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Solar and magnetic activity control on nighttime enhancement in IEC at equatorial anomaly latitude

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Abstract : The control of solar and magnetic activity on night-time enhancement in Ionospheric Electron Content (IEC) at Lunping (14 08°N geomag.), a station near the crest of northern equatorial anomaly, has been studied, using the IEC data for a period of January 1981 to December 1987. Two kinds of enhancements, namely pre-midnight and post-midnight were found. The occurrence of enhancements is more pronounced in post-midnight hours than that in pre-midnight hours and is more frequent during summer months, less during equinox and least during winter months. The occurrence of enhancements and their peak amplitude show strong dependence on solar and magnetic activities. The mean half amplitude duration is found to be dependent on solar activity but is independent of magnetic activity. All the enhancement characteristics show maximum dependence on solar and magnetic activities during summer months. The results have been compared with the earlier ones and discussed in terms of possible source mechanism responsible for the enhancement at anomaly crest region

Keywords : Night-time enhancements in IEC, solar activity, magnetic activity.

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1. Introduction

Night-time enhancements in Ionospheric Electron Content (IEC) are reported to occur at a number of stations over a wide latitudinal belt [1 and references therein]. The night-time enhancement in IEC and its various characteristics at low latitude were first reported by Young *et al* [2]. Several workers [3–6] have studied the occurrence and other characteristics of the enhancements in equatorial anomaly region. The diurnal, seasonal and solar cycle variations of IEC at Lunping have also been studied by Jain *et al* [7]. Many theories [8–10] have been put forward to explain the night-time enhancements but there is no single mechanism which can account for the observed features of the phenomena at all latitudes. Janve *et al* [11] have made a study of these enhancements at low latitude stations in the Indian zone (Ahmedabad, Bombay, Patiala and Udaipur) and reported that neither the occurrence of enhancements nor their peak size are correlated with geomagnetic disturbance. The study of the latitudinal variations of the various characteristics of night-time enhancements by Balan and Rao [12], showed minima at 30°N and 60°N and maxima at 50°N (dip latitude). Unlike at other latitudes, in the equatorial anomaly region, night-time enhancements occur during both pre-midnight and post-midnight hours [1]. The pre-midnight enhancements are caused by the pre reversal increase of the equatorial fountain [13] : the mechanisms for the post-midnight enhancements are yet to be identified.

Considerable solar and magnetic activity dependencies of the latitudinal variation have been reported by Balan *et al* [1]. There has not yet been a detailed study of solar and magnetic activity control on the enhancements at the anomaly crest region using long database. In order to reinforce the features of latitudinal variation reported in the above studies, with limited database, it seems necessary to make a detailed study with long database, similar to the studies for the stations, Hawaii and Tokyo. Hence in the present paper, an attempt has been made in above context at Lunping (25°N, 121.17°E geographic, 14.08°N geomagnetic), a station near the crest of anomaly in the Asian sector, using IEC data during a period of 1981-1987, which corresponds to descending phase of 21st solar cycle. The results are compared with earlier ones and discussed in terms of the mechanisms responsible for the phenomena at anomaly crest region.

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2. Data and method of analysis

The ionospheric electron content data from January 1981 to December 1987 at Lunping (25°N, 121.17°E geographic; 14.08°N geomagnetic) measured using the Faraday rotation of the 136.1124 MHz signal from ETS II, form the database for the present study. The sub ionospheric points at 420 Km correspond to 23.03°N, 121.96°E (geographic) and falls near the crest of the northern equatorial anomaly. The data of night-time enhancements have been grouped into three seasons as winter (January, February, November, December), summer (May, June, July, August) and equinox (March, April, September, October). The enhancements are also divided into pre-midnight and post-midnight events, depending on the local time (LT) at which the prominent peak of the enhancement occurred. The criterion adopted in the present study is the same as that adopted by Young *et al* [2] for identifying the night-time enhancement in IEC. Only those enhancement which have a peak size (ΔIEC_{max}) $\geq$ 20% of the background content are considered in the present study.

Solar and magnetic activities are represented by the 10.7 cm solar flux (*Sa*) and *Ap* index, respectively. During the period of the present study, the daily value of *Sa* varies from 66 to 302 units and *Ap* index from 01 to 68 units. The data of solar 10.7 cm flux and *Ap* index are taken from "A catalogue of solar geophysical data (1971-81 and 1982-88)" published by Radio Science Division, National Physical Laboratory, New Delhi, India.

3. Results

Examples of typical variation of night-time enhancements in IEC during different levels of solar and magnetic activities are shown in Figure 1. The examples show that the amplitude and duration of the enhancements increase with solar 10.7 cm flux (Figure 1a) but not so with magnetic activity (Figure 1b). The night-time enhancement in IEC that occurred during 1981 to 1987, have been statistically analyzed and results are presented in Figures 1-5.

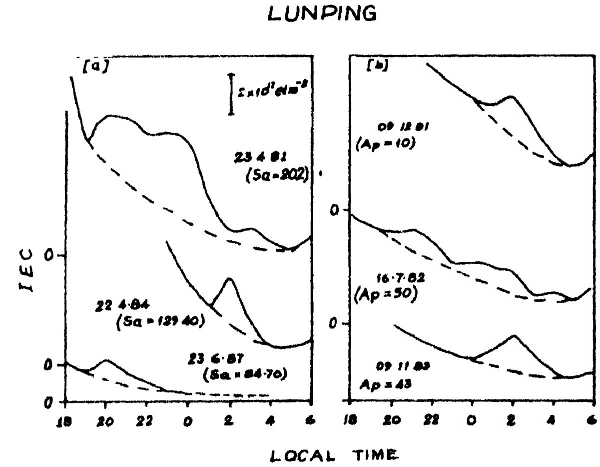

Figure 1. Various example of night-time enhancement in IEC for different levels of (a) solar activity and (b) magnetic activity.

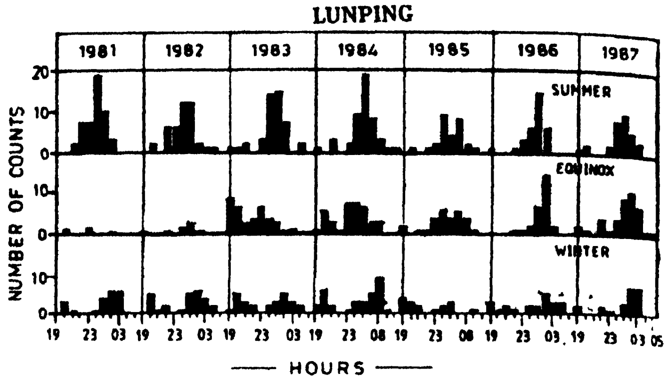

Figure 2. Distribution of the occurrence time of enhancements peak in IEC for each season for each year.

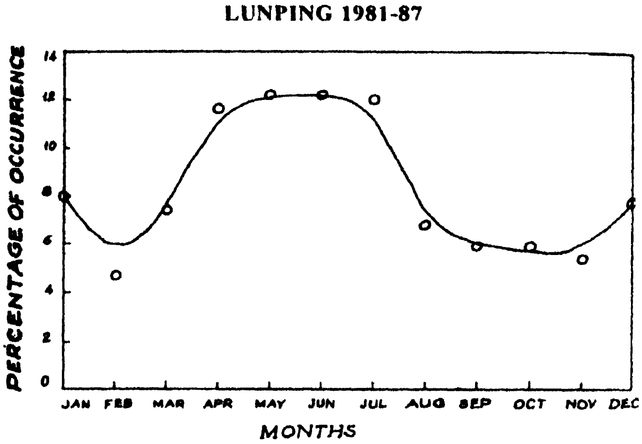

Figure 3. Monthly variation of percentage occurrence of the IEC enhancements

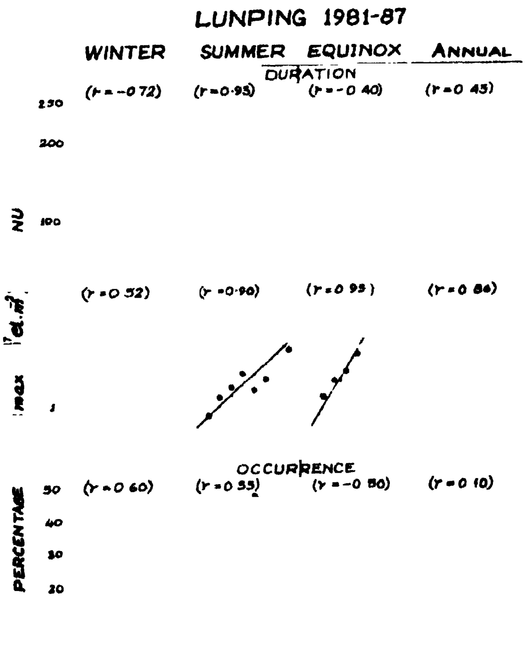

Figure 4. Solar activity (10.7 cm) variation of the percentage of occurrence, peak amplitude and half amplitude duraiton of the IEC enhancement

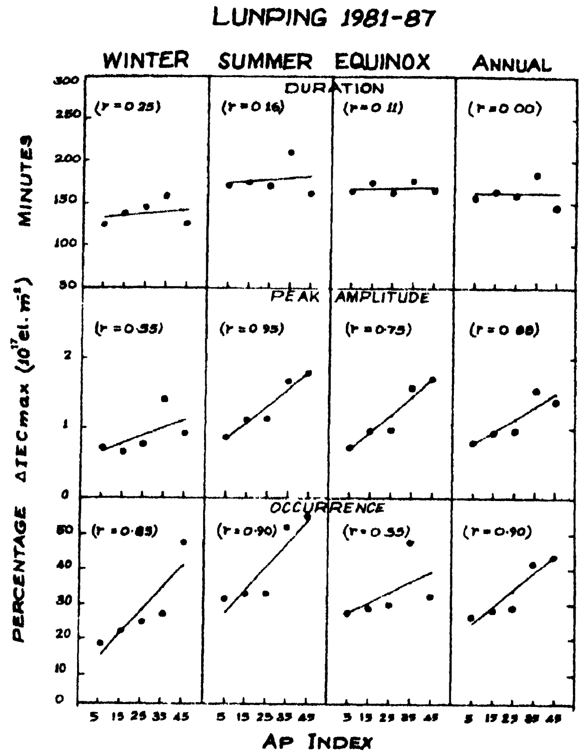

Figure 5. Magnetic activity (*Ap* index) variation of the percentage of occurrence, peak amplitude and half amplitude duration of the IEC enhancement

(a) General features of enhancements :

In the present study, 637 enhancements were found out of which 185 events occurred during pre-midnight and 452 events occurred during post-midnight hours. The percentage occurrence of the total events during summer, winter and equinoxial months are 43%, 31.3% and 25.7% respectively, which indicates that enhancements are more pronounced during summer months at Lunping. Frequency of occurrence of the enhancements as a function of local time for the three seasons winter, summer and equinox for each year, shown is in Figure 2. This figure shows that occurrence of the enhancements vary with seasons. The most striking new finding from Figure 2 is that during summer months, night-time enhancements in IEC occur most frequently in post-midnight hours with peak occurring in between 0100-0200 hrs (LT). The mean seasonal variation of frequency of occurrence of the IEC enhancements is shown in Figure 3, which also reveals the dominance of enhancements during summer months.

(b) Solar activity control :

In the construction of Figure 4, the data from the days for which $72 \geq Sa \geq 250$ have been used. The solar 10.7 cm flux data have been grouped into nine equal groupings, from 71 to 250 units. The starting time, peak amplitude (ΔIEC_{max}), half amplitude duration (τ) and occurrence time of enhancement peak have been noted from daily plots of IEC. The mean values of the enhancement characteristic (*i.e.* frequency of occurrence, peak amplitude and half amplitude duration) have been determined for each groups of *Sa* for different seasons and for combined data.

Solar activity control on frequency of occurrence, peak amplitude and mean half amplitude duration of the night-time enhancements in IEC for different seasons and also for the combined data is brought out in Figure 4, where the correlation coefficients have also been indicated. The dark circles give the mean value of enhancement characteristics for each group of solar 10.7 cm flux and the lines represent the results of regression analysis. Dotted lines (equinox) show the expected trend during which data were not available. The percentage occurrence during the winter and summer months shows significant positive correlation with solar activity but during equinox months occurrence shows negative correlation with solar activity. While total occurrence shows insignificant correlation with solar activity. As seen from Figure 4, the peak amplitude of the enhancement increases with solar 10.7 cm flux during all seasons; the rate of increase is largest during summer and equinox months and least during winter months. The mean half amplitude duration increases with solar activity during summer months; in winter the half amplitude duration is found to decrease with increase in solar activity. Thus, the occurrence and other characteristics of the enhancements are very well correlated with solar activity. During summer months the enhancement characteristics show a specially strong dependence on solar activity.

(c) Magnetic activity control :

In the construction of Figure 5, the data from the days for which $01 \geq Ap \geq 50$ have been used. The *Ap* index data has been grouped into five equal groupings from 01 to 50 units. The starting time, peak amplitude (ΔIEC_{max}), half amplitude duration (τ) and occurrence time of enhancement peak have been noted from daily plots of IEC. The mean values of the enhancement characteristic (*i.e.* frequency of occurrence, peak amplitude and half amplitude duration) have been determined for each group of *Ap* index for different seasons and for combined data.

To examine the control of magnetic activity on night-time enhancements in IEC, the seasonal variation of frequency of occurrence, peak amplitude and half amplitude duration with *Ap* index is shown in Figure 5. The correlation coefficients have also been indicated on respective curves. The dark circles give the mean value of enhancement characteristic for each group of *Ap* index and the line represents the regression analysis. It is found that the frequency of occurrence and peak amplitude increases with *Ap* index during all the seasons. Figure 5 shows that the mean half amplitude duration of the enhancements is not controlled by magnetic activity (*Ap* index). The poor correlation coefficient confirms that the half amplitude duration of enhancements is not controlled by magnetic activity. Thus, the occurrence of the enhancements and their peak amplitude strongly depend on magnetic activity whilst half amplitude duration does not show any significant dependence on magnetic activity.

4. Discussion and conclusions

The salient features of the above study may be summarized as :

1. The occurrence of night-time enhancements in IEC is predominantly a post-midnight phenomenon. From a total of 637 enhancements, 185 occur during pre-midnight and 452 occur during post midnight hours.
2. The frequency of occurrence depends upon solar and magnetic activities during all seasons.
3. Peak amplitude of the enhancements increases with solar and magnetic activities during all seasons. The correlation coefficient is found to be maximum during summer and equinoxial months and minimum during winter months.
4. The half amplitude duration of the enhancements is found to be dependent on solar activity and independent of magnetic activity. Significant positive correlation during summer months and negative correlation during winter and equinox months have been found between the half amplitude duration and 10.7 cm solar flux.
5. The occurrence of enhancement and other characteristics show strong dependence on solar and magnetic activities during summer months. They increase with increase in solar and magnetic activity.

The results presented here provide a reasonable comprehensive picture of the solar and magnetic activity dependencies at Lunping, a station in the northern equatorial anomaly region. The observations reported in the present paper at northern equatorial anomaly region are in general agreement with the results reported in earlier studies. However, a comparison with results of Hawaii and Tokyo bring out certain subtle difference as shown in Table 1. It is clear from Table 1 that the various characteristics of night-time enhancements in IEC at Lunping are similar to the features reported at Tokyo [4] in the same magnetic declination and longitudinal zone. They show differences to the observations at Hawaii [3] which lies in the opposite magnetic declination and longitudinal zone. Similarly the mean magnetic field is also different as shown in Table 1. The features reported by Janve *et al* [11] for the Indian low latitude locations also show significant differences from the present results, *i.e.* in the magnetic activity variations. So some of the differences may be due to the difference in the longitude and magnetic declination of these locations, which may have important bearing on the discussed mechanisms. It appears that the night-time enhancements in IEC are caused by different mechanisms at different latitudes [1,2,5,11] and it is difficult to identify one single mechanism, which is responsible for all observed enhancements.

Table 1. Various characteristics of night-time enhancement in IEC.

Stations → parameters ↓	Lunping	Hawaii	Tokyo
1 Geographic coordinates	25°N 121.17°E	21.2°N 157.7°W	33.8°N 138.7°E
2. Sub-ionospheric points	(at 420 Km)	(at 400 Km)	(at 300 Km)
(a) Geomagnetic latitudes	12.3°N	19.7°N	23.16°N
(b) Magnetic declination*	–2.25°	10.65°	–4.73°
(c) Mean magnetic field*	35796	29339	38860
3 Nocturnal behaviour	Post midnight	Pre midnight	Post midnight
4. Seasonal behaviour	Maximum in summer	Maximum in winter	Maximum in summer
5. Solar activity control on			
(a) Occurrence	Positive	Positive	Positive
(b) ΔIEC_{max}	Positive	Positive	Positive
(c) Half amplitude duration (τ)	Positive	Positive	
6 Magnetic activity control on			
(a) Occurrence	Positive	Not studied	Not studied
(b) ΔIEC_{max}	Positive	Not studied	Not studied
(c) Half amplitude duration (τ)	No	Not studied	Not studied
7 Most probable value of			
(a) ΔIEC_{max}	0.4 Units	0.6 Units	0.3 Units
(b) τ	120 Minutes	100 Minutes	180 Minutes

*(From IGRF model through Prof. G. K. Rangrajan, IIG, Bombay)

In the region around the equatorial anomaly crest, the pre-reversal increase in the vertical EXB drift velocity [14] can lift the equatorial F-region to altitudes of lower chemical loss, and the subsequent diffusion of ionization along the magnetic field lines gives rise to the night-time enhancement in IEC [13]. The night-time enhancements in IEC do not occur on all days, although evening enhancements in the EXB drift occur on all magnetic quiet days during solar maximum [14]. Also, the pre-reversal increase in EXB drift increases with solar activity [15]. The seasonal dependence of the IEC enhancements presented in this paper show that the enhancements are strongest during equinox. This indicates that the pre-reversal increase of the vertical EXB drift is the primary source for the IEC enhancements, which is strongest during equinox. Theoretical studies show that the pre-reversal increase of the vertical drift velocity is primarily due to a local time gradient in the F-region zonal neutral air wind velocity in conjunction with the conductivity gradient at the dusk terminator [16]. Further, they show that the displacement of the geomagnetic and geographic equators and the magnetic declination angle are important parameters in the determination of the seasonal and the longitudinal variations in the pre-reversal increase [17]. The solar activity control of the IEC enhancements and the pre-reversal increase of the EXB are similar, both becoming stronger with increasing solar activity. Modeling studies [18] also show that, for an average EXB drift at the equator, effect of equatorial fountain can only reach latitude of about 25° even during the solar maximum. At night equatorial neutral air wind can impede the downward field aligned flow of plasma and raises the F-region to altitude of lower chemical loss. Thus, if equator-ward wind is strong enough and the reversal time of the EXB drift is late enough, a strong enhancement in IEC can occur even after midnight as has been observed in summer at this latitude.

From the results presented in this paper, it appears that the pre-reversal increase in vertical EXB drift is the main source of IEC enhancements at latitudes around the crest of the anomaly region. Although, routine measurements of vertical EXB drift velocity at Jicamarca (12°S, 77°W) showed the pre-reversal increase in vertical EXB drift velocity to be strongest in equinox, the amplitude of TEC enhancements is maximum during summer months. This is due to early reversal time during summer (2100-2200 LT). Anderson and Klobuchar [13] have used the mathematical model for equatorial anomaly region and they have shown that the post sunset increase in EXB drift velocity is mainly responsible for night-time increase in IEC for Ascension Island. Buonsanto and Titheridge [19] have shown that at ±21° latitudes, neutral air winds have a major effect on the distribution of ionization from the equatorial fountain. Neutral air wind can also modulate the enhancements in IEC through northern wind by transportation of ionization from the Southern Hemisphere [20]. A phenomenon closely related to the night-time enhancements is the night-time equatorial scintillation, which also depends on EXB drift [21,22]. It has been shown that the seasonal behaviour of scintillation at different longitude sectors is controlled by the alignment of the geomagnetic flux tubes with solar terminator, which in turn depends on the magnetic declination [23].

Thus, the primary source of the night-time enhancement in IEC at equatorial anomaly latitudes is the pre-reversal increase in EXB vertical drift and the neutral air winds modulate the process. The magnetic declination and longitude of the station play important roles in controlling EXB drift and affect the neutral wind, which in turn, affects the distribution of plasma in the ionosphere.

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