CHAPTER V

IONOSPHERIC ELECTRON CONTENT AND EQUIVALENT SLAB THICKNESS
IN RELATION TO SOLAR AND MAGNETIC ACTIVITY

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CHAPTER V

IONOSPHERIC ELECTRON CONTENT AND EQUIVALENT SLAB THICKNESS
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5.1 Introduction

It is well known that the critical frequency, $f_{o}F_2$, of the $F_2$ layer varies markedly with the solar cycle. Bhonsle et al (1965) found, the solar cycle dependence of $N_T$, the total electron content up to about 1000 km over middle latitudes for sunspot numbers higher than 40. Yeh and Flaherty (1966) extended these observations to sunspot numbers less than 40. Hibberd and Ross (1966) have examined the relationship between 10.7 cm solar flux and total electron content over middle latitudes. Over low latitudes, these effects have not been studied in detail. In this Chapter, the dependence of $N_T$ and $N_T/n_{\text{max}}$ on 10.7 cm solar flux and the effect of moderate magnetic activity (defined by $A_p$ index) on electron content have been studied and the results are presented. Before examining the data for such effects the reasons for not studying the magnetic storm variations may be mentioned. Since the satellite technique provides only a few measurements in a day, it is not possible to follow the effects of individual magnetic disturbances throughout its life. Further, the ionosphere fluctuates from day to day even under magnetically quiet conditions and it is often difficult to decide whether a change observed in a short interval of time is really related...
to the storm or is a random variation. Because of such drawbacks in the technique of investigation, storm time variations could not be studied in detail. Instead, the dependence of $N_T/N_{\text{max}}$, $N_a/N_b$ and $h_pF_2$ on moderate magnetic activity defined by $A_p$ is studied.

5.2 Dependence of daytime $N_T$ on solar flux

In Fig. 5.1 the values of $N_T$ measured between 12 hours and 16 hours are plotted against the daily values of 10.7 cm solar flux. In order to get over the effect of diurnal variation, the time around mid-day hours has been chosen. The $N_T$ values have been plotted separately for summer, winter and equinox. In all the seasons it can be seen that $N_T$ increases linearly with 10.7 cm solar flux. In winter, $N_T$ seems to increase at a slow rate till the solar flux reaches a value of about 100 units, and beyond this, it increases with solar flux at a faster rate. In summer and equinox, this transition at the solar flux value of about 100 units is not noticeable. The change of $N_T$ per unit of 10.7 cm solar flux is about $0.04 \times 10^{17}$ in summer and $0.054 \times 10^{17}$ in equinox. In winter, this is about $0.02 \times 10^{17}$ when the solar flux is below 100 units, and $0.06 \times 10^{17}$ unit flux, above 100 units.

The value of the logarithmic gradient, $\frac{\partial \ln N_T}{\partial \ln 10^{17}}$ comes out to be 0.025 in winter and 0.01 in summer and equinox.
AHMEDABAD S-66 1964-67 1200-1600 HOURS

DEPENDENCE OF MID-DAY TOTAL ELECTRON CONTENT ON 10.7 CM. SOLAR FLUX

![Graph showing dependence of mid-day total electron content on 10.7 cm solar flux for Equinox, Winter, and Summer phases.](image)

**Fig. 5.1** Dependence of afternoon (12-16 hrs) total electron content on 10.7 cm solar flux.
5.3 Dependence of night-time $N_T$ on solar flux

Between 23 hours and 03 hours $N_T$ remains nearly steady. The values of $N_T$ measured during this part of the night have been used for studying the effect of solar flux at night. In Fig.5.2, the night-time values of $N_T$ have been plotted against the daily values of 10.7 cm solar flux separately for summer, winter and equinox. In all the seasons, night-time $N_T$ also seems to have a linear dependence on solar flux. The rate of increase with solar flux seems to be nearly the same in all the seasons. $N_T$ increases at the rate of about $0.007 \times 10^{17}$ per unit flux. The night-time logarithmic gradient comes out to be about 0.02.

5.4 Dependence of daytime $N_T/n_{max}$ on solar flux

It is generally accepted that solar extreme ultraviolet radiation is an important source responsible for the heating of the F region (Hunt and van Zandt, 1961). Satellite drag measurements show that the thermopause temperature and hence the neutral particle densities at F region heights vary linearly with the solar activity (Nicolet, 1963). Since the average equivalent slab thickness, $N_T/n_{max}$, is an indicator of scale height and electron-ion mean temperature, it must have positive correlation with solar flux. In Fig.5.3, the daytime values of $N_T/n_{max}$ are plotted against the daily values of 10.7 cm solar flux. It can be seen that there is linear relationship between $N_T/n_{max}$ and 10.7 cm solar flux (S). The rate of increase
Fig. 5.2 Dependence of night time (23-03 hrs) total electron content on 10.7 cm solar flux
AHMEDABAD S-66 1964-67

DEPENDENCE OF $N_T/N_{MAX}$ ON SOLAR FLUX

---

**Equinox**

---

**Summer**

---

**Winter**

---

Fig. 5.3 Dependence of daytime $N_T/N_{MAX}$ on 10.7 cm solar flux
of \( T \) per unit flux is about 1 km in winter, 1.2 km in equinox, and 1.5 km in summer. The empirical linear relationship between \( T \) and \( S \) may be written as

\[
T \text{ (km)} = 175 + 1.0 (S-70) \text{ for winter}
\]

\[
T \text{ (km)} = 210 + 1.2 (S-70) \text{ for equinox}
\]

\[
T \text{ (km)} = 200 + 1.4 (S-70) \text{ for summer.}
\]

5.5 Dependence of daytime \( N_T \) on moderate magnetic activity

In Fig.5.4, the day-time values of \( N_T \) have been plotted against the daily values of \( A_p \) separately for summer, winter and equinox. In summer and equinox, the total electron content decreases with increase in magnetic activity. In winter there is probably a similar effect but it is not clear.

5.6 Dependence of night-time \( N_T \) on magnetic activity

In Fig.5.5, the values of \( N_T \) measured between 23 hours and 03 hours are plotted against \( A_p \) index separately for summer, winter and equinox. It can be seen that \( N_T \) increases with magnetic activity. In summer the figure shows more scatter. A whole-year plot is also given in Fig.5.6. It thus appears that while the total electron content decreases with increase in magnetic activity in the afternoon hours it increases with increase in \( A_p \) in the late night hours.
AHMEDABAD S-66 12-16 HOURS
DEPENDENCE OF DAYTIME $N_T$
ON MAGNETIC ACTIVITY

EQUINOX

WINTER

SUMMER

$N_T \times 10^7 \text{ m}^2$

$A_p$ INDEX

FIG. 5-4
AHMEDABAD S-66 23-03 HOURS
DEPENDENCE OF NIGHT-TIME $N_T$ ON MAGNETIC ACTIVITY

**EQUINOX**

**WINTER**

**SUMMER**

$N_T \times 10^{17} / M^2$

$A_p$ INDEX

**FIG. 5.5**
AHMEDABAD S-66 1964-65 23-03 HRS
DEPENDENCE OF NIGHT-TIME $N_T$ ON
MAGNETIC ACTIVITY (ANNUAL PLOT)

$N_T \times 10^{17}$ M$^{-2}$

$A_p$ INDEX

FIG. 5-6
5.7 Dependence of day-time slab thickness (τ) on magnetic activity

Since the diurnal variation of τ is small, the day-time values have been used for studying the effect of magnetic activity. In Fig.5.7, the day-time values of \( N_t/n_{max} \) have been plotted against \( A_p \) index separately for summer, winter and equinox. In winter, τ increases with increase in \( A_p \). In equinox this effect is not so pronounced. In summer, τ does not show any clear dependence on \( A_p \).

5.8 Dependence of night-time \( N_t/n_{max} \) on magnetic activity

In Fig.5.8, the night-time values of \( N_t/n_{max} \) have been plotted against \( A_p \) index separately for summer, winter and equinox. In summer and equinox night-time \( N_t/n_{max} \) increases with increase in \( A_p \) values. In winter night, \( N_t/n_{max} \) does not seem to depend on magnetic activity.

5.9 Dependence of day-time and night-time values of \( N_a/N_b \) on magnetic activity

The day-time and night-time values of \( N_a/N_b \) have been studied separately. In Fig.5.9, the day-time values of \( N_a/N_b \) have been plotted against \( A_p \) index separately for summer, winter and equinox. In summer \( N_a/N_b \) decreases with increase in \( A_p \) index. In equinox the ratio does not seem to depend on magnetic activity. In winter the ratio increases with \( A_p \) index.
AHMEDABAD S-66 64-65

VARIATION OF $N_T/N_{MAX}$ WITH MAGNETIC ACTIVITY ($A_p$) DURING DAYTIME

(A) SUMMER  (B) WINTER  (C) EQUINOX

FIG. 5-7
AHMEDABAD S-66 1964-65
DEPENDENCE OF NIGHT TIME
$\frac{N_t}{n_{\text{MAX}}}$ ON MAGNETIC ACTIVITY

EQUINOX

WINTER

SUMMER

FIG. 5-8
AHMEDABAD S-66

VARIATION OF $N_a/N_b$ WITH MAGNETIC ACTIVITY ($A_p$) DURING DAYTIME

(A) SUMMER (B) WINTER (C) EQUINOX

FIG. 5.9
The night-time values of $N_a/N_b$ have been shown in Fig. 5.10. These values are plotted against $A_p$ index separately for summer, winter and equinox. Since the ratio becomes very large early in the morning, these values have not been included. It can be seen that in equinox the night-time values of $N_a/N_b$ also do not seem to depend on magnetic activity. While the night-time ratio increases with $A_p$ in summer, it decreases in winter.

5.10 Dependence of day-time and night-time values of $h_pF_2$ on magnetic activity

Since the electron content variations are connected with the changes in the height of maximum electron density, the dependence of mid-day and mid-night values of $h_pF_2$ on magnetic activity has also been studied. Fig. 5.11 shows the dependence of mid-day $h_pF_2$ on $A_p$. In winter and equinox, mid-day $h_pF_2$ does not seem to depend on magnetic activity.

In Fig. 5.12 the values of $h_pF_2$ at 22 hours have been plotted against $A_p$ index separately for summer, winter and equinox. In winter, night-time $h_pF_2$ increases with $A_p$. In summer and equinox, night-time $h_pF_2$ does not seem to depend on magnetic activity.

5.11 Discussion

In Fig. 5.1, the best fitting straight lines have been drawn and these lines have been extended to zero solar flux. It
AHMEDABAD S-66 1964-65
DEPENDENCE OF NIGHT TIME $N_a/N_b$
ON MAGNETIC ACTIVITY

(C) EQUINOX

(B) WINTER

(A) SUMMER

$N_a/N_b$

\[ \begin{array}{c|c}
0 & 1 \\
2 & 3 \\
4 & 5 \\
6 & 7 \\
8 & 9 \\
10 & 11 \\
12 & 13 \\
14 & 15 \\
16 & 17 \\
\end{array} \]

$A_p$ INDEX

FIG. 5.10
AHMEDABAD 1964-65
DEPENDENCE OF MID-DAY $h_p F_2$
ON MAGNETIC ACTIVITY ($A_p$)
(A) EQUINOX (B) WINTER (C) SUMMER

FIG. 5-11
AHMEDABAD 1964-65
DEPENDENCE OF 2200 HOUR $h_p F_2$
ON MAGNETIC ACTIVITY ($A_p$)
(A) EQUINOX  (B) WINTER  (C) SUMMER

FIG. 5-12
can be seen that in all the seasons the line passes through the origin. Taylor (1966) has reported that the winter line intercepts the solar flux axis at a point significantly away from the origin. This might have been due to the fact that there were no observations corresponding to solar flux values less than 100 units. In the present result also it can be seen that the winter line which fits the observations corresponding to solar flux values higher than 100 units intercepts the x axis at a point away from the origin. If the change in the slope of the line in the region of solar flux less than 100 units is taken into account, the winter line also passes through the origin.

An approximate linear relationship between $N_T$ and sunspot number has been found by Bhonsle et al (1965) for sunspot numbers larger than 40. Yeh and Flaherty (1966) have extended these observations to sunspot numbers less than 40. They find that the linear dependence breaks down when the sunspot number falls below 40. At Ahmedabad in winter, a change in the linear relationship between $N_T$ and $S$ can be seen when the solar flux falls below 100 units. In summer and equinox, this feature is not noticeable even though there are observations corresponding to solar flux values between 70 units and 130 units. Somayajulu et al (1966) have shown that $N_T$ over Delhi is independent of solar flux when the flux is less than 80 units. From Fig.5.1 it can be seen that $N_T$ over Ahmedabad definitely shows an increase with flux even in the region of solar flux less than 80 units.

Bhonsle et al (1965) have determined an empirical relationship between $\tau$ in middle latitudes and the mean
sunspot number ($\tau$). Over middle latitudes, the rate of increase of $\tau$ with sunspot number is about 1 km in winter, 1.2 km in equinox and 1.35 km in summer. These values have been normalised by Bhonsle et al (1965). After normalising they get a coefficient of 0.005 in all the seasons. Normalising is done by dividing the rate of change of $\tau$ by the value of $\tau$ corresponding to zero sunspot number. In the present result over Ahmedabad also, it can be seen that the rate of change of $\tau$ with solar flux is minimum in winter and maximum in summer. If these values are normalised by dividing the rate of change of $\tau$ by the value of $\tau$ corresponding to solar flux of 70 units, the coefficient comes out to be about 0.006 in winter and equinox and 0.007 in summer. Since the measurements have been made within a limited range of solar flux the values of these coefficients determined by this analysis are to be treated with caution.

The variation of middle latitude $N_T$ with 10.7 cm solar flux has been studied by Hibberd (1964). He has calculated the rate of change of $N_T$ with flux ($S$) for summer and winter. In summer and winter he finds $\delta N_T/\delta S$ to be $0.028 \times 10^{17}$ and $0.038 \times 10^{17}$ respectively. Over Ahmedabad, $\delta N_T/\delta S$ seems to be higher. From the results of Hibberd, it can be seen that the logarithmic gradient, $\frac{\delta N_T/\delta S}{N_T(100)}$, is nearly the same in winter and summer. Over Ahmedabad this is about 0.01 in summer and equinox and about 0.026 in winter. In winter the middle and low latitude results show the same value of logarithmic gradient of $N_T$. 
Ross (1960), Yeh and Swenson (1961) and de Mendonca (1962) have shown that electron content figures are depressed following a magnetic storm. Ross has shown an inverse dependence of $N_T$ upon $\sum K_p$ for the previous 24 hours during the months of June, July and August 1959. Over middle latitude Ross (1960) and Garriott (1960) have found no systematic dependence during the winter months. Our results over Ahmedabad are also in conformity with these middle latitude results. Lyon (1965) has also found that the middle latitude $N_T$ is inversely dependent upon the magnetic activity index in summer months and not in winter months.

In summer and winter, day-time and night-time values of $N_a/N_b$ exhibit opposite dependence on magnetic activity. In summer, while the day-time values of $N_a/N_b$ decrease with $A_p$, the night-time values increase with $A_p$. In winter, day-time shows positive correlation and night-time shows negative correlation.

Summer and winter also behave differently. During day time it can be seen that $N_a/N_b$ decreases with $A_p$ in summer and increases with $A_p$ in winter. In the night also this seasonal effect can be seen. Night-time value of $N_a/N_b$ increases with $A_p$ in summer and decreases with $A_p$ in winter. It can also be noticed that when $h_p F_2$ increases with magnetic activity $N_a/N_b$ decreases. A summary of the results has been provided in Table I.
## Table 1

Changes of $N_T$ and related parameters with increase in $A_p$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Summer</th>
<th>Winter</th>
<th>Equinox</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_T$</td>
<td>Negative</td>
<td>Uncertain</td>
<td>Negative</td>
</tr>
<tr>
<td>$N_T/n_{\text{max}}$</td>
<td>Nil</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>$N_a/N_b$</td>
<td>Negative</td>
<td>Positive</td>
<td>Nil</td>
</tr>
<tr>
<td>$h_p F_2$</td>
<td>Positive</td>
<td>Nil</td>
<td>Nil</td>
</tr>
</tbody>
</table>

### Day-time

### Night-time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Summer</th>
<th>Winter</th>
<th>Equinox</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_T$</td>
<td>Positive</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>$N_T/n_{\text{max}}$</td>
<td>Positive</td>
<td>Nil</td>
<td>Positive</td>
</tr>
<tr>
<td>$N_a/N_b$</td>
<td>Positive</td>
<td>Negative</td>
<td>Nil</td>
</tr>
<tr>
<td>$h_p F_2$</td>
<td>Nil</td>
<td>Positive</td>
<td>Nil</td>
</tr>
</tbody>
</table>