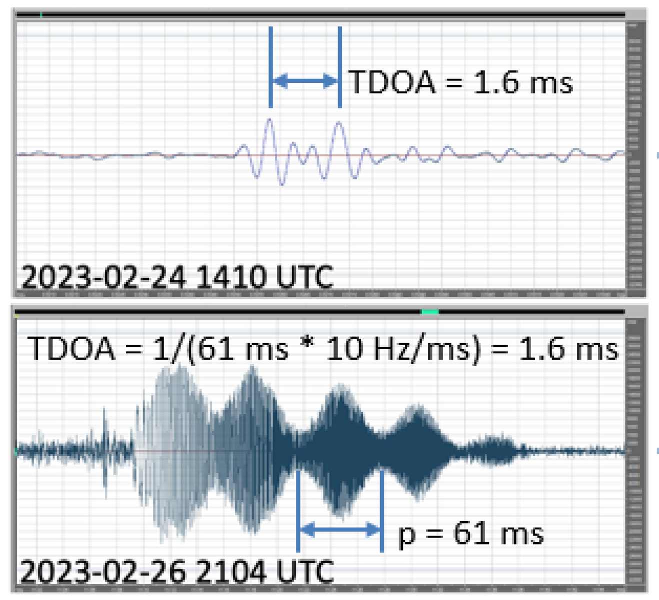

Fig. 3a Short Pulse and Chirp TDOA Measurements

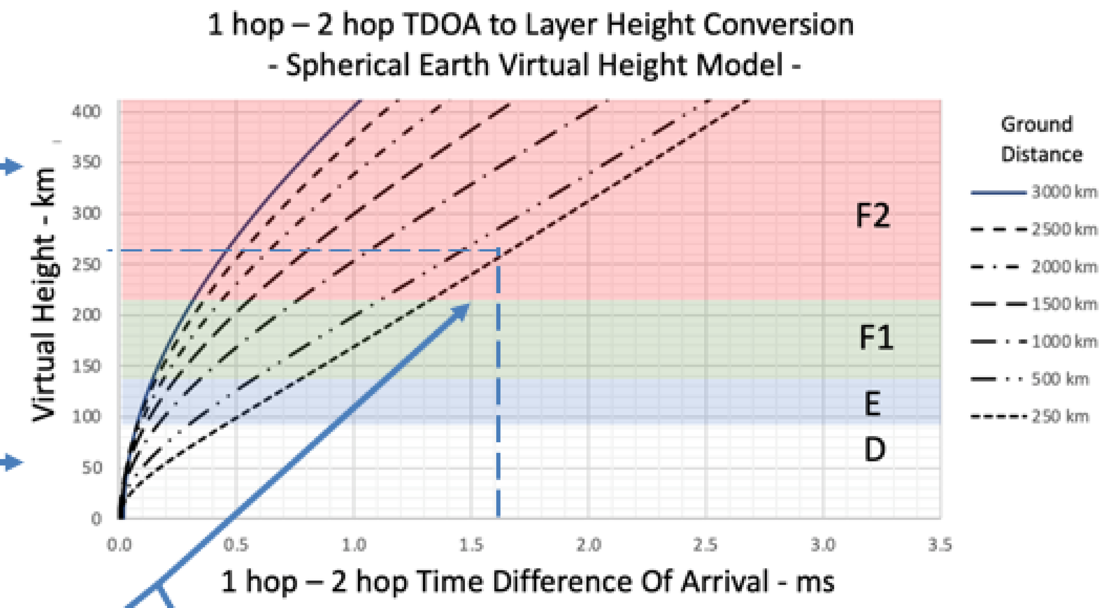

Fig. 3b Convert 1.6 ms TDOA Measurements to 270 km Layer Height

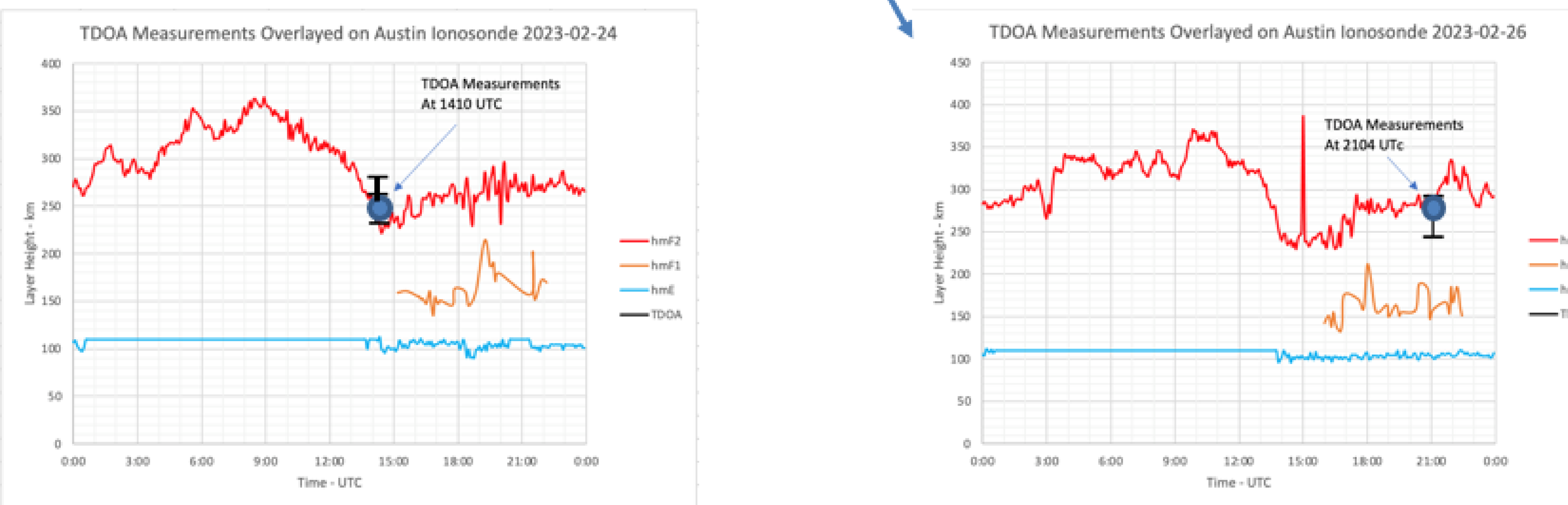

Fig. 3c Overlay Layer Height Estimation on Ionosonde hmF2 Data for Day and Time of Measurement. Error bars show range of 18 separate measurements using short pulses and 10 to 50 Hz/ms chirps.

III. 14 Oct 2023 Annular Eclipse Data

Paths and Frequencies. TDOA data were taken over two propagation paths in Texas on eclipse day. The first was a 317 km path between WA5FRF near San Antonio and N5DUP near Abilene. This path passed near the Austin Ionosonde. The second was from WA5FRF to nearby AB5YO at a ground distance of only 8.77 km, a NVIS path directly under the Path of Maximum Annularity (see inset above). Possible multipath modality for this path include ground wave and NVIS, or consecutive 1-hop and 2-hop NVIS. Data were taken on both the 40 meter (7.2 MHz) and 60 meter (5.3 MHz) amateur bands.

Procedure and Results. An audio waveform coded by KD8OXT consisting of a Morse Code station identifier and grid square locator, a series of 1-cycle audio pulses, an array of linear sweeps of different sweep rates, PN noise bursts and time calibration markers was transmitted by WA5FRF every 15 minutes from 1130 UTC to 1930 UTC on both bands. N5DUP and AB5YO received and recorded the waveforms. Autocorrelation analysis by K1FR on data from eclipse day is presented in Figure 4. Beat frequency extraction from chirp data was in process as a student exercise at the time of this writing. Figure 5 shows hmF2 data from the Austin ionosonde for eclipse day and the day after.

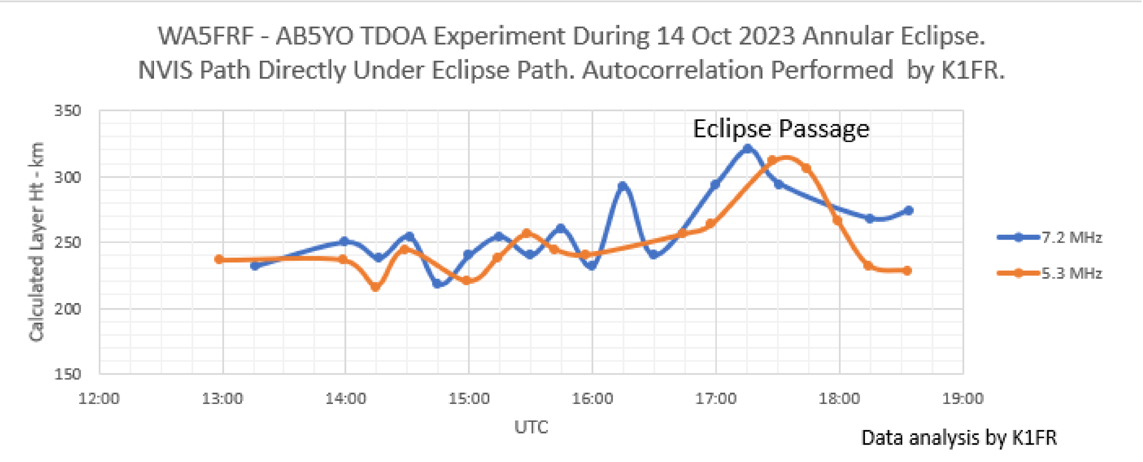

Fig. 4. NVIS Layer Height Calculated by TDOA Method During 2023 Annular Eclipse. Definite peaking was observed at time of local eclipse passage.

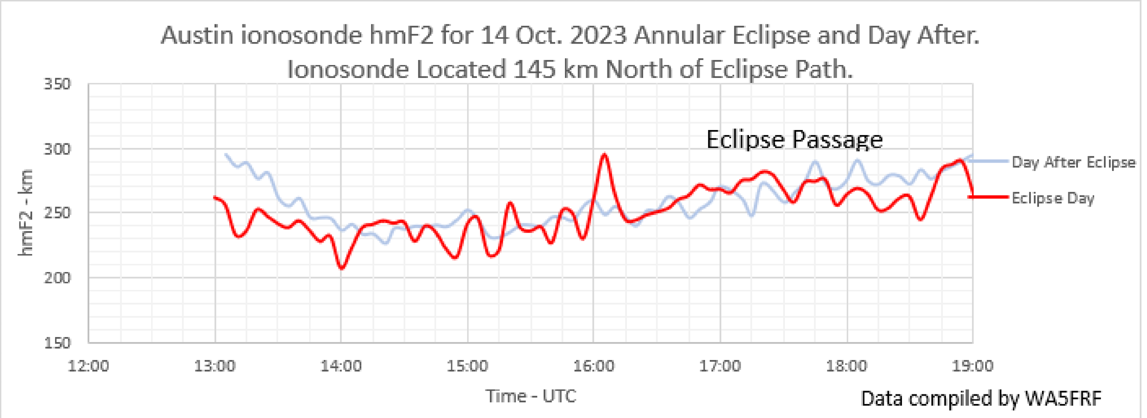

Fig. 5. Austin Ionosonde hmF2 Data for Eclipse Day and Day After.

Only modest peaking was observed in Austin data. Prior to eclipse passage both the Austin Ionosonde and the NVIS TDOA measurements agreed the layer height was near 240 km.

References

1. *ARRL Handbook* and *Antenna Book*. ARRL, 225 Main Street, Newington, CT, 06111.
2. *Here to There: Radio Wave Propagation.* ARRL, 225 Main Street, Newington, CT, 06111.

We are grateful for the support of NSF AGS-2045755, AGS-2002278, AGS-2230345, AGS-2230346, and NASA 80NSSC23K1322.

Steve@cerwinconsulting.com