The Effects of the Solar Eclipse on Radio Waves

Arthur Fumarola

Brookdale Community College

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Mentors: Kevin Squires and John Magliacane

Advisors: Nancy Cizin and Ana Teodorescu

Email: arthur.fumarola@gmail.com

Abstract

When the Moon covers the Sun during a solar eclipse, the layer of air high above Earth called the ionosphere changes. The ionosphere changes due to the reduction in solar radiation, mainly in its lower D-layer and upper F-layer. This can make some radio signals travel farther or become clearer. Using data from the WWVB signal (60 kHz) and propagation modeling software (Proplab-Pro), the following research will show how these signals behave when there's less sunlight. By looking at how radio waves act during different eclipses, we can get a deeper understanding of how this affects radio communication.

I. Introduction

Radio waves depend on the ionosphere for reflection and propagation, especially at lower frequencies. The ionosphere's D-layer is particularly sensitive to changes in solar radiation. During a solar eclipse, the temporary reduction in solar radiation leads to decreased ionization in the D-layer, which could then alter the transmission of radio waves. These changes can enhance signal clarity and range for certain frequencies. Radio waves are crucial for communication and navigation systems. Radio propagation depends on interactions or reactions with the Earth's atmosphere, particularly the ionosphere. The D layer is important because it absorbs instead of reflecting or refracting like the E and F layers.

Solar eclipses have unique atmospheric and ionospheric properties. During an eclipse, the moon covers the sun and at that time the ionization in the D layer decreases (Temperature also drops). The sudden decrease in ionization causes disruptions in high-frequency (HF) radio propagation and enhanced low-frequency signal transmission. The primary objective of this research was to analyze how the sudden reduction in solar radiation during a solar eclipse alters ionospheric ionization and, consequently, radio wave propagation.

II. Information review

The WWVB signal, broadcasting at 60 kHz from Fort Collins, Colorado, was suited for observing these effects. During the April 8, 2024, solar eclipse, this signal intersected the eclipse's path over Ohio, with a receiver located in New Jersey.

One interesting observation was a “bow wave” or “shockwave” effect that happened before the eclipse even started [1]. It showed that the ionosphere was already reacting to the eclipse as the Moon began to block the Sun. This pre-eclipse effect was caused by the gradual reduction in solar radiation as the Moon moved into position [1].

The data collected during the eclipse showed that the ionosphere didn’t react the same way everywhere. The radio signals took multiple paths, which caused small changes in the signal strength. These were especially noticeable at the peak of the eclipse, where the ionosphere and radio waves were interacting. The ionosphere’s D-layer, which usually absorbs lower-frequency radio waves during the day, became less ionized during the eclipse [1]. This allowed low-frequency signals, like the 60 kHz WWVB signal from Fort Collins, Colorado, to travel farther and become clearer [1]. As the eclipse progressed, the ionization levels dropped, and the region of the ionosphere grew in altitude, causing the radio path between New Jersey and Colorado to lengthen. This increased the phase shift of the signal. Once the eclipse ended, the ionosphere started to return to normal, and the phase shift decreased.

III. Background

A. What Radio Waves Are / Do

Radio waves are a type of electromagnetic radiation used for communication, navigation, and broadcasting. They have frequencies ranging from about 3 kHz to 300 GHz and can travel long distances through the atmosphere. Radio waves are used for technologies like AM/FM radio, television, mobile phones, and GPS [5].

Band	Frequency Range	Wavelength Range
Extermely Low Frequency (ELF)	<3 kHz	> 100 km
Very Low Frequency (VLF)	3 to 30 kHz	10 to 100 km
Low Frequency (LF)	30 to 300 kHz	1 m to 10 km
Medium Frequency (MF)	300 kHz to 3 MHz	100 m to 1 km
High Frequency (HF)	3 to 30 MHz	10 to 100 m
Very High Frequency (VHF)	30 to 300 MHz	1 to 10 m
Ultra High Frequency (UHF)	300 MHz to 3 GHz	10 cm to 1 m
Super High Frequency (SHF)	3 to 30 GHz	1 to 1 cm
Extremely High Frequency (EHF)	30 to 300 GHz	1 mm to 1 cm

Figure 1. Image of radio waves frequency ranges. [7]

B. **What the Ionosphere Is / What It Does**

The ionosphere is a layer of Earth's upper atmosphere, located between 60 and 1000 km above the surface. It is divided into layers: D, E, and F. The D-layer, which is closest to Earth, absorbs lower-frequency radio waves during the day, while the E and F layers reflect and refract higher-frequency waves [2]. That enables long-distance communication. The ionosphere's behavior changes with solar radiation, time of day, and geomagnetic conditions. During a solar eclipse, the reduction in sunlight causes the D-layer to become less ionized, which affects how radio waves propagate. This makes the ionosphere a very important factor in understanding radio communication, especially during events like eclipses.

C. **What a Solar Eclipse Is**

A solar eclipse occurs when the Moon passes between the Earth and the Sun, temporarily blocking sunlight. This creates a shadow on Earth and causes a sudden drop in solar radiation. During a total solar eclipse, like the one on April 8, 2024, the Moon completely covers the Sun, creating a brief period of darkness in the path of totality. This reduction in sunlight affects the Earth's atmosphere, particularly the ionosphere, which relies on solar radiation to maintain its ionization levels [4]. The eclipse mimics nighttime conditions which cause changes in temperature and ionization.

D. **How a Solar Eclipse Affects Radio Waves**

During a solar eclipse, the reduction in solar radiation causes the ionosphere's D-layer to become less ionized. This decrease in ionization allows low-frequency radio waves, like the 60 kHz WWVB signal, to travel farther and become clearer since they are no longer being absorbed as strongly. At the same time, high-frequency radio waves may weaken because the upper layers of the ionosphere (E and F) are less reflective [1].

E. **How the Ionosphere gets effected by the Solar Eclipse**

The Ionosphere is significantly affected by a solar eclipse due to the temporary loss of solar radiation [3]. During an eclipse, the Moon blocks sunlight, causing a rapid decrease in ionization. This leads to weakened radio wave propagation, and it alters communication and navigation signals. As the eclipse finishes and sunlight starts to return, ionization levels gradually come back to normal [1].

IV. What My Research is Proving or Creating

This research aims to prove that the temporary decrease in solar radiation during a solar eclipse leads to measurable changes in the ionosphere's structure, particularly a decrease in ionization in the D-layer and an increase in F-layer electron density. These changes influence radio wave propagation, improving the transmission quality and range for both LF and high-frequency (HF) signals.

This project contributes to a deeper understanding of how natural phenomena can temporarily enhance or hinder radio communications. Specifically, it shows that LF signals experience less attenuation during an eclipse due to the reduced D-layer ionization. It also shows that HF signals benefit from improved reflection off the strengthened F2 layer, enhancing long-distance communication.

V. Research and Implementation

Data Collection

Signal strength measurements were taken during the April 8, 2024, total solar eclipse and compared to control measurements taken one month later. The Proplab-Pro software suite was utilized to simulate ionospheric conditions, signal propagation paths, and frequency responses.

Tests

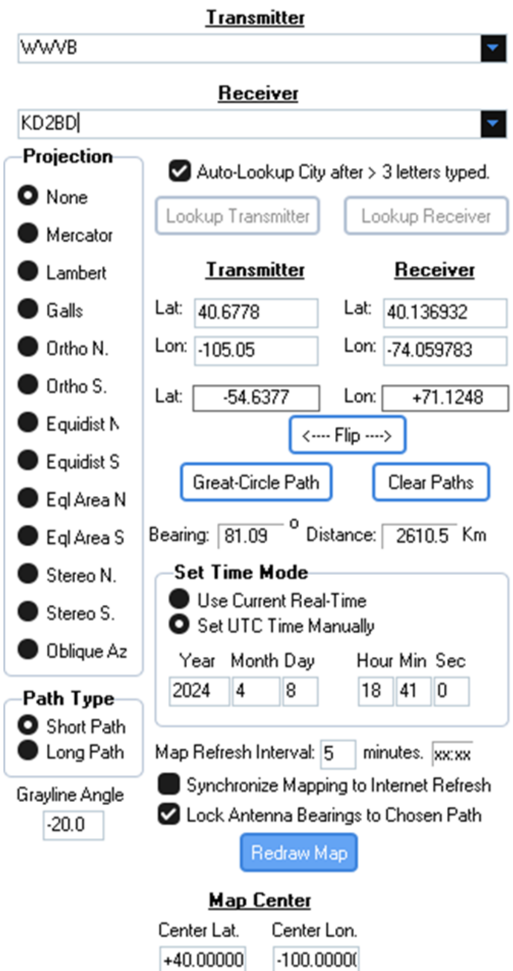

Figure 2. Coordinates of WWVB station transmitter in Colorado and KD2BD Station receiver in New Jersey. [6]

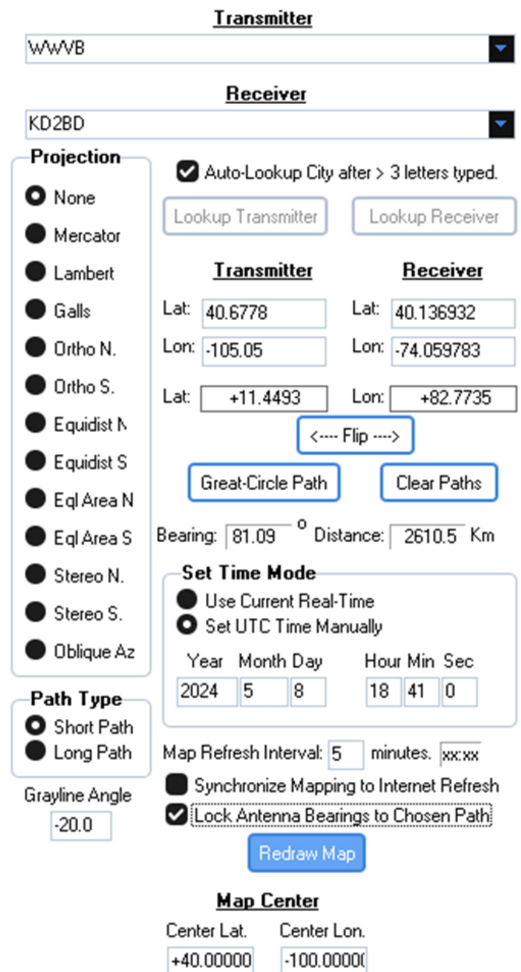

Figure 3. Coordinates of WWVB station transmitter in Colorado and KD2BD Station receiver in New Jersey one month later. [6]

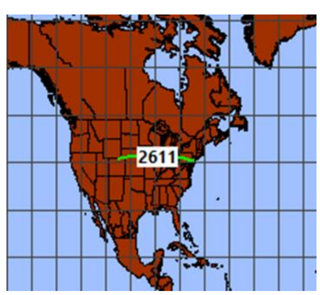

Figure 4. Map of the distance of the coordinates connected by the Great-Circle Path

(shortest path, also follows the natural curve of Earth) [6]

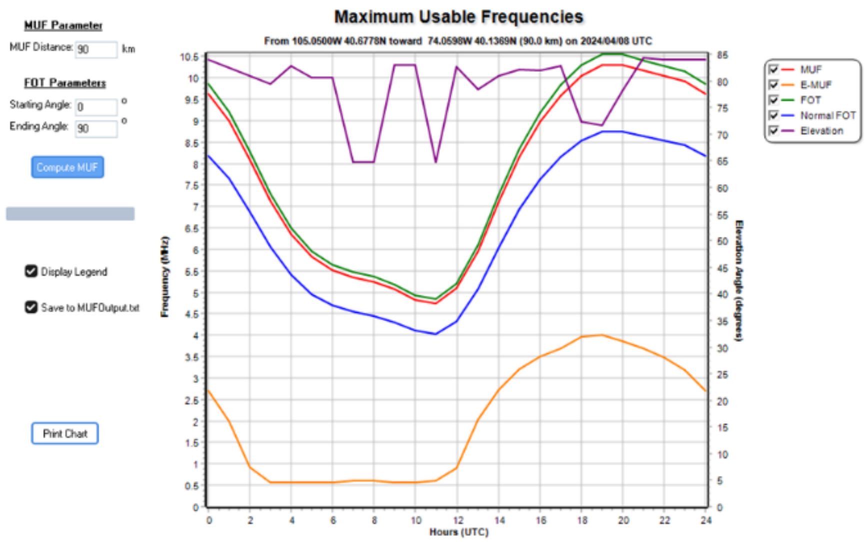

Figure 5. Chart of Maximum Usable Frequencies (MUF) on day of Eclipse. MUF is between 10-10.5. Frequency increases on the day of the eclipse. This could transmit LF waves over greater distances, but for HF is does grant better communication for long-distance. [6]

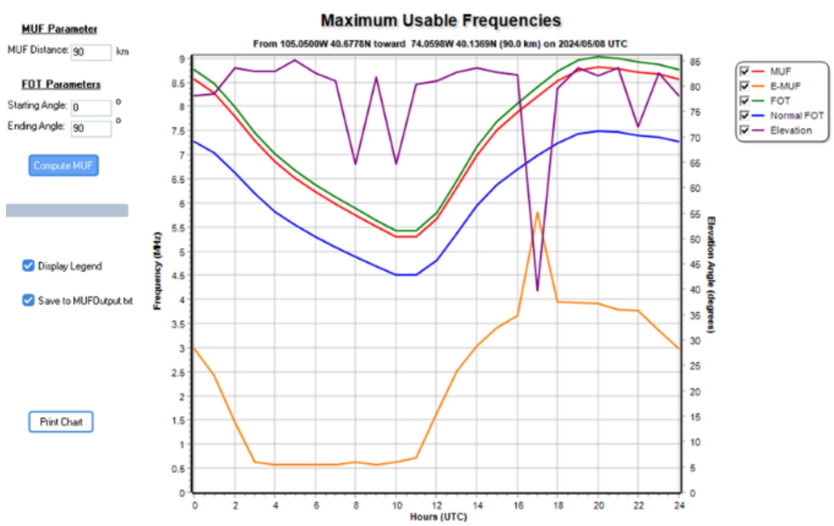

Figure 6. Chart of Maximum Usable Frequencies (MUF) after the Eclipse. MUF is between 8.5-9. Frequency decreases after the eclipse. [6]

Ionospheric Statistics

Critical F2-Layer Freq:	10.00
M(3000)F2:	2.60951
Max. F2-Layer Height:	331.08
Max F2 Electron Den:	1.24e+12
Critical F1-Layer Freq:	5.49
Max. F1-Layer Height:	227.44
Max F1 Electron Den:	3.73e+11
Critical E-Layer Freq:	3.80
Max. E-Layer Height:	110.00
Max. E-Layer Density:	1.79e+11
Critical D-Layer Freq:	0.36
Max. D-Layer Height:	81.01
Max. D-Layer Density:	1.58e+09
Solar Zenith Angle:	34.86
Elevation Angle:	55.14
Solar Declination:	7.83
Spread-F Prob:	0.00
Magnetic DIP:	68.16
Sunspot Number:	144
Magnetic Ap Index:	0.0
Transmitter Height:	1580.0
Receiver Height:	20.0

(in meters)

Eclipse day is on the left.
One month later is the right.

Ionospheric Statistics

Critical F2-Layer Freq:	8.60
M(3000)F2:	2.54592
Max. F2-Layer Height:	329.03
Max F2 Electron Den:	9.18e+11
Critical F1-Layer Freq:	5.65
Max. F1-Layer Height:	242.37
Max F1 Electron Den:	3.95e+11
Critical E-Layer Freq:	3.91
Max. E-Layer Height:	110.00
Max. E-Layer Density:	1.89e+11
Critical D-Layer Freq:	0.37
Max. D-Layer Height:	81.01
Max. D-Layer Density:	1.68e+09
Solar Zenith Angle:	25.93
Elevation Angle:	64.07
Solar Declination:	17.52
Spread-F Prob:	0.00
Magnetic DIP:	68.15
Sunspot Number:	149
Magnetic Ap Index:	0.0
Transmitter Height:	1580.0
Receiver Height:	20.0

(in meters)

Figure 7. Shows that D-layer electron density slightly decreases on the day of the eclipse. Lower electron density means a drop in the ionosphere. A drop for LF allows for better propagation. [6]

Figure 8. F2-Layer frequency increases on the day of the eclipse. Higher frequency for HF means better travel over long distances. Higher electron density means improved propagation. [6]

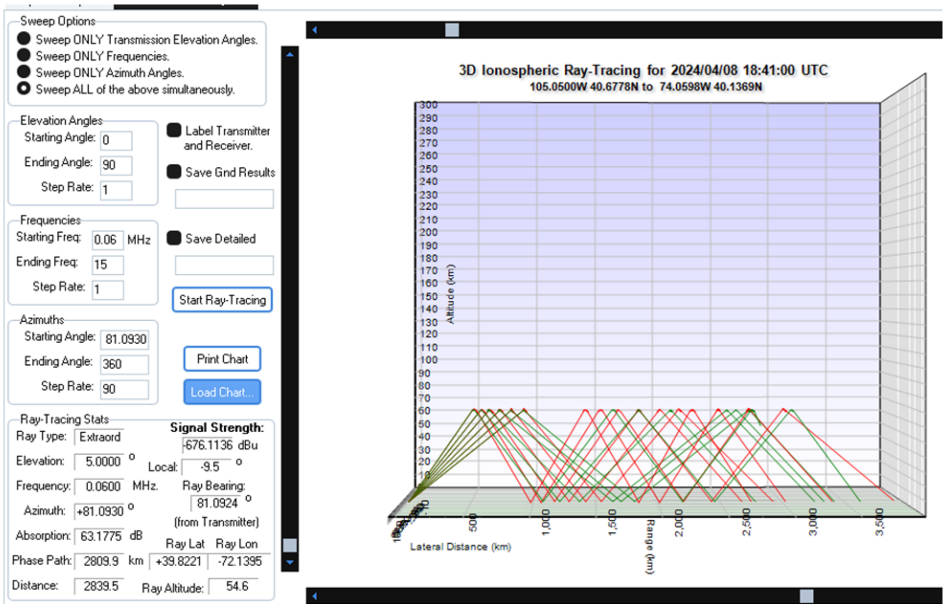

Figure 9. On the day of the Eclipse, it is hard to see but the distance for Ray-Tracing is slightly better. Phase path and lateral distance slightly lengthened. [6]

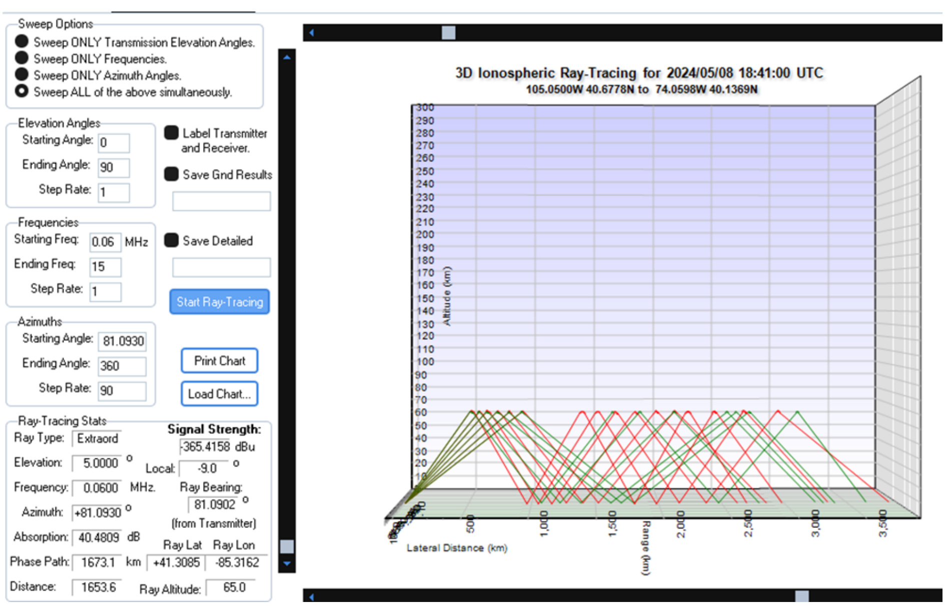

Figure 10. One month later the distance for Ray-Tracing is slightly worse. Phase path and lateral distance stayed the same. [6]

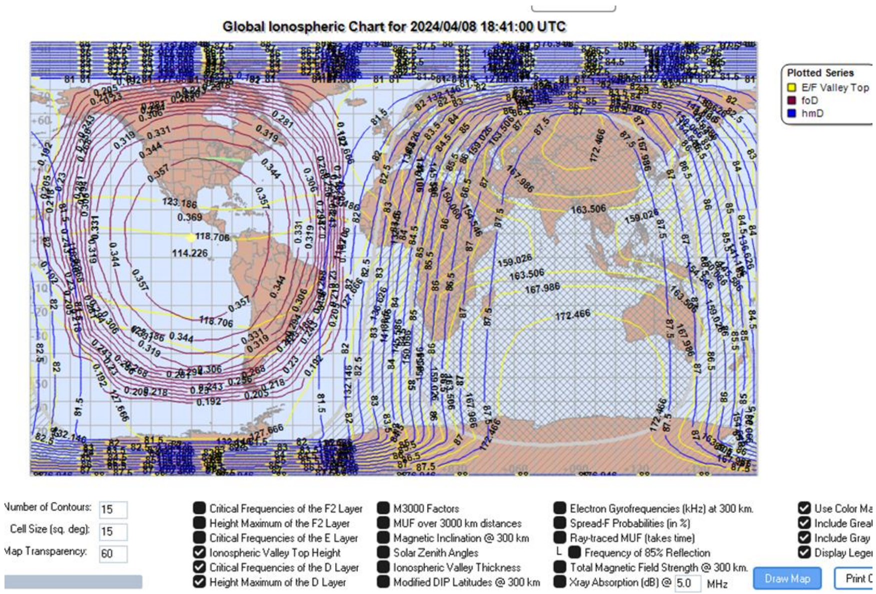

Figure 11. On the day of the Eclipse, the graph shows slightly decreased critical frequencies for the D-layer which proves that LF signal strength gets a little better overall. [6]

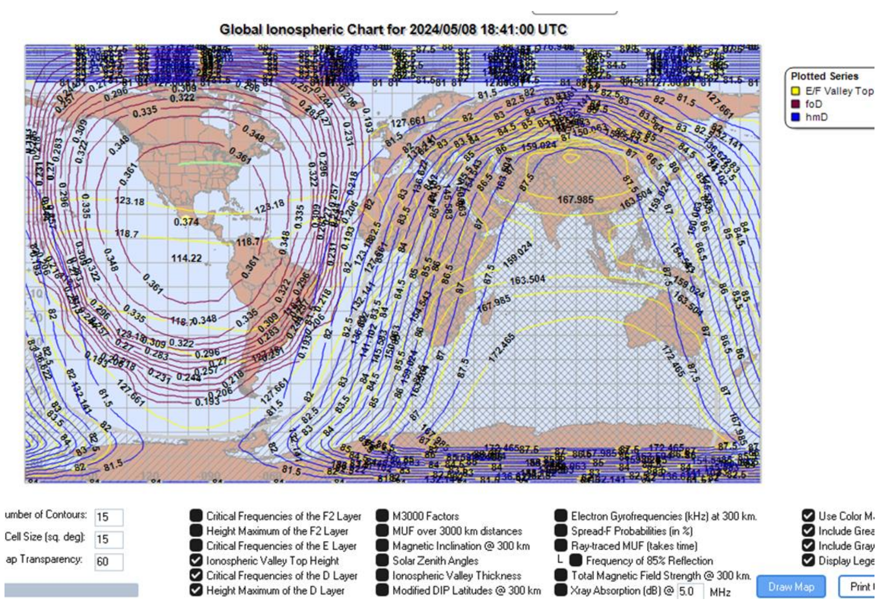

Figure 12. One month later, the graph shows slightly increased critical frequencies for the D-layer which proves that LF signal strength gets a little worse compared to the eclipse. [6]

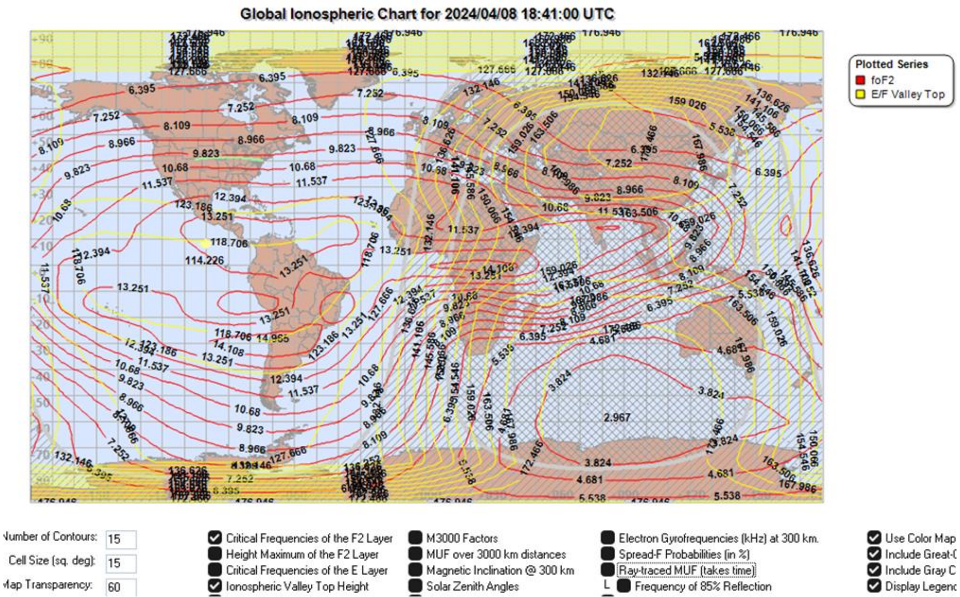

Figure 13. On the day of the eclipse, the graph that the critical frequencies for the F-layer increases, HF waves get better and stronger reflections which leads to improved long-distance communication. [6]

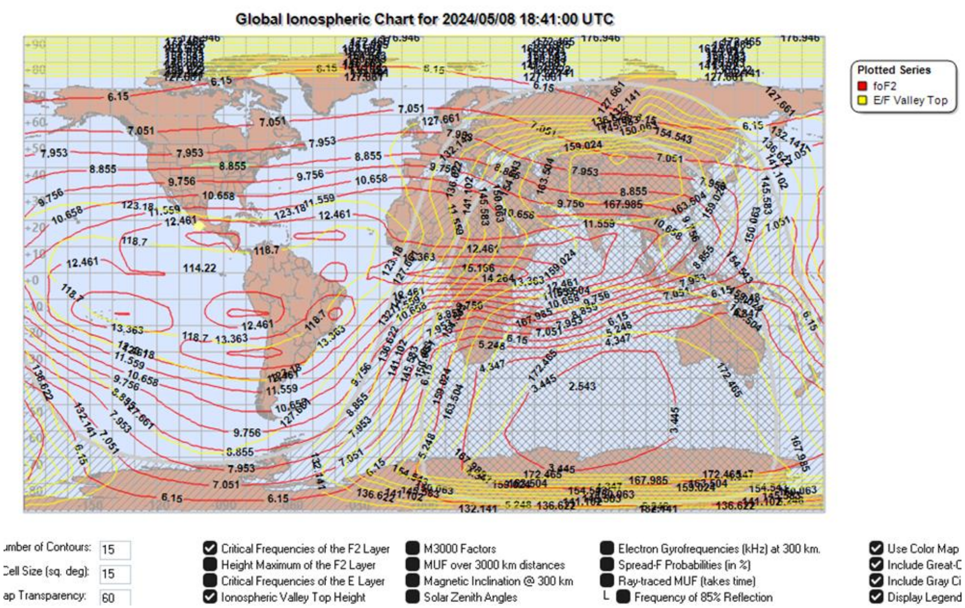

Figure 14. One month later, the graph shows the critical frequencies for the F-layer decreases, HF get weaker reflections which leads to worse long-distance communication. [6]

VI. Key Observations

- **F2-Layer Frequency Increase:** During the eclipse, the F2-layer showed higher critical frequencies, suggesting stronger HF reflection capabilities.
- **D-Layer Electron Density Decrease:** Reduced D-layer ionization during the eclipse led to less absorption of LF signals, allowing them to travel greater distances.

- **Ray Tracing:** Propagation path lengths increased slightly during the eclipse, indicating enhanced LF transmission and improved signal travel distance.
- **Frequency Behavior:** On the day of the eclipse, transmission frequencies were generally higher across the ionospheric layers compared to a normal day.

VII. Results

The data confirmed that LF Signals strengthened during the eclipse due to decreased D-layer absorption. The D-layer usually absorbs LF signals during daytime, making their range limited compared to nighttime. The eclipse temporarily mimicked nighttime conditions during the day, leading to enhanced LF propagation [1]. HF Signals experienced improved propagation, with stronger reflections and more reliable long-distance communication due to the denser F2 layer. Ray Tracing Simulations showed slightly longer phase paths, consistent with enhanced propagation conditions. Critical frequencies increased for the F-layer and decreased slightly for the D-layer.

These results have practical implications for emergency communications, navigation systems, and radio operations during eclipse events [5]. Understanding these changes allows operators to optimize frequencies and prepare for temporary signal improvements. Overall, radio communications, especially for LF and HF bands, were more efficient during the eclipse.

VIII. Limitations

- **WWVB antenna damage:** WWVB's south antenna was out of service due to storm damage, resulting in reduced transmission power. Reduced power (30 kW vs. 70 kW) [1]. There is a possibility that if the antenna was at full power, then the data might have looked different.

•**Geographic and Time:** Observations were taken in a short range from Colorado to New Jersey. The eclipse also isn't a long event, if it were longer we would get a much better grasp of all impacts the solar eclipse has on radio waves.

IX. Future Work

Future studies should focus on broader frequency ranges, using multiple geographic locations and incorporating real time measurements from ground-based and satellite instruments. Other future work would include analyzing the 2017 and 2023 eclipse data to see how LF and HF waves were affected. This would further refine our understanding of ionospheric dynamics during eclipses and other solar events.

X. Conclusion

This research successfully demonstrated that solar eclipses significantly impact ionospheric behavior, improving both LF and HF radio wave propagation. The temporary decrease in D-layer electron density benefits LF communications by reducing absorption, while the enhanced F2-layer electron density strengthens HF signal reflection.

In conclusion, these findings help bridge theoretical predictions with real-world applications, offering valuable insights into atmospheric physics and communication sciences.

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