*Indian J. Phys.* **72B** (1), 1-10 (1998)

**IJP B**
· an international journal

# Nighttime ionospheric electron content enhancements and associated amplitude scintillation at Lunping

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*Received 23 May 1997, accepted 13 November, 1997*

**Abstract** Association of nighttime enhancements in ionospheric electron content (IEC) with VHF-amplitude scintillations has been studied using the ETS II data obtained at Lunping (14 08° N, geomagnetic), a station near the crest of the equatorial anomaly, for a period of March 1977 to December 1982 The results show that the various characteristics of scintillations are well correlated to corresponding characteristics of the IEC enhancements Scintillations occur on average 1 5 to 2 hours later than the IEC enhancements Both the phenomena start in pre-midnight period and maximise around midnight The enhancement and scintillation occur very frequently during summer months but the amplitude of both phenomena maximises in equinoxes. The time of peak scintillation activity and that of IEC enhancements are highly correlated during all seasons Mean peak amplitude and occurrence time of both the phenomena show strong dependence on solar and magnetic activity. The results has been compared with earlier observations elsewhere and discussed in terms of possible source mechanisms common for both phenomena.

**Keywords** Nighttime enhancements in IEC, scintillation, correlation

**PACS Nos.** 94.20 Vv, 94 20 Ss

## 1. Introduction

The scintillation technique applied to radio star and satellite signal has extensively been used for studying the ionospheric irregularities in the past 3-4 decades. The phenomena of anomalous nighttime enhancements in ionospheric electron content (IEC) and scintillations have both been studied by several workers beginning with Young *et al* [1] and Aarons [2] respectively. The possible relationship between these two, has not received much attention except the work done by Kersley *et al* [3] and Balan and Rao [4]. Such a detailed study, it is hoped, may lead to some additional insight into processes manifesting the two phenomena.

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There exist some related studies, done by other workers [5–7] which established the relationship between amplitude scintillation and Faraday Polarization Fluctuations (FPF's). Bhuyan and Huang [8] reported that FPF activity increases with an increase in sunspot activity at Lunping. They concluded that FPF's occur either simultaneously or with a time lag after the onset of amplitude scintillations. Several groups [9 and references therein] have reported association of total electron content (TEC) depletion with the scintillation activity in the nighttime equatorial and low latitude ionosphere and identified these depletions with ionospheric bubbles. Kersley *et al* [3] established a possible relation between nighttime enhancement in TEC and VHF-scintillation by analysing 16 months data recorded at Arecibo, a low latitude station. Their results show that nighttime enhancement and wave activity in IEC are correlated with scintillation index (SI). Tyagi *et al* [10] also reported that the occurrence of TEC enhancements are associated with amplitude scintillations at Natal, Brazil. Later at equator, Balan and Rao [4] studied the relationship between nighttime TEC enhancements and VHF- scintillation for Indian locations. They find that both the phenomena start mostly prior to midnight with TEC enhancements delayed by 1 to 1.5 hours with respect to scintillation activity. Discussing the results in terms of vertical drift, they have suggested that the IEC enhancements can not be regarded as a source for the small scale irregularities but rather they both seems to depend on the post sunset vertical drift in the F-region. Mathew and Iyer [11] reported that peak value of SI linearly increases with the amplitude of TEC fluctuation for the lower mid latitude station, Tokyo.

Although separate studies of the nighttime enhancement in IEC [12] and amplitude scintillations [13] at Lunping had been made, in order to reinforce the relationship between IEC enhancements and scintillations reported by earlier workers, it seems necessary to make a detailed study. In the present paper, an attempt has been made in the above context at Lunping (25°N, 121.17°E geographic), a station near the crest of anomaly in the Asian sector using IEC and scintillation data during a period of 1977-1982 which corresponds to ascending phase of 21st solar cycle. The results are compared with earlier ones and discussed in terms of the mechanisms believed to be responsible for two phenomena.

## 2. Data and method of analysis

The ionospheric electron content and amplitude scintillation data used in this analysis were obtained at Lunping (25.0°N, 121.17°E geographic; 14.08°N geomagnetic) measured using the 136 MHz beacon signal transmitted from ETS-II (135°E) from March 1977 to December 1982 [14]. The sub-ionospheric points at 420 km corresponds to 23.03°N, 121.96°E (geographic) and 12.1°N, 192.0°E (geomagnetic) and falls near the crest of the daytime equatorial anomaly. The scintillation index (SI) is defined by the following equation to represent the scintillation activity

$$SI(dB) = P_{max} - P_{min},$$

where $P_{max}$ is the power amplitude of the third peak down from the maximum excursion in *dB* and $P_{min}$ is the power amplitude of third level up from the minimum excursion in *dB*. The criterion adopted in the present study is the same as that adopted by Young *et al* [1] for identifying the nighttime enhancements in IEC. Only those enhancements which have peak amplitude ($\Delta IEC_{max}$) ≥ 20% of the back ground level and scintillation activity ($SI_{max}$) ≥ 0.5 dB have been considered. Various characteristics such as occurrence time, peak amplitude and duration of nighttime enhancement in IEC and that of scintillation activity have been determined; then average values of characteristics during the course of the events are computed.

The data were grouped into three seasons as Winter (January, February, November and December), Summer (May, June, July and August) and Equinox (March, April, September and October). The magnetic activity and solar activity are represented by Ap index and the 10.7 cm solar flux values (Sa) respectively.

## 3. Results

Two examples of nighttime enhancement in IEC and corresponding scintillation activity on given nights are represented in Figure 1. From a total of 565 IEC enhancements events, only 306 events occur with the scintillation activity. Both the phenomena are more frequent during the summer (216), less during the equinox (69) and least during the winter (21) months. These 306 events are used in the present study for the statistical purpose.

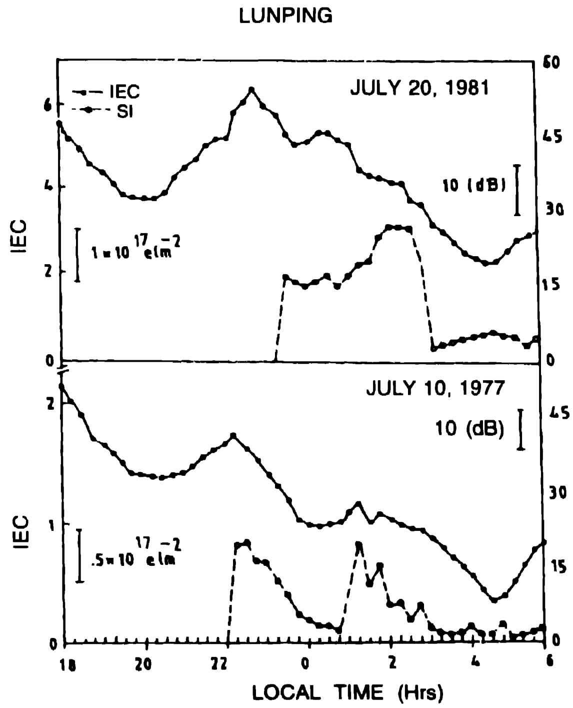


**Figure 1.** Examples of temporal variation of the IEC enhancements and amplitude scintillations on the given dates

### *3.1. Occurrence and time of peak amplitude :*

The seasonal variation for the occurrence of nighttime enhancement in IEC alone, scintillation activity alone and both together are shown in Figure 2. Obviously, the common occurrence are much less than individual ones. Again the frequent occurrence of the two phenomena in summer is evident.

In Figure 3, the histograms show the temporal distribution of the occurrence of the peak amplitude of the enhancements ($\Delta IEC_{max}$) and that of scintillation index ($SI_{max}$) for each season separately and for all seasons combined. We found that $\Delta IEC_{max}$ and $SI_{max}$ can reach their maximum value at any time between 19 hrs and 04 hrs LT but the maxima located around 00 LT for $\Delta IEC_{max}$ and 01 LT for $SI_{max}$. Thus, it is noted that the scintillation activity maximises 01 hour later than the nighttime enhancement.

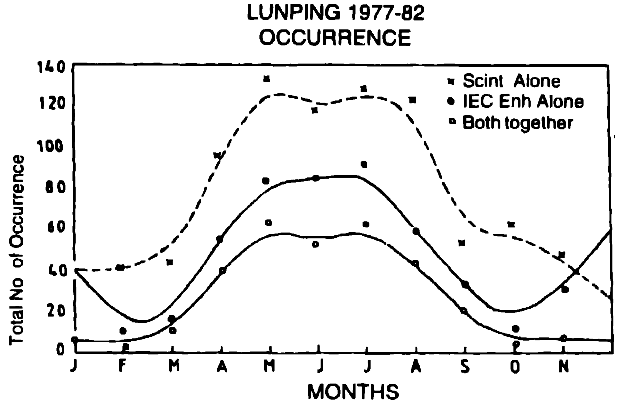


**Figure 2.** Monthly variation of occurrences of the nighttime IEC enhancements, scintillations and both together

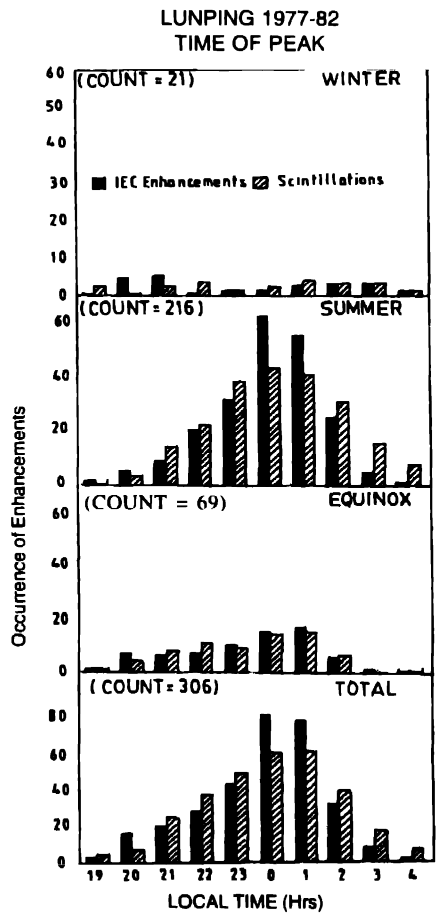


**Figure 3.** Histograms of the local time of the peak amplitude of IEC enhancements and that of scintillations at Lunping

*3.2. Mean peak amplitude and duration :*

Figure 4 shows the variation of mean peak amplitude and duration of nighttime enhancement in IEC and that of the scintillation activity with time. An increasing trend is observed in $\Delta IEC_{max}$ upto midnight after which $\Delta IEC_{max}$ decreases with time, while $SI_{max}$ shows an increasing trend throughout the night. Similar variation is also observed in the duration of the two phenomena. The duration of IEC enhancements is large, as compared to scintillation. Thus during pre-midnight hours, the amplitude and duration of the two phenomena are well-correlated while during post-midnight hours, they are anti-correlated.

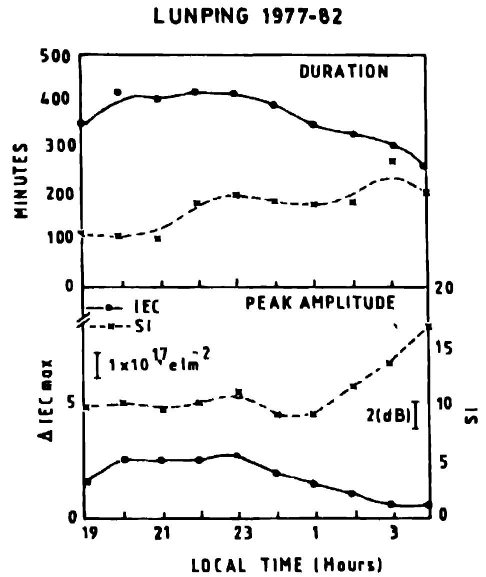


**Figure 4.** Variation for mean peak amplitudes and durations of IEC enhancements and scintillation activity with time.

*3.3. Seasonal variation :*

Figure 5 shows the monthly means of peak amplitude, duration, time of peak and occurrence time which indicates the seasonal variation of characteristics. The variations in peak amplitude are more or less similar as reported at Indian equatorial stations [4] with two distinct maxima in equinoctial months and with minima in summer months. The correlation coefficient ($r$) between these two curves is 0.65. The duration of the nighttime enhancement in IEC is greater than that of scintillations by a factor of 2 to 3. The durations of both the phenomena are well-correlated ($r = 0.75$) and they are maximum in summer months and minimum in February and October. Although a little difference is observed between the peak times of the two phenomena but their seasonal variations are highly correlated ($r = 0.85$). The peak occurred late in summer and early in equinoctial months. The scintillations activity always occurs later with respect to the nighttime enhancement in IEC with an average of about 1.5 hours. A good correlation coefficient (0.60) is computed between the occurrence time of the two phenomena. Thus, the phenomena occurs latest in February and December months and earliest in equinoctial months.

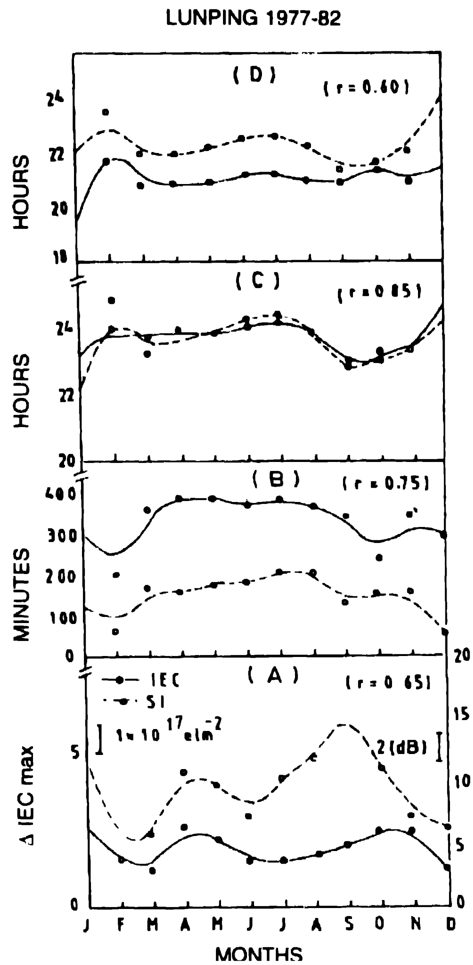


**Figure 5.** Monthly mean variation of (A) peak amplitude, (B) duration, (C) peak time and (D) occurrence time of the two phenomena The correlation coefficients between the two are also indicated

*3.4. Effect of solar activity :*

Solar activity variation of peak amplitude, duration, peak time and occurrence time of the scintillation and that of IEC enhancements are shown in Figure 6. The points (● for IEC enhancement and ○ for scintillations) give the mean values of these characteristics for given Sa value, the best fit lines show the trend of their variation with solar flux. Only summer months data are used in the construction of Figure 6. The correlation coefficients ($r$) of the various characteristics with the x-axis parameter (Sa) are indicated in the figure. As Figure 6 shows, the amplitudes of the two phenomena increase and the occurrence times decrease with increase in solar flux and corresponding significant positive and negative correlations are also computed. The duration of the IEC enhancement increases and that of scintillation decreases with increase in solar activity. The peak time of scintillation is positively correlated while that of IEC enhancements is negatively correlated with solar activity.

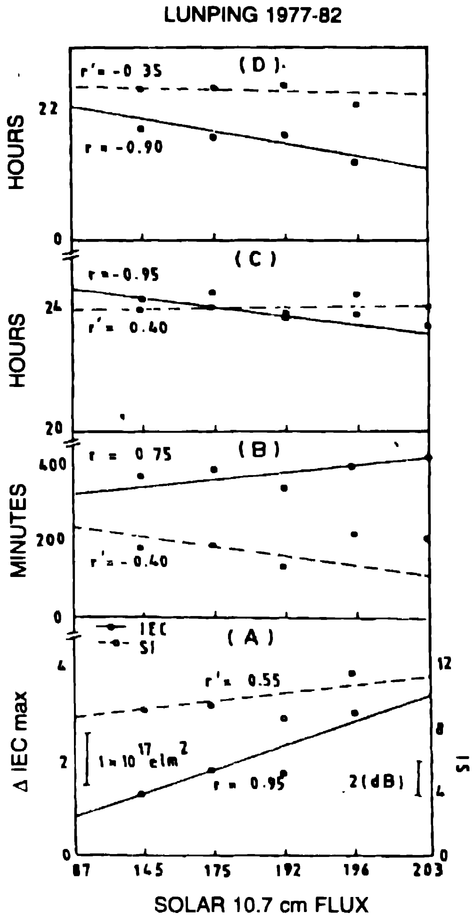


**Figure 6.** Solar activity (10 7) variation of the (A) mean amplitude, (B) duration, (C) peak time and (D) occurrence time of the IEC enhancement and that of scintillation at Lunping.

### *3 5. Effect of magnetic activity :*

In order to investigate the effect of magnetic activity on the possible correlation, between the scintillation activity and nighttime enhancement in IEC, the Ap index is used as a diagonastic tool. We grouped Ap index for each 10 units and computed mean values of all characteristics for each grouping namely, 1-10, 11-20, 21-30, 31-40 and 41-50. Only the summer months data are considered for this purpose and the analysis is confined to the geomagnetic condition with Ap index less than 50 units. Figure 7 represents the magnetic activity variations of all the characteristics of IEC enhancements and that of scintillations. The points (● for IEC enhancement and + for scintillations) give the mean values of these characteristics for each grouping, the best fit lines show the trend of their variation with Ap index. As seen from Figure 7, the amplitude of IEC enhancements increases and that of scintillation decreases with increase in magnetic activity and respectively good positive and negative correlations are observed. Figure 7 also shows that the duration, peak time and occurrence time of the two phenomena decrease with increase in magnetic activity. The rate of decrease is greatest for the occurrence times and least for the durations of the two phenomena.

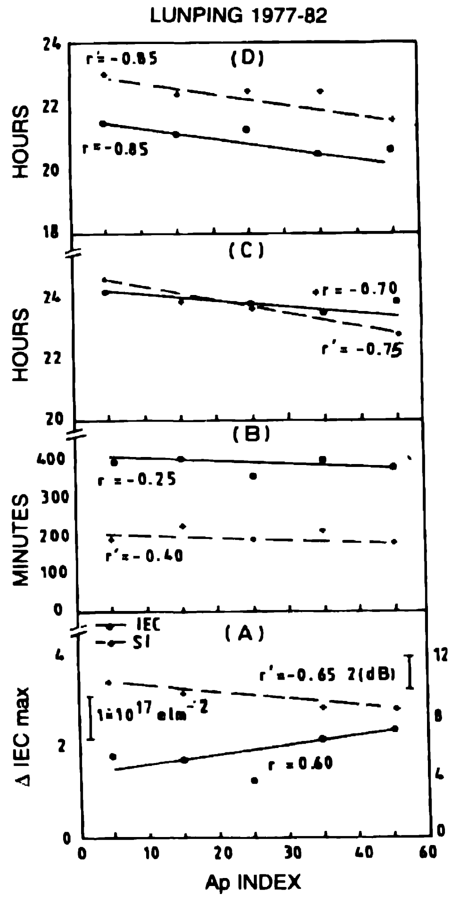


**Figure 7.** Magnetic activity (Ap) variation of the (A) mean amplitude, (B) duration, (C) peak time and (D) occurrence time of the IEC enhancement and that of scintillation at Lunping.

## 4. Discussion and conclusions

Some of the most striking features of the association of the nighttime enhancement in IEC with scintillation activity at Lunping may be summarized as :

(1) The IEC enhancements and associated scintillation activity occur more frequently during summer months and around midnight.

(2) The different characteristics of the two phenomena, such as peak amplitude, duration and time of peak are highly correlated and show seasonal variation.

(3) Scintillation activity occurs on average, 1.5 hours later than enhancements in IEC.

(4) The occurrence time and amplitude of the two phenomena show strong dependence on solar activity. The peak time and duration of IEC enhancements respectively, show negative and positive correlation while that of scintillations show positive and negative correlation with solar activity.

(5) All the characteristics of the two phenomena show strong magnetic activity dependence. The occurrence time, peak time and duration are negatively correlated while the

amplitude of IEC enhancement shows positive and that of scintillation shows negative correlation with magnetic activity.

Simultaneous occurrence of amplitude scintillation and nighttime enhancement in IEC near the equatorial region may have some relevance to the processes responsible for these two phenomena. The post sunset enhancements in the upward equatorial $\boldsymbol{E} \times \boldsymbol{B}$ drift velocity combined with meridional neutral air wind and reverse plasma fountain are believed to be responsible for the observed nighttime enhancements in IEC around the crest of the equatorial anomaly. On the other hand, nighttime amplitude scintillations in this region are mainly associated with Equatorial Spread F (ESF) irregularities. The reverse plasma fountain provides favourable condition for generation and propagation of plasma bubbles and spread F irregularities.

An upward $\boldsymbol{E} \times \boldsymbol{B}$ drift raises the equatorial F region to a height of lower chemical loss and diffusion of ionization along the magnetic field lines, may contribute to the nighttime enhancement in IEC near the equatorial anomaly region. However, nighttime enhancement in IEC do not occur on all days, although evening enhancements in the $\boldsymbol{E} \times \boldsymbol{B}$ drift occur on all magnetically quiet days during solar maximum [15]. The extra ionization lifted to the topside ionosphere due to the interaction between an equator-ward neutral air wind and the ionospheric plasma may also have to be considered. Anderson and Klobuchar [16] have developed a mathematical model and concluded that $\boldsymbol{E} \times \boldsymbol{B}$ drift velocity is mainly responsible for nighttime enhancement in IEC at the equatorial crest region. They also suggested that after inclusion of the meridional neutral air wind, the observed values show closer agreement with modelled values.

The post-sunset enhancements in $\boldsymbol{E} \times \boldsymbol{B}$ drift and consequent raising of the evening F-layer over the equator is known to have a significant role in the generation and growth of the ionospheric irregularities responsible for scintillation. The extension of the equatorial scintillation belt upto anomaly crest latitudes is also controlled by the above process [17]. Hence, the observed correlation between nighttime enhancements in IEC and amplitude scintillations at Lunping are understandable. Lee *et al* [18] have shown that ionospheric irregularities with large $\Delta N$ and large background electron density $N$ causes refractive scattering resulting in strong scintillations. The IEC enhancements which occur about 1.5 hours prior to the scintillation onset may be aiding the above mechanism. The good number of cases of scintillation not associated with the enhancement (Figure 2), may be due to more frequent diffractive scattering type irregularities.

At the equator, an increase in occurrence as well as strength of amplitude scintillation with sunspot activity was observed by Aarons [2]. These results are also supported by Dasgupta *et al* [19] and Mathew *et al* [20] for Indian stations. Most of the characteristics of amplitude scintillation (Figure 6) at Lunping, show strong positive correlation with solar activity which confirms the earlier results. It has been shown that the seasonal behaviour of scintillation at different longitude sector is controlled by the alignment of the geomagnetic flux tube with solar terminator, which in turn, depends on the declination [21]. The observed summer maxima in the different characteristic of the both phenomena may be due to the negative magnetic declination [12] of the Lunping (–2.25°). So some of the differences may be due to the differences in the longitudes and magnetic declination of these locations which may have important bearing on the above discussed processes. The observed nighttime enhancement in IEC and amplitude scintillation are to be viewed as the composite effect of certain common processes contributing to both and discussed above separately.

## Acknowledgments

The authors are grateful to Dr. Y N Huang for providing IEC and scintillation data observed at Lunping and Prof. K N Iyer for valuable discussions. The authors are also thankful to the referees for their constructive comments to improve the presentation of the paper.

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