Quasi Periodic Echoes Induced by a Partial Solar Eclipse

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Abstract

The observations of mid-latitude quasi-periodic (QP) echoes during the partial solar eclipse on 22 July, 2009, using the MU radar at Shigaraki (34.85°N, 136.1°E) are presented. The rapid reduction in the E-region density, caused by the eclipse exposes the long-lived metallic ions within the Sporadic E-layers making it conducive for the gradient drift instability. These echoes resemble the normal post-sunset QP echoes observed over mid-latitudes. The present observations confirm that the mid□latitude Es plasma process is mainly controlled by density gradients. This example also reveals a hitherto unobserved aspect of mid-latitude ionospheric responses to eclipses.

1. Introduction

A solar eclipse provides a unique opportunity to investigate the changes in the ionosphere as a response to the sudden and transitory withdrawal of solar radiation. Recently, Patra et al. [3] using the Gadanki radar observations from a low latitude location in India have reported that solar eclipse can induce/enhance plasma irregularities in the E region. They conjectured that the irregularities could grow on the density gradients formed on the metallic ion layers when molecular ions are recombined during the solar eclipse. Observations to support this notion, however, have so far been limited to Gadanki only. In this context, we examine the mid-latitude E region observations during a solar since the generation of mid-latitude E region plasma irregularities, especially the Quasi-periodic echoes [6] are believed to be heavily linked with the gradients associated with the plasma density structures. In this paper, we study the MU radar observations of E- region irregularities during a partial solar eclipse on 22 July 2009.

2. Observations

The solar eclipse of 22 July 2009 was the longest total solar eclipse during the 21st century with the maximum eclipse occurring over the ocean about 100 km south of the Bonin Islands, south east of Japan. The eclipse was partial over the radar beam location with a maximum obscuration of about 77%. The event occurred in the interval 00:49-3:24 UT with the maximum obscuration at 02:06:06 UT (Japan Standard Time, JST = UT+9 h). The MU radar (46.5 MHz radar with peak power 1 MW) observations were done in a multi-channel (25 receiving channels) mode [4]. Figure 1(a) shows the Range-Time-Intensity (RTI) map, and Figure 1(b) and Figure 1(c) show corresponding Doppler velocities and spectral widths. The RTI plots display echoes from the E-region FAI, with the presence of typical morning time "continuous echoes" up to ~09:35 JST. These are similar to that reported earlier by Yamamoto et al [6]. The echoes re-appeared around 10:35 JST, around 30 minutes after the commencement of the

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eclipse. These echoes appeared at a higher range, and displayed discrete and coherent patterns in the RTI maps, which are similar to the "QP type", observed usually in the post-sunset period. These QP type echoes lasted for ~30 minutes, with ~8-10 minutes periodicity. Figure 1(b) shows the corresponding Doppler velocities. Positive values denote Doppler velocities away from the radar (upward and northward).

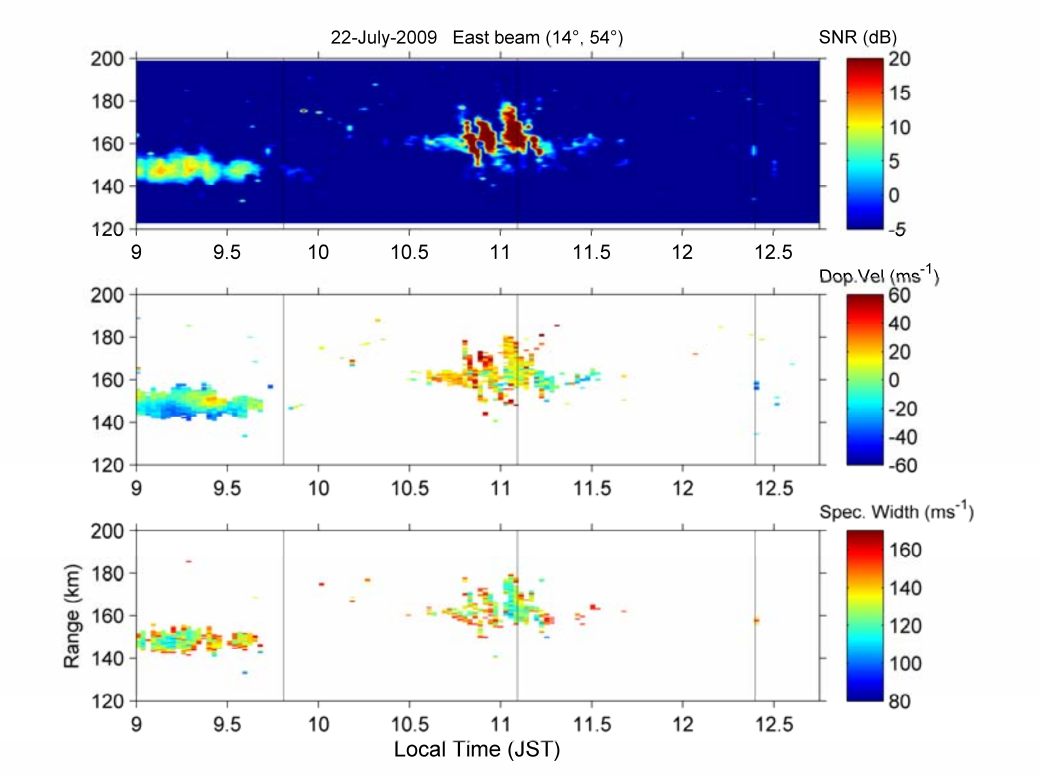

Figure 1: RTI, Doppler velocity and spectral width plots obtained from the MU radar observations on 22 July 2009. The times of beginning, maximum obscuration and end of the eclipse are marked using vertical lines.

The fine structure in the figure mimics the fine structure in the RTI maps to some degree. The Doppler velocities for the QP echo period were in general larger than that for the continuous type echoes, which is similar to the previous observations for the post-sunset QP echoes [6]. The spectral widths are comparable in magnitudes for both continuous and QP echoes.

Figure 2 shows few samples of FAI echo distribution in the horizontal and vertical plane. They are generated by the radar imaging technique with the MU radar Ultra-multi channel receiver system [4]. Color indicates the Doppler velocity and color intensity indicates echo power. The morphological differences of the 'continuous' and 'QP' echoes are clear from the images. For the QP echoes, the altitude of echoing region is from 100-120 km, and the band of the echoing region is similar to the "ribbon" shape reported earlier [4]. The echoes drifted closer to the radar with apparently decreasing altitudes. All these features resemble the night-time QP echo morphology.

A Frequency-modulated-continuous-wave (FM-CW) sounder is being continuously operated at the MU radar location. On all the three days, strong E_s layers were seen (not illustrated). If we compare the altitude of Es layer with that of FAI, it can be seen that the altitude of continuous echoes in the morning appeared at a lower altitude (not illustrated), whereas the QP echoes during eclipse occurred at the same altitude as Es layer. Since the

Es layer has long-lived metallic ions inside, the presence of large $f_t E_s$ is a desirable condition for the generation of QP echoes, if the necessary gradients are generated.

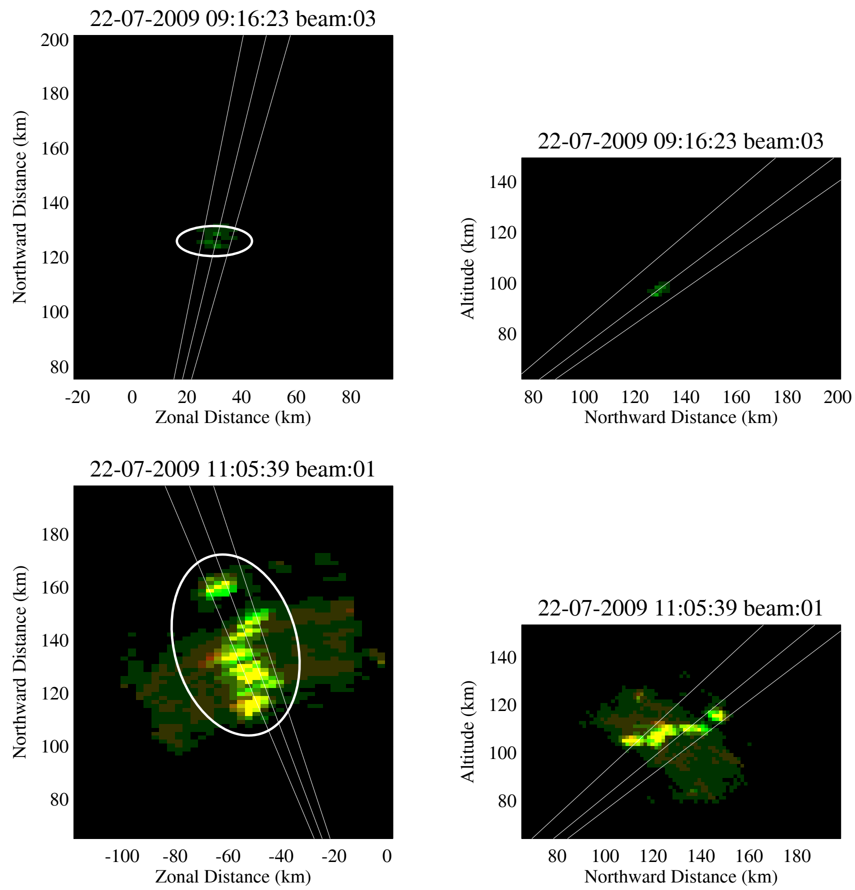

Figure 2 Radar images obtained from the MU radar observations on 22 July 2009.

3. **Discussion**

Most plasma irregularities in the mid-latitude E-region are believed to be produced by the gradient-drift instability induced by steep plasma gradients in the Es layer. For explaining the quasi-periodic nature of the observed echoes, there have been several suggestions, like the gravity wave modulation of the gradient drift instabilities [5], Kelvin Helmholtz (KH) billows [2], and direction dependent Es layer instability [1]. The fact that QP echoes always occur at night with preference for the pre-midnight sector and the close association of QP echoes with Es layers provides strong evidence that ∇N (gradient in plasma density) plays an important role in the production of FAI.

The MU radar incoherent scatter (IS) observations of the E-region were made during a partial solar eclipse on September 23, 1987 [7]. It was seen that the electron densities at different heights in the E-region showed a 20% decrease relative to that of a normal day. Just like in the night time, during the eclipse, the molecular ion density should decrease with a 1 min time scale, in the E-region. However, the metallic ions have a very long photochemical lifetime, owing to their weak recombination rates. This means that, during a solar eclipse, the fast reduction in the back ground E-region molecular ions would favor the metallic ions inside the Es layer to provide the density gradients that can destabilize the plasma.

The quasi-periodic nature of the observed echoes can be related to the patchy Es layer itself, similar to the explanation for the nighttime QP echoes. The solar eclipse helped the patchy type Es layer to become unmasked during the day, providing necessary gradients for gradient drift instability to work. The rapid reduction in the E-region density, caused by the eclipse would also reduce the field line integrated Pedersen conductivity, so that the polarization electric field can be maintained. The present observations from the mid-latitudes confirm that the mid-latitude Es plasma process is mainly controlled by the density gradients.

4. Conclusion

The first observations of solar eclipse induced mid-latitude plasma irregularities using MU radar are presented. During the eclipse, QP echoes were observed, which resembled the normal post-sunset QP echoes. Blanketing type Sporadic E□layers were observed, which indicated the presence of long□lived metallic ions. The sudden withdrawal of solar radiation could deplete the background E-region densities, thus making it conducive for the gradient drift instability. This observation is a unique example of the mid-latitude ionospheric response to a partial solar eclipse.

5. Acknowledgments

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