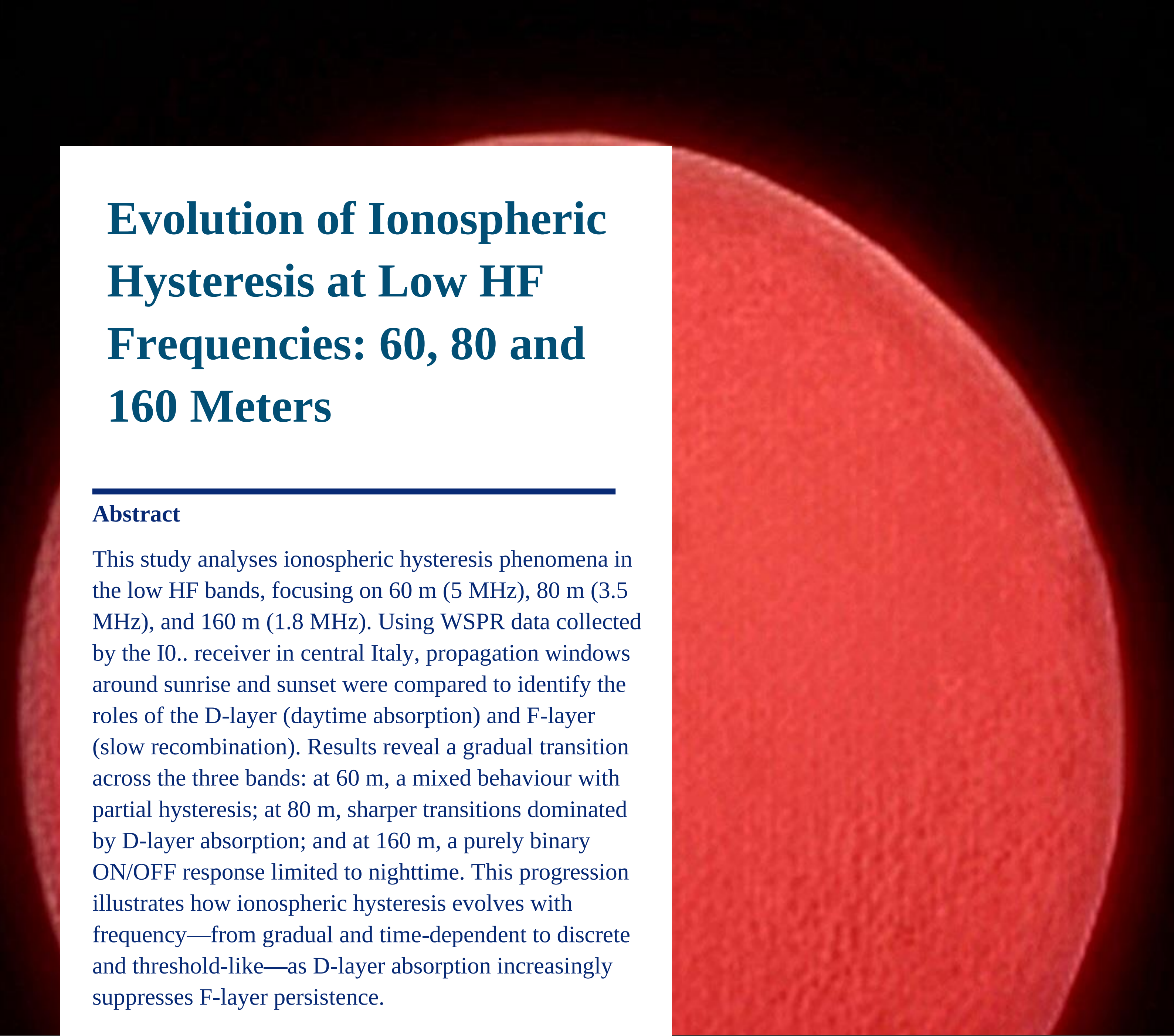

Evolution of Ionospheric Hysteresis at Low HF Frequencies: 60, 80 and 160 Meters

Abstract

This study analyses ionospheric hysteresis phenomena in the low HF bands, focusing on 60 m (5 MHz), 80 m (3.5 MHz), and 160 m (1.8 MHz). Using WSPR data collected by the I0.. receiver in central Italy, propagation windows around sunrise and sunset were compared to identify the roles of the D-layer (daytime absorption) and F-layer (slow recombination). Results reveal a gradual transition across the three bands: at 60 m, a mixed behaviour with partial hysteresis; at 80 m, sharper transitions dominated by D-layer absorption; and at 160 m, a purely binary ON/OFF response limited to nighttime. This progression illustrates how ionospheric hysteresis evolves with frequency—from gradual and time-dependent to discrete and threshold-like—as D-layer absorption increasingly suppresses F-layer persistence.

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Amateur Radio Propagation Studies
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Evolution of Ionospheric Hysteresis at Low HF Frequencies: 60, 80 and 160 Meters

Introduction
The ionosphere's response to variations in solar irradiation (sunrise and sunset) is not instantaneous: some layers exhibit slow recombination, while others act through nearly immediate absorption. The phenomenon known as *ionospheric hysteresis* manifests as temporal asymmetries in propagation windows. The aim of this work is to analyse and compare propagation characteristics in three low HF bands (60, 80, and 160 m) using WSPR signals received by I0.., in order to clarify how the dominant hysteresis mechanism changes with frequency.

Methodology
The data used consist of WSPR receptions collected by the I0.. receiver, located in central Italy. For all analysed bands (60, 80, and 160 meters), the same extraction and aggregation criteria were applied: each point in the graphs represents a single WSPR reception, with local timestamp and raw SNR value. Vertical lines indicate local sunrise and sunset times. Observations were conducted under geomagnetically quiet conditions to minimise the influence of external disturbances. Specifically, the period from 13 to 17 October 2025 was characterised by low geomagnetic activity, as confirmed by the planetary Kp and Ap indices:

- 13 October: Kp avg. 2, Ap 6
- 14 October: Kp avg. 1–2, Ap 5
- 15 October: Kp avg. 2, Ap 7
- 16 October: Kp avg. 2–3, Ap 8
- 17 October: Kp avg. 2, Ap 6

All values remained below the geomagnetic storm threshold (Kp < 4), indicating quiet conditions ideal for analysing local ionospheric mechanisms without interference from solar or magnetospheric events. Using data collected under quiet conditions allows for more confident isolation of D- and F-layer transition effects and attribution of observed dynamics to intrinsic ionospheric responses.

Note: The I0.. receiver is located in central Italy; the data represent stations received by its antenna and therefore reflect heterogeneous propagation paths. In particular, on the 60 m band, propagation paths are predominantly regional and NVIS-type (Near Vertical Incidence Skywave), involving short-range ionospheric reflections primarily through the F-layer. In contrast, on the 160 m band, paths tend to be more direct and low-angle, with greater exposure to D-layer absorption. These geometric differences influence the visibility of hysteresis phenomena and must be considered when interpreting WSPR data.

Results

60 meters (5 MHz)

The graph in Figure 1 shows WSPR receptions on the 60 m band at I0... The band exhibits strong nighttime activity but also shows some daytime receptions, albeit less frequent.

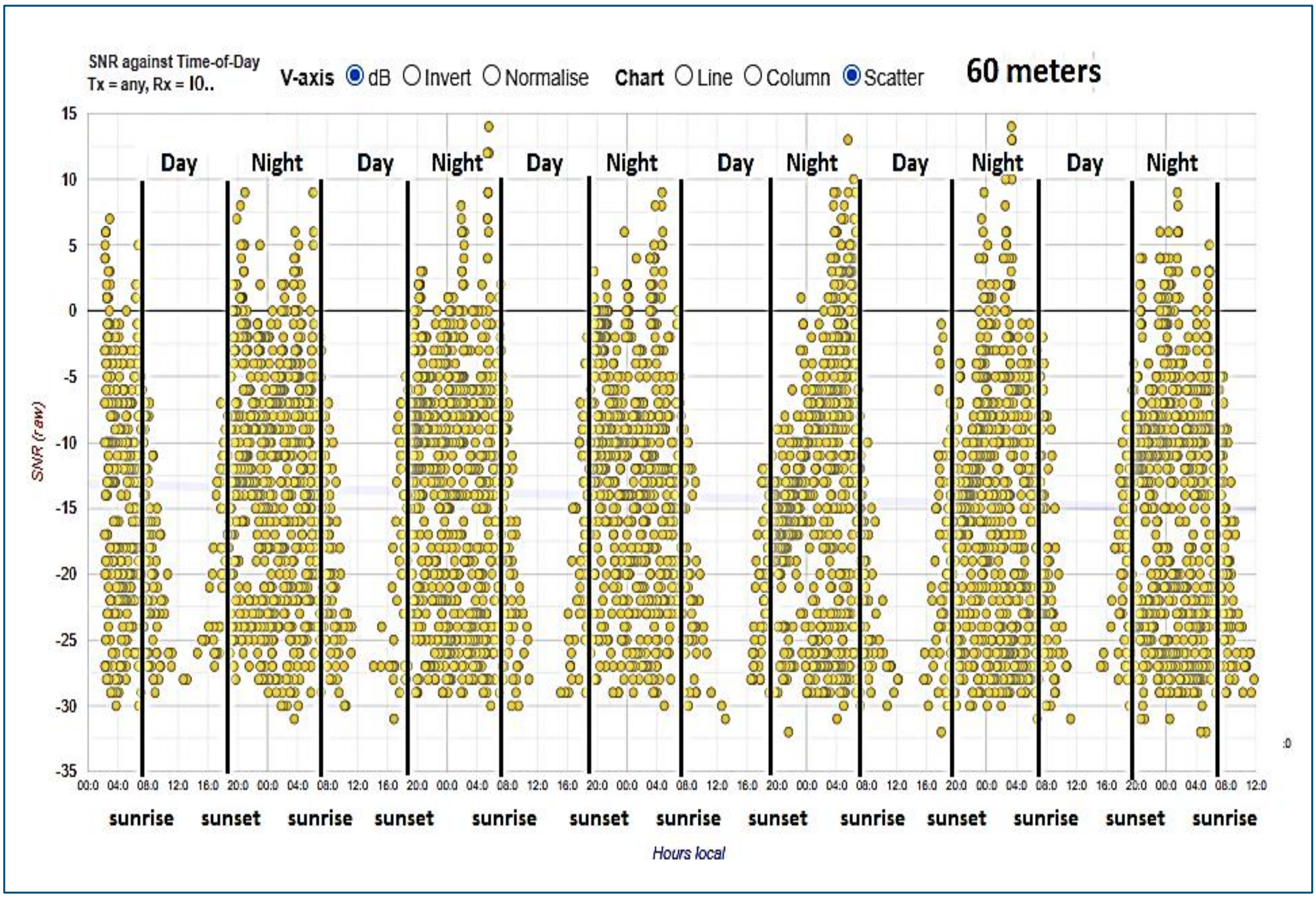


Fig. 1 – WSPR reception in the 60 meter band (5 MHz) at I0... Analysis: The distribution of data points indicates an intermediate behavior between absorption and reflection. At sunrise, a gradual thinning of receptions is observed (progressive formation of the D-layer). Conversely, at sunset, reopening begins even before the geometric sunset and intensifies gradually. These signals highlight a nocturnal persistence of the F-layer and a progressive dissolution of the D-layer in the morning, indicating a form of partial hysteresis.

80 meters (3.5 MHz)

The graph in Figure 2 (based on historical data and WSPR processing at I0..) highlights the typical dynamics of this band: D-layer absorption predominates, with relatively sharper transitions compared to 60 m.

Analysis: The 80 m band shows distinct evening openings and rapid morning closures. Although some specific paths may exhibit tails or delays, in most cases the D-layer plays a dominant role, suppressing the F-layer persistence observed in higher bands.

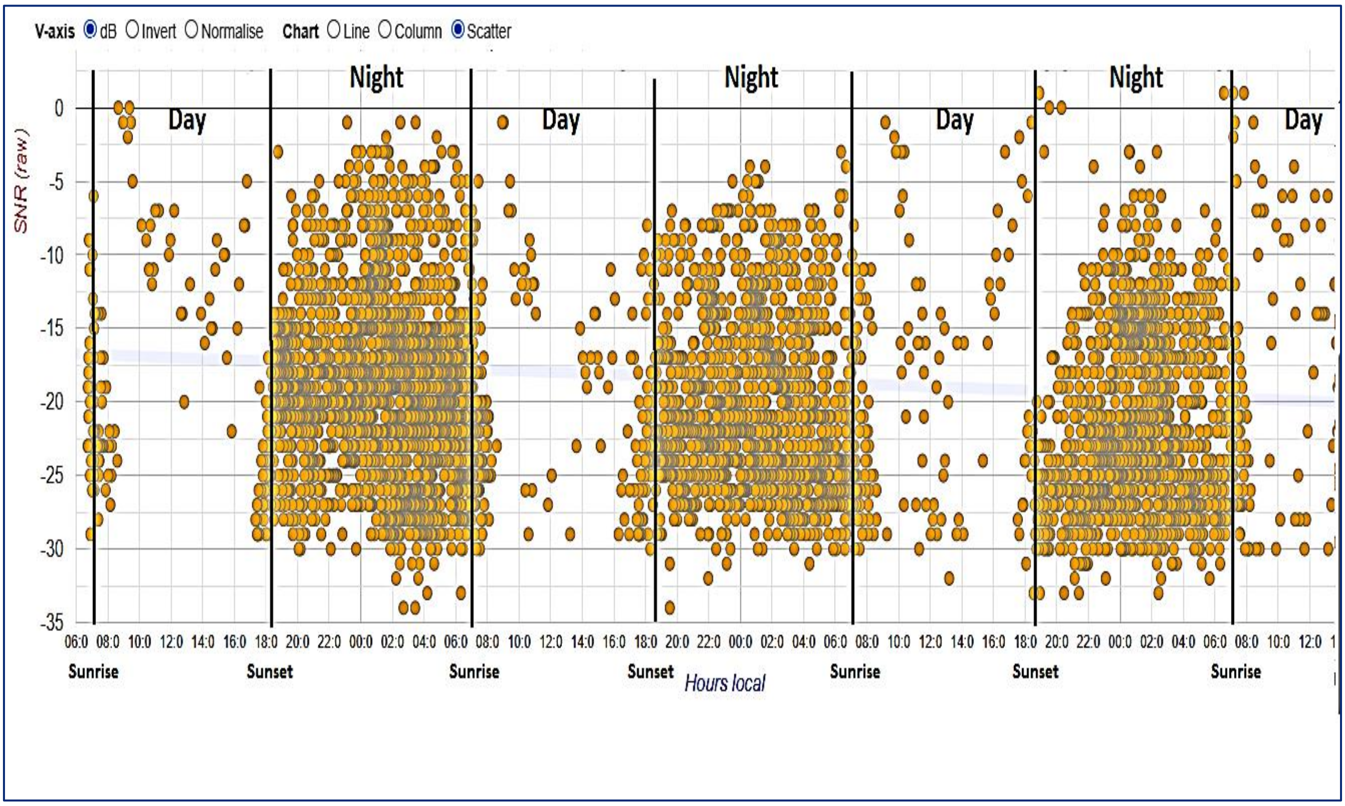


Fig. 2 – WSPR reception in the 80 meters band (3.5 MHz) at I0... Analysis: The 80 m band shows sharp evening openings and rapid morning closings. Although lingering signals or delays may be observed in some specific situations and paths, the D-layer generally plays a dominant role, suppressing the F-layer persistences that emerge in the higher bands.

160 meters (1.8 MHz)

The graph in Figure 3 shows an extremely sharp behaviour: the band opens only during nighttime and closes instantly at sunrise.

Analysis: At 1.8 MHz, D-layer absorption is so efficient that even QRP signals are cancelled by minimal increases in ionisation. The behaviour is threshold-like or ON/OFF, with no measurable persistence or delay.

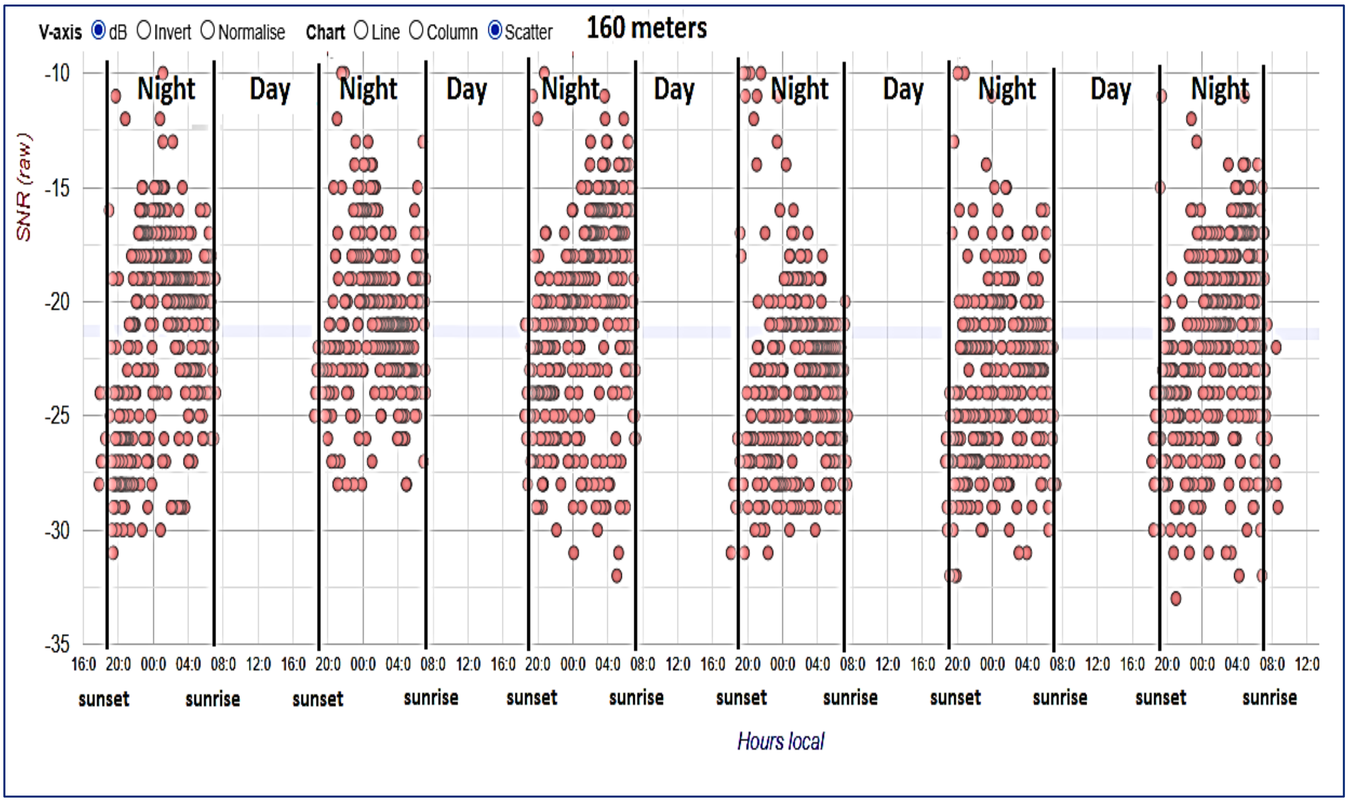


Fig. 3 – WSPR reception in the 160 meters band (1.8 MHz) at I0... Analysis: At 1.8 MHz, D-layer absorption is so efficient that even QRP signals are nullified at the slightest increase in ionization. The behavior is threshold/ON-OFF type, with no measurable persistence or delay results. The band opens only during the nighttime hours and closes instantaneously at sunrise.

Detailed Analysis of SNR Behaviour on 60 m: Sunrise–Sunset Dynamics

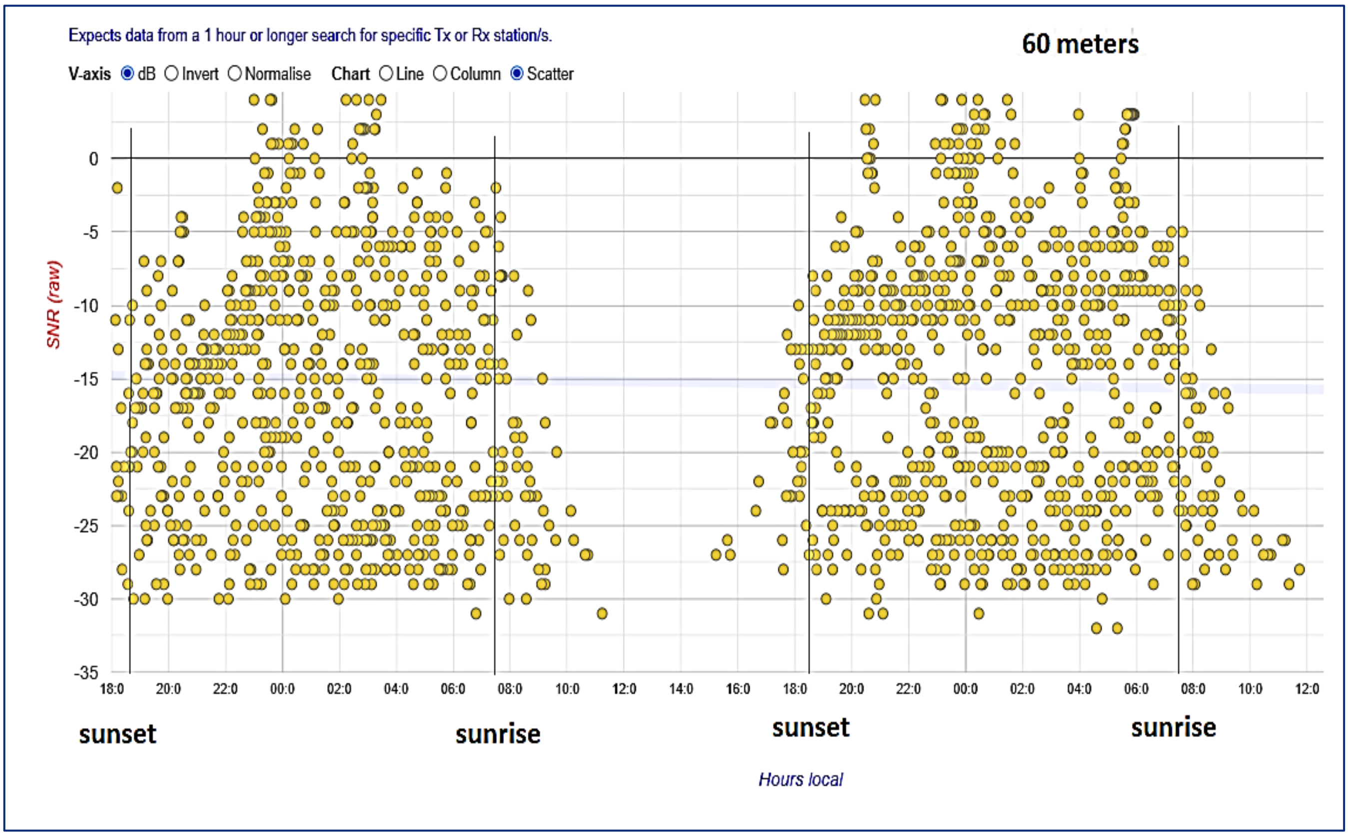
A closer analysis of the 60 m graph reveals distinctive features in the distribution of SNR values near solar transitions. Persistence beyond solar limits After sunset, receptions extend up to approximately two hours beyond geometric sunset, with generally attenuated SNR values (around –30 dB or lower). This suggests a gradual decay of ionisation in the D-region, which does not cease abruptly at sundown. Before sunrise, receptions are detected up to about two hours prior to sunrise, with comparable or slightly lower SNR values. This indicates that propagation can begin before the sun appears on the horizon, likely due to early ionisation induced by diffuse solar radiation.

Asymmetry between sunrise and sunset

The data reveal a clear temporal asymmetry between the two transitions. After sunrise, propagation resumes more abruptly, accompanied by a progressive increase in SNR values. In contrast, the decline before sunset is slower and less pronounced. This behaviour is consistent with the ionospheric hysteresis phenomenon, where the ionosphere's response to changes in solar irradiation is not symmetrical. Specifically, morning ionisation rebuilds more efficiently than the evening decay, likely due to the higher photon flux and the increase in electron temperature after dawn.

Ionospheric Propagation Dynamics on 60 m: Evidence of Hysteresis

The following graph presents a two-day focus on the 60 m band (5 MHz), based on WSPR receptions by I0... Each yellow dot represents a single reception, with local timestamp and raw SNR value, while vertical lines mark local sunrise and sunset times for each day. Propagation persists for up to two hours after sunset and resumes up to two hours before sunrise, with generally attenuated SNR values. This behaviour reveals a form of partial ionospheric hysteresis, typical of the 60 m band under geomagnetically quiet conditions: the evening decline is gradual, while the morning recovery is sharper, suggesting slower nocturnal recombination compared to morning re-ionisation. The 60 m band, lying at the boundary between NVIS and medium-distance propagation, is particularly sensitive to ionospheric transitions, and the absence of geomagnetic disturbances allows for clear observation of the natural dynamics of the D and E layers. The regularity of WSPR receptions and their temporal distribution also provide a valuable basis for statistical analysis and educational modelling.



Comparison and Discussion

Comparing the three bands reveals a clear progression: at 60 m, a balance between the F-layer and D-layer is observed, with a significant component of time-dependent hysteresis; at 80 m, D-layer absorption strongly limits persistence, resulting in sharper transitions; at 160 m, D-layer effects are so dominant that they suppress any residual propagation from upper layers. From an operational perspective, 60 m is well suited for investigating hysteresis under transitional conditions, while 80 and 160 m are more appropriate for observing ionospheric absorption and threshold behaviour. Understanding these regimes is useful for planning WSPR experiments and predicting operational windows in amateur radio activities. The progression across the three bands can be summarised in the following comparative table, highlighting the shift from gradual and time-dependent behaviour (60 m) to increasingly sharp and threshold-like responses (80 and 160 m), consistent with the growing dominance of the D-layer.

Cross-Validation with European Stations

To assess the broader applicability of the observed hysteresis mechanisms, additional analyses were conducted using WSPR data from other European stations. These independent datasets revealed similar temporal asymmetries and transition behaviours across the same frequency bands (60, 80, and 160 metres). This cross-validation supports the generality of the findings beyond the specific I0.. location, confirming that the hysteresis dynamics described in this study are representative of wider ionospheric behaviour under quiet geomagnetic conditions.

HF Band	Frequency	Behaviour at solar transition	Ionospheric dominance	Type of hysteresis observed
60 m	5 MHz	Gradual, with post-sunset persistence and pre-dawn reactivation	F/D balance	Partial, time-dependent
80 m	3.5 MHz	Sharper transitions, with distinct opening and closing	D-layer dominant	Weak, threshold-limited
160 m	1.8 MHz	Threshold-like ON/OFF behaviour, immediate shutdown at sunrise	Strong D-layer dominance	Absent, binary response

SNR Distribution as a Function of Distance: Geometric and Absorption Evidence

The following graphs show the distribution of SNR values as a function of the distance of stations received by I0.., for each of the analysed bands (160, 80, 60, and 40 metres). Each point represents a single WSPR reception, with the horizontal axis indicating distance (in kilometres) and the vertical axis the raw SNR value. This visualisation highlights the geometric and absorptive characteristics of ionospheric propagation at different frequencies. In the lower bands (160 and 80 m), propagation is strongly constrained to short-to-medium ranges, with signals generally absent beyond 2000 km due to the high efficiency of D-layer absorption. In contrast, the 60 m band exhibits a broader and more articulated distribution, with NVIS (Near Vertical Incidence Skywave) receptions at short range and medium-distance signals extending up to approximately 3750 km. This confirms its intermediate role between F-layer reflection and D-layer absorption. The 40 m band, included as an upper reference, displays the most extensive propagation, with regular receptions beyond 10,000 km and high SNR values. This underscores the reduced influence of the D-layer and the predominance of ionospheric reflection at this frequency. The SNR-versus-distance analysis reinforces the progression observed in the temporal graphs: from threshold-limited and discrete propagation (160 m), to a more gradual and stratified response (60 m), culminating in extended and continuous propagation (40 m).

Band (Wavelength)	Frequency (MHz)	Ionospheric Dominance	Manifestation of Hysteresis (Temporal and Spatial)
160 m	1.8	D-layer Prevalent	**Absent**, threshold behavior. Propagation confined to **short-to-medium range** (< 1500 km). Instantaneous closing at sunrise.
80 m	3.5	D-layer Dominant	**Weak**, attenuated threshold. Propagation concentrated in **short-to-medium range** (< 2000 km). Sharp and rapid transitions.
60 m	5.0	F/D Equilibrium	**Partial, temporal**, and gradual. NVIS/Medium range propagation with DX signals. Persistence after sunset and pre-sunrise re-activation.
40 m	7.0	F-layer (Reference)	Hysteresis less critical. **Extended Long-Distance** propagation (> 10.000 km). Used as a contrast to D-layer dominance.

Conclusions

This work summarises experimental evidence that the *nature* of ionospheric hysteresis changes with frequency: from gradual and time-dependent at 60 m, to increasingly binary and dominated by absorption at 80 and 160 m. The WSPR approach using QRP power levels proves to be a sensitive tool for highlighting these mechanisms. Future developments include seasonal analysis, integration of geomagnetic data, and systematic study of propagation paths to isolate geometric effects.

Important notes

WSPR reception data were sourced from the public database WSPR.Rocks, curated by Phil (VK7JJ). Explicit written permission for the use of these data in this publication was kindly granted by the site administrator.