Simultaneous observations of D-, E- and F-regions of the ionosphere during the solar eclipse of 22 July 2009 over South Korea : First results

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Abstract

A Solar eclipse event occurred on 22 July 2009 over South Korean Peninsula with a maximum obscuration of ~84% has been investigated to discuss the variations in the mid-latitude ionosphere. Study of solar eclipse effect on the different ionospheric regions (espcially D-region) has been limited till today, although there is a few studies concentrated on the electron density variations and GPS TEC measurements in ionosphere. Present study aims to investigate the effect of solar eclipse on all ionospheric regions including D-, E-, and F-regions simultaneously by conducting a campaign in South Korea. The observations reported here therefore should shed some light on the solar eclipse induced mid-latitude ionospheric dynamics which leads to the changes in D-, E- and also F-regions of the ionosphere.

1 Introduction

The solar eclipse of 22 July 2009 was the longest total solar eclipse during the 21st century with totality centered 20 ~ 30° N latitude belt. The eclipse swept over South Korean peninsula with starting phase at 00:30 UT (09:30 KST) and ending phase at 03:13 UT (12:13 KST) with maximum at 01:47 UT (10:47 KST), respectively, having maximum solar obscuration of about ~84%. The total solar eclipse effects include the variations not only in the ion/electron densities but also in the other background parameters such as magnetic field, temperature and neutral compositions [1]**.** The effects of solar eclipse on different regions of the atmosphere have been studied extensively by different ground based instruments (coherent and incoherent scatter radars) [3] and satellite based measurements (Global positioning system (GPS), Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC) etc.) [6], and these observations are well supported by the simulation results [4]. Recent efforts in the last decade try to unravel the eclipse effects on the ionosphere [4], however, the results were fewer and inconclusive. Particularly because of its lower electron density and weak echoes from coherent scatter radars, and the mesosphere (D region) cannot be easily probed with even ground based or satellite measurements. Numerous consequences have been discussed earlier in the literature regarding the reduced solar heating and responses of E- and F-regions to the total solar eclipse. The variations in the ionospheric current systems and also the weakening of equatorial electrojet (EEJ) thereby forming a counter electrojet during the solar eclipse have been investigated [5]. Recently, the E-region plasma irregularities triggered by the solar eclipse which was occurred on 11 August 1999 was investigated [3]. They conjectured that the solar eclipse can provide nighttime ionospheric conditions which provide the necessary electron density gradient and make the layers unstable through gradient-drift instability mechanism. However, studies related to lower ionospheric variations during total solar eclipse have not been explored yet. Hence, the need to explore the dynamic coupling from lower to upper ionospheric variations simultaneously is of great importance. In this context, present study aims to investigate and discuss the changes in the mid-latitude D-, E- and F-regions of the ionosphere during solar eclipse period by using observations from Busan Sudden Ionospheric Disturbance (SID) monitor, and magnetometer in Jeju Islands in South Korea. Further, the vertical electron density data from COSMIC radio occultation and the Total Electron Content (TEC) data from GPS receivers have also been used to study the ionospheric variations during this solar eclipse. The observations

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reported here should be of great importance on the solar eclipse induced mid-latitude ionospheric dynamics which leads to the changes in D-, E- and also F-regions of the ionosphere.

2 Data

The data observed by SID monitor (22.2 KHz), which has been tuned to the radio transmitter station JJI in Ebino, Japan (32.04^{o}N, 130.81^{o}E) and installed in Korea Science Academy of Korea Advanced Institute of Science and Technology (KSA), Busan, Korea (35.23^{o}N, 129.08^{o}E), are used. The ground magnetic field data, x- and y-components of magnetic fields and total magnetic field, are obtained from Jeju magnetometer (33.31^{o}N, 126.19^{o}E) in Korea operated by Radio Research Agency (RRA). The temporal resolution and accuracy of the data are 1 sec and 0.2 nT, respectively. In addition, the vertical electron density profile data from FORMOSAT-3/COSMIC (in short F3/C) is also used in this study. The F3/C is a constellation of six micro satellites orbiting around 800km altitude, 72° inclination angle, and 30° separation in longitude. Each F3/C satellite has a GPS occultation experiment payload, performing the radio occultation observations in the ionosphere. F3/C satellites provide ~2000 vertical electron density profiles per day which are uniformly distributed all over the globe. The vertical profile data in 50% solar obscuration region during the eclipse period are considered in this study to observe the changes in the F2-layer peak region.

3 Results

Figure 1 shows the IMF Bz variation and Sym-H index with universal time on 21-23 July 2009. The gray shaded box shows the time period of solar eclipse occurred on 22 July 2009. This figure clearly shows both the solar eclipse and geomagnetic storm events occurred almost at the same time. The main task is to quantify both solar eclipse and geomagnetic storm effect individually. One possibility of separating these events is to look at the variations in all the other parameters in the before and at the initial phase to know the actual effect on the ionosphere by geomagnetic storm. However, the main phase and ending phase of solar eclipse is completely dominated by the geomagnetic storm effects.

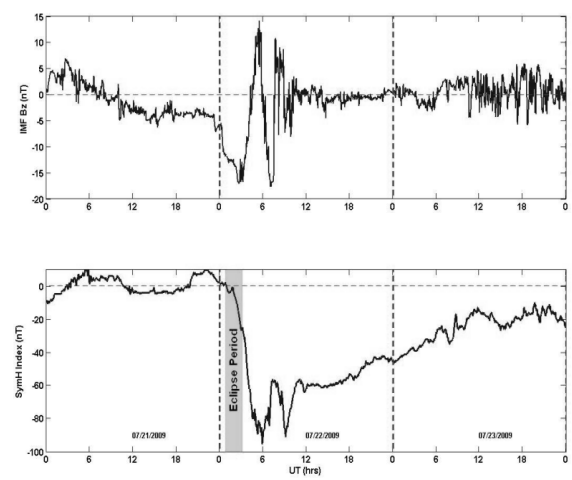


Figure 1. IMF Bz variation and Sym-H index to show the period of solar eclipse as well as geomagnetic storm which occurred simultaneously.

Figure 2 shows the VLF signal amplitude with universal time variation of 20-24 July 2009 from SID monitor in Busan, Korea. This figure clearly shows the general diurnal pattern of the signal from SID monitor having two minima at sunrise (20:00 UT which corresponds to 05:00 KST) and sunset (09:00 UT which correspond to local time 18:00 KST), respectively. These two minima observed basically occur because of day-night variation of propagating VLF [2]

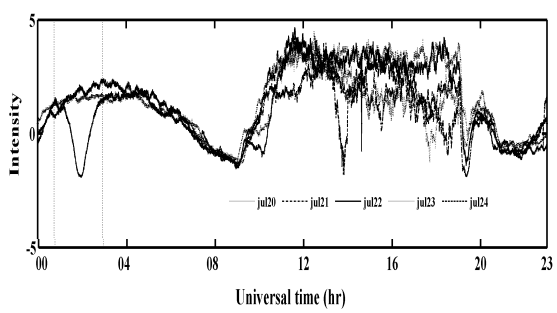


Figure 2. SID monitor signal strength with universal time from 20-24 July 2009 is plotted.

It is clearly seen that the reduction in signal strength started from 00:40 UT and interestingly minimum was around 01:50 UT (maximum obscuration) and started recovering to the original position around 03:15 UT in eclipse day, 22 July 2009. As can be seen, the amplitude pattern of the signal from SID monitor for eclipse period differs from the preceeding and succeeding days of the order of two clearly showing the effect of solar eclipse on the propagation of VLF signals. Interestingly, there is a simultaneous occurrence of solar eclipse and geomagnetic storm event almost at the same timeThe main phase of the storm event just started at the time of the eclipse.

The main phase of the geomagnetic storm has started around 01:30 UT and lasted till 12:00 UT. In this respect, we assume the effect of geomagnetic storm on the VLF signals may be having minimum because of the fact that the VLF signal strength recovered to its original strength right after the final phase (02:47 UT) of the solar eclipse event which is quite consistent in our data.

Figure 3a, 3b and 3c shows the magnetic field component variations in B_X (east-west), B_Y (north-south) and B_{TOT} (total) respectively with universal time from magnetometer operated in Jeju Islands during the 21-22 July 2009 The magnetic field variations on all other control days (which are geo-magnetically quiet) appear to be quite normal on the previous as well as following day (21 July & 23 July). However, there is a significant variation in magnetic field strength on the solar eclipse day is observed (23-01 UT). However, the variation of magnetic field strength after 01 UT is dominated by geo-magnetic storm which was one of the strong geomagnetic storms during 2008-2009 and the effect lasted for almost up to 8-10 hours. Figure 3d shows the difference between magnetic field component variations and all the control days mean with universal time. The observed variation in magnetic field strength is due to solar eclipse because of the fact that the effect of north-south component is minimum; however, the effect is maximum on east-west component and significant amount of variation on total magnetic field is also observed.

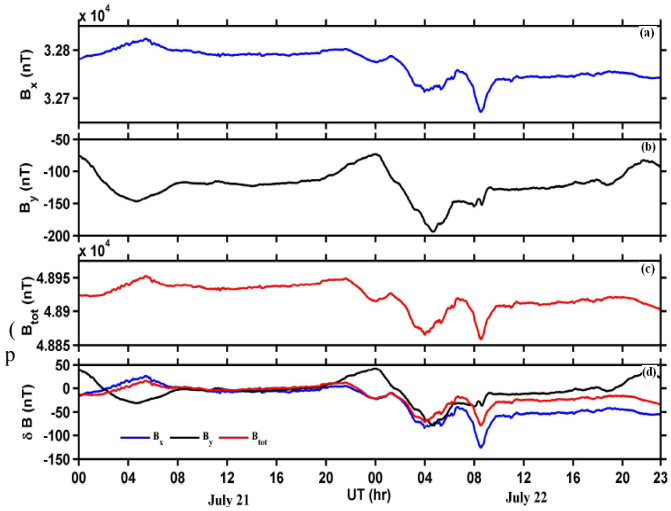
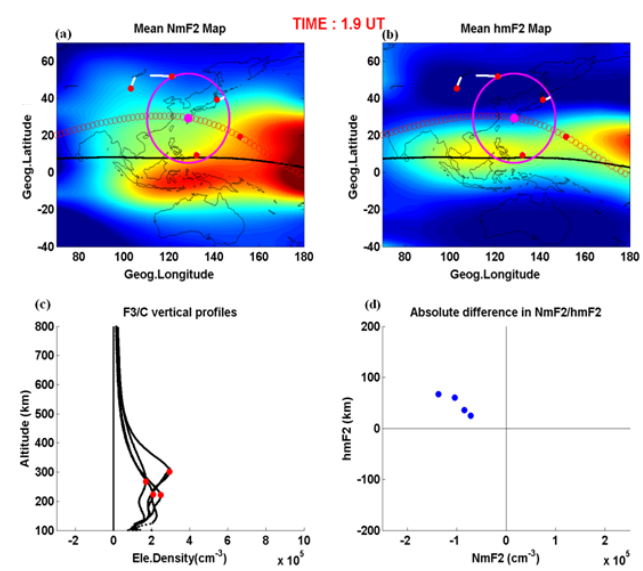


Figure 3. Jeju magnetometer magnetic field components (a) Bx (b) By (c) Btot for 21 & 22 July 2009 and (b) corresponding perturbation in magnetic field components (δBx, δBy and δBtot) with universal time are plotted.

These ground magnetic field variations can reflect the ionospheric current, especially E-region electric current at mid latitude. The strong decrease of the east-west component of magnetic field indicates the strong decrease of the southward current due to decrease of solar radiation during the solar eclipse period. The above explanation would be meaningful if the total solar eclipse event occurring alone without geomagnetic storm is considered and has real meaning on changes of ionospheric current or magnetic field for solar eclipse event. Unfortunately, magnetic storm and eclipse events occurred simultaneously making it difficult to explain for pure eclipse effect on magnetic field or E region in the present study. However, we tried to carry out the similar observations for future eclipse events.

For example, Figures 4(a) and 4(b) show the monthly mean NmF2 and hmF2 variation from -40 to 70° geographical latitudes and 70 to 180° geographical longitudes to examine the variations in the electron density in F2-region. These figures correspond to the time when the maximum solar obscuration over Korean peninsular region i.e., 1.9 UT. The pink circles in these figures indicate the region of 50% of solar obscuration and the white lines with red dots indicate the locations of F3/C radio occultation observations on the eclipse day at 1.9 UT. The black solid lines indicate magnetic equator. Figure 4c shows the vertical electron density profiles corresponding to the occultations in the 50% of solar obscuration region. The red dots in Figure 4(c) indicate the F2-peak height (hmF2) and electron densities (NmF2). The Figure 4(d) shows the absolute difference between the hmF2 and NmF2 on the eclipse day and the corresponding background (monthly mean) values. Clearly it can be seen from this figure that the NmF2 exhibits negative response and hmF2 exhibits positive response.



F

Figure 4. COSMIC electron density profiles on 22 July 2009 at ~02:00 UT

This indicates that the electron density at F2-region peak region and the bottom side ionosphere are quickly lost due to recombination. However, the recombination in the topside ionosphere (above F2-peak) is relatively slower. The rapid decrease in the bottom side electron density manifest as a decrease in NmF2 and an increase hmF2 as can be seen in Figure 4(d). This fact is also evident from the ionosonde foF2 and hmF2 parameters, however, clear variation cannot be seen because of strong sporadic-E layers observed at the same time.

Figure 5a and 5b shows the total electron content maps at 02 UT from ground based GPS receivers on total solar eclipse day and previous 3 day mean with latitude and longitude, respectively. From this figure, it can be clearly seen that a decrease in total electron content of about 4-5 TEC units along with eclipse path compared to previous 3-day mean.

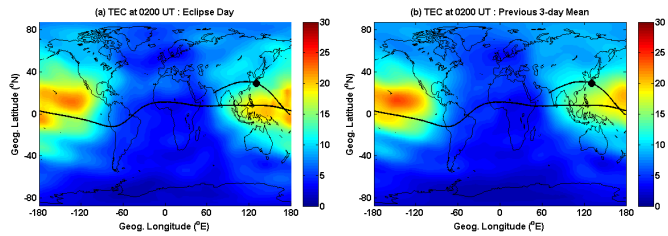


Figure 5. GPS TEC maps of latitude and longitude variation are plotted

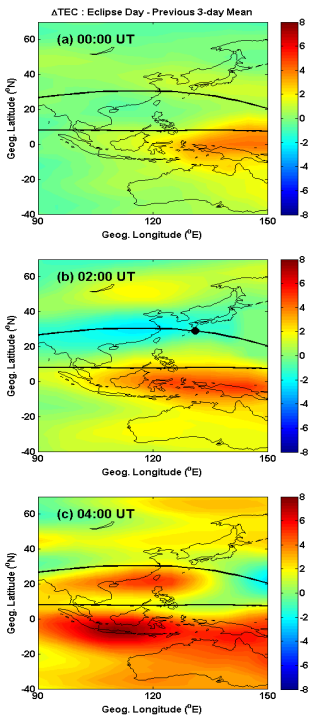


Figure 6. GPS TEC maps of latitude and longitude variation are plotted.

Figure 6a-c shows the ΔTEC (Eclipse day – previous 3-day mean) plots at the beginning, maximum solar obscuration and final phase of the solar eclipse, respectively, as function of geographic latitude and longitude. It can be clearly observed from the Figure 6b is that, at the maximum of solar obscuration there is a significant decrease in TEC decrease (~ 4-5 TEC) along the solar eclipse path. However, there is significant enhancement in TEC after the eclipse as can be seen from Figure 6c. This can be attributed as due to the positive response of ionospheric electron density for the geomagnetic storm (main phase) under progressing during the same time.

5 Summary

In this paper, we present the preliminary results observed variations of D-, E- and F-regions of ionosphere over South Korea peninsula during 22 July 2009 solar eclipse event. The reduction in VLF signal intensity and interestingly minimum around maximum phase of solar eclipse has been clearly observed indicating the solar eclipse effect on D region. It is observed that the effect of the solar eclipse on north-south component of magnetic field is minimum, however, the eclipse effect is maximum on east-west component of magnetic field. NmF2 exhibits negative response and hmF2 exhibits positive response in COSMIC satellite data indicating that the electron density at F2-region peak region and the bottom side ionosphere during the eclipse period are quickly lost due to recombination. It is also observed clearly that the maximum solar obscuration decreases in TEC along the solar eclipse path which is evident in the maximum phase compared to initial and final phases.

7 References

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