The solar eclipse of August 21, 2017: view from the Haystack Observatory

L. Goncharenko[1], P. Erickson[1], S.-R.Zhang[1], O. Jonah[1], W. Rideout[1], I. Galkin[2]

[1]MIT Haystack Observatory, [2]University of Massachusetts Lowell

Abstract. A solar eclipse of August 21, 2017 presents a rare opportunity to study ionospheric and thermospheric response to a change in solar energy input and revisit our understanding of major influences that drive variations in the ionosphere-thermosphere system. We use observations made at the Haystack Observatory by the Millstone Hill incoherent scatter radar and digisonde to discuss how the eclipse affected the mid-latitude ionosphere in the partial eclipse zone.

Conclusions

1. A ~50% decrease in ionospheric electron density observed in ISR scans near totality zone.
2. A partial eclipse with 0.7 magnitude (overhead at the Haystack Observatory) induces a 30-40% decrease in electron density, 100-200 K decrease in electron temperature, and 50-70 K decrease in the ion temperature.
3. Although TIDs are clearly observed during the eclipse, their characteristics are similar to those regularly observed in non-eclipse conditions.

1. Background

It is well known that during the eclipse the whole ionosphere, from the E, F1, F2 regions through the topside ionosphere, undergoes dramatic variations due to dynamically induced changes in solar irradiation. Earlier studies of ionospheric response to solar eclipses consistently show a large decrease in electron density (50-60%) in the E and F1 regions [Cherniak and Lysenko, 2013, Salah et al.,1986]. Changes in NmE and NmF1 are directly proportional to the solar eclipsed area [Le et al., 2008b], as decrease in solar radiation leads to a decrease in electron production rates. However, the F-region behavior can be much more complicated and may have a decrease or increase in electron density.

2. Geophysical situation

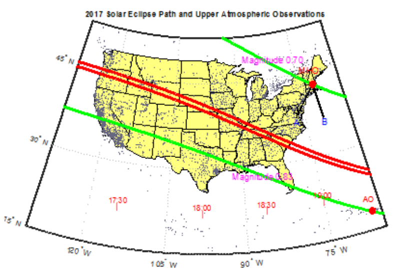


Figure 1. The solar eclipse zones in the continental US and GNSS receiver distribution. Red lines mark the totality zone. The incoherent scatter radars at Millstone Hill (Boston) and Arecibo (Puerto Rico) are within the partial eclipse region. At the Millstone Hill radar location, partial solar eclipse started at 17:27 UT and ended at 19:59 UT, with maximum eclipse occurring at 18:46 UT, with magnitude 0.7 and obscuration 62.92%.

3. Instruments and data

We use observations from Millstone Hill incoherent scatter radar (42.6oN, 288.5oE) to examine the impact of the August 21, 2017 solar eclipse on the mid-latitude ionosphere. The radar operated on August 19-23, 2017 to provide observations prior to and after the solar eclipse. Altitudinal profiles of ionospheric parameters were available with resolution of 4.5 km (best for E and F1-region) and 18 km (best for F2 region). Operation mode included cycles alternating zenith (88° elevation) and steerable antenna observations with integration time of 3 and 4 mins, respectively, and wide regional scans with 6° elevation to the south of radar.

Millstone Hill digisonde data is available continuously with 1-2 min resolution for the summer of 2017, enabling data analysis in both F1 and F2 regions.

4. Eclipse-induced variations

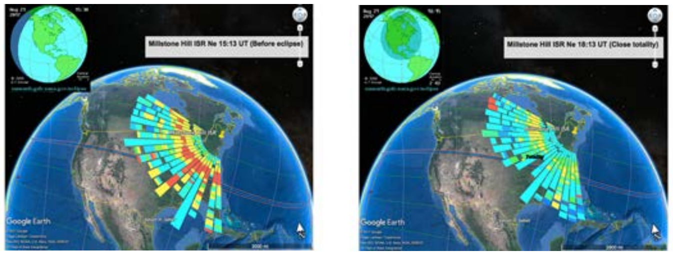


Figure 2. Regional scans demonstrate a ~50% decrease in the electron density Ne near totality zone.

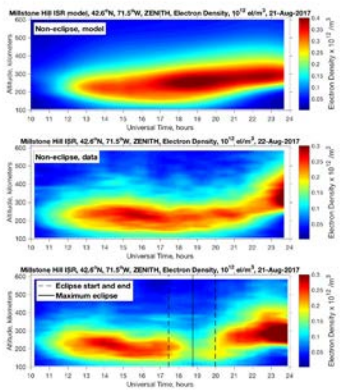


Figure 3. Variations in Ne above Millstone Hill ISR. (a) Predicted by the empirical model, (b) observed on a non-eclipse day, August 22, 2017, and (c) observed during the eclipse on August 21, 2017.

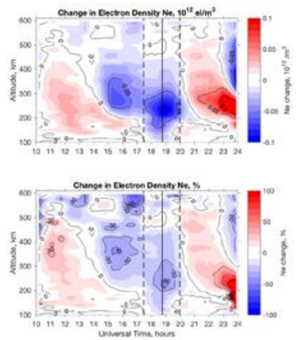
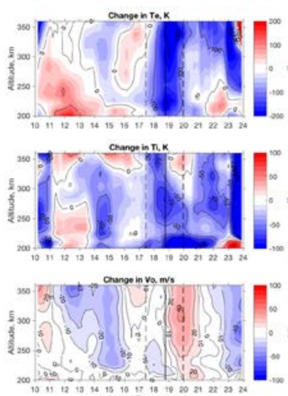


Figure 4. Change in the electron density in comparison with control day August 22, 2017 in absolute (top) and relative (bottom) units. A 30-40% decrease in Ne in the F2-region (200-300 km) is induced by the eclipse, while 20-30% variations above F2-region peak (> 300 km, at 11-16 UT) illustrate other typical variations.



Electron density at altitudes < 200 km recovers faster after the maximum eclipse. Large 20-40 m/s upward velocity observed after the maximum eclipse at 19-21 UT leads to a post-eclipse increase in electron density (20-24 UT).

Figure 5. Changes in electron temperature, ion temperature, and vertical velocity. Electron temperature decreases by 100-200 K during the eclipse, while ion temperature decreases by 50-70 K in the 250-300 km altitude region. The cooling of the atmosphere leads to the downward motion of 10-20 m/s that starts after the beginning of a partial eclipse. Upward velocity after the maximum eclipse (19-21 UT) exceeds 20-40 m/s and is similar to the effects of a sunrise.

5. Traveling ionospheric disturbances

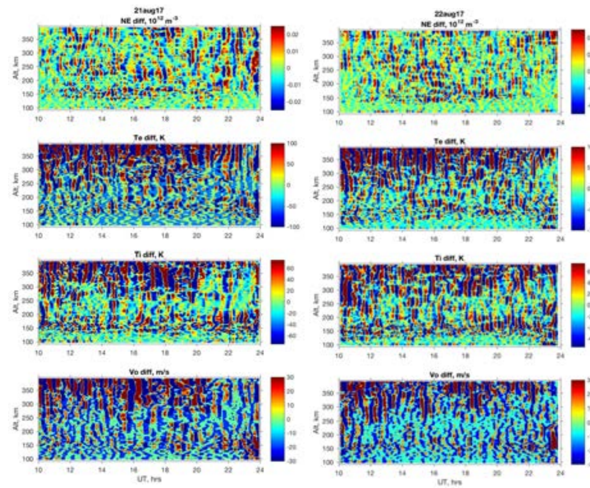


Figure 6. TIDs as seen in ISR data during the eclipse day (left) and non-eclipse day (right). TIDs are seen at all altitudes and in all parameters, with an apparent increase in amplitude on the eclipse day.

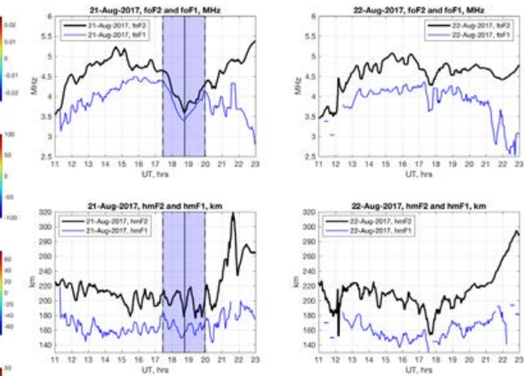


Figure 7. Ionosonde data shows large decrease in critical frequencies foF2 and foF1 induced by the eclipse. Notably, periodic variations in hmF2 and hmF1 are observed on eclipse day, indicating that the TID source is located below the F1 region. Good correlation between them is an indicator of a large vertical wavelength. Note a rapid rise of hmF2 by > 120 km after the eclipse.

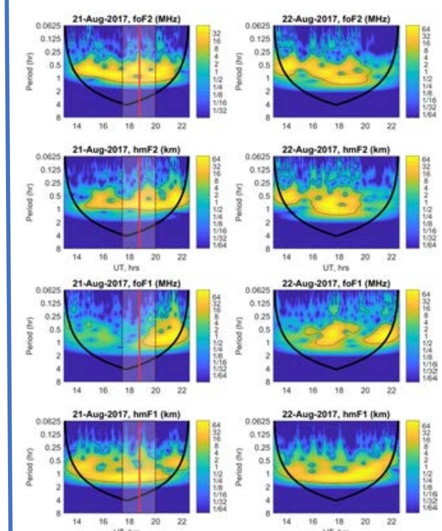


Figure 8. Wavelet analysis of digisonde data indicates the presence of oscillations with periods ~0.5-1.2 hrs in both F2 and F1 regions and during both eclipse day and control day.

Traveling ionospheric disturbances (TIDs) are observed on a regular basis and occur due to a variety of solar-geophysical processes. Their connection to various sources remain a topic of active research. From theoretical considerations, solar eclipse can excite atmospheric gravity waves due to the rapid temperature change either in the stratospheric ozone (30-40 km altitude), or directly in the thermosphere (160-250 km). We analyze a variety of ionospheric data using ISR and digisonde to investigate whether observed TIDs could be induced by the eclipse.

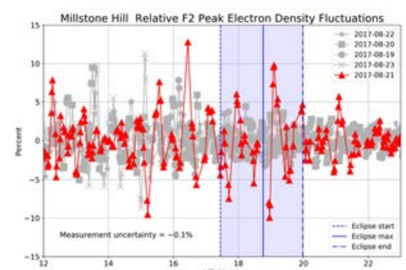


Figure 9. Detrended relative electron density fluctuations at the F2 region peak over Millstone Hill for five days of August 2017. Data was derived from very accurate plasma frequency measurements using weak Langmuir mode incoherent scatter radar echoes ("plasma line"). Measurement uncertainty is estimated to be ~0.1%, indicating that the fluctuations seen are entirely geophysical in nature. Results show that the eclipse day does not have statistically significant increases in relative midlatitude electron density fluctuations during shadow passage as compared to other days.