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Equatorial Ionization Anomaly crest magnitude and its implications on the nocturnal equatorial ionospheric plasma irregularity characteristics

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Abstract

In this study, the association of Equatorial Ionization Anomaly (EIA) with various post sunset ionospheric irregularity manifestations are brought out empirically using Global Positioning System derived Total Electron Content (GPS - TEC) data from five stations centered around 77deg E longitude as well as ionosonde data at a dip equatorial station Trivandrum (geographic latitude 8.5deg N ; geographic longitude 77deg E) for the days of vernal equinox season of distinct solar activity conditions. The study reveals that the EIA crest magnitude in the evening hours has a direct control on the base height of post sunset ionospheric F- layer (the primary factor responsible for the generation of ionospheric plasma irregularities) on a day-to-day level. Under the condition of strong (weak) EIA crest, the equatorial spread F irregularities are observed to be manifested earlier (later) and are sustained for a longer (shorter) duration. Further, the GPS signal scintillation intensity (quantified by the parameter S4 index) exhibits a direct association with EIA crest strength. This work emphasizes the need to incorporate various EIA features in the current models for better prediction of post sunset ionospheric plasma irregularities which are known to be hazardous for communication and navigation systems

1. Introduction

The double humped latitudinal distribution of ionization at the equatorial and low latitude regions characterized by a trough at the geomagnetic equator and crests located ~15deg apart on either side of the geomagnetic equator is termed the Equatorial Ionization Anomaly (EIA) (Appleton, 1946). The off- equatorial E- region zonal elec tric field which is mapped to the equatorial F- region produces the upward ́E xB(́E - Electric field, B - Magnetic field) drift of plasma and eventual diffusion along field lines under the combined effects of pressure gradient and grav ity, causing the formation of EIA. The latitudinal ioniza tion gradient associated with EIA is proven to be an important background condition for the occurrence of Lband scintillations. The connection of EIA with Equatorial Spread F (ESF), the turbulent plasma structures arising in the nocturnal equatorial ionosphere, has also been studied (Raghavarao et al., 1988). Ragahavarao et al. (1988) demonstrated that the ratio of electron densities (at 270 km) between a EIA crest station, Ahmedabad and a low latitude station, Waltair increased by a factor of ~8–20 on ESF days compared to the factor of 2 on Non– ESF (NSF) days. Their study was based on a limited database of 33 days (with data availability at both stations) covering the winter and vernal equinox seasons of moderate and low solar activity years 1982 and 1984 respectively. Using day-glow measurements from the zenith over Waltair and those at 20 off zenith (towards Ahmedabad which is the crest region), for the moderate solar activity period of January - February 1993, Sridharan et al. (1994) showed that prediction of spreadF is possible several hours ahead. Aswathy et al. (2018), showed that the ESF onset time is anti-correlated to the EIA response time for days when the ionospheric base height is below the threshold height (below the threshold height, ESF occurrence is directly modulated by the meridional circulation). The EIA induced effect on the ionosphere is thus capable of generating favorable conditions for the occurrence of some other dynamical processes in the ionosphere. Hence understanding the EIA induced ionospheric modifications is a subject of intense scientific interest. In the present study, aspects related to the EIA crest magnitude and its implications for the day to day evolution of post sunset ionospheric irregularity morphology, are quantitatively examined for the days belonging to the 'above threshold height regime'. The study unravels the direct correspondence of the EIA crest strength in the eve ning time (16–18 IST), with the post sunset ionospheric height, ESF occurrence, ESF onset, ESF duration and scintillation

2. Data and methodology

Ionosonde data for the magnetic equatorial station Trivandrum (geographic latitude 8.5 deg N) and GPS - VTEC data from Trivandrum, Bangalore (geographic latitude 13 deg N), Hyderabad (geographic latitude 17 deg N), Bhopal (geographic latitude 23 deg N) and Delhi (geographic latitude 27 deg N) which encompass the EIA regime, for the vernal equinox season of the years 2005, 2006, 2014 and 2016 are used in the analysis. The years are chosen based on the availability of data which encompasses high, medium and low solar activity levels. The longitudes of the stations are around 77 deg E geographic longitude.

In the present analysis, the GPS receiver biases are estimated using the method called 'Minimization of Standard deviations' (Ma and Maruyama, 2003). The method involves the iteration through a series of test biases (applied on the Slant Total Electron Content - STEC values) and calculating the standard deviations of VTEC (Vertical Total Electron Content) from their mean at each observation time. Then the sum of the standard deviations are obtained for the whole day. The value of the bias, for which the sum of standard deviations takes the minimum value, is taken as the correct bias of the GPS receiver.

3. Results

3.1 Evening EIA crest strength – Post sunset ionospheric height association

Fig. 1 illustrates the day-to-day variation of mean of EIA crest magnitude in the 16 – 18 IST time bin as a func tion of post sunset h0 F (base height of the ionosphere) for vernal equinox for the combined data of 2005 (Seasonal mean F10.7 = 88.7, F10.7 being the proxy parameter for solar activity), 2006 (Seasonal mean F10.7 = 80.8), 2014 (Seasonal mean F10.7 = 149.4) and 2016 (seasonal mean F10.7 = 92.7).

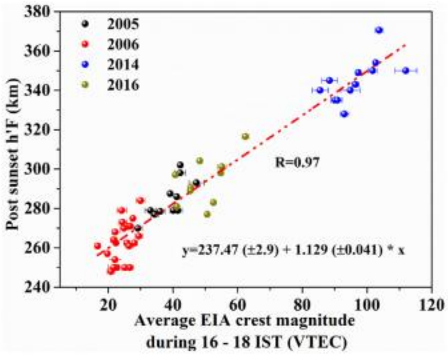

Fig. 1. The day-to-day level association of the mean of EIA crest strength during 16 – 18 IST and post sunset h0 F for the days of vernal equinox for the years 2005, 2006, 2014 and 2016.

It is evident from the figure (Fig. 1) that the EIA crest strength and post sunset h0 F are directly correlated with correlation coefficient of 0.97. The correlation coefficient is more than 99% significant. The relationship between the variables is observed to be linear. The relation shows that, on the days where the evening EIA crest is stronger in magnitude, ionospheric post sunset height is larger.

3.2. Evening EIA crest strength – ESF association

Fig. 2 depicts the scatter plot of VTEC at EIA crest in the evening time and ESF onset time for the days of the vernal equinox season of the years 2005, 2006, 2014 and 2016. The relation between the two parameters is linear, with correlation coefficient 0.6. It is seen that as the VTEC at crest increases, the ESF onset time becomes progressively earlier. The relationship between the variables is more than 95% significant. It is observed from Fig. 5 that the values of ESF onset are distributed stepwise over 19.25 IST, 19.5 IST, and 19.75 IST etc. This is due to the fact that the ionosonde measurement cadence is 0.25 h and the variability within 0.25 h cannot be discerned. Even with this constraint, the overall anticorrelation, between the day time EIA crest strength and ESF onset becomes evident in the analysis.

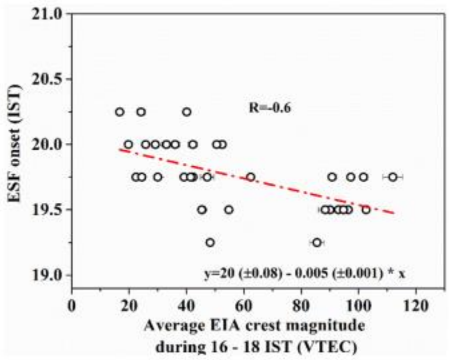

Fig.2. The scatter plot of VTEC at crest and ESF onset, combining the days of 2005, 2006, 2014 and 2016.

Fig. 3 represents the scatter plot of VTEC at crest and ESF duration for the days of the vernal equinox season for the years 2005, 2006, 2014 and 2016. It is clear that the two parameters are interrelated. It is seen that as the VTEC at crest increases the ESF duration becomes longer. The relationship between the variables is more than 95% significant.

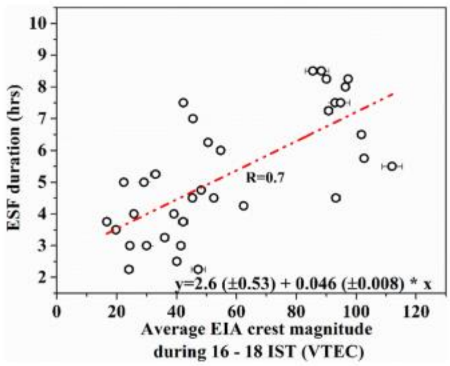

Fig.3 The scatter plot of VTEC at crest and ESF duration

ESF duration is 2 to 5 h. Days with the VTEC at EIA crest in the range of 90 to 120 TECU correspond to high solar activity condition (2014) and ESF persists typically for 6 to 10 h.

3.3. Evening EIA crest strength – Scintillation association

The ESF irregularities are large scale structures which are generated -and, eventually cascade into smaller scale size irregularities affecting GPS signals. In this section, the characteristics of the irregularities causing L band scintillations are examined in relation to EIA crest magnitude. The amplitude and phase of GPS signals undergo rapid fluctuations while traversing through the nocturnal irregular ionosphere and these fluctuations are defined as scintillations. The scintillations are quantified by the normalized variance in the received signal power, referred to as S4 index. The S4 of 0.17 is equivalent to the 3 dB change in the signal intensity. Hence S4 index of 0.17 or greater is considered to represent the scintillation occurrence in the present analysis. Variation of S4 indices at different stations encompassing the EIA regime for a sample day are shown in Fig. 4. Here the maximum S4 index is observed at Hyderabad (Hyd) station with magnitude 0.49 . The maximum scintillation occurs in the low-latitude station (Hyderabad), than the equatorial station (Trivandrum) for the sample day. The large-scale irregularities which are generated at the magnetic equatorial region are transferred to the off-equatorial region via the magnetic field lines. At the crest location where TEC is larger, the density gradients at the edges of the bubbles lead to the generation of secondary irregularities.

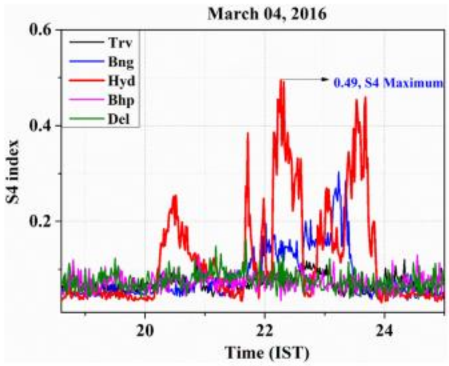

Fig.4 Variation of s4 index at different stations encompassing the EIA regime for a sample day.

Fig. 5 depicts the relation between the magnitude of EIA crest in the evening time and peak S4 index. It is evident from the figure that both the parameters are linearly correlated with a correlation coefficient 0.93. The large scale irregularities are interacting with a more densely populated plasma region when they are transferred to the offequatorial latitudes which are regions of EIA crest or near EIA crest. Here the density gradient at the walls of the primary irregularity are so sharp (due to presence of strong background ionization in the EIA crest or near EIA crest regions), as to generate the secondary plasma irregularities and thereafter stronger scintillations.

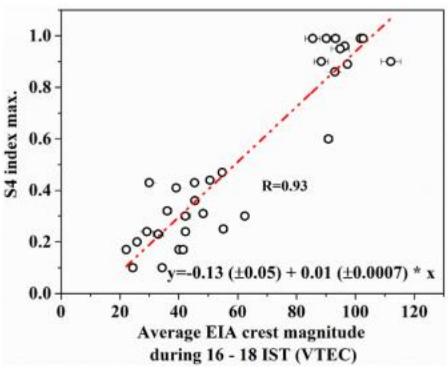

Fig.5. . The association of average EIA crest magnitude during 16–18 IST maximum S4 index.

4. Discussion

In the present study, the clear association obtained between the EIA crest strength (in the evening) and post sunset h' F indicates the strong dependence of post sunset electric field on the evening background parameters. It has been shown by Maruyama (1988) that a poleward (equatorward) wind is capable of pushing the F-region ionization to lower (higher) altitudes along the mag netic field lines, thereby enhancing (reducing) the conductivities at low altitudes and henceforth inhibiting (aiding) the F-region dynamo field. The study region of Maruyama (1988) was magnetic equatorial (Jicamarca, Dip angle = 1.67 deg; Forzeala, Dip angle = 3.36eg). The strength of the F-region electric field depends on the strength of the F-region zonal wind as well as the height integrated conductivities in the equatorial and off-equatorial latitudes. Hence the change in the height- integrated conductivity in the equatorial and off-equatorial regions by the ETWA (Equatorial Temperature and Wind Anomaly) induced meridional wind in the near sunset hours could be a possible factor which modulates F- region dynamo and thereby the pre-reversal enhancement. The above-mentioned day-to-day level association between the post sunset height rise of F layer and EIA crest strength can be incorporated in ESF prediction methodologies. Manju et al. (2007) demonstrated the direct relationship between ESF duration at magnetic equatorial station Trivandrum and scintillation duration at EIA crest locations signifying the need to quantify the ESF duration parameter under different geophysical conditions.

The importance of the present study is that it examines the day-to-day variability of equatorial ionospheric irregularity characteristics in connection with the EIA in the evening time. That is, the prompt post sunset height rise will lead to increased growth rate at the out set itself, thereby favoring early onset of ESF. The lifetime of ESF irregularities depends on their initial strength and the recombination rate with the former increasing with altitude and the latter decreasing altitudinally. The post sunset height rise enhances due to the EIA crest strengthening accompanied by the ETWA related equatorward winds leading to increased integrated F region conductivities. Increased F region conductivities are favourable for development of F region dynamo and hence higher post sunset heights. The increased growth rates of the generalized Rayleigh-Taylor instability for higher post sunset heights will result in decreased recombination rates thereby facilitating the sustenance of the irregularities for longer duration. Moreover, the increased EIA crest and consequent ETWA related winds can result in an off equatorial F region (east of Trivandrum) at higher altitudes than equatorial F region in the time immediately following the field reversal. Such a configuration of tilted ionosphere is unstable against a zonally eastward neutral wind and leads to irregularity generation/sustenance (Kelley et al., 1981). The amplitude and phase of GPS signals undergo rapid fluctuations while traversing through the nocturnal irregular ionosphere and these fluctuations are defined as scintillations. Scintillations are quantified by the normalized variance in received signal power, which is S4 index

In the present analysis, the association of evening time EIA crest with scintillation onset time and S4 index maximum are brought out. The larger scale plasma irregularities generated at the magnetic equator are transferred to the low-latitude region through the highly conducting magnetic field lines. Maximum scintillations are observed at off- equatorial regions. The EIA crest magnitude shows a clear association with the S4 index. This can be explained as follows. The off- equatorial regions have high ambient plasma density compared to the magnetic equator. The large-scale ESF structures are moved to this high density region. This causes sharp gradients at the walls of the large scale plasma bubbles, which are highly unstable. Thus shorter scale irregularities are generated from these unstable regions and they affect GPS signals and causes scintillations.

5. Conclusions

On day-to-day level, the evening time EIA crest strength controls the ESF characteristics like post sunset ionospheric height, ESF onset and ESF duration, for magnetically quiet days.

The amplitude of GPS signal fluctuations (quantified by the parameter S4 index) is related to the evening time EIA crest strength and the relation is quantitatively brought out.

The derived empirical relationships are applicable for low, medium and high solar activity conditions

6. References

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