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COSMIC observations of ionospheric density profiles over Indian region: Ionospheric conditions during extremely low solar activity period

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In the present paper, for the first time, an attempt has been made to study the seasonal, altitudinal, diurnal and latitudinal variation of low latitude electron density obtained using COSMIC radio occultation (RO) measurements over Indian longitudes during the deep solar minimum year 2008. The seasonal variation shows enhanced electron densities at vernal and autumn equinoxes compared to winter and summer seasons. The observations also suggest a shift in the time and altitude at which the peak of the electron density occurs in different seasons. An important finding is that there exists an equinoctial asymmetry in the electron density with respect to altitude and latitude, where the electron density is higher at vernal equinox compared to autumn equinox. The latitudinal and seasonal variation of peak electron density (N_mF_2) during 10:00-14:00 hrs LT indicate enhanced equatorial ionization anomaly (EIA) on either side of the magnetic equator at both vernal and autumn equinoxes compared to the other seasons. Seasonal variation of equatorial electrojet (EEJ) strength obtained from geomagnetic H-field variations also shows strong EEJ at vernal and autumn equinoxes indicating that EEJ strength indeed partly controls the EIA development. Further, the results indicate that N_mF_2 over the northern EIA crest region is correlated well with solar flux.

Keywords: Electron density, Equatorial ionization anomaly (EIA), Equatorial electrojet (EEJ) strength, Ionospheric density, Equinoctial asymmetry

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1 Introduction

The recent solar minimum during 2007-2009 was the deepest and prolonged solar minimum among other solar minimas in the last century[1-7]. Since the solar activity during the years 2007-2009 was extremely low and also the conditions near the sun indicated that sun is much quieter than usual solar minimum, it was speculated that whether sun is heading for long term solar minimum such as 'Maunder minimum' that occurred during 1640-1700. During the same time, solar cycle 24 was not started. Hence, several scientific investigations have been carried out to understand the impact of this low solar activity on different parameters of the atmosphere and ionosphere system[6-7]. During this extreme minimum, the upper atmosphere became thinner, cooler and the thermospheric mass density was lowered by about 10-30% than expected in 2007–2009 (Refs 6-7). So, investigations of such extreme events provide an opportunity not only to examine the performance of various ionospheric empirical or physical models but also to examine the ionospheric electrodynamics under such extremes. Hence, it is important to examine the response of equatorial and low latitude ionosphere under extreme solar conditions.

Since solar flux is very important source of ionization in the ionosphere, it is important to know how the ionospheric parameters varied during this extreme low solar activity period as compared to previous high and low solar activity periods. Low solar activity period also provides an opportunity to look for neutral variations. Previous studies have indicated that electron density varies linearly with solar flux in the low solar activity but non-linearly with high solar activity periods[2,3,5,8-10]. As neutral densities are drastically reduced during this extreme low solar activity period, it may also cause changes in seasonal variation, satellite drag, composition, neutral winds and ionospheric density. It may be mentioned that the equatorial ionosphere is lifted to higher altitudes during daytime due to vertical drift being upward. This causes ionization trough and crest to form in the equatorial and low latitude ionosphere. So, it is also important to understand their temporal and seasonal variability under different solar conditions so as to understand their effects on ionospheric scintillations or irregularity generation. Since seasonal variation of the ionosphere is still debatable, it is worth studying them during such extreme low solar activity period. It is important to study the role of solar flux on the seasonal variation of different ionospheric parameters over low latitude in the Indian region during extremely low solar activity period. Hence, in the present study, it is proposed to use Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC)/ Formosa Satellite 3 [FORMOSAT-3 (F3/C)] (Refs 11-14) observations to study the seasonal and temporal variation of background electron densities, N_mF_2 and their latitudinal and altitudinal variations over Indian region during the year 2008 when such prolonged solar minimum occurred. These observations are compared with ground based EEJ strength.

2 Observational data

2.1 COSMIC density profiles

COSMIC was launched with six microsatellite constellation into circular orbit at an altitude of 512 km and 72° inclination with its major payloads being: (a) radio occultation experiment (GOX) instrument to perform radio occultation observation in both troposphere and ionosphere; (b) tri-band beacon transmitter to perform ionospheric tomography; and (c) tiny ionosphere photometer (TIP) to observe the nighttime ionospheric airglow emission[11-14]. These satellites were later on subsequently raised to 800 km. The height is raised in such a way that the time delay for this increase in elevation is to spread the orbital planes so that individual satellites are spread by 30°.

The basic data used in this study is the electron density profiles which were retrieved from the COSMIC website (http://www.cosmic.ucar.edu) during January - December 2008. The electron density profile data were obtained from radio occultation (RO) using Abel inversion technique[11-14]. When an electromagnetic signal passes through the Earth media, it experiences delay, bending and change in amplitude. These changes are used to extract information about ionosphere in the vicinity of tangent point. Ionospheric electron density measurements are obtained through phase and Doppler shifts of radio signals. The Doppler shift of the GPS L-band signals received by a low Earth orbit (LEO) satellite is used to compute the amount of signal bending that occurs due to refraction as the GPS satellite sets or rises through the Earth's atmosphere as seen from LEO. The bending angles are related to the vertical gradients of atmospheric and ionospheric refractivity. The refractivity is directly proportional to ionospheric electron density in the ionosphere. Through assumption of spherical symmetry, electron density profiles are retrieved either from the bending angles or from total electron content (TEC) data[11-14]. Occultation usually occurs when the GPS satellite sets or rises behind the Earth's ionosphere as seen by a receiver in LEO. Each occultation consists of a set of links with tangent points ranging from the LEO satellite height to the surface of the earth. One occultation roughly takes ~4-10 minutes depending on the relative position of LEO and GPS satellites. Each COSMIC satellite is equipped with four antennas, two of which are used for ionospheric electron density measurements (one for rising and one for setting occultation). These two antennas collect the L1 and L2 GPS phase data from up to 13 GPS satellites every second. The inversion of COSMIC data into electron density profiles is based on the difference between the L1 and L2 GPS phase path measurements. Detailed description of the inversion technique applied to invert the occultation data to ionospheric electron density profiles is reported in the recent works[11-14]. Here, it may be mentioned that the accuracy of estimation of electron density profiles depend on many factors, such as thermal fluctuations of the received signal, sharp gradient of the refractive index, presence of plasma irregularities, etc. leading to many erroneous inversions. Most of these erroneous inversions are deleted using automatic detection though some pass these conditions. The main sources of errors in the ionospheric electron density come from the assumptions made in the inversion method and measurement errors[13,15]. The following assumptions are made while retrieving the ionospheric electron density: (1) LEO and GPS satellites have circular orbits and move in the same plane; (2) straight-line propagation of the radio waves in the ionosphere; and (3) spherical symmetry of electron density distribution. On the other hand, the measurement errors may come from carrier phase errors and the satellite orbital errors. The electron density error induced by the phase measurement error is about 10^7–10^8 m^{-3}, and may be neglected in the F-layer. The approximation of straight-line propagation induces errors at the height of the F1 layer under the solar maximum condition. Out of all, the main source of error comes from the spherical symmetry approximation of electron density distribution.

The electron density profiles obtained using COSMIC radio occultation technique has been compared with ionosondes and incoherent scatter radar facilities and are found to be satisfactory[16]. The daily electron density profiles so obtained are kept in the website only after deletion of erroneous profiles. Using the radio occultation method, nearly 2000-2500 vertical electron density profiles are obtained daily over the entire globe. The observations so obtained using this mission are now extensively used to study the global atmosphere and ionosphere simultaneously. Using such dense observations, already several seasonal and morphological studies have been made and intense research is going on around the world. Some of the initial results led to some interesting findings such as: (a) wave number 3/4 pattern in EIA region and their coupling to some of the equatorial E-region processes; (b) global climatology of F3 layer; (c) longitudinal variation of EIA; (d) equinoctial asymmetry in the background ionosphere over equatorial and low-latitude regions; and (e) effect of solar flux on the ionosphere apart from others[17-19].

In the present work, daily electron density profiles over Indian region from January to December 2008 are used. Using these data, peak electron density (N_mF_2) and its corresponding height (h_mF_2) are obtained. Figure 1 shows: (a) scatter plot of N_mF_2 spread over the globe on a typical day [day of the year (DOY): 100]; and (b) number of daily global COSMIC radio occultation measurements over the year 2008. Figure 1(a) shows the typical global coverage of COSMIC radio occultation measurements of F2-layer peak electron density (N_mF_2) on a typical given day. Here, the N_mF_2 values are represented by color bar. Also for easy reference, superimposed lines

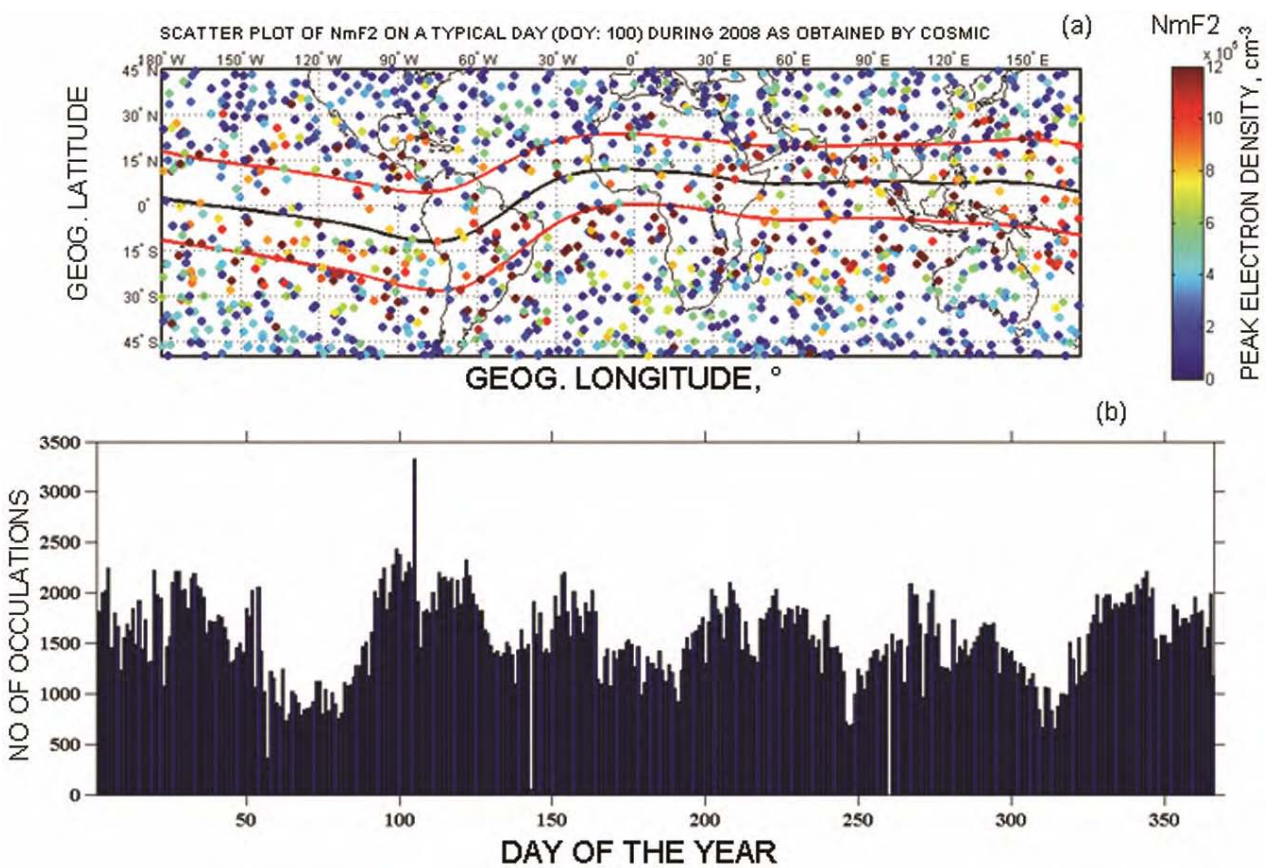

Fig. 1 — (a) Typical global coverage of COSMIC radio occultation measurements of F2-layer peak electron density (N_mF_2) on a given day [superimposed lines show (i) dip latitude (dark black line) and (ii) ±15° dip latitude (red line)]; (b) Daily global number of occultations during 2008

show: (a) dip latitude (dark black line); and (b) ±15 dip latitude (red line). During 2008, the number of occultation varies from 1000 to 2200 per day.

2.2 Geomagnetic data

The ground geomagnetic data from Tirunelveli (8.7°N, 77.8° E, dip latitude 0.4°N) and Alibag (18.5°N, 72.9°E, dip latitude 13.0°N) are used to obtain the hourly ΔH variations, which is commonly known as EEJ strength or EEJ current during January - December 2008. The method through which EEJ strength is obtained is available in literature[20]. First night time magnetic data is subtracted from its original values at each time at each individual station. Later on, taking the difference between Tirunelveli and Alibag magnetic observations so as to minimize the magnetospheric effect, EEJ strength can be inferred[20]. The EEJ strength so obtained is widely used to study the equatorial ionospheric current system. Presently, this data is used to study the association of EEJ strength with ionospheric electron densities.

3 Results and Discussion

3.1 Solar flux at F10.7 and Kp index

The absolute solar flux at 10.7 cm (F10.7), which is a proxy for solar activity, is obtained from National Geophysical Data Center *(*NGDC*)* website while Kp index is obtained from Kyoto University website. Figure 2 shows: (a) monthly F10.7 during 1965-2010 to show how the solar flux varied during different years; (b) F10.7 during 2008; and (c) mean Kp index during 2008. From Fig. 2(a), one can notice the large difference of solar flux values between high and low solar activity periods. In addition, one can also notice that solar flux values are quite low and are prolonged during recent solar cycle minimum. Here, red dotted line in Fig. 2(a) shows the level of recent solar minimum for comparison. While solar flux values are mostly in the range 150 - 200 sfu (1 sfu = 10^{-22} W m^{-2} Hz^{-1}) in high solar activity periods, solar flux values are mostly in the range of 60 - 65 sfu in the present low solar activity period. Figure 2(b) suggests that the solar flux values mostly vary in the range 60 - 65 sfu during 2008 except one occasion. The solar flux

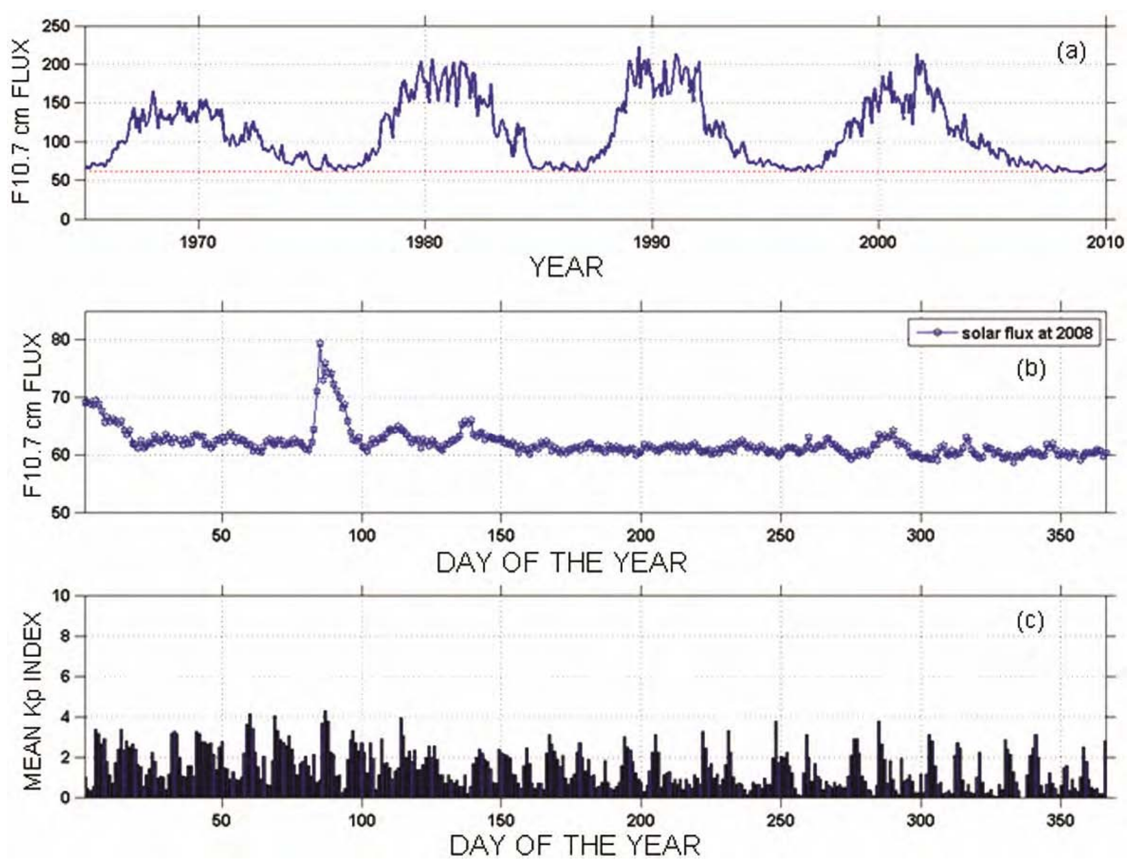

Fig. 2 — (a) Monthly solar flux at F10.7 cm during 1965-2010 (red dashed line is indicative of lowest solar flux level observed during solar cycle 23); (b) Daily solar flux at F10.7 cm during 2008; and (c) Mean Kp index for 2008

during the middle of March-April 2008 increased from 60 to 75 sfu, which could be due to 27-day solar rotation[21]. Attempts have been made to identify the effect of this 27-day solar rotation on the ionosphere using daily zonal average of ionospheric peak density and corresponding altitude. The observations suggest that there exists some enhancement in the density and corresponding increase in h_mF_2 during March-April 2008 when solar flux is increased (data not shown), which it is believed could be due to 27-day solar periodicity. Figure 2(c) shows mean Kp index being mostly below 4 indicating that all these days are geomagnetically quiet.

3.2 Altitudinal variation of electron density profiles during different seasons

Figure 3(a-f) shows the variation of vertical electron density profiles using COSMIC observations during 10:00-14:00 hrs LT over equatorial location namely 5-10°N in Indian longitude zone during: (a) Jan-Feb 2008; (b) Mar-Apr 2008; (c) May-Jun 2008; (d) Jul-Aug 2008; (e) Sep-Oct 2008; and (f) Nov-Dec 2008. The observations suggest that peak electron density occurs at around 250-300 km altitude. In addition, the peak electron density also varies from one season to other. The peak electron density goes to a minimum (5.0×10^5 cm^{-3}) during July-August (summer months) compared to other months. The maximum electron density of $\sim 1.0 \times 10^6$ cm^{-3} is observed in Mar-Apr and Sep-Oct. In addition, the N_mF_2 in Jan-Feb and Nov-Dec (winter months) is higher compared to summer months. Earlier researchers named this as 'winter anomaly' since normally summer season, when Sun is over head and could produce more ions, should have higher density than winter season[22-29]. But the observations show that density is low during summer compared to other seasons. It is suggested that reason for this anomaly could be due to solar zenith angle, changes in the neutral composition and meridional wind circulation[23-30]. In the neutral composition, atomic oxygen density is found to be higher than molecular nitrogen, and molecular oxygen densities during winter season than during summer, which reduces ionospheric loss process abruptly and hence, increases the electron density during winter season.

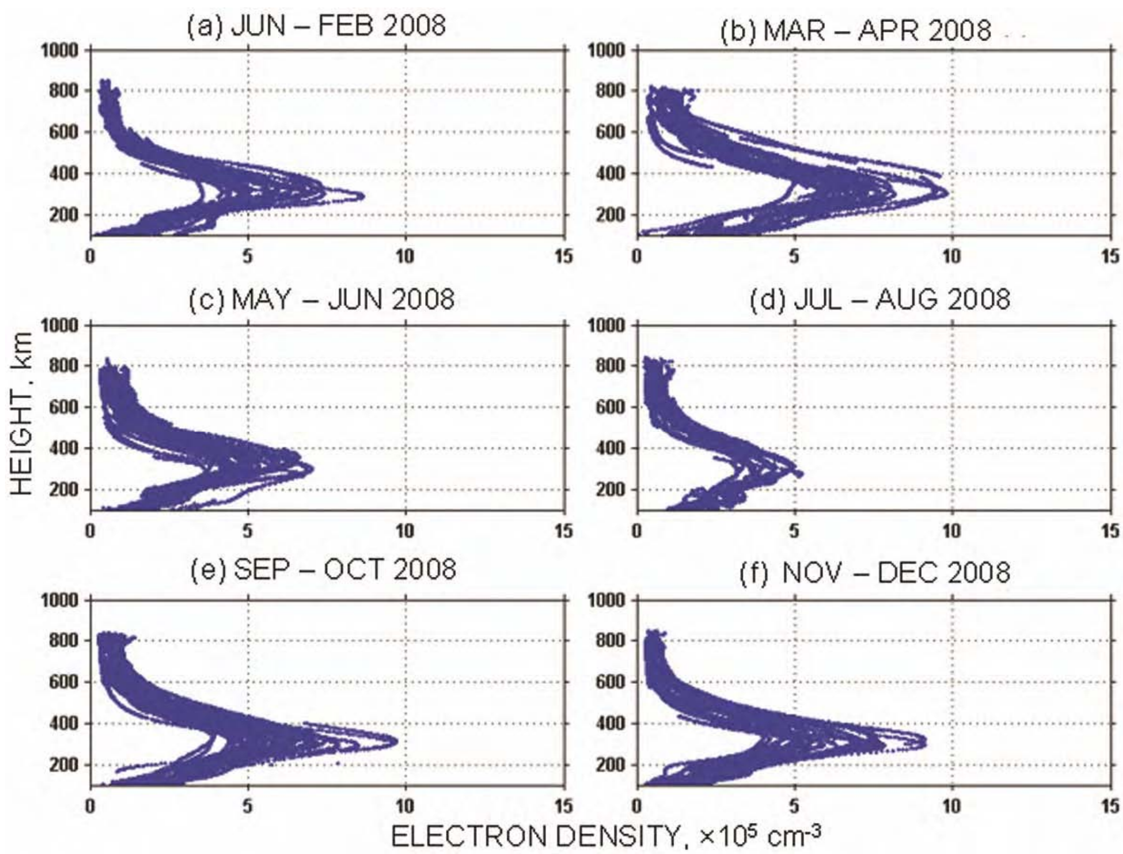

Fig. 3 — Variation of vertical electron density profiles using COSMIC observations during 1000-1400 hrs LT at geographic latitude 5-10°N over Indian longitude region in: (a) Jan-Feb; (b) Mar-Apr; (c) May-Jun; (d) Jul-Aug; (e) Sep-Oct; and (f) Nov-Dec 2008

Earlier studies on electron density profiles over Indian region were made occasionally on campaign modes using rocket measurements. These density profiles are used mainly to understand the role of electron density gradients on the generation of ESF irregularities. So, there were limited observations to study the seasonal variation of electron density profiles. However, f_oF_2 and virtual height obtained using ionosonde at different stations are used to study the seasonal variation of density and its altitude variations. The previous observations reveal that peak density occurs in the afternoon hours and it correlates well with solar flux. However, the observations presented here, using large data sets, show seasonal variation of density profiles during the low solar activity period.

Attempts have been made to study the seasonal variation of electron density profiles near equatorial region over Indian region using monthly mean density profiles. Figure 4 shows the mean monthly variation of COSMIC density profiles near geographic latitude 5-10°N over Indian longitude during 06:00-12:00 hrs LT. Color bar shows the electron density values. The observations indicate clear seasonal variation in the density where electron density maximizes in the equinoctial months followed by winter and summer seasons, which represent semi-annual variation. The observations suggest that the altitude at which the peak of the electron density occurs is around 250-300 km. The observations also suggest that there exists an asymmetry in the mean density during equinoctial months where the density at vernal equinox is stronger than that at autumn equinox. The asymmetry at the equinoxes is found to extend to as high as 700-800 km altitude and can be noticed clearly in the Fig. 4. While the reason for this asymmetry could either be due to the asymmetry in trans-equatorial meridional winds and/or asymmetric vertical drift, the former has been suggested as a major reason for the equinoctial asymmetry in the electron density[22,31-32].

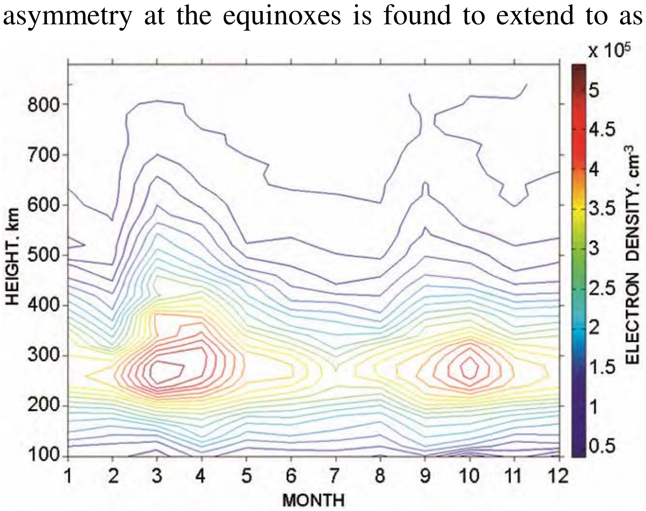

Fig. 4 — Contour map of monthly variation of electron density profiles obtained using COSMIC observations at geographic latitude 5-10°N over Indian longitude during 06:00-12:00 hrs LT

3.3 Diurnal variation of mean electron density profiles

Figure 5 shows the diurnal variation of mean electron density profiles obtained from COSMIC over equatorial location in Indian longitude during: (a) equinox; (b) winter; and (c) summer seasons; x-axis represents local time and y-axis represents height. White gaps are due to non-availability of data. Superimposed line plot is the h_mF_2 during different seasons. For detailed comparison, 3-point smoothing of h_mF_2 and N_mF_2 are plotted in Fig. 6 (a-f) during: (a) equinox, (b) winter, and (c) summer season, respectively. From the figure it can be noticed that maximum electron densities occur at around 250-300 km altitude at different timings in different seasons and has seasonal variation. While density maximizes at 12:00 hrs LT during winter season, the density is found to maximize at 16:00 hrs LT during equinox and summer seasons. The maximum electron density of ~8.0×10^5 cm^{-3} is noted at equinoxes followed by winter and summer seasons. The diurnal variation of electron density at 500 km altitude in the previous low solar activity period over Indian region also suggests that density during summer is much less compared to winter season[33]. In addition, electron density is found to be minimum during 04:00-05:00 hrs LT in all seasons in the present low solar activity period, which is also quite similar to that of previous low solar activity period where minimum occurred at ~04:00 hrs LT (Ref. 33). The diurnal variation of h_mF_2 shows that while peak of the electron density occurs around 300 km altitude during daytime (10:00-12:00 hrs LT) in all seasons, there exists differences between these observations in the evening and post-midnight hours. In all seasons, height is decreased in the post-midnight hours. During summer season, the h_mF_2 is found to come down to as low as 220 km altitude, while it is found to increase during 23:00-24:00 hrs LT. The diurnal variation of h_mF_2, as shown here, has significant implications for the onset of ESF activity since ESF activity depends on the rise in post-sunset F-layer height. The observations presented here may be understood from the effects of solar ionization and E×B drift on h_mF_2

during different seasons[34]. In the morning hours, as solar ionization start building, the height of F-layer starts decreasing due to rapid production of ionization in the lower F-region as can be seen in the Figs 6(a-f). During daytime, the increase of temperature and atomic oxygen density as well as changes in loss coefficients can cause higher h_mF_2. However, in the evening hours, due to decrease of ion production as well as increase of PRE, some enhancement in the h_mF_2 occurs.

3.4 Seasonal and latitudinal variation of N_mF_2 and h_mF_2

Figure 7 shows the seasonal and latitude variation of: (a) N_mF_2 and (b) h_mF_2 over Indian longitude region during the year 2008. From the Fig. 7(a), one can notice that development of EIA on either side of the magnetic equator is very strong during equinoxes compared to other two seasons though there exists some asymmetry in the strength of EIA at the equinoxes. Also, the seasonal variation suggests that EIA development is weak/absent during summer season. The diurnal and seasonal variation of electron density at 500 km altitude using SROSS C2 is studied over Indian longitude during previous low solar activity period[33]. Bhuyan *et al.*[33] found asymmetric development of EIA at an altitude of 500 km at northern and southern latitudes. Further, their observations also show the variation of EIA location with season. Their observations also show that electron density at equinoxes maximizes at 10°N in the northern hemisphere and at 5°S in the southern hemisphere. When N_mF_2 is compared with high solar

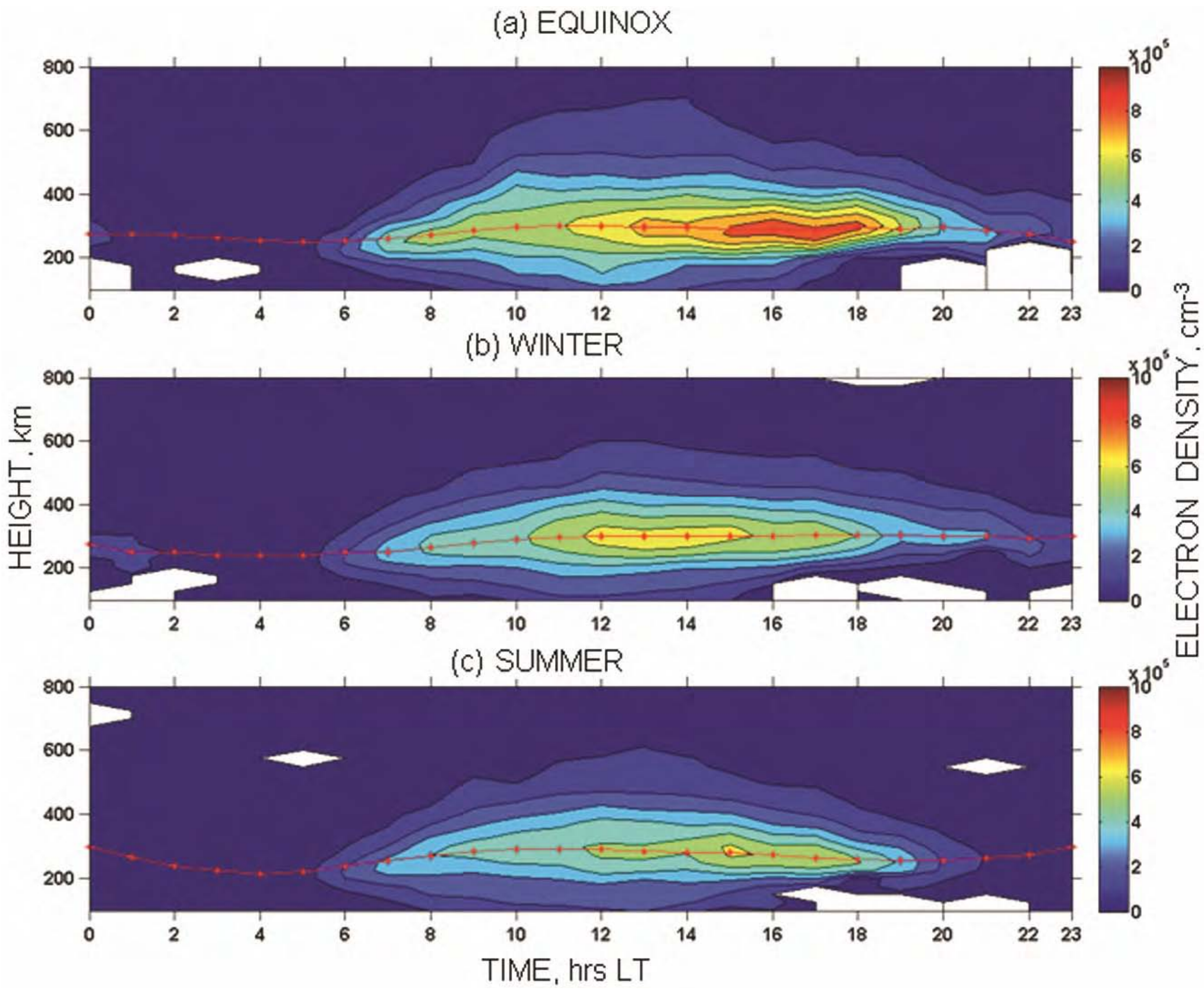

Fig. 5 — Diurnal variation of mean electron density profiles obtained from COSMIC at geographic latitude 5-10°N over Indian longitude region during: (a) equinox; (b) winter; and (c) summer seasons, respectively (superimposed red line on each subplot indicates the mean diurnal variation of h_mF_2 during different seasons)

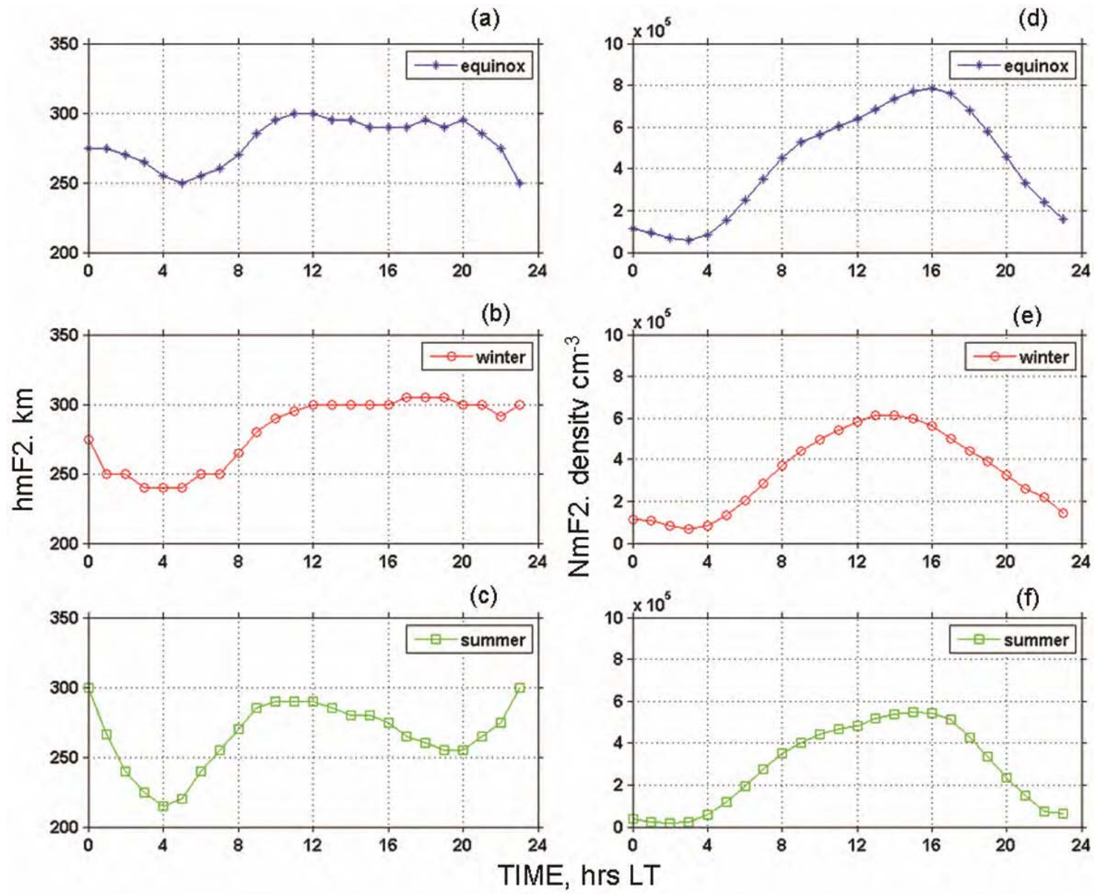

Fig. 6 — Diurnal variation of mean h_mF_2 (left) and N_mF_2 (right) at geographic latitude 5-10°N over Indian longitude region during: (a) equinox; (b) winter; and (c) summer seasons

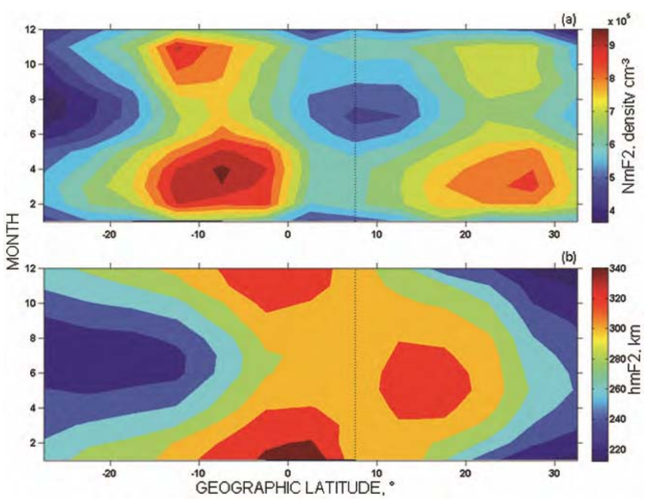

Fig. 7 — Seasonal and latitude variation of: (a) N_mF_2; and (b) h_mF_2 over Indian longitude region during 2008 (dotted line shows the dip equator)

activity period, in general, N_mF_2 during low solar activity period is found to be an order of magnitude less than that during high solar activity period[35]. In addition, earlier studies also indicate that there exist annual and semi-annual variations in the ionosphere[22-29]. While annual variation is dominant over high latitude, semi-annual variations are dominant over equatorial and low-latitude regions. Since the observations presented here are obtained from equatorial and low-latitude regions, seasonal variation presented here suggests that there exist semi-annual variation in N_mF_2. Basically seasonal variation of N_mF_2 depends on the solar zenith angle, chemistry, meridional neutral winds and the ratio between [O] and [N2] (Refs 23-30). Development of EIA on either side of the equator has many implications for equatorial and low-latitude ionospheric irregularities or scintillations. The enhanced scintillations or irregularity generation over equator are mostly associated with symmetry of EIA on either side of the magnetic equator. As EIA on either side of the equator mostly during equinoxes has been noticed, one can expect that enhanced scintillation activity could occur at equinoxes. From

Fig. 7(b), it can be noticed that higher h_mF_2 during winter season is over geographic equator while it shifts to low latitude locations during vernal equinox and summer seasons. The seasonal and latitudinal variation of h_mF_2 can be understood through the parameters such as vertical E×B drift and thermospheric meridional neutral winds. It may be mentioned here that while vertical drift plays important role in h_mF_2 variation over equator, meridional winds plays important role in h_mF_2 variation over low latitudes. Hence, the reason for the asymmetric distribution of h_mF_2 in the latitudinal and seasonal variation, as seen in Fig. 7(b), could be either due to meridional winds or vertical E×B drift through which the height of the F-layer ionosphere can be increased or decreased.

3.5 Comparison with EEJ strength

Figure 8 shows the contour map of monthly mean EEJ strength over the time interval of 06:00-18:00 hrs LT during 2008. Here x-axis represents time in LT, y-axis represents month. The daytime mean EEJ strength is found to be about 50 nT which is less than half that during high solar activity periods when the mean EEJ strength is found to be beyond 100 nT. The EEJ strength maximizes around 11:00 hrs LT over Indian region. Earlier studies have shown that solar flux does show some geomagnetic H-field variations over Indian region during geomagnetically quiet days[36]. It is noticed that EEJ strength increases linearly with solar flux. In addition, their observations also indicate that while EEJ strength maximizes at around 11:00 hrs LT during low solar activity period, it maximizes around 12:00 hrs LT during high solar activity period. The observations shown here also suggests that EEJ strength could maximize at about 11:00 hrs LT which is quite similar to that of earlier reports. Earlier reports suggest that reason for this could be due to the EEJ current being the product of Ne, e and V which would be maximizing sometime between the time of maximum of N_e and V (Ref. 36). The electron density reaches its maximum close to noon while V (or hence the electric field) becomes maximum near 09:00-10:00 hrs LT. Therefore, the product maximizes at about 11:00 hrs LT in the low solar activity periods. From the figure, one can also notice that strong EEJ strength is developed during equinoxes as compared to other two seasons, which could be due to semi-annual variation. Close observations indicate that there exists some difference in the strength of EEJ between vernal and autumn equinox where EEJ strength at vernal equinox is stronger than that at autumn equinox. In addition, from the figure, one can also notice the development of strong counter electrojet (CEJ) during 16:00-18:00 hrs LT during summer seasons.

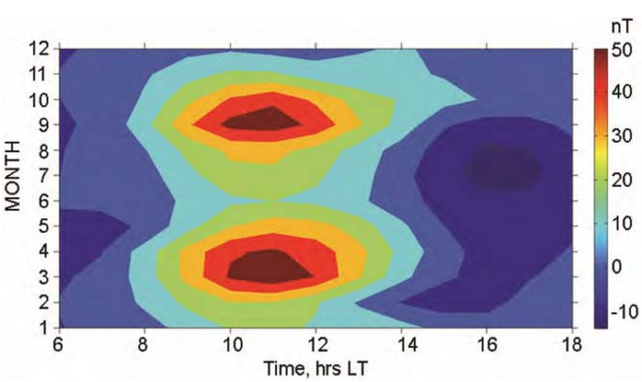

Fig. 8 — Contour map of EEJ strength over the time interval 06:00-18:00 hrs LT during 2008

3.6 Correlation of N_mF_2 with EEJ strength and solar flux

The maximum electron density and its corresponding latitude in the 0-30°N (in Indian longitudes) are compared with EEJ strength and solar flux data during low solar activity period. Figure 9 shows the correlation plots : (a) $N_mF_{2(max)}$ *vs* EEJ strength; (b) latitude of $N_mF_{2(max)}$ *vs* EEJ strength; (c) EEJ strength *vs* F10.7; and (d) $N_mF_{2(max)}$ *vs* F10.7, respectively; their corresponding correlation coefficients are also noted. From the observations, it may be noted that N_mF_2 is very well correlated to the EEJ strength and F10.7 with correlation coefficients of nearly 0.73 and 0.60, respectively. It may be mentioned here that N_mF_2 at high solar activity has a linear relation with F10.7 for F10.7 less than about 175 sfu. However, above 175 sfu, N_mF_2 behaves non-linearly and leads to saturation. Several studies have been made to understand the saturation of N_mF_2 with solar flux using different solar proxies[1,2,5,8-10]. These studies suggest several sources for the ionospheric saturation effect. Since solar flux variations are about 65 sfu in the present low solar activity period, the linear relationship of N_mF_2 with solar flux, which is shown here, very well complement the earlier results. Low correlation co-efficient seen in the present observations may be due to dynamical effect. On the other hand, EEJ strength is not fully correlating with solar flux data indicating that EEJ strength is influenced by other factors such as lower atmosphere apart from solar flux.

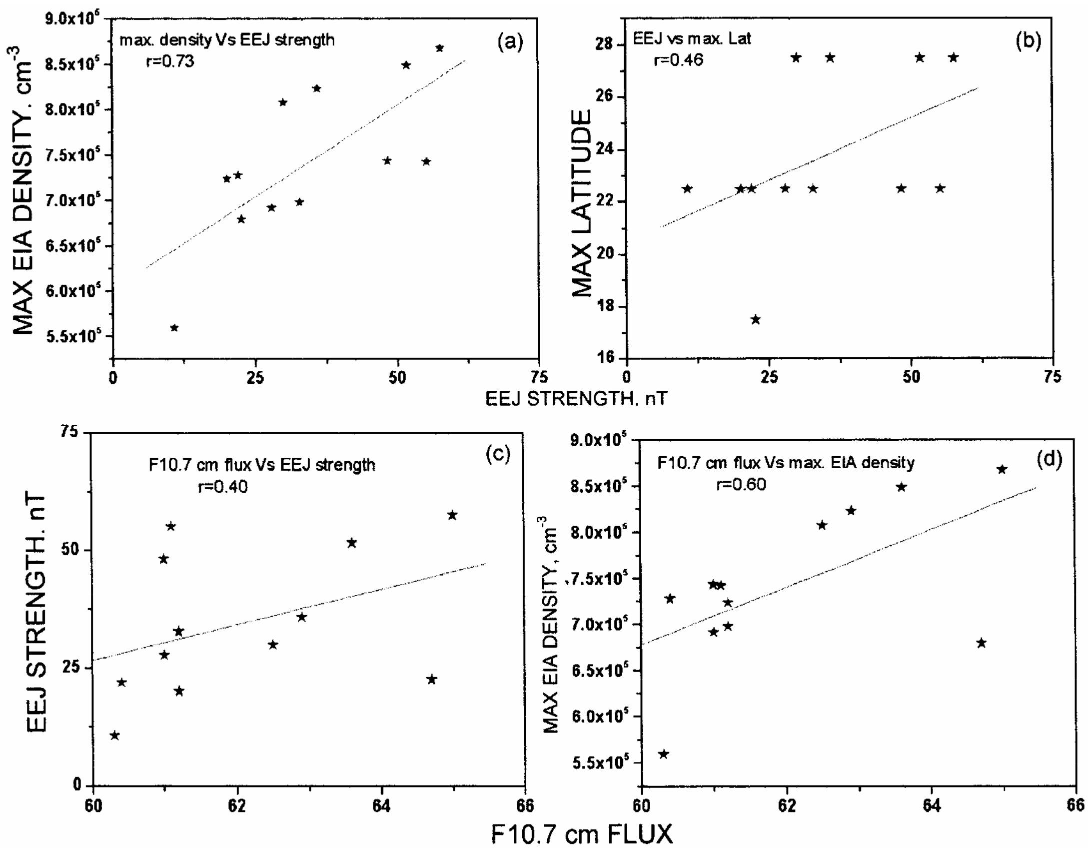

Fig. 9 — Correlation of: (a) max N_mF_2 *vs* max EEJ strength; (b) max latitude *vs* max EEJ strength; (c) max EEJ strength *vs* solar flux (F10.7); and (d) max N_mF_2 *vs* solar flux (F10.7) and their correlation coefficients over Indian region

4 Conclusions

The preliminary observations presented here demonstrate that COSMIC electron density profiles indeed are highly useful to understand some of the contentious issues over equatorial and low-latitude ionosphere. This also can complement the ground based observations. The latitudinal, altitudinal, diurnal and seasonal variation of electron density over Indian region suggests that density during equinoctial months is stronger than that of other two seasons. However, there exists some asymmetry between the equinoxes. Further, latitudinal variation of N_mF_2 over Indian longitude suggests that strong ionization crests are formed on either sides of the equator during equinoctial months during low solar activity period, though densities are quite low. The observations suggest that EIA is more symmetric at vernal equinox than at autumn equinox. In addition, the density over the northern EIA crest is found to correlate very well with EEJ strength as well as solar flux at F10.7 cm. Further, analyses are required to compare other ground based observations to unravel many unknown features over Indian longitude region during low solar activity period, which are left for future work.

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