Chapter 4
Dependence of night-time enhancement on sudden commencement storms

4.1 Introduction

It is well known that the total electron content (TEC) of the ionosphere does not decrease throughout the night as predicted by simple theory but shows anomalous enhancements under a wide range of geophysical conditions (Arendt and Soicher, 1964; Klobuchar et al., 1968; Davies et al., 1979; Leitinger et al., 1982; Balan and Rao, 1984). The various enhancement characteristics such as frequency of occurrence, time of occurrence, amplitude and duration are found to depend on location, season and solar activity. There is no simple explanation to account for the occurrence of the anomalous enhancements in TEC. The modelling results at mid-latitudes for winter, during solar minimum, presented by Bailey et al. (1990, 1991), show night-time enhancements in TEC when there are large downward field-aligned flows of plasma in the topside ionosphere.

The effect of season, solar and magnetic activities on night-time enhancements in TEC have been studied for low-, mid- and high-latitudes (Klobuchar et al., 1968; Young et al., 1970; Essex and Watkins, 1973; Janve et al., 1979; Leitinger et al., 1982; Balan et al., 1986; Lois et al., 1990; Balan et al., 1991; Sudhir Jain et al., 1995).

Chauhan and Gurm (1985) studied the enhancements in total electron content (TEC) and the critical frequency of the F2-layer ($f_0 \text{F}2$) for a chain of five low- latitude stations covering a region with magnetic dip angle varying from 60°N to 45°N. They also theoretically investigated the role of plasma in producing enhancements, by solving the equation of continuity for the plasma at low- and equatorial latitudes of the ionosphere.
Lois et al. (1990) analysed the night-time increase of the ionospheric electron content and the critical frequencies of the F2-layer in Cuba from July 1974 to December 1980. For the first time, the dependence of various characteristics of night-time enhancements on solar activity was found by Balan et al. (1986) and the possible source mechanisms for the observed TEC enhancements were also discussed. In another study, Balan et al. (1991) established the effects of solar and magnetic activity on the latitudinal variations of the night-time enhancements in TEC by considering ten stations in the northern hemisphere covering the latitude range of 10-60°. Also, Sudhir Jain et al. (1995) conducted a study of the anomalous night-time enhancements at Lunping, a station near the crest of the equatorial anomaly.

At low- and equatorial latitudes mechanisms such as plasmaspheric compression, conjugate transfer, etc. may not be operative, as the magnetic field lines do not rise very high above the equator. The enhancements at these latitudes can be due to either another source of ionisation and/or the convergence of plasma from the nearby latitudes. Rishbeth and Hanson (1974) examined the rate of compression of plasma produced locally at F-region heights at mid-latitudes. Without the inclusion of field-aligned motions and the advective terms, they concluded that the large increases observed in F-region plasma concentration could not be produced by a simple compression of the magnetic field.

Bailey et al. (1992) used a fully time dependent mathematical model of the plasmasphere to investigate the effect of the conjugate hemisphere on these enhancements for magnetically quiet conditions at winter solstice during a solar minimum. Though various features of night-time enhancements were studied, no attempt has been made, till date, to analyse this phenomenon during sudden commencement (SC) storms.

The present Chapter consists of two sections. In the first section (4.3.1), the main characteristics of night-time enhancements during SC storms are compared with those during quiet nights for different seasons and various solar activity conditions; the interdependence of these characteristics are also analysed.
for a low-latitude station, Palehua during the period 1980-'89. This study also investigates the effect that the intensity of a storm has on the characteristics of night-time enhancements. In Section 4.4.2, a similar type of study is conducted by considering stations of low-, mid-, and high-latitudes falling under same longitude sector for a high solar activity year, 1989.

4.2 Data and analysis

The TEC data employed for the section 4.3.1, during the period 1980-84 and 1985-89 at Palehua, were obtained by satellites ATS-I (Geographic latitude-18°N, geographic longitude-206°E and geomagnetic latitude-19.6°N) and GOES-3 (19°N, 206°E and 19.6°N) respectively. The TEC data used in section 4.3.2 during the solar maximum year 1989, at low-, (Ramey-17°N, 289°E and 28.7°N) mid- (Sagamore Hill-38° N, 282°E and 50°N) and high- (Goose Bay- 47°N, 285°E and 58.6°N) latitude stations were obtained by the geostationary satellite GOES-2. Here, the latitudinal dependence of night-time enhancements on sudden commencement storms is studied by selecting low-, mid- and high-latitude stations whose longitudes are almost the same, in order to avoid longitudinal effects.

Some source mechanisms have been proposed to account for the general night-time enhancements. To understand the importance of various source mechanisms, it is essential to build a fairly comprehensive picture of all observational aspects of the phenomena. For an elaborate picture, a better understanding of all the possible mechanisms associated with storms and night-time enhancements are essential. It is to be noted that the TEC enhancement observed during the first night after storm commencement has been considered, with the Ap value of that day indicating the intensity of the storm. The SC type storms during the period whose Ap > 20 were selected and classified according to the three seasons: winter, summer and equinox. For comparison seven quiet days were selected prior to each storm with Ap < 10. In characterising a night-time TEC enhancement the same criterion as that adopted by Young et al. (1970) was applied. Accordingly, a night-time TEC enhancement is defined as the excess content (ΔTEC) which remains after the exponentially decaying background part of the
diurnal content is subtracted from the total content. For the present study, only those enhancements which have amplitude greater than 20% of the background content have been considered.

It is conventional to consider the Ap value of a day during storm, as the intensity of the storm on that day. Also, the mean sunspot number of a year is indicative of the solar activity for that year.

The majority of the enhancements were found to have a single peak. However, in the case of the enhancements having multiple peaks, only the prominent peak was considered for a statistical study. The frequency of occurrence, peak amplitude ($\Delta$TEC$_{\text{max}}$), half amplitude duration ($\tau$) and time of occurrence of the peak amplitude were noted during the first night after a SC storm and the corresponding quiet nights. Then, mean values of the frequency of occurrence, peak amplitude and half amplitude duration were determined for each season during SC storms and quiet conditions.

4.3 Results
4.3.1 Comparison of seasonal and solar activity effects on night-time enhancements in TEC during SC storms with those of quiet times at a low-latitude station

Figure 4.1 represents typical variations of night-time total electron content during SC storms and quiet times. Figure 4.2 shows the yearly variations of sunspot numbers, which is used to check the solar activity dependence of night-time enhancement characteristics. Figure 4.3 depicts the variation of mean amplitude, during SC storms and quiet nights with time, in years, during (a) winter, (b) summer and (c) equinox. It is found that the mean amplitude has both a seasonal and solar activity dependence. In summer and winter the mean amplitude values are higher during SC storms as compared to that during quiet nights. This tendency is, however, more pronounced only during moderate to high solar activity periods. But during equinox the mean amplitude during quiet nights is greater than
Figure 4.1: Typical examples of night-time TEC variations during (a) SC storm and (b) quiet conditions.
Figure 4.2: Yearly variation of sunspot numbers.
Figure 4.3: Variations of mean amplitude during SC storms (solid curves) and quiet nights (dashed curves).
that during SC storms, especially during high solar activity years. The maximum values of the mean amplitude in winter, summer and equinox during SC storms respectively are: \(1.8 \times 10^{17} \text{ m}^2\), \(2 \times 10^{17} \text{ m}^2\) and \(1.85 \times 10^{17} \text{ m}^2\).

The corresponding values during quiet times are: \(1.7 \times 10^{17} \text{ m}^2\), \(1.2 \times 10^{17} \text{ m}^2\) and \(3.25 \times 10^{17} \text{ m}^2\). The maximum difference between storm time mean amplitudes and that during quiet nights is approximately \(1.2 \times 10^{17} \text{ m}^2\) and \(1.5 \times 10^{17} \text{ m}^2\) respectively in winter and summer.

The seasonal and solar activity variations of the half amplitude duration during SC storms and quiet times during (a) winter, (b) summer and (c) equinox are exhibited in figure 4.4. In summer and winter, the mean half amplitude durations are higher during SC storms as compared to that during quiet nights. However, this is not true for equinox. The maximum values of the mean half amplitude duration in winter, summer and equinox during SC storms are: 142 minutes, 180 minutes and 150 minutes respectively. The same parameter during quiet nights are: 115 minutes, 135 minutes and 165 minutes respectively. The maximum difference between storm time and quiet night mean half amplitude duration is 40 and 60 minutes respectively during winter and summer. As an exception to this, in equinox, the half amplitude duration during storm time is less than that during quiet time even under high solar activity conditions. The values are, however, more or less equal during the years of low solar activity.

In figure 4.5 the seasonal and solar activity variation of percentage frequency during SC storms and quiet nights for (a) winter, (b) summer and (c) equinox are shown. During winter and equinox the percentage frequency during SC storms is greater than that during quiet nights. The maximum percentage frequency in winter, summer and equinox during SC storms is 100%.

The same parameters during quiet nights are 90%, 88% and 100% respectively; also, the maximum difference of percentage frequency between
Figure 4.4: The seasonal and solar activity variations of mean half amplitude duration during SC storms (solid curves) and quiet nights (dashed curves).
Figure 4.5: The seasonal and solar activity variations of percentage frequency during SC storms (solid curves) and quiet nights (dashed curves).
stormtime and quiet time is more than 65% and 30% during winter and equinox respectively. In summer, the predominance of percentage frequency during SC storms as compared to that during quiet times, is found only during periods of higher solar activity; the opposite is the case during periods of lower solar activity.

It is observed that the highest values of mean amplitude and half amplitude duration are found in summer during SC storms, and the highest values of these parameters are seen in equinox during quiet nights. Also, it is noteworthy that, the mean amplitude, mean amplitude duration and percentage frequency show a strong positive correlation with solar activity during SC storms as well as quiet times.

Figures 4.6, and 4.7 respectively represent the local time distribution of mean amplitude and mean half amplitude duration for (a) winter (b) summer and (c) equinox during SC storms. The maximum value of mean amplitude and the LT of maximisation (in bracket) during winter, summer and equinox are as follows: 1.58x10^{17} \text{ m}^2 (2200-2300 hours); 2.02x10^{17} \text{ m}^2 (2100-2200 hours) and 2.21x10^{17} \text{ m}^2 (2100-2200 hours). It shows that for all seasons, the mean amplitude of night-time enhancement during SC storms attain higher values, if the LT of maximisation falls in the pre-midnight hours. The maximum value of mean half amplitude duration and the LT of maximisation (in bracket) during winter, summer and equinox are as follows: 141 minutes (0200-0300 hours); 210 minutes (0100-0300 hours) and 150 minutes (2200-2300 hours). It shows that only in equinox, the mean half amplitude duration of night-time enhancement during SC storms attain higher values, if the LT of maximisation falls in the pre-midnight hours. However, during winter and summer, this parameter shows higher values, if the LT of maximisation fall is in the post midnight hours.

Figure 4.8 represents the local time distribution of the percentage of number of enhancements during SC storms in (a) winter, (b) summer and (c) equinox. The maximum number of enhancements (%) with the corresponding local time (in brackets) during SC storms in winter, summer and equinox are as: 25% (2200-2300 hours); 23% (1900-2100 hours) and 15% (2100-2200) respectively.
Figure 4.6: Local time distribution of mean amplitude during SC storm.
Figure 4.7: Local time distribution of the mean half amplitude duration during SC storm.
Figure 4.8: Local time distribution of the percentage of number of enhancements during SC storms.
These parameters during quiet times are 27.4% (2200-2300 hours); 23% (2000-2100) and 27.4% (2200-2300) respectively. From these figures it is obvious that the most probable local time of maximisation of night-time enhancements in TEC during SC storms and quiet times occur during pre-midnight hours.

Figures 4.9, 4.10 and 4.11 respectively represent the local time distribution of mean amplitude, mean half amplitude duration and percentage number of enhancements for (a) winter (b) summer and (c) equinox during quiet conditions. During quiet nights, the mean amplitude and the percentage number of enhancements show higher values for all seasons if maximum TEC enhancement occurs during the pre-midnight hours. This is also true in the case of the mean half amplitude duration except for equinox, i.e., where the higher values of this parameter are found during the post midnight hours.

The maximum values of mean amplitude ($\Delta$TEC$_{max}$) and mean half amplitude duration ($\tau_{max}$) in (a) winter, (b) summer and (c) equinox during quiet nights are as: $\Delta$TEC$_{max} = 12.9 \times 10^{17}$ m$^{-2}$ at 2100-2259; $2.35 \times 10^{17}$ m$^{-2}$ at 2200-2300 hours and $3.13 \times 10^{17}$ m$^{-2}$ at 2200-2300 hours. $\tau_{max} = 102$ minutes at 2000-2100 hours; 165 minutes at 2200-2300 hours and 154 minutes at 0200-0300 hours.

Table 1 shows that the correlation coefficients of the intensity of a SC storm (Ap) with the amplitude and half amplitude duration are very low. This study thus indicates that, though the night-time enhancement parameters are affected by SC storms, the intensity of the storm does not directly influence them. Table 2 shows that, in summer and equinox, an appreciable positive correlation exists between the mean amplitude ($\Delta$TEC$_{max}$) and the half amplitude duration ($\tau$) during quiet nights. At times of storm, the correlation coefficient between $\Delta$TEC$_{max}$ and $\tau$ is a maximum during winter and a minimum during equinox. The opposite is, however, true for magnetically quiet nights: the correlation is a maximum during equinox and a minimum during winter.
Figure 4.9: The local time distribution of mean amplitude during quiet nights.
Figure 4.10: The local time distribution of half amplitude duration during quiet nights.
Figure 4.11: The local time distribution of the percentage number of enhancements during quiet nights.
Table 1

<table>
<thead>
<tr>
<th>Season</th>
<th>Correlation coefficient between Ap and $\Delta$TEC$_{\text{max}}$</th>
<th>Correlation coefficient between Ap and $\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>0.197</td>
<td>0.05164</td>
</tr>
<tr>
<td>Summer</td>
<td>0.101</td>
<td>-0.678</td>
</tr>
<tr>
<td>Equinox</td>
<td>0.00024</td>
<td>0.000274</td>
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Table 2

<table>
<thead>
<tr>
<th>Season</th>
<th>Correlation coefficient between $\Delta$TEC$_{\text{max}}$ and $\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>During SC storms</td>
</tr>
<tr>
<td>Winter</td>
<td>0.5762</td>
</tr>
<tr>
<td>Summer</td>
<td>0.438</td>
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<tr>
<td>Equinox</td>
<td>0.309</td>
</tr>
</tbody>
</table>
4.3.2 Latitudinal dependence of night-time enhancement on sudden commencement storms during the solar maximum year 1989

The night-time enhancement characteristics like mean amplitude, half amplitude duration and percentage frequency occurrence exhibit both seasonal and latitudinal dependence.

Figure 4.12 exhibits latitudinal dependence of mean amplitude on sudden commencement (SC) storms in (a) winter, (b) summer, (c) equinox and (d) by considering all data together. It is found that in winter the mean amplitude during SC storm \((1.064 \times 10^{17} \text{ m}^2)\) is higher than that during quiet nights \((0.441 \times 10^{17} \text{ m}^2)\) for the mid-latitude station. However, the opposite trend is seen for the high-latitude station, with higher mean amplitude value during quiet nights \((0.901 \times 10^{17} \text{ m}^2)\) and lower during SC storms \((0.6469 \times 10^{17} \text{ m}^2)\). But these values are almost the same for the low-latitude station. In summer also, the mean amplitude is higher for low- \((1.33 \times 10^{17} \text{ m}^2)\) and mid- \((1.13 \times 10^{17} \text{ m}^2)\) latitude stations during SC storms in comparison with quiet nights \((0.9708 \times 10^{17} \text{ m}^2\) and \(0.705 \times 10^{17} \text{ m}^2\) respectively).

During equinox, the mean amplitude for low- \((1.14 \times 10^{17} \text{ m}^2)\) and mid-latitudes \((1.03 \times 10^{17} \text{ m}^2)\) are greater than those during quiet times \((0.975 \times 10^{17} \text{ m}^2\) and \(0.655 \times 10^{17} \text{ m}^2\) respectively). However, the opposite applies for the high-latitude station. By considering all data, the mean amplitude during SC storms for low- \((1.177 \times 10^{17} \text{ m}^2)\) and mid- \((1.07 \times 10^{17} \text{ m}^2)\) latitude stations are greater than those during quiet nights \((1.004 \times 10^{17} \text{ m}^2\) and \(0.6003 \times 10^{17} \text{ m}^2\) respectively). It is remarkable that, for high-latitudes the mean amplitude during SC storms is less than that during quiet nights, irrespective of the season.

Figure 4.13 represents latitudinal dependence of mean half amplitude duration on sudden commencement (SC) storms in (a) winter, (b) summer (c) equinox and (d) by considering all data together. In winter the mean half amplitude duration during SC storms for mid- and high-latitude stations are greater compared to those of quiet nights. But during equinox, the trend shown by mid-
Figure 4.12: Latitudinal dependence of mean amplitude during SC storms (solid curves) and quiet nights (dashed curves).
Figure 4.13: Latitudinal dependence of mean half amplitude duration during SC storm (solid curves) and quiet nights (dashed curves).
latitude station is similar: (192 minutes for storm time & 183 minutes for quiet nights) which is also true for the low-latitude station in summer. By considering all the data, mean half amplitude duration for mid-latitude station during SC storm is greater (201 minutes) than that during quiet times (186 minutes). However, for the high-latitude station this parameter during SC storm is less than that during quiet nights, irrespective of the season.

Figure 4.14 represents latitudinal dependence of mean percentage frequency of occurrence of night-time enhancement on sudden commencement (SC) storms in (a) winter, (b) summer, (c) equinox and (d) by considering all data together. The percentage frequency of occurrence of night-time enhancement during SC storm is greater than those of quiet nights for all the three seasons. This trend is satisfied by all the stations and also when all the data are considered.

Figures 4.15, 4.16 and 4.17 respectively exhibit the latitudinal and local time dependence of mean amplitude, half amplitude duration and percentage frequency of occurrence of night-time enhancement during SC storms. The local time at which mean amplitude ($\Delta TEC_{\text{max}}$) attains it’s maximum value for low-, mid- and high- latitude stations are respectively given as 2000 hours, 2000 hours and 2100 hours. The local time of maximisation of mean half amplitude duration for low-, mid- and high-latitude stations are 2300 hours, 2400 hours and 0300 hours respectively. The maximum values of percentage frequency of occurrence for low-, mid- and high-latitudes are at 2400 hours, 1900 hours and 2000 hours respectively. These imply that maximum probable local time for night-time enhancement during SC storms with maximum amplitudes is during pre-midnight hours. By data analysis, it is found that for quiet nights also the enhancement characteristics except mean half amplitude duration for high-latitude station maximises in pre-midnight hours for all latitudes.

The correlation between the intensity of the storm (Ap) and mean amplitude ($\Delta TEC_{\text{max}}$) is low for high- and low-latitude stations, whereas it is negative for the mid- latitude station when all data together (station wise) are considered (table 3a). However, this correlation coefficient shows appreciable high
Figure 4.14: Latitudinal dependence of mean percentage of frequency of occurrence during SC storms (solid curves) and quiet nights (dashed curves).
Figure 4.15: Latitudinal and local time dependence of mean amplitude during SC storms.
Figure 4.16: Latitudinal and local time dependence of mean half amplitude duration during SC storms.
Figure 4.17: Latitudinal and local time dependence of mean percentage of number of enhancements during SC storms.
**Table 3a**

<table>
<thead>
<tr>
<th>Station</th>
<th>Correlation coefficient between $\Delta$TEC$_{\text{max}}$ and $A_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramey</td>
<td>0.0531</td>
</tr>
<tr>
<td>Sagamore Hill</td>
<td>-0.08816</td>
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<tr>
<td>Goose Bay</td>
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</table>

**Table 3b**

<table>
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<th>Station</th>
<th>Correlation coefficient between $A_p$ and $\Delta$TEC$_{\text{max}}$</th>
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<tr>
<td>Winter</td>
<td>Ramey</td>
<td>0.0281</td>
</tr>
<tr>
<td></td>
<td>Sagamore Hill</td>
<td>0.3346</td>
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<td>Goose Bay</td>
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<td>Ramey</td>
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<td></td>
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<td>Equinox</td>
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<tr>
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<td>Sagamore Hill</td>
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</tr>
<tr>
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<td>Goose Bay</td>
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values for low- and mid- latitude stations in equinox when station wise data is considered (table 3b).

The interdependence between mean amplitude ($\Delta TEC_{max}$), and mean half amplitude duration ($\tau$) by considering station wise and season wise data are shown by tables 4a and 4b respectively. The correlation coefficient between these quantities is either negative or low positive values for all latitudes when station wise data is considered (table 4a). However, when season wise data is considered, the mid-latitude station shows maximum correlation coefficient during SC storms and quiet nights in equinox. In winter, the mid-latitude station and in summer, the high-latitude station show a high positive correlation (table 4b).

It is found that for all seasons the mid-latitude station shows minimum values for mean amplitude and percentage frequency of occurrence during quiet nights. This is true for mean half amplitude duration also, except in summer. But in the case of night-time enhancement during SC storms, the mean amplitude and mean half amplitude duration exhibit minimum values for the high-latitude station irrespective of season. However, minimum percentage frequency of occurrence is observed for the mid-latitude station during winter and equinox.
### Table 4a

<table>
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<tr>
<th>Station</th>
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<th>Quiet time</th>
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<tbody>
<tr>
<td>Ramey</td>
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<tr>
<td>Sagamore Hill</td>
<td>0.417</td>
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<tr>
<td>Goose Bay</td>
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<td>0.078</td>
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</table>

### Table 4b

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<th>Season</th>
<th>Station</th>
<th>Correlation coefficient between $\Delta\text{TEC}_{\text{max}}$ and $\tau$</th>
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</thead>
<tbody>
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<td></td>
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<tr>
<td>Winter</td>
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<td>Sagamore hill</td>
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<td>Goose Bay</td>
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<tr>
<td>Summer</td>
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<td>Goose Bay</td>
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<tr>
<td>Equinox</td>
<td>Ramey</td>
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4.4 Discussion:

The results presented here, provide a reasonably comprehensive picture of the effects of solar activity, intensity of storm, season and local time of TEC maximisation, on various characteristics of night-time enhancements during SC storms. Previous studies on night-time enhancement were generally conducted by selecting a particular period, which included quiet as well as disturbed nights. (Young et al., 1970; Essex and Klobuchar, 1980; Balan et al., 1986). The latitudinal dependence of night-time enhancements were also studied by selecting quiet and magnetically disturbed nights (Balan et al., 1991). However, all magnetically active nights need not necessarily be associated with SC storms.

The present study, in fact, deals exclusively with night-time enhancements during SC storms and the results are compared with that for quiet nights.

Balan et al. (1986) had observed that at the low-latitude station Hawaii, 77% of the nights had TEC enhancements of which 55% occurred during pre-midnight hours and 22% during post midnight hours during a solar maximum year. However, during a solar minimum year only 16% of the nights had TEC enhancements of which 7% occurred during pre-midnight hours and 9% during post-midnight hours. They also found that the most probable time of maximisation was 2100-2200 LT (during winter) and 0100-0200 LT during summer; while equinox had no such definite probable time for maximisation.

Chauhan and Gurm (1985) assert that the enhancements in TEC are accompanied by an increase in foF2 values and there exists a good coefficient of correlation between TEC and foF2 values for a chain of five low-latitude stations over the Indian zone. In their study the role of neutral winds and \( \text{ExB} \) drift in producing enhancements by the mechanisms of convergence of ionisation has been assessed through the solution of a time dependent equation of continuity of the
plasma in the F-region. Their computations suggest that the convergence of plasma due to neutral wind and $\text{ExB}$ drift can produce enhancements in $\text{foF2}$ and TEC.

Sudhir Jain et al. (1995) had conducted a study of night-time enhancements at Lunping and found that the correlation between amplitude and magnetic activity is negligible. But contrary to the other studies (Balan et al., 1991) found that at Lunping the enhancement was mainly a post-midnight phenomenon and that the occurrence of the enhancements as a whole is negatively correlated with solar activity.

Potential source mechanisms for the observed TEC enhancements have been discussed by several authors (Evans, 1965; Young et al., 1970; Davies et al., 1979; Leitinger et al., 1982; Anderson and Klobuchar, 1983; Balan and Rao, 1987; Balan et al., 1991). The observed features, particularly the time of occurrence and solar activity dependence of the enhancements at different latitudes, indicated that the enhancements are caused by different mechanisms at different latitudes. The important mechanisms are: (1) electrodynamic drifts and plasma motion due to neutral winds, (2) plasma diffusion from protonosphere, (3) cross-L plasmaspheric compression and subsequent enhancement in plasmasphere-ionosphere plasma flow, (4) plasma transfer from conjugate ionosphere, (5) movement of the mid-latitude trough (6) corpuscular ionisation for the first two mechanisms were found significant for night-time enhancements at low-latitudes.

At low-latitudes the electrodynamic $\text{ExB}$ drifts are very effective in transporting ionisation in the ionosphere (Prasad and Rama Rao., 1993). It has also been established that at low-latitudes atomic oxygen is enhanced by transport from higher latitude for the upwelling in the auroral oval (Rishbeth et al., 1987). This combined with the upward lifting of the ionised-neutral air winds would give prolonged enhancements in electron density and TEC (Reddy et al., 1990).
The potential source mechanisms responsible for the observed night-time TEC enhancements at low latitudes are believed to be (a) plasma transfer from the conjugate ionosphere and (b) electrodynamic drifts and neutral winds.

According the conjugate point transfer mechanism of ionisation (Rishbeth, 1968; Wickwar, 1974), a transfer of plasma will occur only when there exists large density or temperature gradients between two magnetically conjugate points. In addition to this, an upward ExB drift raises the equatorial F-region to altitudes of lower chemical loss and the subsequent diffusion of ionisation along magnetic field lines gives rise to night-time enhancements in TEC. The seasonal variations of the post sunset increase in upward ExB drift velocity are such that the increase is greatest at equinox and smallest in summer; the solar cycle variations are such that for each season, the increase becomes greater with an increase in solar activity (Fejer et al., 1979; Namboothiri et al., 1989).

The hypothesis of conjugate ionosphere as well as the post sunset increase in upward ExB drift velocity thus have the potential to explain the following observational features: (a) The general trend of higher night-time enhancement parameters such as mean amplitude ($\Delta$TEC$_{max}$), mean half amplitude duration ($\tau$), and percentage frequency of occurrence during storms as compared to that of quiet nights and (b) the positive correlation between characteristics of night-time enhancements and solar activity.

The direction of the meridional neutral air wind is, in general, poleward during the day and equator-ward during the night. At low-latitudes the maximum velocity of the equator-ward wind occurs during pre-midnight hours (Hedin et al., 1988; Krishna Murthy et al., 1990). This could explain why the most probable local time of maximum enhancement and highest values of enhancement parameters occurred during pre-midnight hours.

By using a mathematical model of the equatorial anomaly region, Anderson and Klobuchar (1983) have shown that the post-sunset increase in the upward
**ExB** drift velocity is primarily responsible for the night-time increase in TEC observed at the equatorial anomaly crest station, Ascension Island. The inclusion of a meridional neutral air wind in the model modulated the post sunset peak of the modelled TEC making the modelled and observed values of TEC in closer agreement. The modelled values for solar maximum showed prominent enhancements in TEC in the anomaly crest region and reduced values for TEC at the magnetic equator. However Balan and Rao (1984, 1987) have observed simultaneous occurrences of enhancements in Faraday content in the northern equatorial anomaly crest region and enhancements in group delay content at the magnetic equator. The discrepancies in the model and observed results can be overcome provided the protonospheric content at the magnetic equator more than compensates for the reduction in the Faraday content caused by the loss of ionisation through the fountain effect.

Many excellent reviews on the current understanding of ionospheric storms have been published in the last few years (Rees, 1996; Schunk and Sojka, 1996; Fuller-Rowell et al., 1997; Prolss, 1997).

The possible processes which might contribute to the magnetic storm associated ionospheric variations are: (1) electromagnetic drift associated with storm time electric fields (2) enhanced thermospheric circulation (waves and winds) generated by auroral zone heating during magnetic storms and the consequent increased loss rate, (3) compression of plasmashpere by enhanced solar wind and (4) changes in atmospheric composition due to enhanced thermospheric circulation.

During storms, positive and negative storm effects influence TEC base values which, in turn affects the parameters of night-time enhancement. During summer the local thermospheric temperature is higher and hence recombination losses are higher than in winter (Rama Rao et al., 1994). This leads to lower base values of TEC in summer than in winter (Unnikrishnan et al., 1996), which may be a possible reason for the half amplitude duration ($\tau$) and amplitude ($\Delta TEC_{\text{max}}$)
being higher in summer than in winter for moderate storms. During magnetic storms the plasmasphere is compressed causing the mid-latitude trough to move to lower latitudes. On either side of the trough, TEC enhancements are strong. This may also influence the night-time enhancement associated with storms.

The fact that the percentage frequency of occurrence of night-time enhancements do not depend on the strength of the storm implies that storms cannot be an additional criteria for occurrence of night-time enhancements. However, if the anomalous night-time enhancement occurs during a storm, its parameters could be influenced by storm associated perturbations. It is well known that the electrodynamic drift and winds are prominent causes which produce storm associated ionospheric changes at low-latitudes. At the same time these are the two probable processes behind night-time enhancements. This may be a possible reason for large values of night-time enhancement during storms compared to quiet nights in most of the seasons.

At mid-latitudes, during all seasons, the meridional neutral air wind is equator ward during night-time and attains its maximum speed at around midnight (Hernandez and Roble, 1984). As at low-latitudes the interaction between the neutral air wind and the ionospheric plasma lifts the ionisation to altitudes of lower chemical loss. In general, the night-time background ionospheric content is least in winter and increases with an increase in solar activity. Thus, a strong downward diffusion of plasma from the protonsphere combined with the neutral air wind interactions can easily produce enhancements in night-time values of TEC for ray paths which traverse the mid-latitude ionosphere.

The mechanisms, which are important at high-latitudes, are corpuscular ionisation and movement of the mid-latitude trough. The mid-latitude trough is the ionospheric manifestation of the plasmapause and is a region of low electron density. TEC enhancements occurring in the trough region are due to corpuscular ionisation (Titheridge, 1968), the intensity of which increases with increasing latitude. This mechanism is supported by the simultaneous observations of TEC enhancements and precipitation of soft electrons (<400 ev) made in the European
sector by Leitinger et al. (1982). Balan et al. (1991) observed that during a solar minimum, the enhancements become more pronounced and occur more frequently as magnetic activity increases, especially at latitudes greater than 50°N. However, the present study reveals that the mean amplitude and percentage frequency of occurrence during SC storms are less than those at quiet nights in the solar maximum year 1989 for the high-latitude station, GooseBay.

Due to the storm associated upper atmospheric heating at high-latitudes, atmospheric circulations are generated near the turbopause in both hemispheres. Air thus moves up at high-latitudes followed by an equator-ward motion and results in the reduction of atomic oxygen. Accordingly, the electron density in the high-latitude F-region decreases. This may be a possible reason for low mean amplitude and percentage frequency of occurrence of night-time enhancements during SC storms, only for the high-latitude station as compared to those during quiet times.

During magnetic storms the plasmasphere is compressed causing the mid-latitude trough to move to lower latitudes. The mid-latitude trough during geomagnetic storms may be a reason for the low value of percentage frequency of night-time enhancement for mid-latitudes during SC storms, when all data was considered and for all seasons except summer.

On either side of the trough, TEC enhancements are strong. On the equatorward side, the strong enhancements are due to magnetospheric compression whilst on the poleward side they are due to enhanced corpuscular ionisation. Mikkelsen (1975) has observed that the ionisation of the auroral zone increases and moves equator-ward under magnetically active conditions. From simultaneous observations of TEC and magnetic field measurements Mendillo et al. (1970) have suggested that magnetospheric compression causes the plasma to be dumped into the topside ionosphere resulting in the observed enhancements in TEC. A simultaneous decrease in protonospheric content during geomagnetic storms has been observed by Kersley and Klobuchar (1980). The important mechanisms at mid-latitudes are field-aligned plasma flow, cross-L plasmaspheric compression and neutral air wind interactions. Downward diffusion of plasma from the
plasmasphere resulting from the cooling of the field tube after sunset can lead to an enhancement in the night-time TEC. Titheridge (1968) has shown, on the basis of flux requirements, that the mechanism would be effective in producing TEC enhancements over a latitude range of about $20^\circ$-$45^\circ$ (geomagnetic). Downward diffusion can be enhanced by cross-L plasmaspheric compression since a westward electric field will move plasma from higher L-shells to lower L-shells with the subsequent effect that the plasma pressure in the lower L-shells will be increased. The effect of the excess plasma pressure is to increase the downward diffusion of plasma which, in turn, increases the ionospheric content at both ends of the L-shell (Davies et al., 1979). The above mechanism of protonsphere-ionosphere plasma flow has been examined in several modelling studies (Bailey et al., 1978, 1987, 1991, Sethia et al., 1985; Saxton and Smith, 1989). It has been shown by the modelling study of Bailey et al. (1991) that large downward field-aligned flows of plasma occur when there are large decreases in plasma temperature in the topside ionosphere. Such decreases in plasma temperature occur in the winter topside ionosphere when the solar illumination in the conjugate (summer) F-region ceases.

An unambiguous picture of night-time enhancement of TEC during storms could be arrived at only by considering all the mechanisms of the above phenomenon and the storm induced upper atmospheric electric field.

4.5 Conclusions

The main characteristics of night-time enhancements during SC storms are compared with that during quiet nights for different seasons and solar activity conditions for a low-latitude station Palehua during the period 1980 - 89; the interdependence of these characteristics are also analysed. In addition to this, the latitudinal dependence of night-time enhancements during SC storms is also analysed for the solar maximum year 1989. This study also investigates whether the intensity of a storm affects the characteristics of night-time enhancements at various latitudes. The main conclusions of this study are:
1. It is generally believed that the frequency of occurrence, amplitude and half amplitude duration have a high positive correlation with solar activity at low latitudes (Young et al., 1970, Balan et al., 1986, 1991). This study also shows that a general positive correlation exists between solar activity and the mean amplitude ($\Delta$TEC$_{max}$), mean half amplitude duration ($\tau$) and percentage frequency during quiet nights for all seasons expect in summer.

2. The times of occurrence of peak enhancements occur during pre-midnight hours for all seasons in quiet nights.

3. The mean amplitude is greatest at equinox for quiet night enhancements.

The important new results presented by this Chapter are:

1. For a low-latitude station, a general positive correlation exists between solar activity and parameters like, mean amplitude ($\Delta$TEC$_{max}$), mean half amplitude duration ($\tau$) and percentage frequency of night-time enhancements during SC storms, for all the seasons.

2. For a low latitude station a general positive correlation exists between the mean amplitude ($\Delta$TEC$_{max}$) and mean half amplitude duration ($\tau$) for night-time enhancements during SC storms, which is highest in winter and least in equinox. But in the case of quiet nights, it maximises in equinox and minimises in winter. However this correlation is highest in equinoctial quiet nights as compared to stormy nights.

3. In equinox, during the solar maximum year 1989, the mid-latitude station shows maximum correlation coefficient between the mean amplitude ($\Delta$TEC$_{max}$) and mean half amplitude duration ($\tau$) for night-time enhancements during SC storms and quiet nights.

4. For a low- latitude station, in winter and summer the mean amplitude and mean half amplitude durations are higher during SC storms as compared to that during quiet nights. This tendency is, however, pronounced only during moderate to heavy solar activity periods.
5. For a low-latitude station, in winter and equinox the percentage frequency during storms is greater than those during quiet nights.

6. In the solar maximum year 1989, the mean amplitude of low- and mid-latitudes during SC storms are greater than those of quiet nights.

7. In the solar maximum year 1989, it is remarkable that generally, the mean amplitude and half amplitude duration during quiet nights are greater than those during SC storms for high-latitude.

8. In the solar maximum year 1989, for low-, mid- and high-latitude stations the percentage of occurrence of night-time enhancements during SC storms are greater than those of quiet nights.

9. This study indicates that the intensity of a storm does not directly influence the parameters of night-time enhancements.

10. For a low-latitude station, the most probable LT of maximisation of night-time enhancements, with maximum amplitude during SC storms, lie in the pre-midnight hours. This is also valid for all the latitudes during the solar maximum year 1989.
4.6 References:


