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THE RESPONSE TIME OF EQUATORIAL IONIZATION ANOMALY CREST: A UNIQUE PRECURSOR TO THE TIME OF EQUATORIAL SPREAD F INITIATION

Aswathy R. P[1], G. Manju[1] and Surendra sunda[2]
(1)Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum-695022, India
(2)Space Application Centre, Ahamedabad, India

Abstract

The time delay with which the magnitude and location of the Total Electron Content (TEC) at the Equatorial Ionization Anomaly (EIA) crest responds to the mean height of F – layer (hmF_2) is examined seasonally using the ionosonde data at Trivandrum and the GPS data at different stations in the EIA region for low and high solar activity years. The study brings out the fact that for the low solar activity year, the crest TEC responds fastest in winter solstice (ws) compared to other seasons. Further, the response time of the crest is found to decrease with solar activity. The seasonal variation in the EIA response time is attributed to the modulation by meridional neutral winds whereas the solar activity variation seems to be basically controlled by the diffusion times and the background ionization gradients in the respective epochs. The derived relationship between EIA crest location/ magnitude and hmF_2 for any season can be used for the prediction purposes. Furthermore, this study for the first time, establishes the relation of EIA response time to Equatorial Spread – F (ESF) start time, for days when the F layer is in the neutral dynamically controlled domain. The deleterious effects of ESF irregularities on communication and navigation systems are well- known and the above result is significant in this context. The present study has the potential to be extended into a model to predict the ESF start time, from the EIA response time, earlier in the day.

1. Introduction

Equatorial Ionization Anomaly (EIA) is the double humped structure in ionization distribution with a trough at the magnetic equator and two crests on either side around 15^0 separated from the trough (Appleton, 1946). When the atmospheric winds move the ionospheric plasma along Earth's magnetic field, electric fields are developed in the E-region of the ionosphere. The day time E-region electric fields are mapped in to the equatorial F-region, through geomagnetic field lines, causing the plasma at the equator to move upward by the $E \times B$ drift (E - electric field, B - magnetic field). At the higher altitudes, plasma diffuses downwards along the geo-magnetic field lines under the influence of gravity as well as the pressure gradient force. EIA crest ionization which is formed in the morning changes with time. Although the EIA pattern is generated by the fountain effect, the latitudinal ionization distribution is drastically modified by the meridional neutral winds. The meridional winds are able to push the ionization along the geomagnetic field lines causing asymmetry in the crest magnitude as well as crest altitude (Balan et al, 2010). If other factors do not contribute the EIA crest should respond promptly to the mean height of the F_2 layer (hmF_2) without much delay because hmF_2 is a proxy form the electric field controlled fountain effect. The first part of the present work systematically brings out the seasonal and solar cycle variations of the response time of the EIA crest magnitude and location to hmF_2 variations at the magnetic equator. Further, the EIA response times along with the regression relations between hmF_2 and magnitude/location of crest are employed successfully to predict EIA evolution.

Equatorial Spread F (ESF) irregularities are night time F region plasma density fluctuations with wide ranging scale sizes (cms to hundreds of kms). The role of EIA in causing favorable conditions for ESF to occur has been studied (Raghavarao et. al, 1988). Sridharanet.al (1994) has shown using OI 630.0 nm data that the strength of the EIA during day time as well as in the evening time, are important for triggering ESF. While all these studies essentially address the control of day time EIA to the post sunset ESF through the variations in the electric field, the latter part of the present study, provides the first observational evidence of the control of the day to day variability of ESF start time by the EIA delays (which implicitly contain the meridional wind signatures), for the days when the post sunset rise (PSSR) of the layer, is below the threshold height. This work is extremely important since it paves the way for prediction of the start time of ESF irregularities which are hazardous to communication and navigation systems.

2. Data &methodology

Ionosonde data from Trivandrum (8.5^0 N) and GPS data from Trivandrum, Bangalore (13^0 N), Hyderabad (17^0N), Raipur (20^0 N) Bhopal (23^0 N) and Delhi (27^0 N) which encompass the EIA regime, for the vernal equinox (ve), summer solstice (ss), autumnal equinox (ae) and winter solstice (ws) of low solar activity year 2005 and ve and ws of high solar activity year 2014, are used for the study. Data for the other seasons of high solar activity period is not available. The longitude of the stations is around 77^0 E. Only magnetically quiet days with $Ap < 18$ are presented here. In this database, days with significant disturbance effect in Dst (Dst < -50nT) are also removed. The meridional wind data from TIE-GCM (Thermosphere-Ionosphere-Electrodynamics General Circulation Model) is also used for the study.

The 'hmF_2' parameter from the ionosonde, which is the height of F_2layerpeak, is scaled manually for each day from 07 IST to 21.00 IST (IST represents the Indian standard time which is ahead of Universal Time by 5.5 h.). For the same duration the VTEC (Vertical Total Electron Content), is for the abovementioned stations. The VTEC at crest is delineated for each day and seasonally averaged.

The default 'hmF_2' values with a cadence of 15 minutes are correlated with the VTEC values at the crest and the process is repeated by shifting the VTEC over 15 minutes consecutively. The time delay for which the highest correlation is obtained is taken as the response time of the EIA crest with respect to hmF_2 variation.

Threshold height is that height of the base of the F layer in the post sunset hours above which ESF occurrence is controlled by the electric field and below which ESF occurs only if the meridional wind polarity is equatorward (Jyoti et al., 2004). The seasonal, solar cycle and magnetic activity variations of the threshold height are reported (Manju et al., 2007, MadhavHaridas et al., 2013, Manju and MadhavHaridas 2015). For the analysis of the control of ESF start time by EIA response time, only days for which the PSSR at 19.00 h. is below the threshold height is considered. These days are understood to belong to the domain where thermospheric meridional wind controls ESF occurrence. For this part of the analysis data for low solar activity year 2006 is also used in addition to 2005 and 2014.

3. Results

3.1 The seasonal and solar cycle variations of the delays of EIA crest magnitude and location and their plausible causes

The seasonal mean of the delays of EIA crest magnitude (left panel) and location (right panel) for ve, ss, ae and ws of 2005 and ve and ws of 2014 are shown in Fig.1. It is evident that the EIA crest magnitude shows maximum delay for ss (3.5 h.) followed by ve (3.25 h.), ae (2.75 h.) and ws(2 h.) for 2005. The delays of EIA crest magnitude are 2.5 h. and 1.25 h. respectively for ve and ws of 2014. Similarly, the EIA crest location responds with maximum delay for ss (3.5 h.) followed by ve (2.75 h.), ae (2.5 h.) and ws (2 h.) for 2005. The delays of EIA crest location are 2.5 h. and 1.5 h. respectively for ve and ws of 2014. That is, for both crest magnitude and location the seasonal delays are maximum for summer and minimum for winter.

Fig.2 panels a and b depict the variations of meridional neutral wind and hmF_2 respectively. The latitudinal variation VTEC for the stations of Bangalore, Hyderabad and Bhopal are shown in Fig.2 panel c along with the corresponding magnitude of the slope of the latitudinal gradient in VTEC in Fig.2 panel d. Here mean VTEC at the three stations are taken for the time 1 hour before the crest appears at Hyderabad. The magnitude of the slope of this latitudinal gradient is taken as a proxy for the pressure gradient acting on the ionization at the equatorial regions.

It is evident from the figure 2 that the seasonal variation of the EIA delay is controlled by the meridional winds. The strong pole ward wind existing in the winter (~25 m/s) causes a rapid diffusion of plasma away from the equator along the field lines, resulting in a lower delay in. The magnitude of the latitudinal ionization gradient (Fig.2d) represents the ionization pressure gradient prevalent in the background.

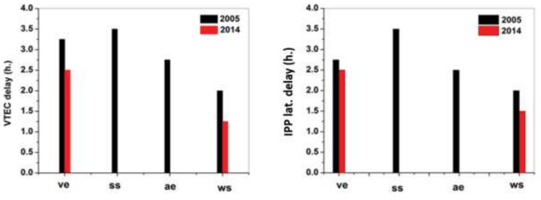

Fig.1 The seasonal mean of the delays of EIA crest magnitude (left panel) and location (right panel) for ve, ss, ae and ws of 2005 and ve and ws of 2014

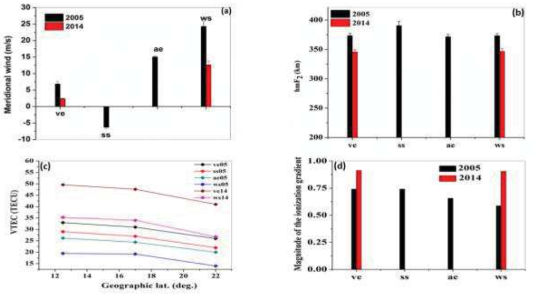

Fig.2 Variations of meridional neutral wind (panel a), hmF_2 (panel b), latitudinal variation in VTEC over the stations of Bangalore, Hyderabad and Bhopal (panel c) and slope of the latitudinal gradient in VTEC (panel d)

The EIA delays are found to decrease with solar activity for both ve14 and ws14 (Fig.1) in relation to 2005 values. The meridional winds (Fig.2 (a)) are found to decrease with solar activity and hence this reduced wind will lead to a slower movement of ionization along the field lines which should lead to more delay, contrary to the observations. Although the hmF_2 is lower in 2014 than for 2005, leading to less distance along the flux tube in 2014, the lower altitude also leads to reduction in the diffusion coefficient and these two aspects together lead to no significant effect on the delays. The magnitude of the latitudinal ionization gradient (Fig.2 (d)) represents the ionization pressure gradient prevalent in the background before EIA development. When this pressure gradient is high the ionization diffuses rapidly along the field lines. This larger ionization density (pressure) gradient existing in the high solar activity year will be effective in moving the plasma more rapidly along the field lines. The wind related effects only seem to modulate over and above the basic diffusion time coupled with background ionization gradient. Hence the solar cycle effects essentially depend on the latter two parameters.

3.2 Relation between EIA delay and ESF start time

Fig.3 illustrates the variation of ESF start time with EIA delay for high and low solar activity periods. The days used for this analysis are those in which the post sunset base height manifested below the threshold height and ESF occurred on or before 21.00 h.

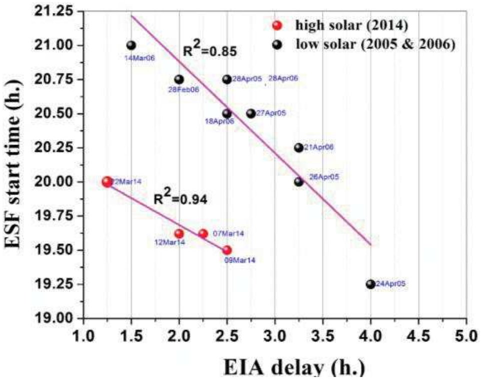

Fig.3 The scatter plot showing the variation of ESF start time with EIA delay

The analysis reveals that the ESF start time is anti-correlated with the EIA delay for both high and low solar epochs but with different slopes. That is, for a day with higher EIA delay, the ESF will start earlier and vice versa. A higher delay indicates the presence of a strong equatorward meridional wind. The vertical wind generated at the equator depends on the strength of the equatorward wind. The thermospheric meridional winds are part of the Equatorial Temperature and Wind Anomaly (ETWA) (Raghavarao et al. 1991) related circulation cell. The circulation results in a vertical wind at the magnetic equatorial regions. As the meridional wind varies proportionately the vertical wind also changes. A strong downward vertical wind indicated by the larger delay manifesting in the day time EIA, depicts the favorable background wind conditions on such days well ahead of post sunset hours. Hence as soon as the sunset occurs ESF triggering happens without much delay with the aid of the conducive vertical winds.

4. Summary

A systematic analysis of the response time of the EIA to hmF_2 variations at the magnetic equator is undertaken for low and high solar epochs. Clear seasonal and solar cycle variation in EIA response time is brought out in the study. The solar cycle variation of response time is attributed to the diffusion time with higher (lower) diffusion time in low (high) solar epoch, while the seasonal variation of the same is controlled by the seasonal pattern of meridional winds in the respective solar epochs. Regression analysis is used to predict EIA evolution and excellent agreement with observed values is obtained. The day to day variability of ESF start time in the neutral dynamical domain is directly controlled by the EIA response time for both high and low solar epochs. Overall, this work is of extreme relevance to the topical areas of prediction/modeling of EIA and prediction of Equatorial Spread F day to day variability. Hence it will definitely contribute to the global efforts to handle communication/navigation outages.

5. Acknowledgements

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6. References

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