Observed Changes in Skywave HF Doppler Shifts As Cycle 25 Ramps Up

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Abstract

The authors have been observing and analyzing Doppler shifts on skywave high frequency (HF) signals for the Ham Radio Science Citizen Investigation (HamSCI) community since 2017 to 2022. During these five years the sunspot cycle has transitioned through the very deep minimum between cycles 24 and 25 to part way up cycle 25. Significant changes have been observed in Doppler behavior between 5 years ago and now. During the quiet years, the mode splitting seen on 5 MHz WWV over a Colorado to Texas path showed high order modes that manifested abruptly partway through the morning transition from night into day. More recent spectrograms show these modes to be continuous from start to finish. At 10 MHz the daytime frequency turbulence is now showing markedly greater excursions with exceptional excursions seen during some of the many solar flares that have occurred during this cycle. This paper presents comparative spectrograms highlighting some of these effects. Included are old and new comparisons of simultaneous three frequency spectrograms of the 2.5, 5, and 10 MHz WWV carriers and selected examples of mode splitting .

Introduction

Doppler shift characteristics in skywave high frequency (HF) signals have been observed to change as the sunspot cycle has transitioned from the low years between cycle 24-25 to the elevated sunspot numbers encountered in 2022. The characteristics showing the most change over a Colorado to Texas path are enumerated in Figure 1. Figure 2 shows the regions of the sunspot cycle compared in this study.

Solar Minimum Years 2017-2020	Active Cycle 25 in 2022
1. Nighttime Doppler variations do not scale with frequency in simultaneous three frequency recordings (Fig. 3).	1. Nighttime Doppler variations are greater in amplitude and do scale with increasing frequency.
2. Higher order Doppler modes often show abrupt manifestation partway through morning transition (Fig 4.).	2. Higher order Doppler modes are becoming continuous throughout entire morning transition.
3. Mode splitting almost never observed at 10 MHz or higher (Fig. 5).	3. Mode splitting now present at 10 MHz during morning and some evening transitions.
	4. Daytime absorption effects are stronger.

Figure 1. Major Differences Observed in Doppler Records

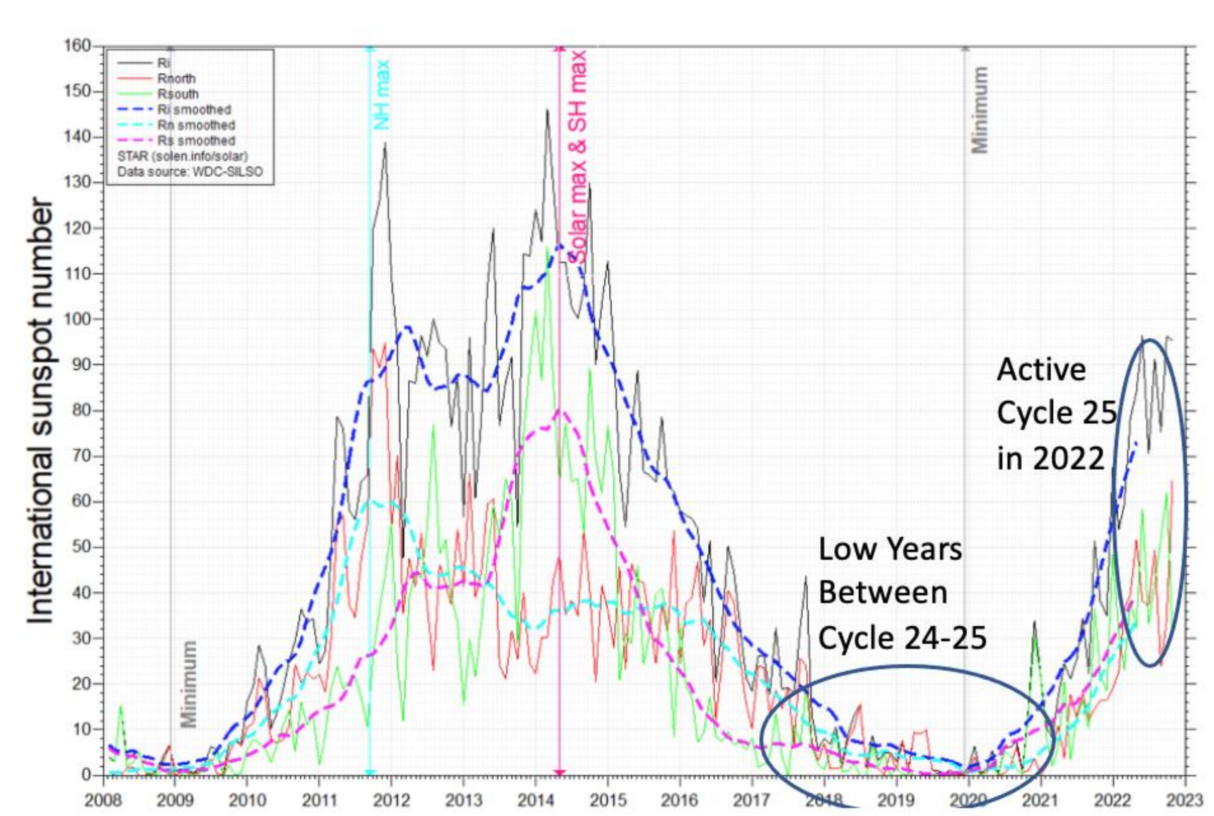
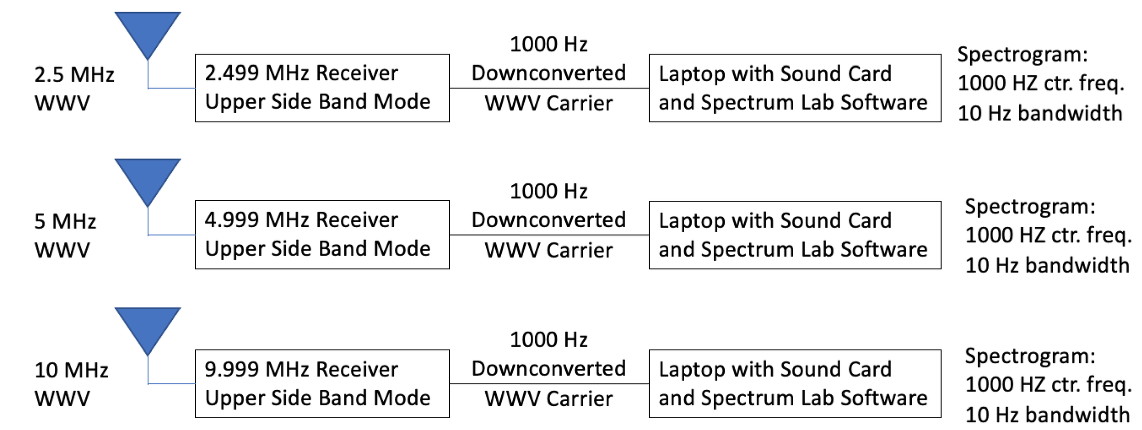


Figure 2. Sunspot Numbers in Compared Regions

https://solen.info/solar/images/cycle24.png

Instrumentation for Acquiring Simultaneous Spectrograms on 2.5 MHz, 5 MHz, and 10 MHz WWV Carriers



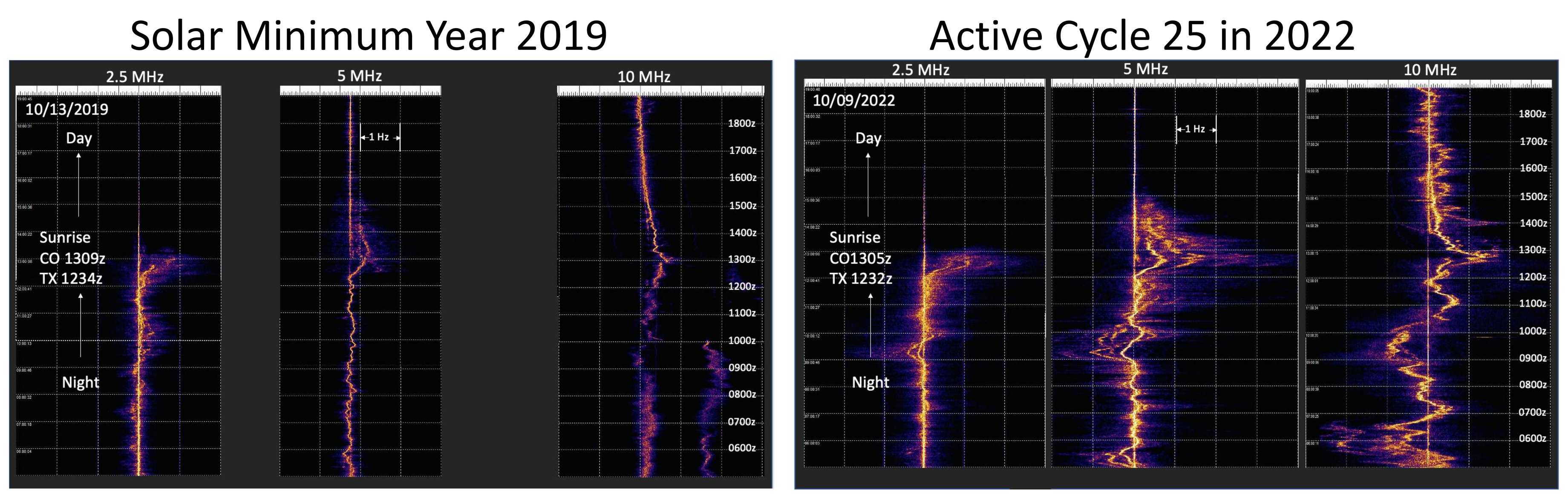


Figure 3. Simultaneous Three Frequency Records from 2019 and 2022.

Nighttime Doppler Shifts Have Increased in Amplitude and Scale with Frequency.

Path: WWV in Colorado to Amateur Radio Station WA5FRF in Texas.

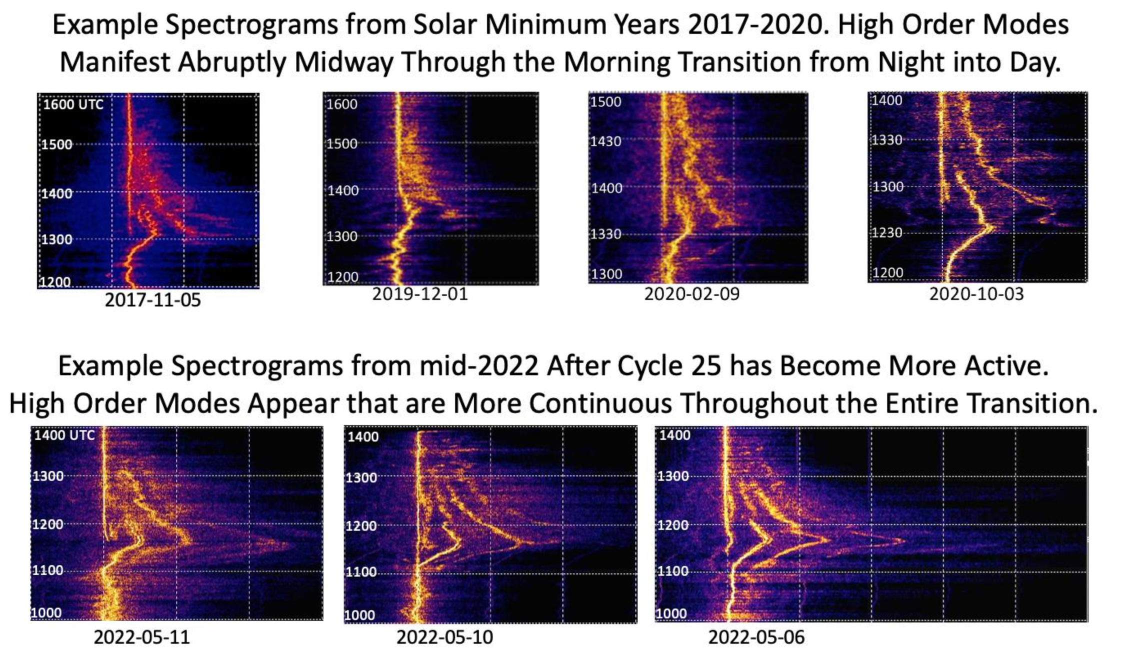


Figure 4. Higher Order Modes Manifested Abruptly at 5 MHz During Low Years (Top Row) but Were More Continuous After Cycle 25 Ramped Up (Bottom Row).

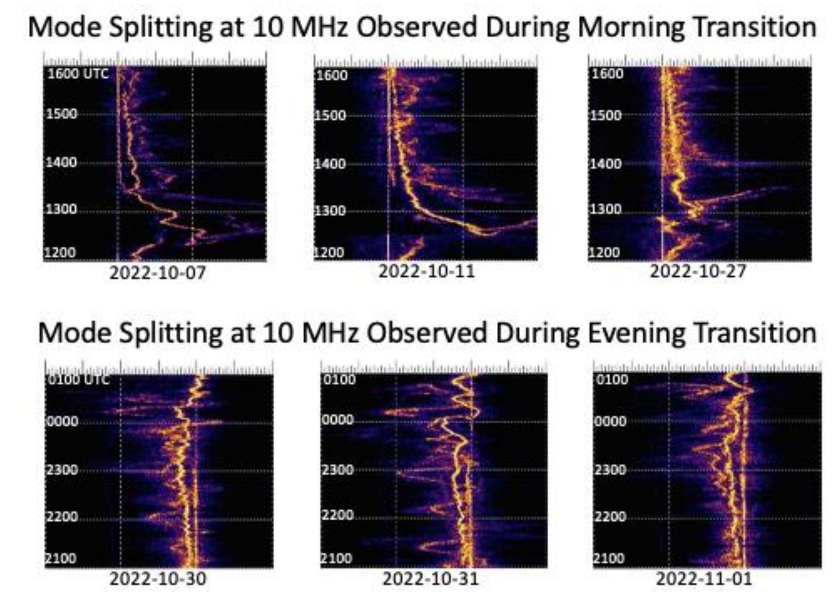


Figure 5. Mode Splitting at 10 MHz was Not Observed During the Low Years but was Observed During both Morning (Top) and Evening (Bottom) Night-Day Transitions in Late 2022.

Discussion

1. Theoretical Doppler shift scales with operating frequency and time rate of change of path length or path velocity between transmitter and receiver. However, frequency scaling was not observed in the 2019 record of Fig. 3. But the 3-frequency record from 2022 does show nighttime frequency variations that scale with frequency.

2. Mode splitting occurs when a Doppler trace splits into one or more divergent tracks, often in an overtone progression. Several instances of mode splitting on 2.5 and 5 MHz WWV carriers are shown in Figures 3 and 4. Previous studies suggest mode splitting is a consequence of the different path velocities of multiple hop modes that occur when layer height is changing. A sudden manifestation of a higher order mode part way through a morning transition is theorized to happen because the mode must wait for the ionization to reach a level sufficient to support a higher angle of radiation required by that mode. The upper half of Figure 4 shows examples of abrupt mode manifestation during the low years at 5 MHz. The lower half shows 2022 data where ionization levels are sufficient to support the modes continuously throughout the entire transition from night into day.

3. Mode splitting was never observed at 10 MHz or higher during the low years from 2017 through 2019. Figure 5 shows 10 MHz mode splitting observed both morning and evening in 2022. These results suggest an improved ability of the ionosphere to support higher order modes at higher frequencies. Critical Frequency, or foF2 ionosonde data is an indicator for possible high angle propagation, along with ray trace analyses. Figure 6 compares foF2 data between 2019 and 2022 showing the large increase in daytime critical frequency ushered in by cycle 25.

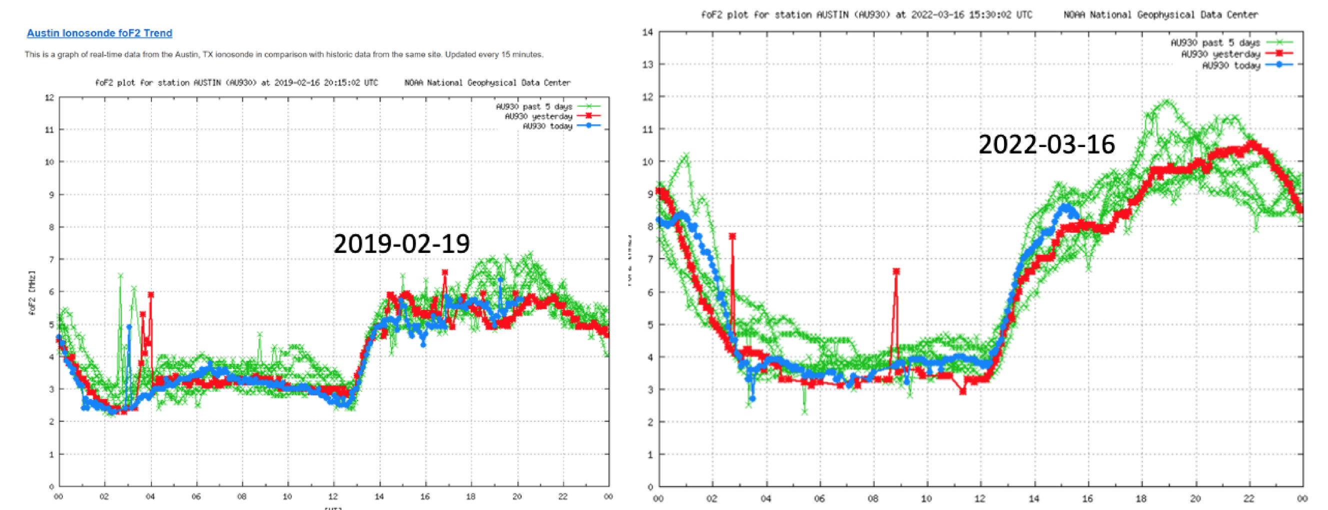


Figure 6. Comparison Of Morning and Daytime Critical Frequency Data between 2019 and 2022.

https://region6armymars.org/resources/solarweather.php

References

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