Ionospheric Disturbances at Dawn, Dusk, and During the 2017 Eclipse

HamSCI Workshop 2019

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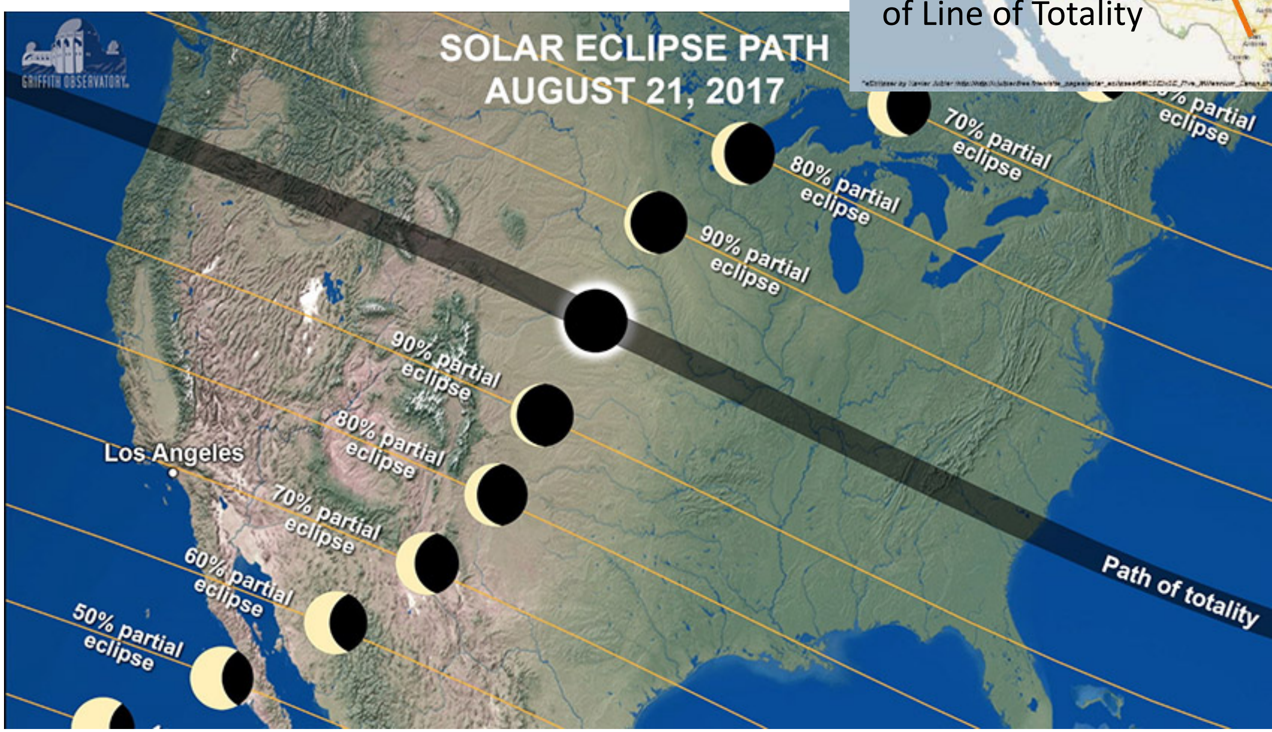
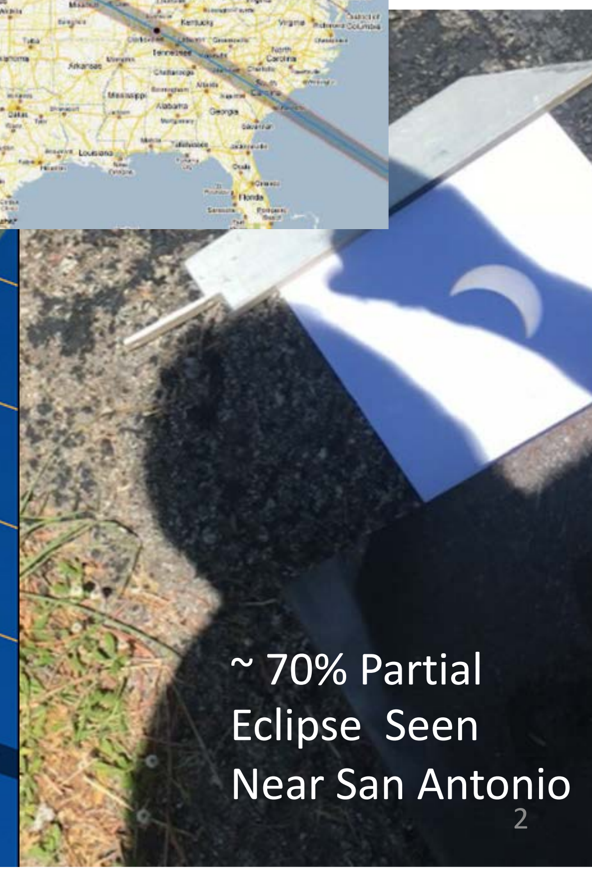
Eclipse Effects on Propagation at HF and LF on a Ft. Collins, CO to San Antonio, TX Path

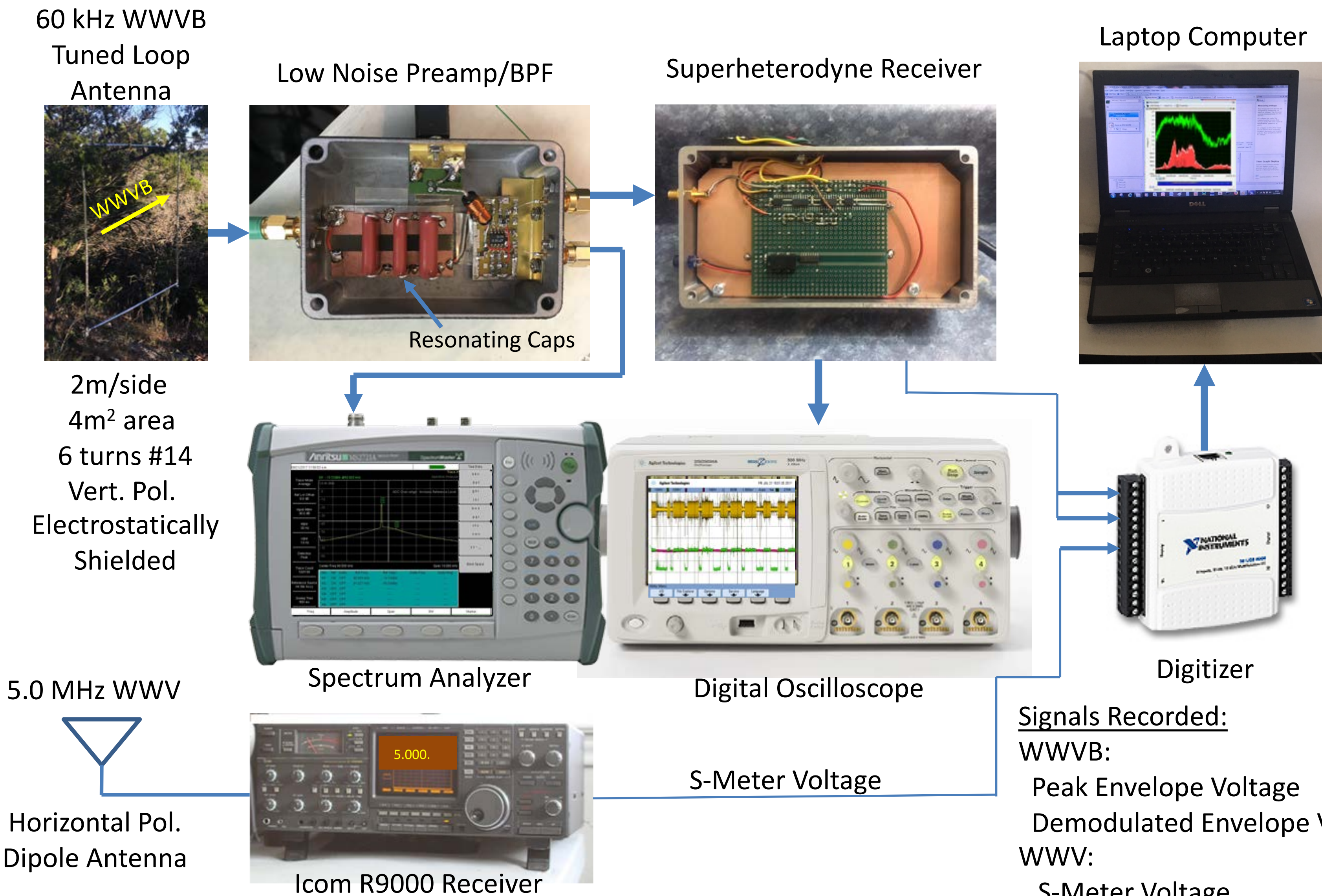
WWVB to WA5FRF:
153’ True
1348 km
837 miles
270 wavelengths
4.5 ms propagation delay

Frequencies:
5MHz WWV
60kHz WWVB





WWVB and WWV Instrumentation

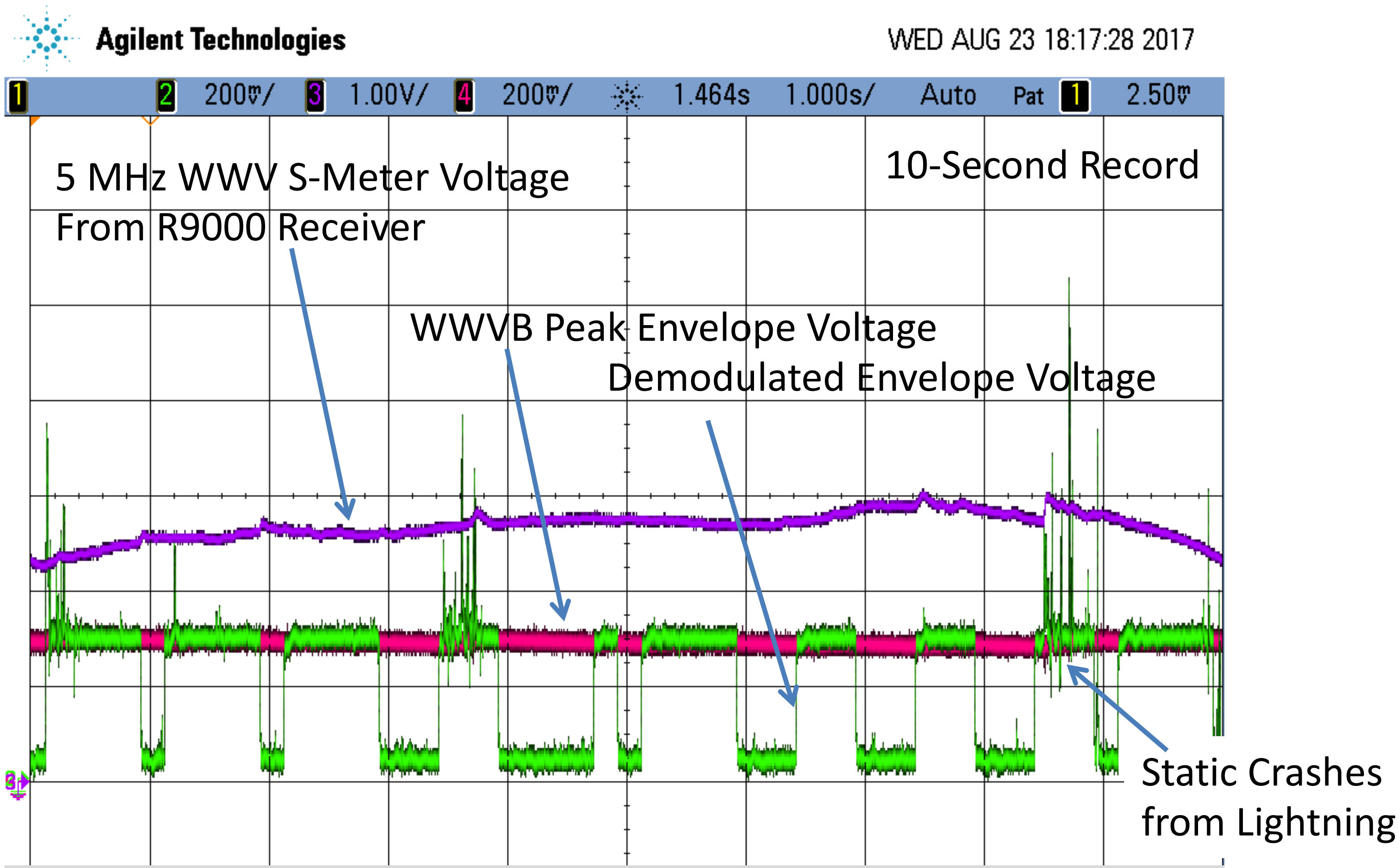


<u>Signals Recorded:</u>

WWVB:
- Peak Envelope Voltage
- Demodulated Envelope Voltage

WWV:
- S-Meter Voltage

Expanded Scale Example of 5 MHz WWV S-Meter Voltage and WWVB Peak and Demodulated Waveforms Recorded by Data Logger



5 MHz WWV S-Meter Voltage is Linear-in-dB
WWVB Envelope Voltages are Linear Volts

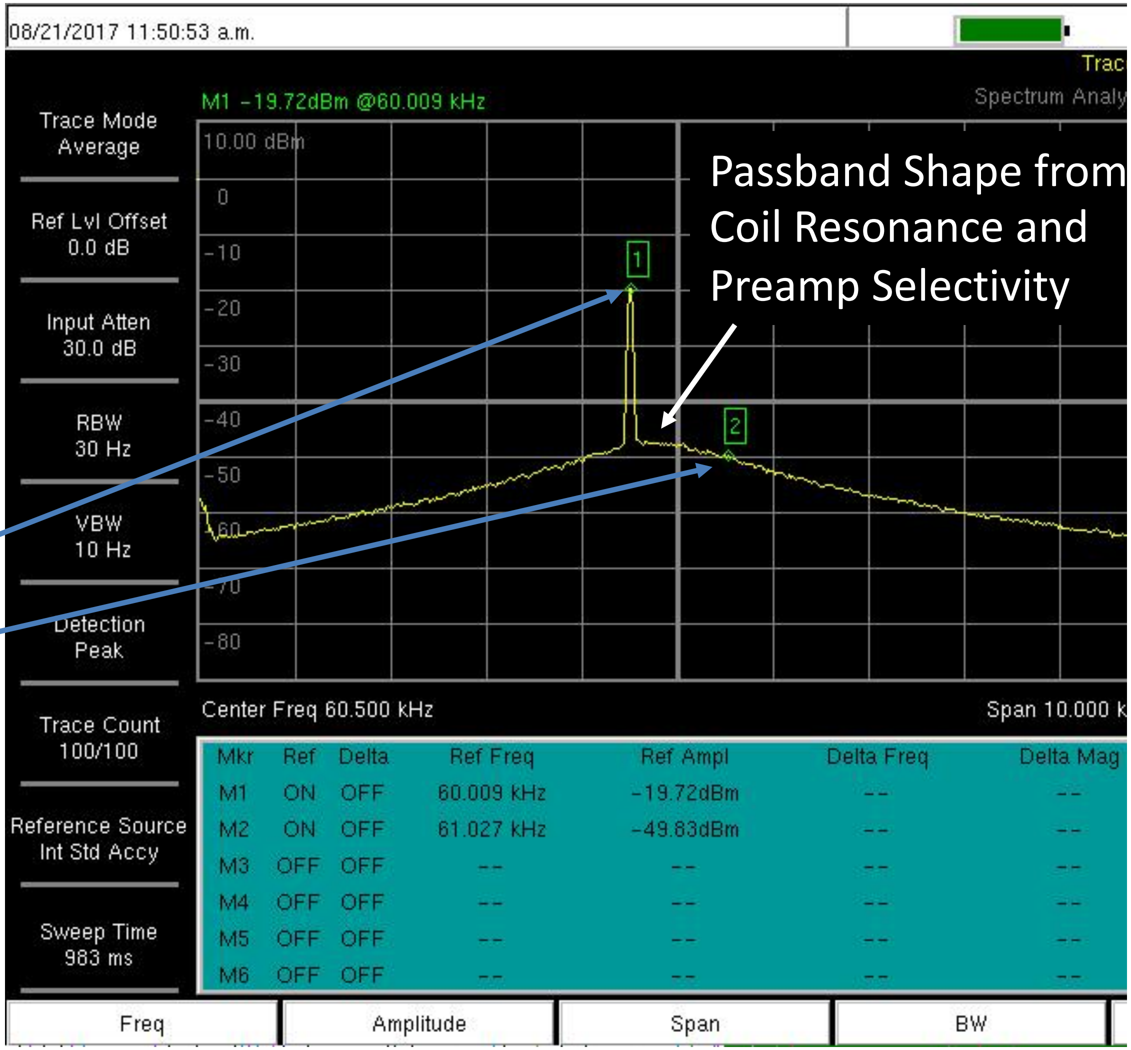
Example of Spectrum Analyzer Data

Analyzer set to average 100 scans.

Data recorded at:

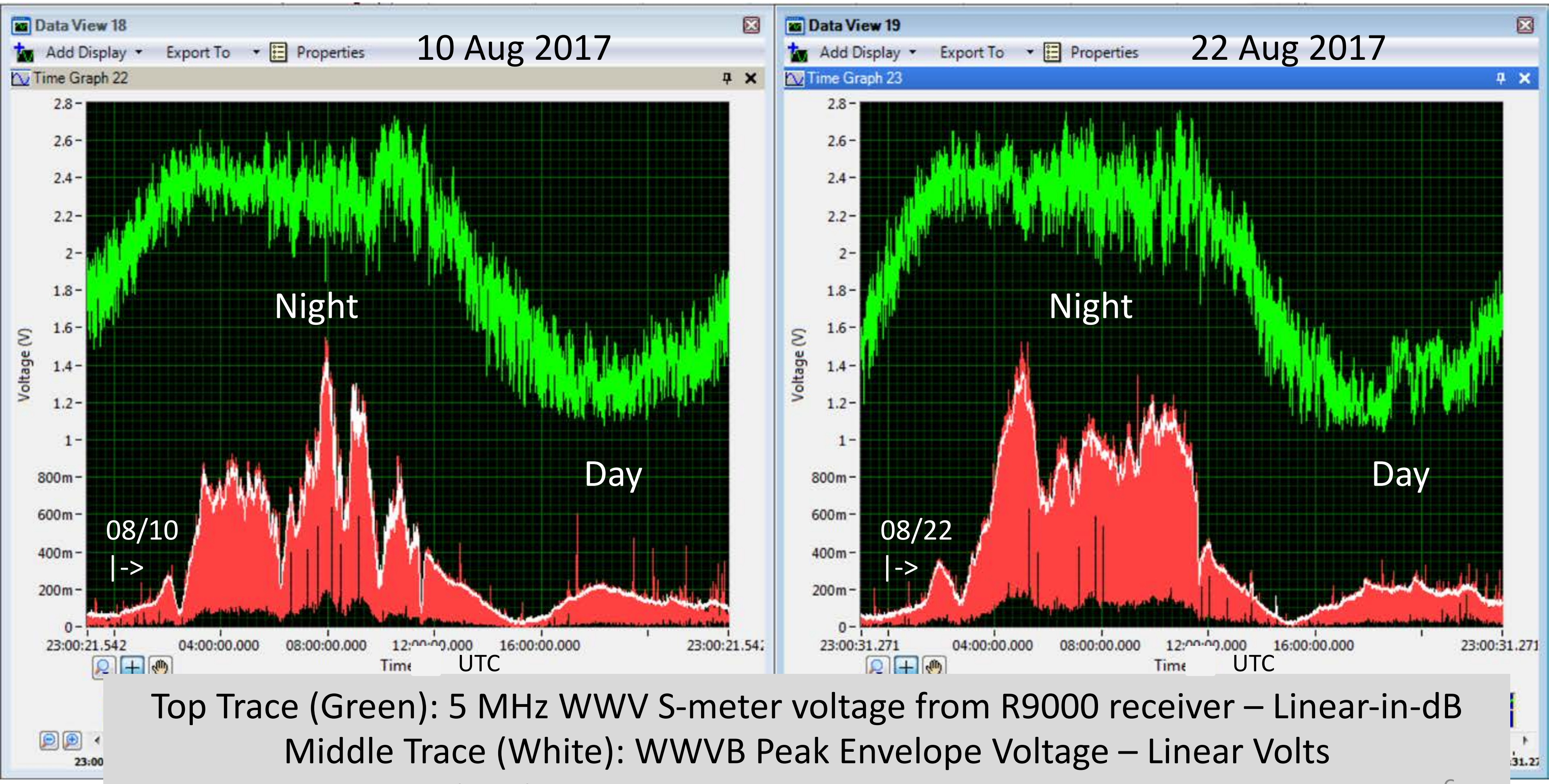
60 kHz for WWVB

61 kHz for background noise.



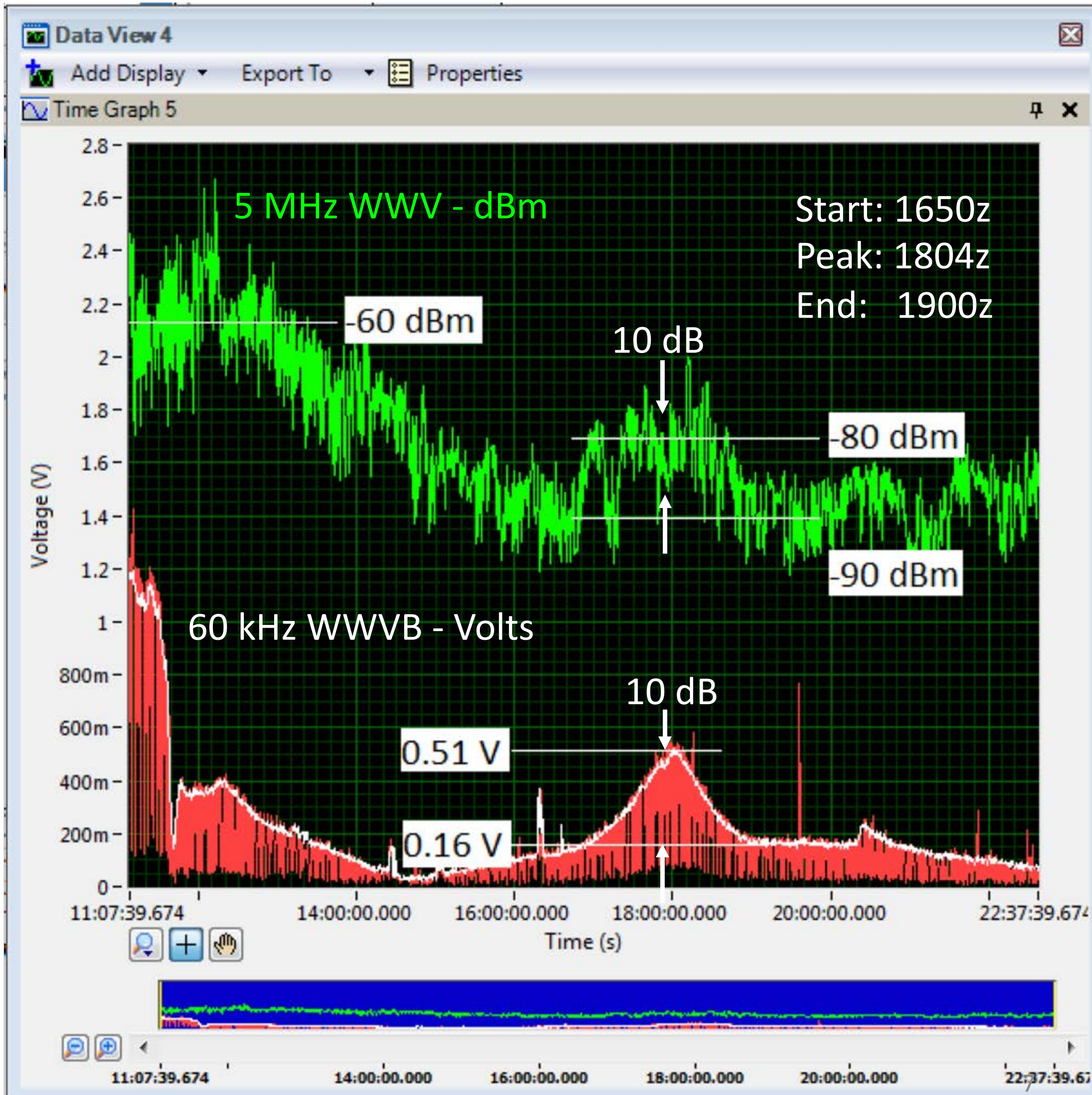
WWVB and 5 MHz WWV Signals at WA5FRF Before and After the Day of the Eclipse Showing Typical Nighttime and Daytime Propagation

Ft. Collins, CO to San Antonio, TX Path 23-23z

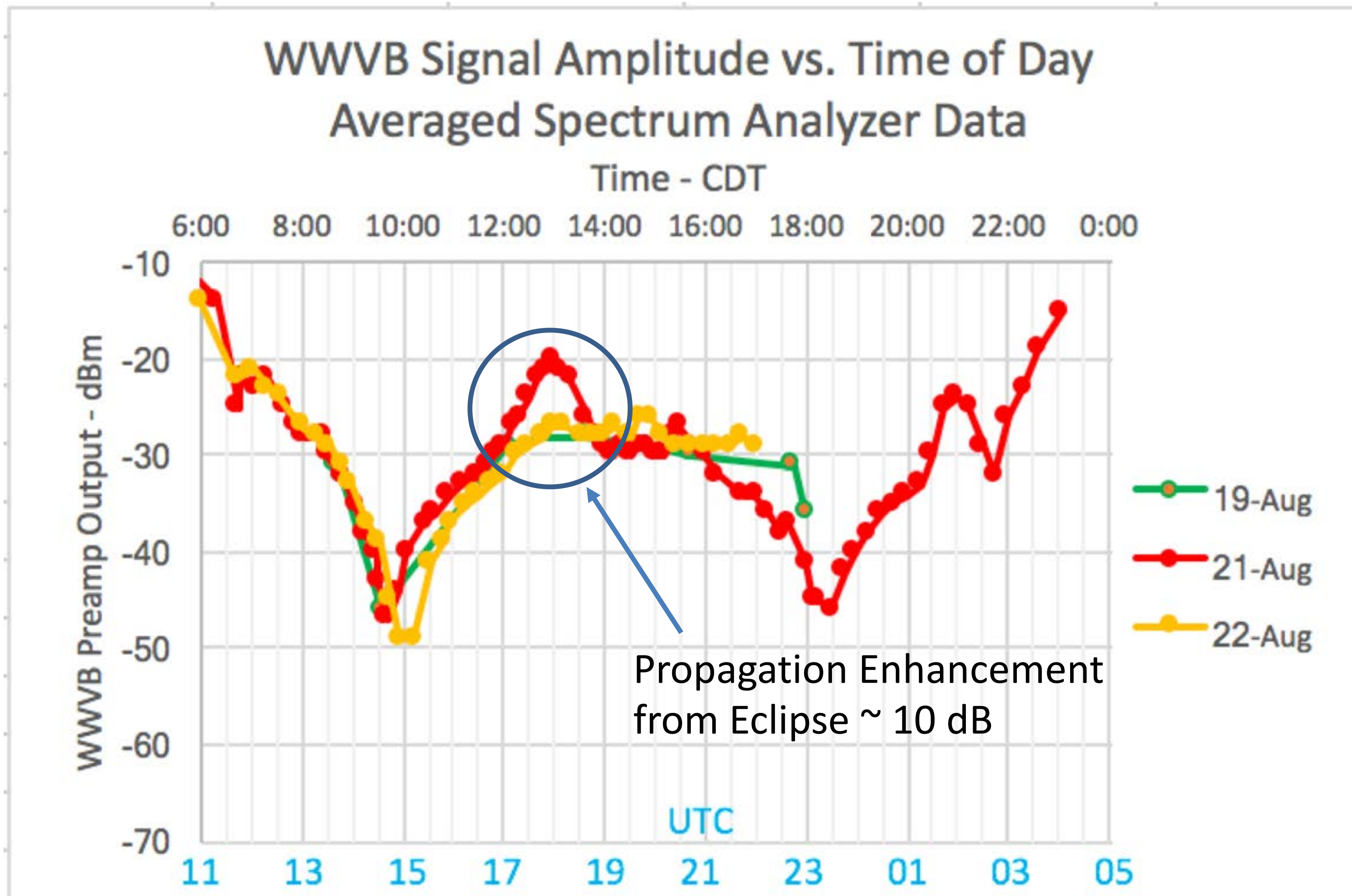


Top Trace (Green): 5 MHz WWV S-meter voltage from R9000 receiver – Linear-in-dB
Middle Trace (White): WWVB Peak Envelope Voltage – Linear Volts
Bottom Trace: (Red): WWVB Demodulated Envelope Voltage – Linear Volts

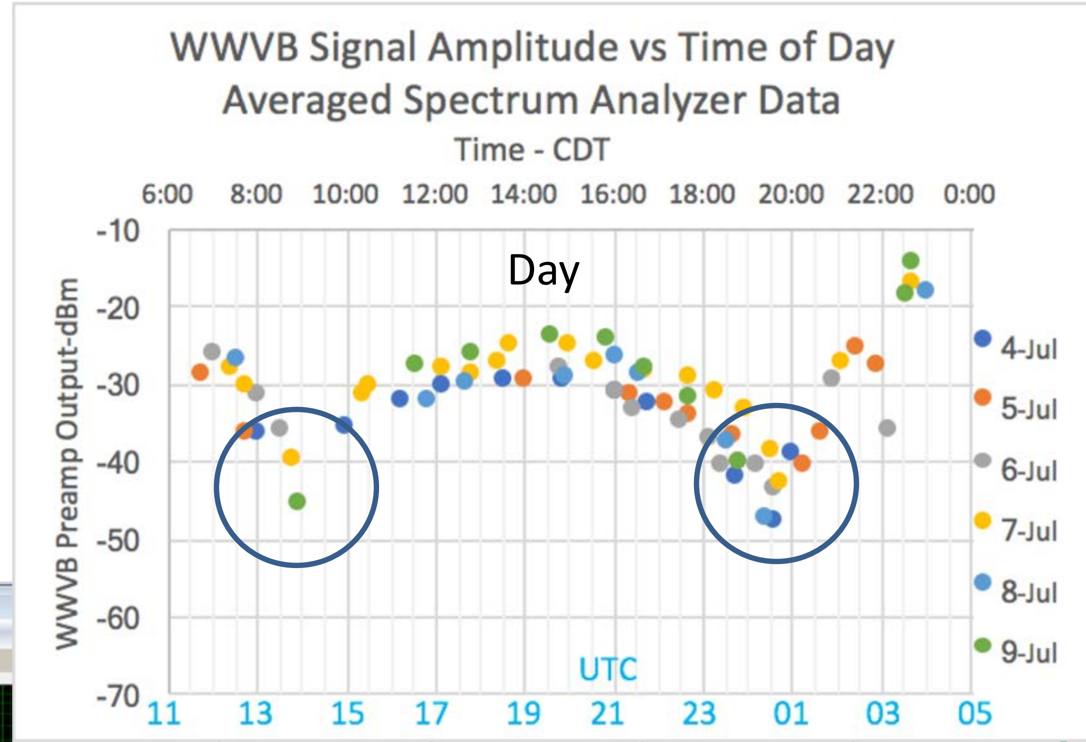
The Observed Eclipse-Induced Enhancement Was 10 dB For Both 5 MHz WWV and 60 kHz WWVB

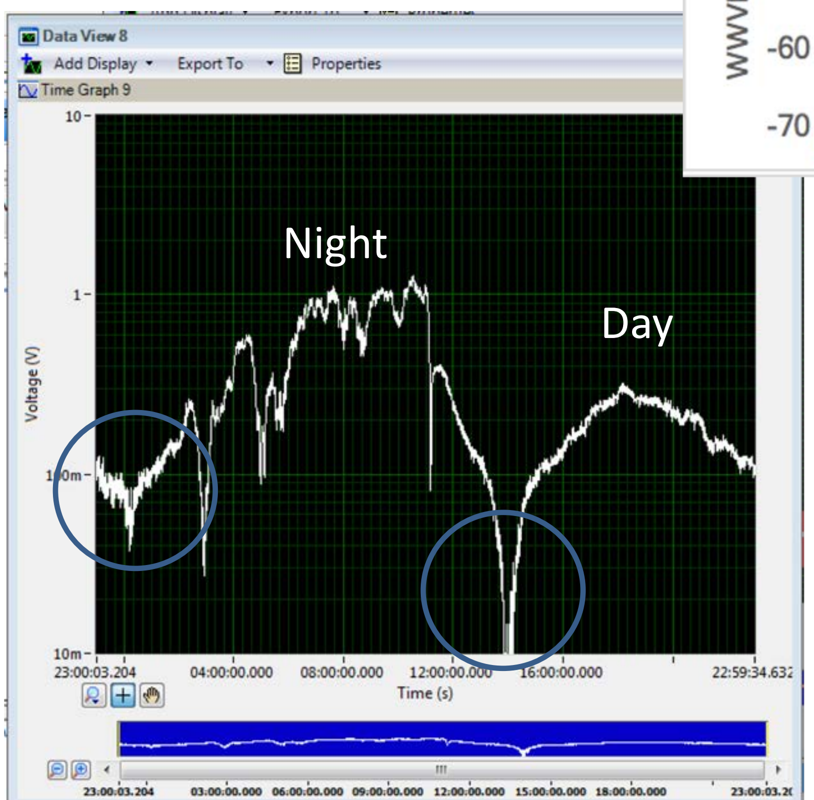


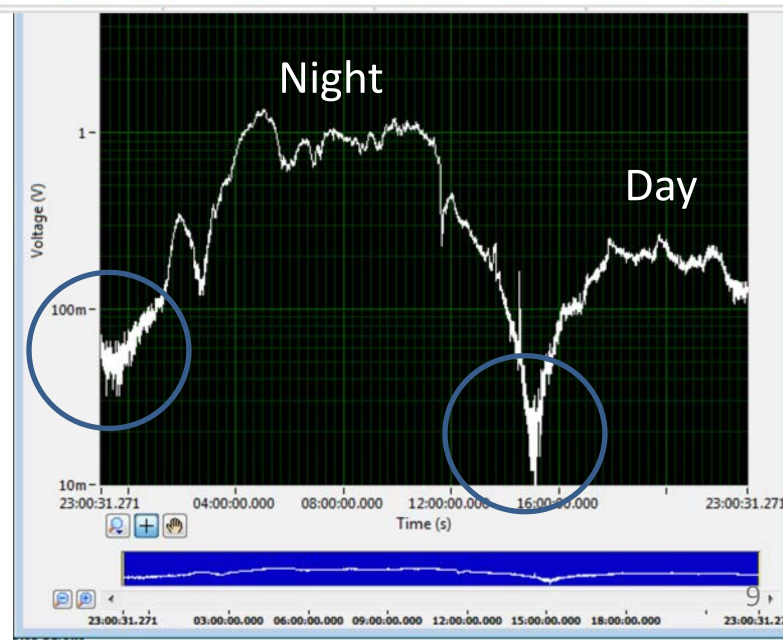
Spectrum Analyzer Data Taken Manually Before, During, and After Eclipse Agreed with Data Logged from WWVB Receiver



WWVB Transition from Nighttime to Daytime Propagation Was Delineated by Deep Nulls

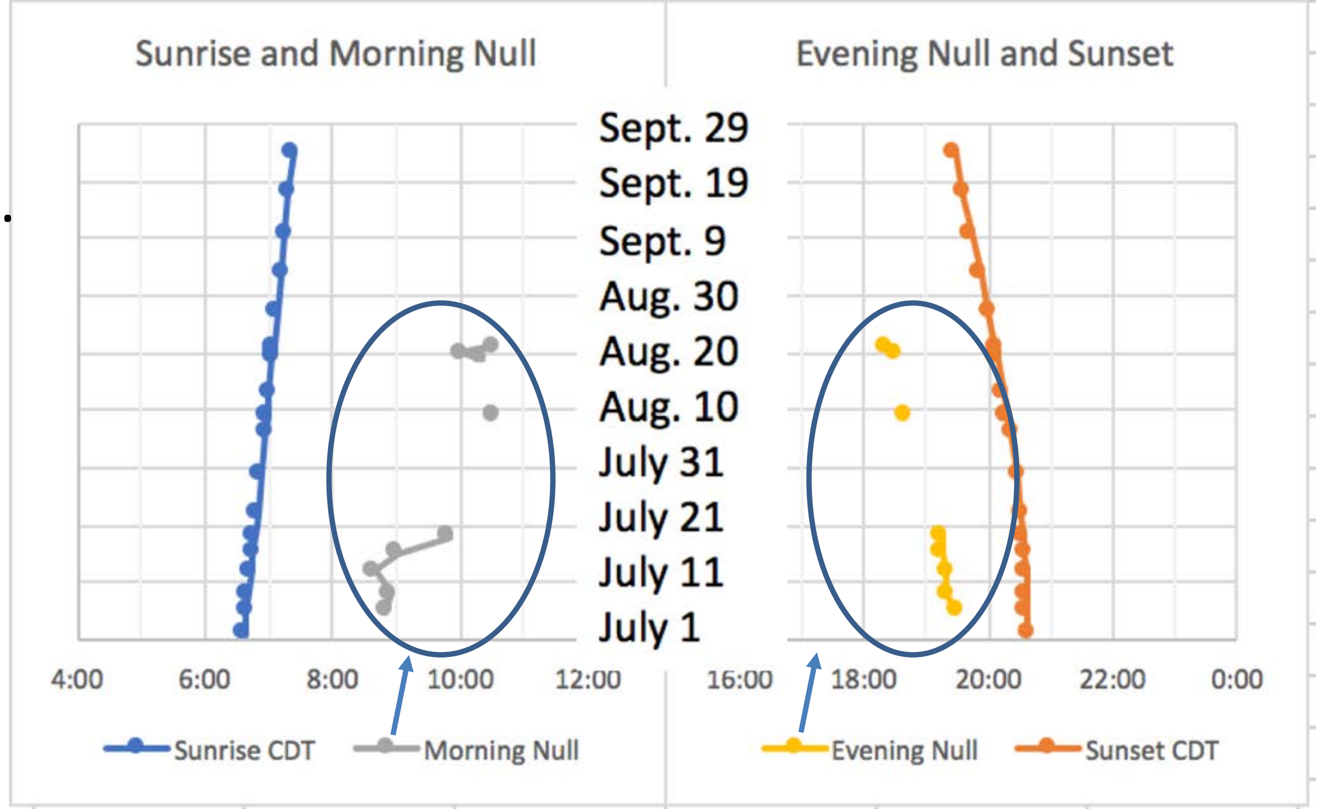






Occurrence of Night/Day propagation Nulls Followed the Sun

Timing of the nulls generally tracked sunrise and sunset. As the days got shorter, the morning null occurred later in the day and the evening null occurred earlier.



Possible null mechanisms: 1) Multipath interference between competing daytime and nighttime propagation modes of different path length or wave speed. E.g., Nighttime ground wave and Daytime elevated duct or phase shift caused by elevation-dependent wave speed.

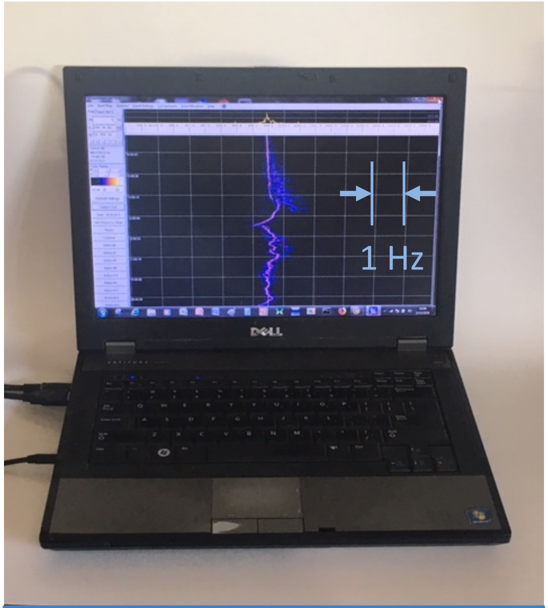
Summary of Eclipse Observations

- The August 21, 2017 eclipse resulted in peak enhancement of 10 dB for both 60 kHz WWVB and 5 MHz WWV signals for a Ft. Collins, CO to San Antonio, TX path, even though propagation was completely below the path of totality.
- The transition from nighttime to daytime propagation for WWVB was marked by sharp and deep nulls suggesting multipath interference between competing propagation modes. Timing of the nulls was observed to track sunrise and sunset from day-to-day.
- Besides being stronger, nighttime WWVB propagation exhibits much more selective fading than daytime propagation. On some days the selective fading showed periodicity. By contrast, daytime WWVB propagation exhibited a mostly smooth half-sine wave amplitude shape between the morning and evening nulls, free from selective fading.

Skywave Frequency Measurement Challenges For ARRL FMT

- Objective: measure the frequency of a skywave HF signal to sub-Hz precision.
  - e.g., < 0.1 ppm
- Communications receivers do not have enough significant digits or accuracy.
- The ionosphere changes the apparent frequency through Doppler effects and/or varying wave speed.

- A solution: use USB mode, tune RX low by a fixed offset to get an audible beat note, then use an audio spectrum analyzer to accurately measure the offset.
- Calibrate to nearest WWV frequency.



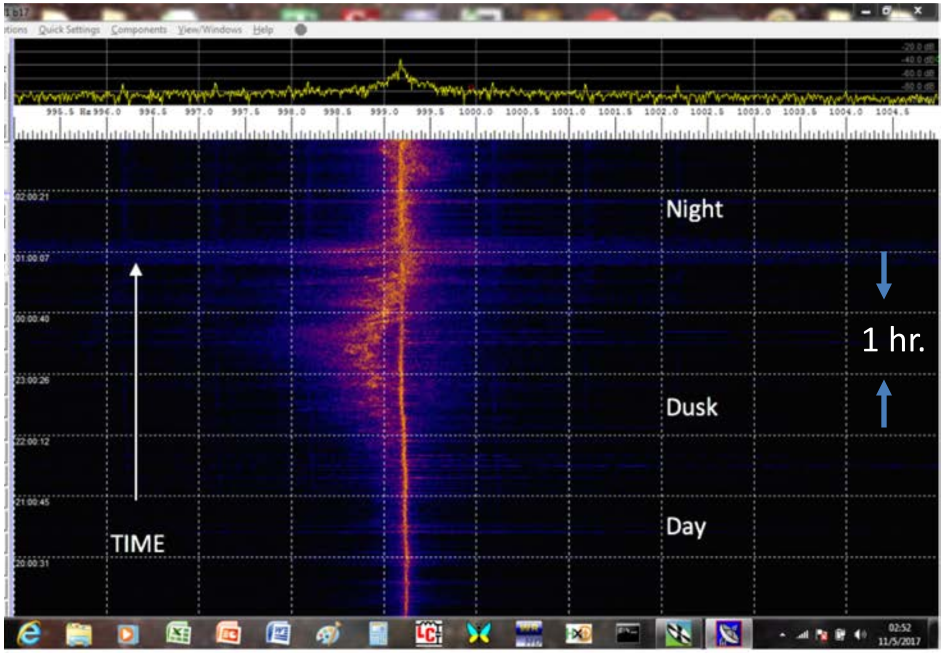
5.0 MHz WWV

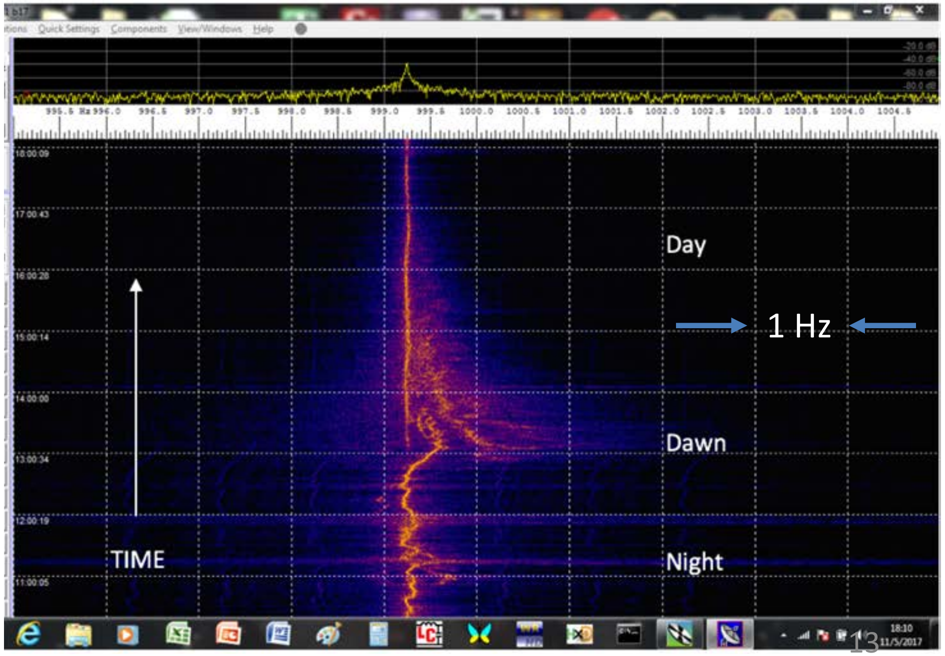
Laptop Running Spectrum Lab Audio Analyzer

Icom R8600 Communications Receiver

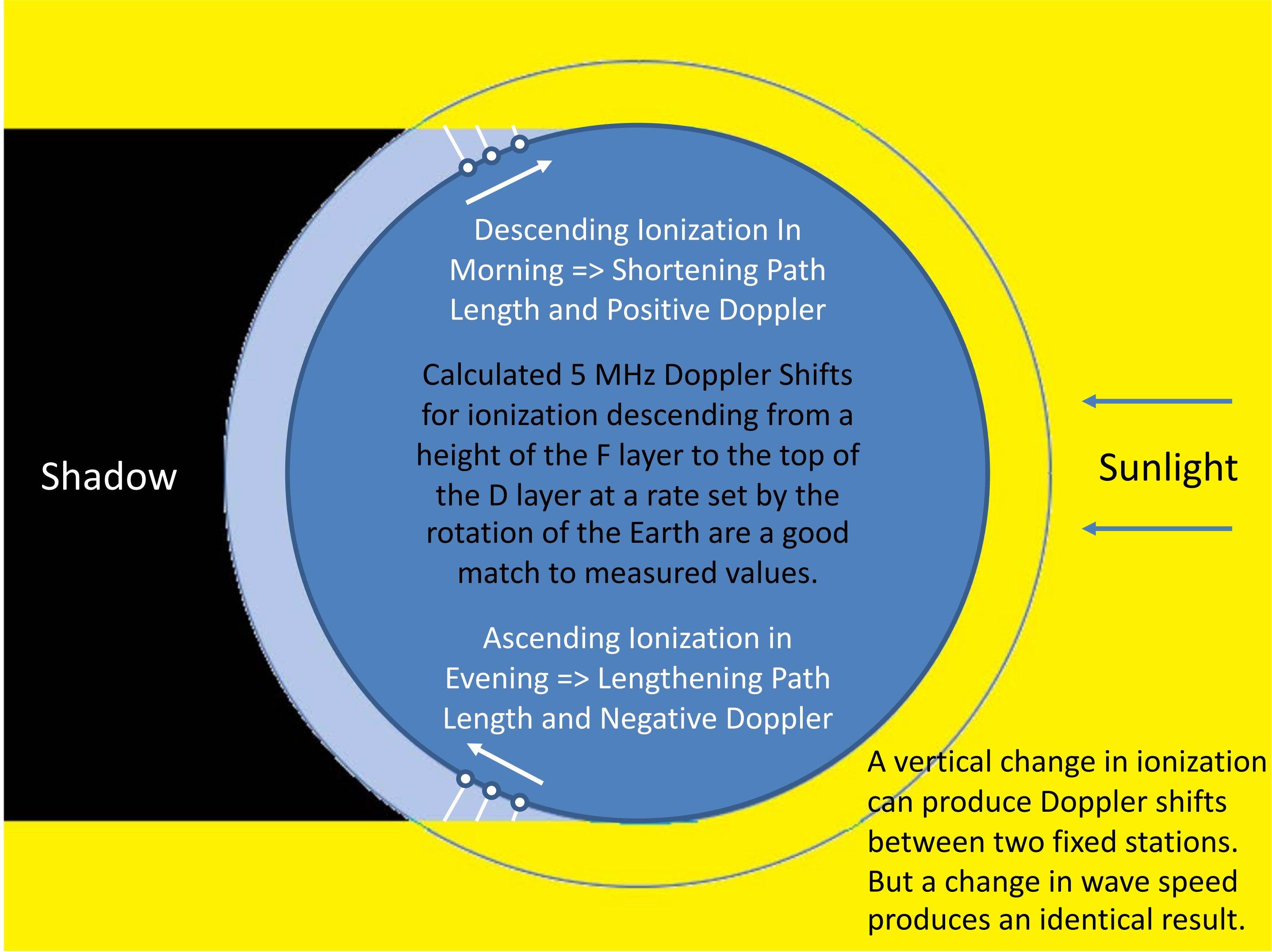
Check WWV before and after FMT.

On-Air Frequency Measurements of 5 MHz WWV Showed Smooth Daytime and Turbulent Nighttime Characteristics with a Prominent Negative Swing at Dusk and Positive Swing at Dawn. The Dawn Swing Additionally Showed Multiple Harmonically Related Swings.

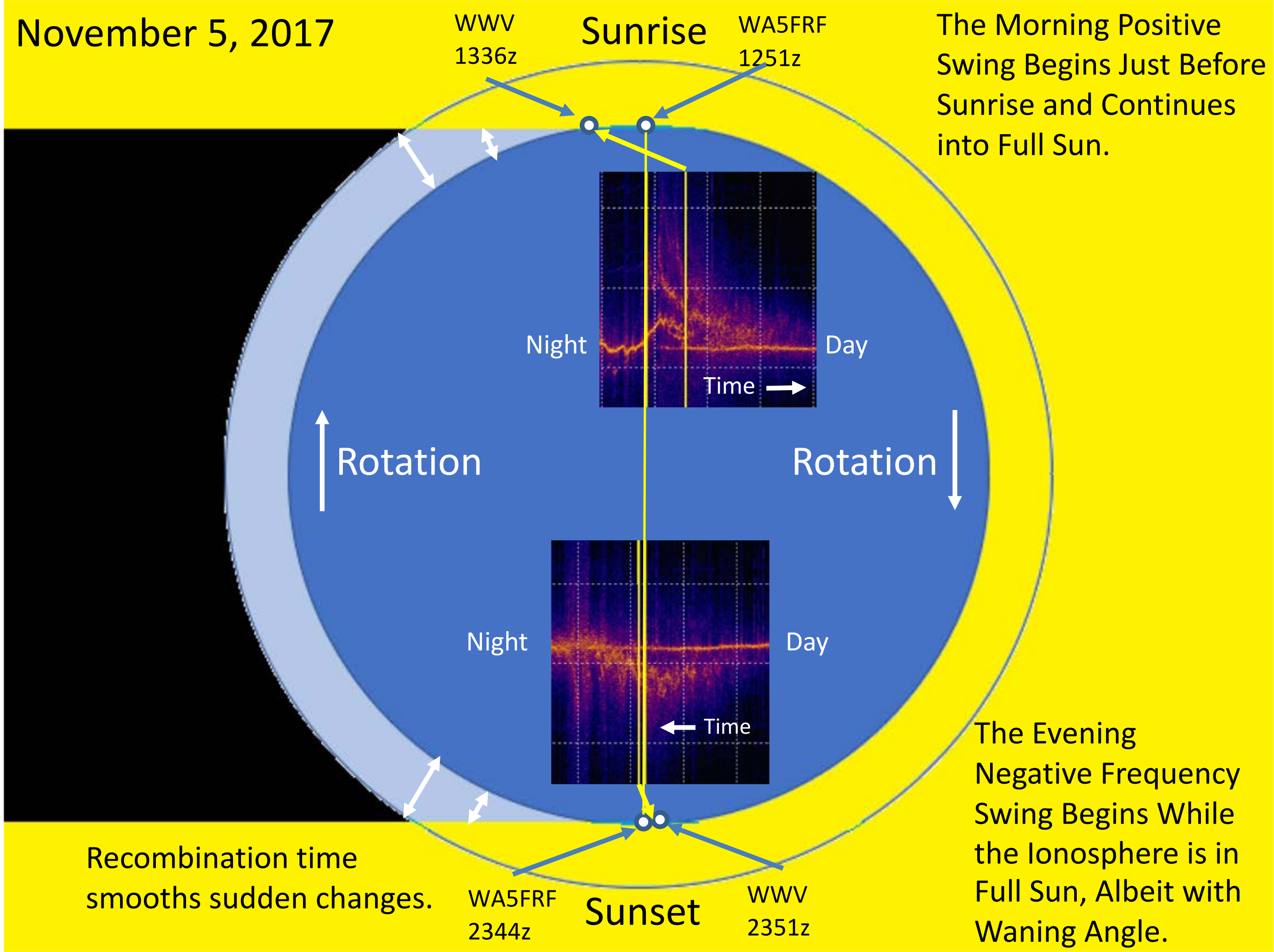




Descending and Ascending Ionization Regions Caused by Rotation of Earth Can Provide the Changing Path Length Required for Doppler



Timing of Frequency Swings Shows Partial Correlation to Shadowing. But the Swings Extend Well Into Full Sun Suggesting Changing Wave Speed Plays a Role.



Possible Contributors to Multiple Frequency Swings During Night-Day Transition

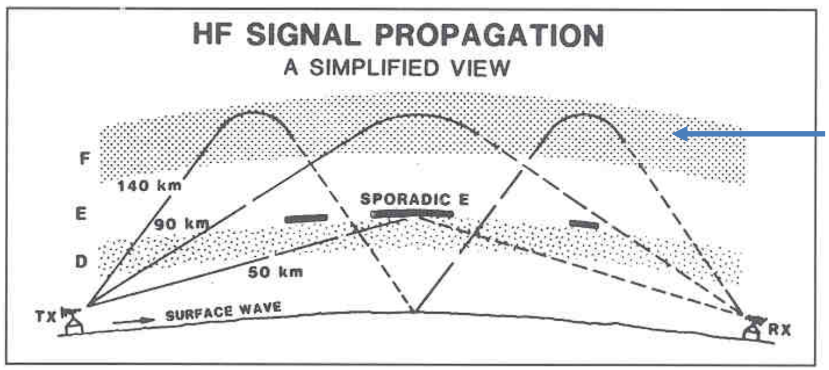
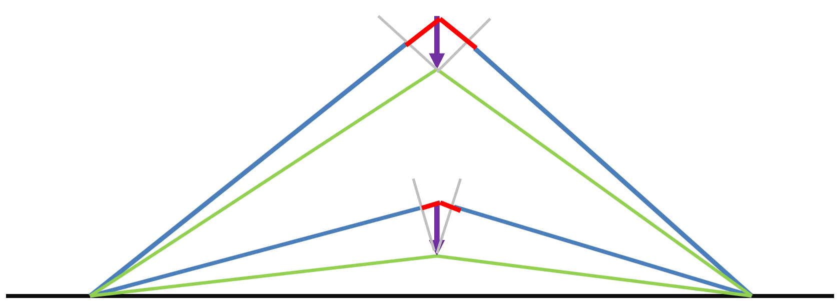


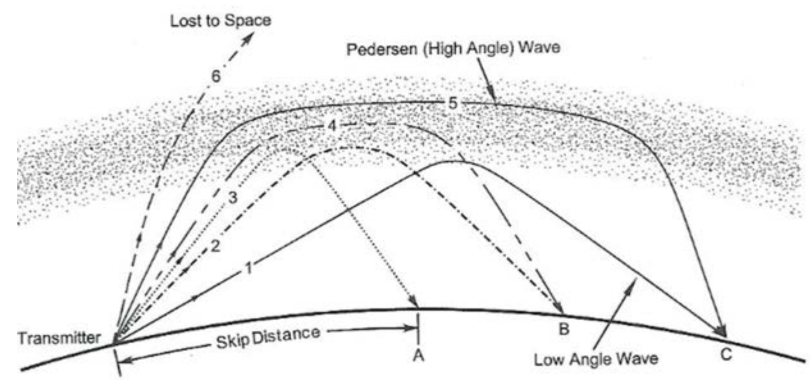
Figure 1. Radio wave propagation using the ionosphere. Courtesy Gerald Oicles/BR Communications, Sunnyvale, CA

With descending ionization at dawn or increasing wave speed, simultaneous Multiple Hops multiplies path length and rate of change by number of hops.

Critical Angle must support frequency in use for high-angle modes.

Multiple Hops: Each Additional Hop Adds an Overtone-Related Swing





From ARRL Antenna Book

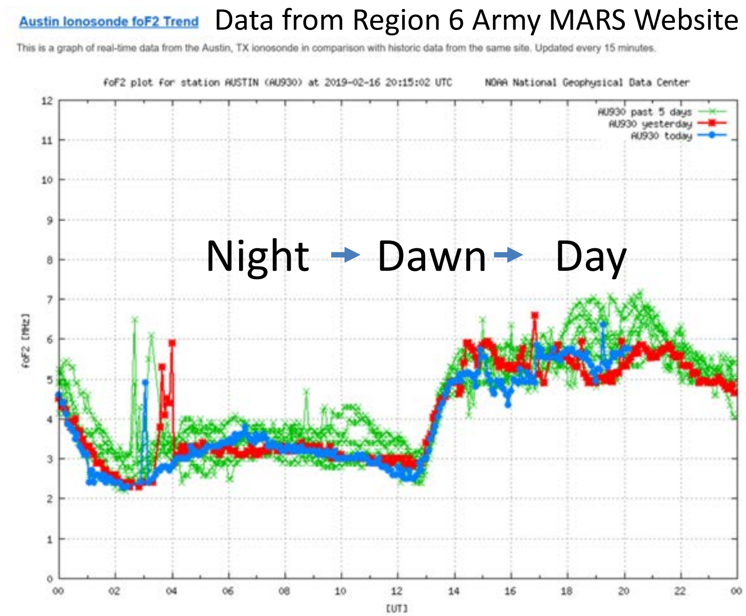
A given change in reflection height produces a larger change in path length at higher takeoff angles, exaggerating frequency swings for multi-hop modes.

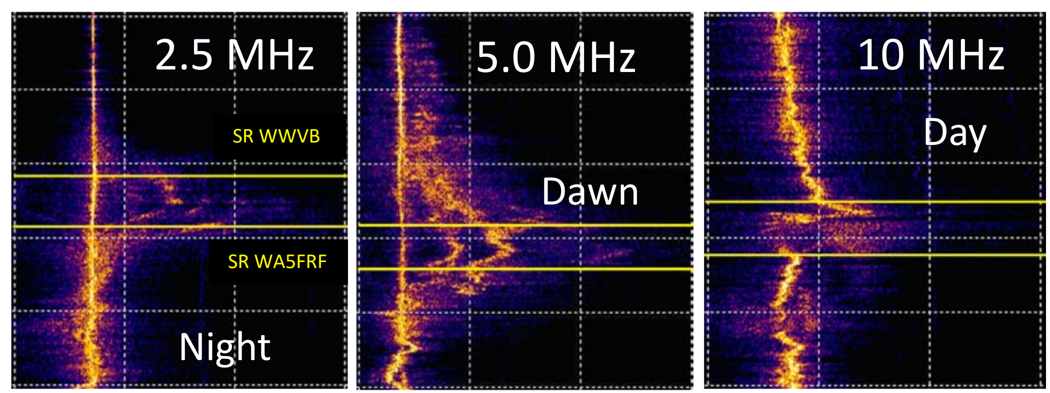
Multiple and Single Hop modes can have different path lengths, wave speeds, and rates of change.

Nonlinear effects from accelerating wave speed caused by rapidly increasing free electron density can generate overtones.

Dawn Critical Frequency Data Enables High Angle Multiple Hops at and Below 5 MHz

- Critical frequency opens 2.5 and 5MHz for high angle modes at dawn, enabling multiple hops.
- Overtone related frequency swings do not appear on 10MHz WWV; critical frequency data shows high angle propagation and multiple hops not possible.
- Multiple swings sometimes appear at 2.5MHz, though not as prominent, suggesting D-layer absorption.
- Critical frequency data suggests the overtone frequency swings come from multiple modes that open at dawn.





02/17/2019 10/14/2018 10/30/2018

Summary of Frequency Observations

- The ionosphere changes the apparent frequency of a skywave signal through Doppler effects and/or varying wave speeds. These effects cannot be ignored if on-the-air frequency measurement to better than 1Hz precision at HF is required.
- Vertically changing ionization caused by changing sun illumination angle can produce Doppler shifts between two fixed stations. But a changing wave speed produces an identical result.
- On-air frequency measurements of both 2.5 and 5 MHz WWV showed smooth daytime and turbulent nighttime frequency characteristics with a prominent negative swing at dusk and positive swing at dawn. Frequency characteristics at 10 MHz were turbulent for both day and night and did not exhibit higher order swings.
- The shadowing effect from rotation of the earth into and away from sunlight produces descending illumination at dawn and ascending illumination at dusk. These could produce the descending and ascending ionization responsible for positive and negative Doppler shifts. However observed timing of the swings, especially at dusk, does not align with shadowing geometry. Slow day-long and night-long frequency drifts were also noted. These suggest changing wave speed from changing free electron density plays a large if not dominant role as well.
- The dawn swings at 2.5 and 5 MHz showed multiple frequency overtones but 10 MHz did not. The critical frequency data shows opening of high angle propagation below 6 MHz at dawn, enabling multiple hops. Additional hops multiply effective path length changes, suggesting multiple hops and/or high angle propagation modes are the underlying cause for the overtone swings.