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Ionospheric Effects of Total Solar Eclipse on 22 July, 2009 Observed Over Crest of EIA, Bhopal

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ABSTRACT

A solar eclipse provides us with a rare opportunity to study the ionospheric effects associated with an accurately estimated variation of solar radiation during the eclipse period. An exceptionally long total solar eclipse occurred on Wednesday, 22 July 2009, that traversed the eastern hemisphere in a narrow corridor. The Ionosonde observations taken at Space Science Laboratory, Department of Physics and Electronics, Barkatullah University, Bhopal during the three days centered on the total solar eclipse of 22 July 2009 are described. The eclipse was sufficient to decrease the ionization of some regions of ionosphere by the solar disc which was obscured at the maximum phase. The effects on the ionospheric parameters are observed when eclipse reached its maximum totality. A magnetic disturbance occurred during the period of the observation. Therefore the Ionosonde observations are discussed in conjugation with the changes which occurred in the earth's magnetic field and the ionosphere during the event of the eclipse.

Introduction

Solar eclipse is one of the important solar terrestrial events which have a direct impact on Earth's ionosphere. During solar eclipse the amount of solar radiation reaching the Earth diminishes, which results in reduced production of plasma. Hence compared to a normal day the loss rate of plasma on an eclipse day dominates over production rate. Thus, during solar eclipse lower electron density in the ionosphere is expected.

Studies concerning eclipse induced effects on the ionosphere are important mainly due to the fact that the processes that control the ionosphere are extremely complex. Since the atmospheric system supports multiple processes and what one sees is always a resultant of the multiple forcing, investigating phenomena like solar eclipse at different times and epochs could give clues to the relative importance of the respective processes and their dependence on time and epoch. Total solar eclipse is a rare event, with each eclipse occurring at different hours of the day, study of the impact of every eclipse on the ionosphere is desirable.

As the solar flux in each wavelength range is progressively reduced during a solar eclipse, the chemical equilibrium in the ionospheric layers is disturbed and also due to higher recombination coefficient in lower regions of the ionosphere, significant reduction in the ionization is observed in these regions. In the altitude range of 140-170 km, the NO^+ ions are dominant and its rate is high when compared with O^+ ions, which becomes dominant above 170 km [1]. The same reason holds good for the late response in the upper regions when compared with that of the lower regions of the ionosphere.

Sporadic E is a thin layer with dense patches of ionization around E region altitudes, sporadic E is generally observed between height of 95 km and 120 km. The Es structure and the related winds and wind shears for the formation of Es at magnetic equator (Thumba, dip 2° N) were studied in detail by [2]. Sequential sporadic E layers at low latitude in the Indian sector were presented by [3] by comparing Waltair (dip 20° N) with Trivandrum (dip 2° N) and SHAR (dip 10° N). They provide the experimental evidence for the wind shear theory for the formation of descending night time sporadic E layers by using three Ionosonde data. They concluded that the night time descending sporadic E layers are produced by the combined effect of the equator ward propagating gravity wave and the increased pole ward neutral wind which brings the ionization downward through the field-line [4].

The Es consistently occurs around 100 km and the ordinary critical frequency of Es layer (foEs) is unpredictable. Sometimes the value of foEs is many times higher than its mean value [5]. For the shadowing Es-layer that occurred on 22 and 23, July, 2009 the blanketing frequency fbEs was approximately equal to the critical frequency foEs [6-7]. The sudden increase of foEs in the solar eclipse period was also observed over Haringhata [8-9]. It is worth noting that, when the solar radiation decreases during totality the maximum electron concentration of Es did not fall but rose. The meridoinal airflow accelerates the ionized clouds in the Es layer to from the wind shear. It is the wind shear that induces intensification in the Es layer [10-12] and increase of foEs during the solar eclipse period [13].

A study on the temporal variation of h′F, foF_2, foF_1, and dh′F/dt on the eclipse day has also been carried out by many workers. It has been found that h′F shows an oscillatory behavior during the course of the eclipse. In comparison with temporal variation of foF_2 on the control days it drops by about 15% on the eclipse day. On the other hand foF_1 decreases by as much as 50% on the eclipse day with no time lag between the time of maximum obscuration and the time of maximum decline of foF_1 [14]. Reduction of 20% was noticed both in f_{min} and in the F_1 layer critical frequency during total solar eclipse of 11 August 1999. The signal strengths of the oblique incidence paths

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also point to eclipse associated decreases in ionization in the D and lower E-region [15].

The ionosonde measurements made at Waltair (20° N dip) during the solar eclipse of 24th October 1995 showed significant decrease in both the critical frequency and the height of the F layer during the eclipse. Also significant oscillatory variations were observed in h′F and foF_2 during the course of eclipse. When compared with the control days foF_2 and foF_1 drop about 15% and as much as 50% respectively on the eclipse day. These studies at Waltair, a low latitude station, however differ from mid latitude observations [16-17] where a slight increase in foF_2 is reported. The ionosonde measurements at low latitude station, Bangkok on a similar event of total solar eclipse also showed an initial increase in foF_2, but decreased 25 minutes after the maximum phase [18]. At the same time $h'F_2$ has shown a substantial increase. The interesting feature observed in this study [18] was the formation of $foF_{1.5}$. This feature is observed only at stations whose magnetic dip angle is ≤ 10°N.

[19] reported results for the eclipse of 11 August 1999 from Western Europe based on a chain of 12 ionosondes within 5°W and 5°E longitudes. A 37% decrease of foF_1 was noted for a station with 100% obscuration, while a decrease of 24% was noted for a station with 71.6% obscuration. The decrease in foF_2 was weak at all stations. The maximum decrease in foF_1 was found to occur at the time of maximum obscuration, while maximum decrease in foF_2 occurred with a delay of 20 minutes from the maximum obscuration. An eclipse associated depletion in F-region electron density was also noted.

[20] modeled the effects of total solar eclipse event of 11 August 1999 on the thermosphere-ionosphere using the Coupled Thermosphere-Ionosphere-Plasmosphere Model (CTIP). Simulations were made for a height of 240 Km, assuming a solar flux index of 190 and a magnetic activity index Kp of 2^+. A decrease of about 45 K in neutral temperature near the totality (50°N) was predicted with a lag of 30 minutes. Neutral winds up to 26 m/s would be generated as a consequence. The generation of gravity wave was also predicted. For the region of 50°N, 0° longitude, an increase in [O] and an initial increase followed by decreased level for several hours of $[N_2]$ were shown. This results in an increase of foF_2 during eclipse.

In the present work we have investigated the behavior of ionospheric parameters during the total solar eclipse that occurred on Wednesday, 22 July 2009. It was one of the exceptionally long eclipses that traversed the eastern hemisphere in a narrow corridor. For observation, we have used the data of digital ionosonde (KEL IPS 71) system, installed at the Space Science Laboratory, Department of Physics and Electronics, Barkatullah University, Bhopal. Although a magnetic disturbance also occurred around the same time but still we could record the decrease in electron density and critical frequencies and at the same time an increase in heights in different layers of the ionosphere.

Observation and Data

In this study we collected the data by digital ionosonde (KEL IPS 71) system, which has been installed at the Space Science Laboratory, Department of Physics and Electronics, Barkatullah University, Bhopal since November 2006 and being operated every 15 minutes interval data recording system, but on the event day of total solar eclipse, we obtained the data of two minutes interval. The raw data was then processed and analyzed by an appropriate analysis method to study the changes that take place in the ionosphere during the solar eclipse.

Figure 1 show the total solar eclipse path which passes through India. The moons umbral shadow began in India and crossed Nepal, Bangladesh, Bhutan, Burma and China. Afterwards the path crossed Japan’s Ryukyes Island and curves southeast through the Pacific Ocean where maximum duration of totality reaches 6 min. 30 sec. Even at Bhopal, 40 km north of the central line, it succumbs to 3 min 9 sec of the total phase, just 19 sec less than the maximum duration at the path’s center by 00:55 UT (06:25 LT).

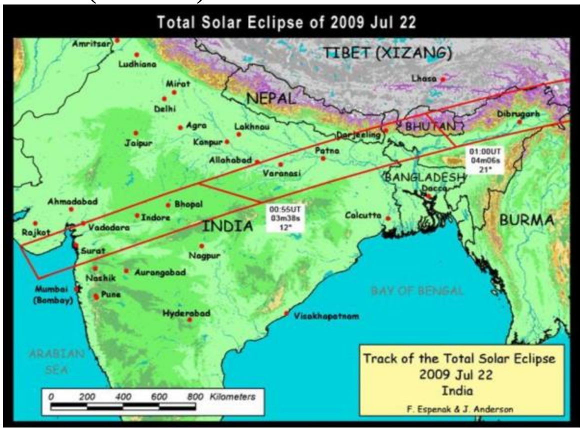

Figure 1. Path of the total solar eclipse in India

Results

We begin the presentation of our results separately for different parameters as follows

Geomagnetic measurement

The variation of geomagnetic indices during the eclipse and control days is presented in the Figure 2. From the plot it can be seen that a magnetic disturbance of moderate intensity occurred on the eclipse day in the post eclipse period. The Geomagnetic activity index Kp was observed as +6 nT prior to onset of eclipse and -5 nT during eclipse. At the same time Ap index was observed to achieve a maximum value of 68 nT. One of the most important parameter, Dst index characterizing geomagnetic storm was observed to be -76 nT after the end of eclipse period. In spite of this geomagnetic disturbance we found the decrease in the critical frequency parameters of different ionospheric layers. Since the geomagnetic storm gives a counter eclipse effect, the change in certain ionospheric parameters was not much pronounced as recorded is some previous studies.

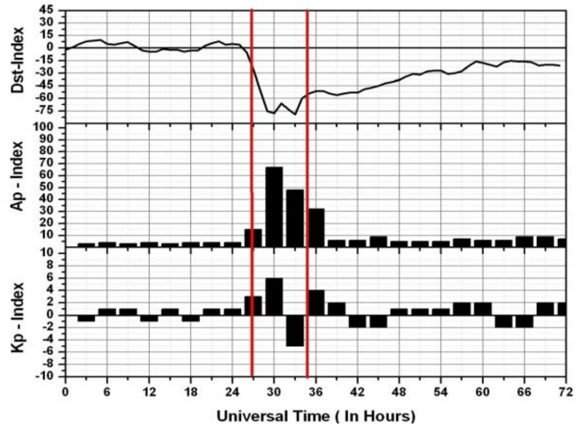

Figure 2. Variation of Geomagnetic indices during the control and eclipse days

Ionospheric measurements

Observations for the height and density parameters of different regions of the ionosphere by returning energy at vertical pulse sounding incidence were made at 15 min. data recording interval during the observation days from 21 to 23 July 2009. During the period of solar eclipse they were repeated as rapidly as possible and on all frequencies, echoes were observed in 2 minutes interval. We separately present the results of the changes observed in different layers in terms of their frequency and height parameters.

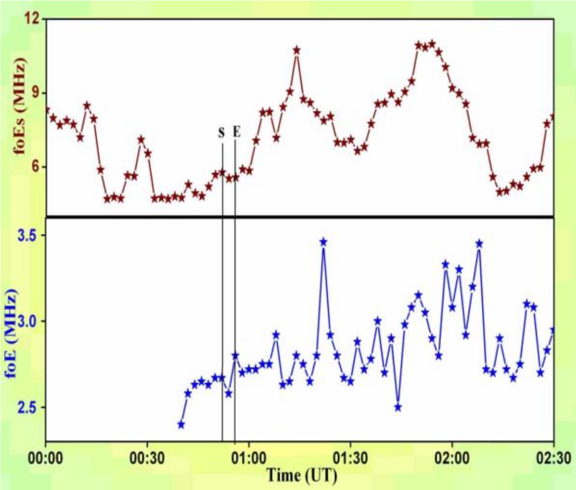

Figure 3. Variation of foE and foEs during eclipse period

Changes observed in the E layer

The variation of the E layer frequency parameters on 22 July 2009 as a function of UT from 00:00 hrs to 02:30 hrs is presented in Figure 3. The letters S and E indicate the start and end of the eclipse totality. From 00:40 hrs to 01:00 hrs the value of foE was between 2.67 MHz and 2.7 MHz but the value deceased to 2.57 MHz at the eclipse totality 00:55 hrs and then suddenly increased to 2.8 MHz just after the end of totality. Thus showing decrease of about 0.10 MHz. Afterwards, we could observe an oscillatory type behavior in the variation of foE. Similarly one of the important parameters foEs was found to show a slight decrease during the eclipse totality, but a remarkable increase right after the end. Thus we can say that it showed a delayed response. Although the behavior of foEs is considered to be unpredictable during eclipse, most of previous studies carried out in the past have recorded a sharp increase in it while some others have reported it, not being measurable. Since during the present case a magnetic disturbance also occurred around the same time that is why the behavior of the foEs was slightly different.

The plot of virtual height h´E and h´Es as a function of time is shown in Figure 4. From the plot it is clear that an enhancement occurred in the values of h´E and h´Es during the eclipse time. A lift in the height of this layer to higher altitudes may have resulted in the decrease of density hence we get decrease in E layer critical frequency, foE. After the eclipse an oscillatory type behavior was observed in the h´Es.

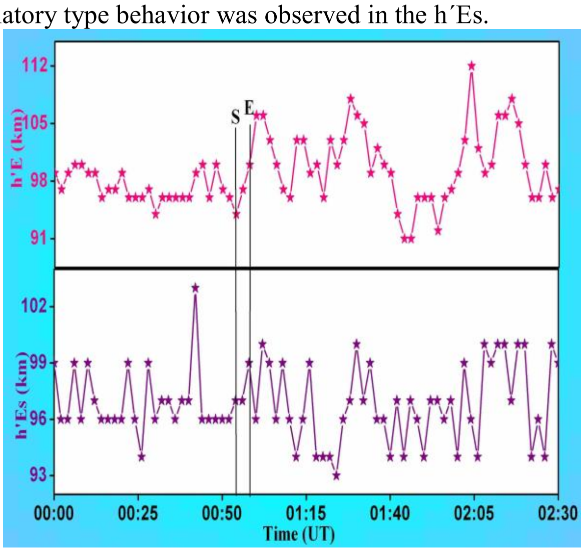

Figure 4. Variation of h´E and h´Es during eclipse period

Minimum frequency of reflection of D layer (fmin)

The effect of eclipse is found to be more on lower layers than on upper layers. So we also studied the variation of fmin during the period of eclipse (fmin is the minimum frequency reflection of D layer). The variation of fmin on 22 July 2009 between 00:00 hrs to 02:30 hrs is shown in the bottom panel of Figure 5. As the eclipse started at 00:52 hrs the values of fmin also started decreasing and fell to 1.57 MHz (from 1.65 MHz) as eclipse totality was reached. Here again we find the decrease was slight, that is only 0.06 MHz. This indicates a reduction in the D layer ionization during the eclipse. Although in previous studies a decrease upto 20% has been reported.

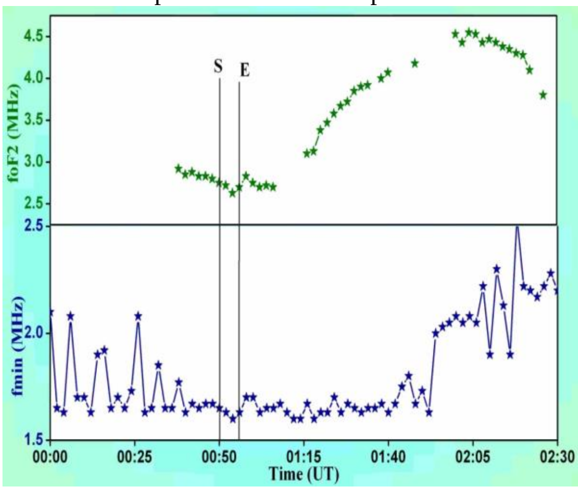

Figure 5. Variation of fmin and foF2 during eclipse period

Changes observed in the F layer

One of the important parameters of F layer, the critical frequency of F2 layer, foF2 also showed a decrement in response to solar eclipse of 22 July 2009. The variation of foF2 on the eclipse day and during the eclipse period is shown in top panel of Figure 5. A decrease in this frequency parameter is clearly observed in this figure. As soon as the eclipse totality seized a slight increase occurred in foF2 after which it returned back to its normal pattern. A decrease of only 0.9 MHz was noticed in the values of foF2. While at low latitudes more than 20% decrease has been reported. Thus the effect at mid latitudes is different from that at low latitudes. The height of both F1 and F2 layers was falling before the start of eclipse. As soon as the eclipse started the height parameters started increasing and continued to increase even after the end of eclipse totality. Owing to this increase in height the frequency parameters showed a decreasing trend.

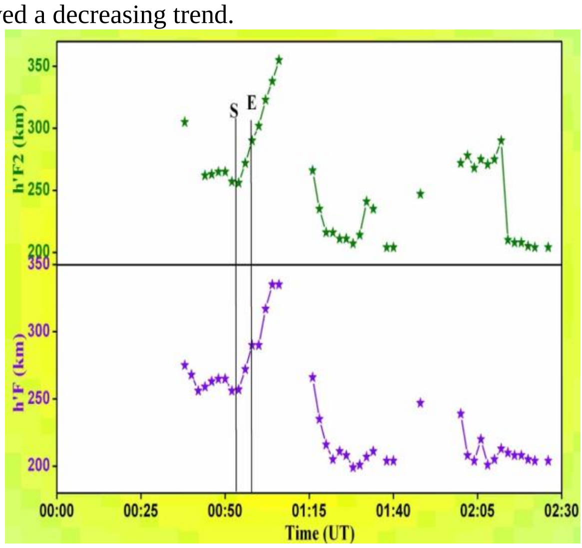

Figure 6. Variation of h´F and h´F2 during eclipse Time

The variation of maximum usable frequencies MU(3000)F and MU(3000)F2 is shown in Figure 7. From the plot we see that MU(3000)F2 increases remarkably while MU(3000)F increase slightly.

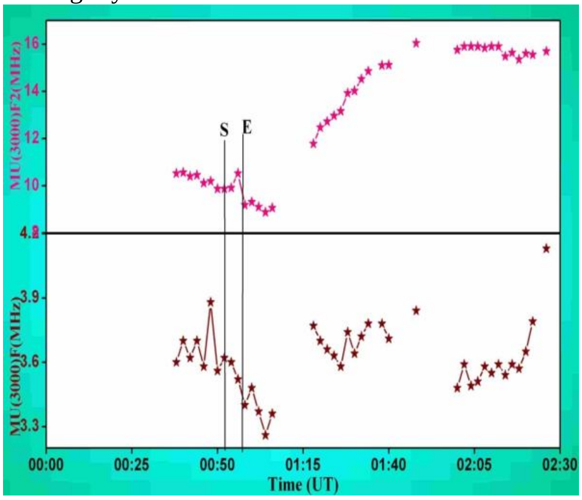

Figure 7. Variation of MU(3000)F and MU(3000)F2 during eclipse time

Discussion

The total solar eclipse of 22 July 2009 was a rare, by its characteristic time of onset. The eclipse was observable right from the sunrise in the Indian region. In fact it was an eclipsed sun that rose on the morning of 22 July 2009.

The changes in the F-layer density caused by total solar eclipse can be interpreted as to be associated with electric field generated by internal gravity waves. Such fields can penetrate the F-region of ionosphere and move the layer up or down due to E × B drift and bring out the changes in plasma density. The decrement found in density may be the result of this eclipse induced field. The density can also decrease if an electric field of sufficient magnitude develops at sufficient heights.

It has been shown above that, along with the general effect on the F2 region by a magnetic disturbance which was in progress throughout the day of the eclipse, there was a marked effect due to the eclipse itself. This eclipse effect resulted in a considerable increase in the minimum equivalent height accompanied by a marked decrease in the maximum ionization of F2 region.

The loss rate of ionization at different altitudes depends on the composition of the ionosphere. The decrease in the electron density in the F2 region (in which O^+ is dominant) is found to show a time delay in the decrease due to the slower loss rate of O^+. [21] have shown that the formation of an electron density trough in the eclipse zone is due to an increase in the charge order ($O^+ + N_2 \rightarrow NO^+ + N$; $O^+ + O_2 \rightarrow O_2^+ + O$) processes, in which O^+ ions (which are dominant in the F_2 region) will be driven through neutral atmosphere producing NO^+ and O_2^+ (which are dominant in the F1 region). Thus, the above processes are responsible for the faster recovery of foF1 and delayed recovery of foF2 after the end of the eclipse and before returning to the control values. It has been found that the stratification of the F-layer into F1 and F2 layers is more significant during the eclipse period. [22] proposed that a large upward drift is a necessary condition for the stratification of the F-layer into F1 and F2 regions The raising of the F-layer to higher altitudes during the solar eclipse may also slow down the diffusion and hence reduce the ionization of the F2 region and increase the accumulation of ionization in the F1 region, making the stratification more prominent. In addition to the above two reasons, factor G, which is proportional to B^2/aq (where B = linear loss coefficient, a = recombination coefficient and q = rate of production of ions and electrons), quantifies the stratification of the F1 and F2 regions [23]. During the solar eclipse, q decrease as the solar disc is obscured and 'a' also decrease as the temperature decreases due to the eclipse shadow region. Hence the value of G becomes larger around the eclipse time, which is attributed to increased stratification of the F-layer [14].

The equatorial ionosphere during a solar eclipse would be significantly affected by the E × B vertical drift because the large depletion of electrons at low altitudes can be transported to high altitudes through the plasma vertical drift. Then the large depression in number density of electrons (Ne) in the equatorial region would reduce the plasma diffusion flux reaching the equatorial ionization anomaly (EIA) region along magnetic field line and hence affect the ionosphere [24].

Conclusions

The observations on July 22, 2009 at Space Science Laboratory, Bhopal confirmed that the effect of the eclipse is described by the scenario of "transition to the nighttime ionosphere," namely, the layer altitudes increased and their frequencies decreased. Changes were observed in all ionospheric layers, and the strongest effect was recorded for the F layer. All parameters changed within one hour after the onset of the eclipse and had maximum amplitudes at the moment of the maximum phase or a few minutes later. The diurnal behavior of the parameters was restored in 1.5 hours after the eclipse totality. In spite of a magnetic disturbance during the eclipse we were able to record the marked effect due to eclipse; therefore the above results are discussed in conjugation with magnetic disturbance. To gain a better understanding of the effect of the solar eclipses on the ionospheric layers, a more detailed analysis must be carried out based on more advanced mathematical methods and including data obtained at other observatories.

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